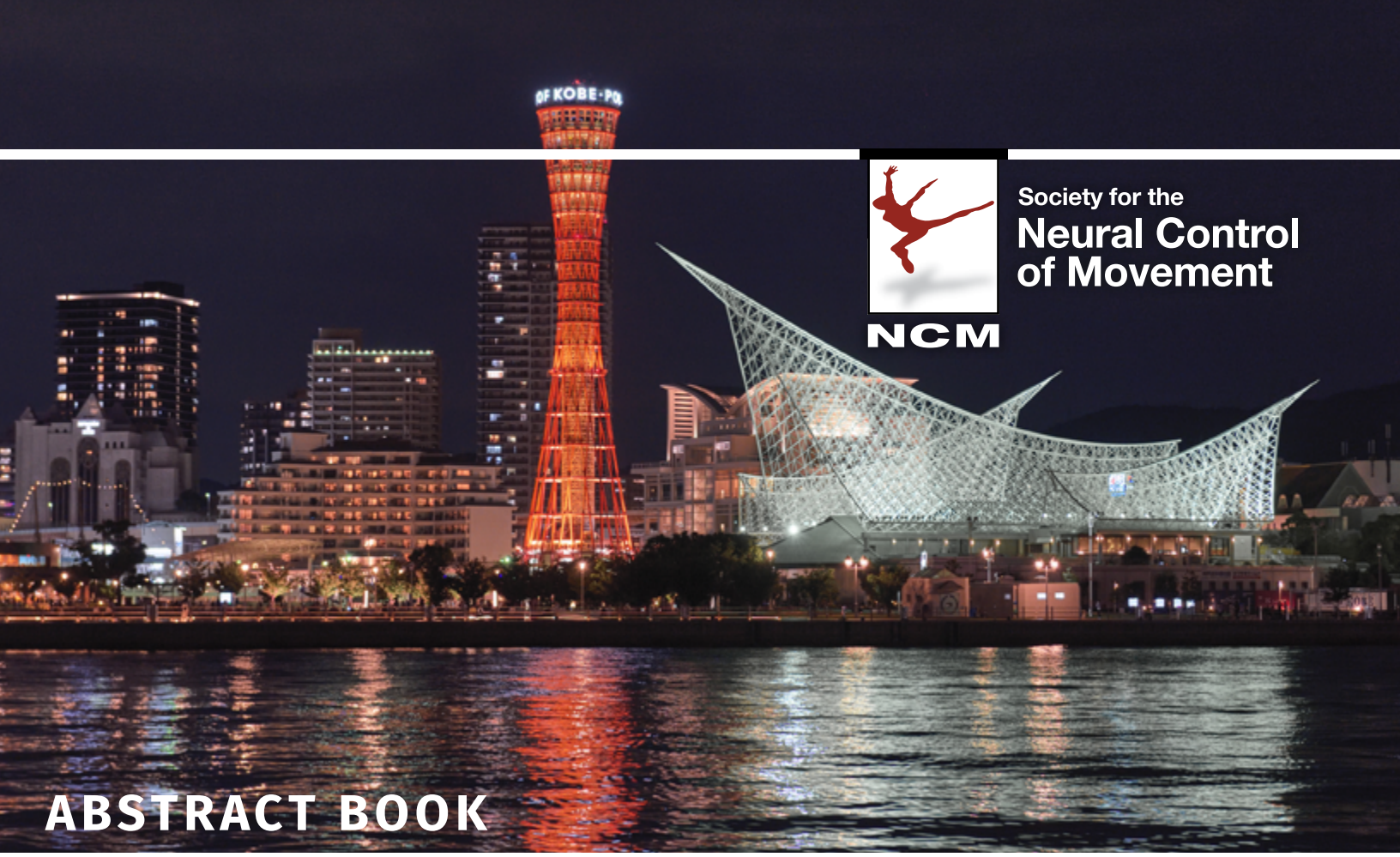

Society for the
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ABSTRACT BOOK

35th Annual Meeting

Kobe, Japan

Portopia Hotel

2026

SATELLITE MEETING
April 20, 2026

ANNUAL MEETING
April 21 – 24, 2026

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Satellite Meeting Abstract

Session 1: Gait and mobility

Neural mechanisms of perceptual ability contributing to flexible balance control: implications for (p)rehabilitation

Michael Borich, *Emory University*

The ability to appropriately perceive relevant internal and external stimuli is necessary for successful sensorimotor function. Flexibly adapting to changing environmental contexts is diminished in several neurologic conditions and declines with aging. However, the underlying neural mechanisms of how perception contributes to flexibility are not well understood. In this talk, I will summarize our recent work demonstrating that perturbations to standing balance elicit a characteristic neural signature that reliably scales with stimulus predictability in younger adults that is disrupted in older adults with and without stroke or Parkinson's disease. This disruption is associated with balance deficits and lower cognitive flexibility. I will end my talk by outlining translational opportunities that leverage an improved understanding of the neural and behavioral mechanisms of perceptual flexibility into precision rehabilitation and real-world applications.

Longitudinal gait analysis integrated into inpatient rehabilitation

James Cotton, *Northwestern University*

Improving motor control is a fundamental goal of rehabilitation, yet changes in movement quality are rarely quantified during therapy. The requirements for formal gait analysis make it impractical for routine assessments. To address this gap, we integrated a markerless motion capture system into an inpatient rehabilitation unit and developed a smartphone application to streamline data acquisition during standard clinical assessments such as the 10-meter walk test. An automated gait analytics pipeline obtains gait kinematics, spatiotemporal parameters, and gait events, enabling longitudinal monitoring of kinematic changes throughout a patient's rehabilitation stay without disrupting clinical workflow. This reveals a diversity in changes in gait kinemematics beyond the improvements in speed quickly quantified. When evaluating quantitative gait metrics, including both standard kinematic indices and learned movement biomarkers from self-supervised models, these show responsiveness favorable to speed alone. We also developed natural language interfaces to this data, including BiomechGPT, a multimodal motion-language model, and BiomechAgent, a code-writing analysis agent, enabling clinicians to query gait data conversationally and obtain quantitative results. Together, these tools demonstrate a pathway toward scalable, AI-powered longitudinal gait analysis embedded in routine rehabilitation care.

On time mobility: Neuromechanics to support early play and participation

Katherine Steele, *University of Washington*

The ability to move and explore the world, supports our learning, development, and social engagement. However, for many children with disabilities, mobility is often delayed and limited due to physiological impairments, societal expectations, and environmental barriers. Understanding the neuromechanics of how children learn, play, and explore their world is critical to support mobility in all its forms. This talk will share some of our team's recent work examining new tools and technology support on time mobility for children with disabilities. From walking to wheels, we will examine how children learn to use alternative mobility devices, like the Explorer Mini, and their impacts on development. Let's get moving!

Optimal strategies for robot-assisted gait training in patients with hemiparesis
Yohei Otaka, *Fujita Health University*

Although the effectiveness of robot-assisted gait training (RAGT) for hemiparetic stroke has been proven and it is recommended in clinical guidelines, several significant challenges remain. Specifically, these include the mechanisms underlying its effectiveness, the appropriate type of robot to use, and how RAGT should be positioned within the overall gait rehabilitation process. Furthermore, the challenge of determining the optimal RAGT parameters tailored to each patient's specific condition remains. In this presentation, I will introduce "Welwalk," a gait training robot for hemiparetic patients jointly developed by our university and Toyota, and discuss the challenges related to the optimal strategies for RAGT.

Session 2: Upper extremity function

Neural control of upper limb muscles: New insights into plasticity
Monica Perez, *Northwestern University*

Multiple descending motor pathways contribute to upper limb control, and their reorganization after cervical spinal cord injury (SCI) may underlie asymmetrical recovery of distal and proximal muscles. Our findings indicate that the reticulospinal tract supports hand control during gross finger movements after SCI but contributes less to fine dexterous tasks. Reticulospinal input is enhanced to elbow flexors, whereas elbow extensors remain markedly weakened, at least in part due to loss of corticospinal drive. Importantly, the capacity for plasticity—such as that induced by Hebbian stimulation—varies across muscles, being greatest in distal hand muscles and progressively lower in proximal flexors and even more limited in extensors, consistent with a hierarchical organization. These results underscore the importance of rehabilitation strategies that integrate pathway-specific contributions and muscle-specific plasticity to optimize functional recovery after SCI.

Impaired reward-based learning but preserved invigoration: From group effects to individual phenotypes
Sebastian Sporn, *University College London*

Reward plays a central role in motor behaviour, both by invigorating performance and by supporting learning of action–outcome associations. After stroke, the ability to use reward feedback may be impaired, potentially limiting the efficacy of reinforcement-based rehabilitation. However, it remains unclear whether stroke induces a global or selective disruption of reward processing. We assessed reward-based learning and invigoration in 40 chronic stroke survivors and 30 age-matched controls using a probabilistic reversal learning task.. Participants reached to one of two targets with changing reward probabilities, requiring continuous updating of choice behaviour. Stroke survivors showed reduced reward-based learning, with lower choice accuracy and reduced win–stay behaviour, particularly for the weak limb. These effects were not explained by general motor or cognitive deficits. Hierarchical Gaussian Filter modelling showed that stroke survivors updated beliefs about action–reward contingencies more slowly, while volatility learning remained intact. In contrast, reward-based invigoration was preserved: reward expectations increased movement speed similarly in both groups. Inter-individual variability indicated that some patients retained intact learning, suggesting distinct motor learning phenotypes after stroke rather than uniform impairment. This supports stratified, mechanism-based rehabilitation approaches and motivates future work linking these phenotypes to underlying neurophysiological and neurochemical mechanisms.

Epidural spinal cord stimulation for post-stroke upper limb hemiparesis
Marco Capogrosso, *University of Pittsburgh*

Chronic arm and hand hemiparesis is a major cause of disability after stroke. Unfortunately, standard of care rehabilitation falls well short of the high doses required to experience improvements. In this feasibility study we explored the use of cervical epidural spinal cord stimulation (SCS) to assist motor function and provide meaningful functional improvements without the need of a high-dose rehabilitation program. We report the final outcomes of this study testing safety, feasibility and preliminary efficacy of cervical SCS as a neuroprosthetic approach for chronic post-stroke upper-limb hemiparesis. We implanted seven participants with profound motor deficits (Fugl-Meyer Assessment [FMA] scores 15–35) using two leads implanted unilaterally in the cervical spinal cord for 4 weeks. No serious adverse events occurred. Under SCS ON, motor function immediately improved regardless of impairment severity (average +32% strength and +5.6 FMA-points). Notably, 3/7 participants with residual corticospinal connectivity to finger muscles improved hand/finger movement with SCS. Despite performing only 8.6hrs of motor activity (5.5hrs with SCS ON), participants improved by average +6.6 FMA-points at the end of the study compared to baseline and spasticity decreased in all participants. While all benefited, our preliminary analysis indicates that spared sensory function may be a determinant of responsiveness to SCS. These findings provide preliminary evidence of the safety, feasibility and efficacy of cervical SCS for chronic post-stroke hemiparesis, suggesting its feasibility as a fully implantable neuroprosthetic solution for assisting upper-limb function in daily living.

Multi-phase CNS adaptation after tendon transfer in humans and non-human primates
Kazuhiko Seki, *National Center of Neurology and Psychiatry*

Tendon transfer surgery has a long history, with the first report published in 1896. In this procedure, the tendon of a non-paralyzed muscle is rerouted to compensate for a paralyzed muscle. It is still widely used to improve hand function and quality of life in patients with paralysis, including those with spinal cord injury. However, the central nervous system (CNS) mechanisms underlying recovery after tendon transfer remain poorly understood. To address this question, we have been investigating how the CNS adapts to major musculoskeletal changes in both human patients and non-human primates. In this talk, I will first present a human case study in which electromyographic and fMRI recordings obtained before and after surgery were used to infer the mechanisms of recovery. I will then introduce our work in non-human primates using an experimental tendon transfer model. By surgically relocating finger flexor and extensor muscles and recording muscle activity as well as cortical activity (ECoG) during different types of grasping, we examined how the CNS reorganizes its control of finger movements. Although grasping was initially disrupted, the monkeys showed substantial recovery within two months. Our findings suggest that recovery proceeds through at least two phases: an early phase that enables functional use of the transferred muscles, and a later phase in which a control strategy closer to the original one re-emerges. These results provide new insight into the multi-phase CNS adaptation underlying recovery after major changes in the musculoskeletal system.

Session 3: Speech and communication

Evidence for sensorimotor impairment in hyperfunctional voice disorders
Cara Stepp, *Boston University*

For the 30% of individuals who will develop a voice disorder across their lifetime, most will be diagnosed with a hyperfunctional voice disorder (HVD). Clinically defined by excessive and/or uncoordinated (peri)laryngeal

tension, these communication disorders result in symptoms related to speech production, including vocal effort, fatigue, pain, and even complete loss of voice. Although HVDs respond to behavioral voice therapy, long-term treatment responses are variable (8–10), with high recurrence rates (11,12). This mixed long-term success may be due to the near-exclusive focus of current therapies on musculoskeletal aspects of voice production. This talk will focus on potential mechanisms of HVDs driven by impairments in sensory and/or sensory-motor integration. We will discuss recent evidence for impaired sensorimotor function in HVDs from psychoacoustic studies, altered auditory feedback paradigms, and laryngeal kinematics inferred from high speed videoendoscopy. Combined, this evidence may motivate a paradigm shift for understanding the development and thus the treatment of HVDs.

Computational modeling of speech motor control – applications to clinical speech disorders
Srikantan Nagarajan, *University of California, San Francisco*

Speech production is a remarkable neural control process where the muscles of the vocal tract are activated in just the right manner to produce the intended message for a listener. Behavioral speech production responses to real-time auditory feedback alteration have been widely used to understand the mechanisms of speech motor control in typical speakers and in clinical populations. We have developed a computational model for speech motor control based on state feedback control (SFC) that can account for behavioral and neural processes in the control of pitch and speech formants. Combining computational modeling with Bayesian inference techniques helps us to understand behavioral speech data in clinical populations in terms of interpretable parameters of speech motor control models. In this talk, I will review our work on computational modeling of speech production, and illustrate how this approach helps us to understand speech behaviors in patients with cerebellar ataxia and laryngeal dystonia.

Non-invasive closed-loop brain-computer interface for the treatment of laryngeal dystonia
Kristina Simonyan, *Harvard Medical School & Massachusetts Eye and Ear Infirmary*

Laryngeal dystonia (LD) is a focal, task-specific dystonia that affects speaking but not whispering or emotional vocalizations. Therapeutic options for LD are limited. We developed and tested a non-invasive, closed-loop neurofeedback brain-computer interface (BCI) that provided visual feedback of individual real-time electroencephalographic (EEG) activity during symptomatic speaking compared to asymptomatic whispering. Over five consecutive days of intervention, patients used the personalized BCI to learn to modulate their abnormally increased brain activity during speaking and match it to near-normal activity during whispering. Compared with baseline, LD patients showed a statistically significant reduction in voice symptoms on Days 1-5 of the BCI intervention. This was paralleled by improved controllability of the visual neurofeedback and a significant reduction in left frontal delta power, including the superior and middle frontal gyri, on Day 1, and in left central gamma power, including the premotor, primary sensorimotor, and inferior parietal areas, on Days 3 and 5. The majority of patients (70%) reported sustained positive effects of the BCI intervention on their voice quality 1 week after the study participation. The closed-loop BCI neurofeedback intervention specifically targeting disorder pathophysiology shows significant potential as a novel treatment option for patients with LD and likely other forms of task-specific focal dystonia.

Finding the beat: Why timing matters in the neurorehabilitation of stuttering

Soo-Eun Chang, *University of Michigan*

Developmental stuttering is increasingly viewed as a disorder of speech motor timing. This presentation examines how beat-based timing—supported by the basal ganglia–thalamocortical (BGTC) circuit—differs in adults and children who stutter, and how disrupted neural oscillations may contribute to temporal discoordination within auditory–speech motor networks reported in stuttering. I will discuss how beat-based timing strategies and rhythmic entrainment using noninvasive brain stimulation may bypass unreliable internal timing cues to stabilize speech motor output. The talk will highlight ongoing and future work, including a novel beat-based rhythm training delivered through gameplay for children who stutter. Future intervention for stuttering will likely treat stuttering not only as a behavioral speech difficulty, but as a timing-based movement disorder that may benefit from a precision approach to help the brain “find its beat” through integrated neuroscience-informed interventions.

Individual and Team Abstracts

Tuesday April 21, 2026

08:00 – 10:00 Session 1, Panel I

The role of descending control systems in recovery after cerebral lesions: Insights from mice, primates, and humans

Vibhu Sahni [1], Nicolo Macellari [2], Eleni Sinopoulou [3], Monica Perez [4]
[1] Weill Cornell Medicine, [2] University of Pittsburgh, [3] University of California, San Diego, [4] Shirley Ryan Ability Lab, Northwestern University
Discussant: Elvira Pirondini

Descending cortical projections to the brainstem and spinal cord form the essential substrate through which the cortex shapes skilled movement. A central unanswered question is how reorganization within these circuits contributes to recovery after injury, and whether insights into their developmental and evolutionary origins can guide strategies to promote repair. However, emerging work across species now reveals how the organization of this circuitry diverges across mammals, raising new questions about how these differences shape motor control and recovery potential. Integrating these cross-species insights might allow us to infer the roles these pathways play in both the intact and injured CNS promoting the development of novel intervention and technologies. This symposium brings together new molecular, anatomical, and functional insights from mice, primates, and humans to refine our understanding of these descending projections in motor control and their role in recovery after cerebral damage.

Dr. Vibhu Sahni will present findings from the mouse that dissect how descending corticobrainstem and corticospinal pathways emerge during development, integrating molecular delineation, axonal anatomy, and circuit-level function. These developmental principles provide a framework for understanding both the consequences of early disruptions on movement control as well as the opportunities they provide for recovery after adult injury. Dr. Eleni Sinopoulou will then present findings comparing rodent and primate descending systems, highlighting conserved features as well as key species-specific divergences in connectivity that potentially shape motor capabilities and recovery potential. Finally, Dr. Nicolo Macellari and Dr. Monica Perez will turn the focus to evidence from primates and humans demonstrating how plasticity within corticofugal circuits supports functional recovery after cortical and spinal lesions, and how plasticity mechanisms within these networks can be leveraged to design more precise and effective therapeutic interventions to restore motor function.

Together, the talks will illustrate how a cross-species, developmental-to-clinical perspective on descending control systems can uncover fundamental principles of motor circuit organization and resilience, offering a framework to understand normal function and inform strategies for restoring function after injury.

10:30 – 11:05 Early Career Award Presentation and Talk

How reward sculpts human movement

Pierre Vassiliadis, *University College London & Imperial College London*

Movement, like perception and cognition, is fundamentally shaped by the pursuit of reward. Across species, reward is known to be a powerful modulator of action, guiding action selection, movement invigoration and reinforcing successful behavior. Most work on reward has leveraged decision-making paradigms, in which agents have to learn to select among a discrete number of actions through reinforcement. Yet growing evidence indicates that reward is also instrumental in tasks with richer motor demands, such as motor learning, where individuals refine movement kinematics through practice. Despite the clear potential of incorporating reward into motor rehabilitation, the precise behavioral and neural mechanisms by which reinforcement shapes motor learning remain underexplored.

In this talk, I will first present evidence that specific properties of reinforcement feedback such as its extrinsic value, timing, and the quality of concurrent sensory feedback profoundly influence how humans control, learn, and retain motor skills. I will also discuss the feasibility, efficiency, and constraints of delivering personalized reinforcement in real time during continuous motor control in healthy adults and patients with chronic stroke.

In the second part, I will present work investigating the causal role of the striatum in motor and reinforcement learning, using transcranial Temporal Interference Stimulation (tTIS)—a non-invasive method for deep-brain neuromodulation in humans—in combination with fMRI. In particular, I will discuss data supporting the causal involvement of specific striatal rhythms in reinforcement and sensory-based motor learning, and highlight their possible implications for neuropsychiatric disorders that impact the motor and reward systems. Overall, these results illustrate the breadth of mechanisms by which reward shapes movement and delineate the promise—as well as the potential limitations—of reward-based approaches to motor rehabilitation.

11:05 – 12:35 Session 2, Perspective I

The next frontier: Dissecting the middleware for movement using multi-neuronal recordings in the spinal cord

Kazuhiko Seki [1], Martyn Goulding [2], Aya Takeoka [3]
[1] National Center of Neurology and Psychiatry, [2] Salk Institute for Biological Studies, [3] RIKEN Center for Brain Science
Discussant: Simon Giszter

For more than a century, the field of sensorimotor control has aimed to clarify the organization of central nervous system circuits. The field is now entering a pivotal phase, as multiple research streams converge on the same conclusion: to move forward, we need large-scale recordings from spinal circuits during natural behavior.

This shift is driven by advances in molecular-genetic circuit dissection. Since Sherrington, spinal physiology has identified fundamental circuit modules using electrophysiological approaches. Modern genetic tools have now refined these modules with remarkable precision, enabling causal tests by selectively removing specific components. Transcriptomic profiling further reveals extensive cellular heterogeneity. Yet real-world behavior is clearly not governed by isolated modules but by their coordinated interaction. To understand what each module contributes—and how they work together—we need direct recordings during natural movement.

A similar momentum comes from population-level research in the cerebral cortex. Since Evarts, systems neuroscience has shown that individual cortical neurons regulate force, direction, and motor patterns. Recent advances in large-scale recording and computational analysis now link population dynamics to behavior. Yet cortical commands are rarely executed directly; most are routed through spinal circuits. Without understanding this spinal "middleware," long treated as a black box, we cannot fully explain motor control. Large-scale spinal recordings in behaving animals will therefore be essential.

In this session, we will discuss—together with the audience—how such recordings are beginning to revise long-standing textbook views of the neural control of movement, drawing on the speakers' recent experimental findings and their implications.

The session will open with Kazuhiko Seki outlining the motivation and historical context of this Perspective session, followed by his latest experimental results showing how spinal interneuron dynamics are differentially recruited during rat and monkey reaching, depending on various movement parameters. Martyn Goulding will then discuss how sensory information that is used to control movement is represented in the spinal cord and brainstem, followed by Aya Takeoka's talk demonstrating how the multiunit activity recorded from the spinal cord opens new avenues for the circuit mechanisms underlying movement adaptation and learning. The session will conclude with a discussion led by Simon Giszter, exploring—with audience participation—how the spinal cord serves as a "middleware" for the sensorimotor control and motor learning, and what new insights are emerging from this line of research.

15:25 – 17:05 Session 4, Individual I

O1.1 - An output-null neural manifold for planning-on-the-fly during free manual control

Nicolas Meirhaeghe [1], Julio Rodino [2], Shrabasti Jana [3], Lucio Condro [3], Frédéric Barthélemy [3], Junji Ito [2], David Dahmen [2], Alexa Riehle [1], Sonja Grün [4], Thomas Brochier [1]
[1] CNRS, [2] Institute for Advanced Simulation (IAS-6), Jülich Research Centre, [3] Aix-Marseille University, [4] Institute for Advanced Simulation (IAS-6) Jülich Research Centre
Presenting Author: **Nicolas Meirhaeghe**

Studies of the neural basis of motor planning have largely focused on scenarios in which a single movement is specified in advance and prepared “offline” prior to execution. However, much of natural behavior cannot be reduced to a sequence of discrete, preplanned steps. Instead, everyday actions unfold as a continuous stream of movement that is controlled “online,” updated in real time as errors are detected and goals evolve. This raises two key unresolved questions for the field of motor control: How are unconstrained, naturalistic actions planned at the neural level, and do offline and online planning rely on shared neural principles?To address these questions, we analyzed motor cortical population activity from two macaque monkeys trained to perform both offline- and online-prepared reaches to visual targets. In both tasks, animals initiated behavior with a center-out reach to a randomly chosen peripheral target. They were then either (1) free to reach the remaining simultaneously presented targets in any order (unconstrained task), or (2) required to follow a sequence imposed by targets that appeared one at a time (constrained task).In the constrained task, we first replicate and extend classical findings: preparatory activity associated with offline planning of center-out reaches is (1) low-dimensional, (2) expressed in output-null dimensions forming a preparatory subspace, and (3) organized as direction-specific preparatory states lying on a circular manifold. We then show that this manifold is preserved across different initial hand positions and generalizes to any reach direction planned offline within sequences of the constrained task. This invariance suggests that the manifold provides a substrate for context-independent encoding of reach direction—analogous to the ring-like structure observed in the mammalian head-direction system.Crucially, we demonstrate that this same manifold is re-engaged during the unconstrained task, when movements are planned online and continuously updated. The strongest evidence for such reuse comes from our ability to predict upcoming reach direction hundreds of milliseconds in advance during free movement, using only activity projected onto the manifold defined from the center-out preparatory epoch. We further confirm that this predictive signal reflects genuine planning rather than motor execution: although hand trajectory can also be decoded from the execution subspace, these signals exhibit systematically shorter temporal lags than predictions derived from the orthogonal preparatory subspace.Together, these results provide a unified view of how motor cortex supports both discrete and continuous action planning. They reveal shared neural mechanisms underpinning offline and online planning and offer new opportunities for leveraging invariant preparatory structure to design more robust and efficient brain–machine interface decoders suited for naturalistic movement.

O1.2 - Neural population geometry underlying sequential reach in the macaque motor cortex

Di Zhu [1], Tianwei Wang [2], Yu-Qi You [1], Yao Chen [1], He Cui [3], Ru-Yuan Zhang [1]
[1] Shanghai Jiao Tong University, [2] Lin Gang Laboratory, [3] Chinese Institute for Brain Research, Beijing(CIBR)
Presenting Author: **Di Zhu**

Natural motor behavior relies on the smooth concatenation of discrete actions. When generating multiple actions in sequence, the motor cortex must encode not only the physical features of each action (e.g., reach direction) but also integrate them into a coherent behavioral sequence. Previous studies

have proposed three distinct hypotheses regarding how sequencing influences neural representations of individual actions. The competition hypothesis suggests that representations of adjacent actions interfere with one another due to increased cognitive load or limited neural resources. In contrast, evidence for coarticulation in some motor tasks indicates that blending actions into a sequence actually enhances the representation of each component. A third account, the independence hypothesis, posits that individual actions are generated separately and thus sequencing should not alter individual's neural encoding. However, these competing hypotheses have not been systematically tested at the neural population level.Here we analyzed population activity from the primary motor cortex of two rhesus macaques (monkey C: 118 units; monkey G: 44 units, Utah array) performing a sequential reaching task. The task was a variant of the center-out delayed-reach paradigm and included both single-reach (SR) and double-reach (DR) trials. In SR trials, one target was presented, followed by a random delay, after which the monkey executed one reach. In DR trials, two targets were presented and remembered, and the monkeys executed two reaches sequentially without an inter-movement pause. Comparing neural activity between SR and DR trials allowed us to examine how planning and executing a subsequent action influences the neural representation of the first action.We report three main findings. First, decoding accuracy for the first reach direction in the DR condition was significantly higher than that in the SR condition throughout most of the preparatory and execution periods. This enhancement indicates that planning an additional action strengthens the representation of the first action, consistent with the coarticulation hypothesis. Second, neural population geometry revealed that improved representations arose from increased separation between manifolds corresponding to different reach directions, driven by systematic tuning changes at the single-neuron level. Third, population subspace analyses showed that this manifold separation originated primarily within the preparatory subspace rather than the execution subspace. In addition, analyses of single-neuron responses uncovered several nonlinear tuning modulations that further contributed to the strengthened population representation.These results provide direct neural evidence supporting the coarticulation hypothesis in the coding of sequential actions. Our findings also highlight the importance of examining neural population geometry to understand how action sequencing can enhance the encoding of individual movements in the motor cortex by optimizing neural resources.

O1.3 - Disrupting PnC activity impairs skilled hand reaching and grasping in non-human primates

Yiping Sun [1], Reona Yamaguchi [1], Tadashi Isa [1]
[1] *Kyoto University*
Presenting Author: **Yiping Sun**

Dexterous finger control is important for daily hand functions in nonhuman primates and humans. Maintaining balanced muscle strength and tone is necessary for precise finger coordination, but its control mechanisms are less clear compared to the mechanisms of individual finger movement, primarily attributed to the corticospinal tract. Recent evidence suggests that reticulospinal neurons (RSNs) play a critical role in this process.In this study, we recorded single-unit activity in two healthy Macaca fuscata to localize startle-reaction neurons, presumably RSNs, in the caudal pontine reticular formation (PnC). The

identified location was consistent with previous studies. Based on this anatomical information, we manipulated the RSNs by microinjections of muscimol, a GABAA receptor agonist, into the PnC to investigate their contribution to hand dexterity. To quantify the behavioral effects of PnC inactivation, we developed a markerless 3D kinematic reconstruction pipeline based on DeepLabCut™, enabling frame-by-frame extraction of multi-joint kinematics of the index finger and thumb—including joint angles, fingertip trajectories, and apertures—during natural reach-and-grasp tasks.Transient inactivation of the PnC produced clear impairments in hand dexterity without overt changes in overall posture. Across grasp types, monkeys showed significantly prolonged grasping time, distinct aperture modulation patterns across individuals, and compromised thumb–index coordination. Although the two monkeys adopted different natural grasping strategies, both exhibited task-dependent abnormalities in aperture control during the pre-shaping phase. To determine whether these differences reflected a shared deficit, we applied dynamic time warping (DTW) to all time-varying joint angles and apertures. Increased DTW distances reflected lower similarity between movement time-series. Following muscimol injection, both monkeys exhibited significantly greater DTW distances, indicating that PnC inactivation disrupted finger coordination during grasping.These findings suggest that PnC neurons contribute to fine finger control by regulating the coordinated activation of finger muscles. Future physiological studies will further elucidate the role of RSNs in sensorimotor integration and brainstem contributions to dexterous motor control.

O1.4 - Deep brain stimulation of the motor thalamus alleviates post-stroke upper-limb motor deficits

Arianna Damiani [1], Nicolo Macellari [1], Mel Xu [1], Miles Uribe [1], Lucy Liang [1], Catherine Jezerc [1], Jordyn Ting [1], Sirisha Nouduri [1], Erinn Grigsby [1], Lilly Tang [1], Marco Capogrosso [1], Jorge Gonzalez-Martinez [1], Elvira Pirondini [1]

[1] *University of Pittsburgh*

Presenting Author: **Arianna Damiani**

Stroke is among the leading causes of permanent disability in the United States, affecting approximately 795,000 people each year. Infarcts mostly damage subcortical areas, thus interrupting long-range connections between cortical and spinal centers that regulate movements, i.e., the corticospinal tract (CST). Consequently, humans with stroke invading the CST suffer from the most severe and permanent upper-limb motor deficits, including loss of strength and dexterity. Despite the large population size of affected individuals, intense physical therapy remains the only significant intervention with limited impact on moderate to severe paresis. Therefore, novel and effective therapeutic approaches are necessary. We previously demonstrated that Deep Brain Stimulation targeting the motor thalamus (mThDBS), a subcortical region with direct excitatory projections to the motor cortex, facilitates residual CST axons and consequently increases motor output in anesthetized monkeys. Yet, whether motor thalamus stimulation leads to functional improvements for post-stroke hemiparesis remains unclear. Here, we hypothesized that mThDBS increases the excitability of the CST also when voluntarily activated to perform a movement and thus alleviates post-stroke upper-limb motor deficits. To test this hypothesis, we trained n=2 monkeys to perform a battery of tasks to measure hand and arm dexterity and strength. We then performed a controlled thermocoagulation of the CST inducing chronic stroke

with moderate upper-limb paresis. We also implanted a DBS electrode in the motor thalamus and assessed behavioral performances and kinematics with and without DBS, both in subacute and chronic stages. Following the CST thermocoagulation, the monkeys developed hallmark post-stroke motor symptoms, including mild loss of arm dexterity, and moderate loss of finger and hand control. mThDBS immediately facilitated 3D arm and finger control, as evidenced by higher task success rate and improvement in several kinematic variables, such as velocity, joints range of motion and endpoint precision. Finally, we replicated these results in n=1 human patient with post-stroke hemiparesis, who received a temporary DBS implant in the motor thalamus and was stimulated for 4 weeks, 2h per day during motor tasks. Our intervention led to immediate improvements in strength across multiple joints, increased dexterity and range of motion. Notably, electrophysiological testing confirmed enhanced corticospinal excitability after only 4 weeks of DBS, as evidenced by the emergence of transcranial magnetic stimulation-induced motor evoked potentials in the forearm muscles. Importantly, we also observed clinically relevant improvement in clinical scales (+8 points in Fugl-Meyer). These findings demonstrate for the first time the potential of motor thalamus DBS to alleviate motor symptoms developed after stroke and pave the way towards novel therapies for upper-limb hemiparesis.

O1.5 - Behavioral and neural determinants of speech motor memory

Nishant Rao [1], Rosalie Gendron [2], Timothy Manning [2], David Ostry [2]
[1] Yale University, [2] McGill University
Presenting Author: **Nishant Rao**

In speech motor behavior, the involvement of auditory and somatosensory streams offers a unique opportunity to probe the relationship between sensory inputs and motor output. In this study, we sought to determine the behavioral and neural underpinnings of speech motor memory using speech formant frequency perturbation as a model task to induce motor learning. Akin to a visuomotor reach adaptation task, the speech formant perturbation task records formant frequencies (constituents of vowels in any language) via a microphone, alters the first formant frequency, and plays back the modified speech in real time to the participants via headphones. When subjected to several such trials, participants learn to compensate for the perturbed formant frequency by shifting the first formant in their speech output in an opposite direction. In a first experiment (n=14), we show that this speech motor learning paradigm enables participants to produce new speech movements leading to speaking a new vowel, which is sufficiently different from the well-learned vowels. In a second experiment (n=58), participants first performed the speech motor learning task and returned either 8- or 24-hours later for retention assessment. We find that the newly acquired motor memory is substantially retained for at least 24 hours post learning. The retention is similar to that when probed 8 hours following learning, and with abrupt or gradual formant shifts. Importantly, the memory was retrieved only when speech feedback was available, but not in presence of noise feedback, highlighting the context dependence of the speech motor memory upon presence of speech feedback. In a third experiment (n=60), the neural underpinnings of speech motor memory were investigated by separately disrupting either the primary motor, somatosensory, or auditory cortex using continuous theta burst transcranial magnetic brain

stimulation (cTBS). Participants first underwent the speech motor learning task, immediately after which they received cTBS, and returned 24 hours later for retention assessment. We found that disruption of either auditory or somatosensory cortex impaired the retention of speech motor memory. In contrast, retention following disruption of motor cortex was not different than a no-TMS control, indicating the causal involvement of sensory cortex in retaining speech motor memory. Taken together, the study documents the behavioral and neural underpinnings of speech motor memory and underscores the relationship between sensory inputs and motor output when both auditory and somatic sensory streams are involved in guiding motor behavior.

Wednesday, April 22, 2026

08:00 – 10:00 Session 5, Panel II

Reinforcement learning of motor skills

Adrian Haith [1], Nidhi Seethapathi [2], Eric Yttri [3], Alexander Mathis [4]
[1] Unaffiliated, [2] Massachusetts Institute of Technology, [3] Carnegie Mellon University, [4] EPFL
Discussant: Jörn Diedrichsen

Humans can learn to perform a seemingly limitless array of complex motor skills. But how are we able to learn these skills? This panel will explore reinforcement learning as a potential theoretical framework for understanding learning of new motor skills. Existing computational theories of learning are largely founded on principles of supervised learning, appealing to notions of internal models and error-driven learning. Such theories account very well for short-term adaptation of existing behaviors, but don't seem to account for how we learn new motor skills over timescales of days, weeks or months. A lot of work has examined reinforcement-based learning in operant-learning paradigms and in simple, adaptation-like tasks, and it has often been proposed that reinforcement learning may play an important role in more challenging forms of motor learning, but few concrete theories have been proposed. Meanwhile, the robotics community has leveraged reinforcement-learning-based approaches to power remarkable advances in recent years. This panel will present emerging work examining how these same approaches can be applied to understand biological learning. The panel will describe key ideas and approaches used in modern RL, and show how they can be applied to model biological learning. Adrian Haith will introduce policy-gradient reinforcement learning, a simple and widely-used model-free method, and show how this can account for dynamics of learning through practice over thousands of trials across a range of motor learning tasks. Nidhi Seethapathi will extend these ideas to consider reinforcement learning in continuous control settings, focusing on the interplay between exploration and stability during locomotor learning. Eric Yttri will provide causal evidence from animal studies demonstrating how cell types within the basal ganglia exert continuous control through policy-based RL across a range of motor tasks. Alexander Mathis will argue that, despite advances in RL, insights from psychology are currently necessary to learn skills with high-dimensional musculoskeletal models, and will furthermore illustrate what can be concluded about biological motor control from these models. We will conclude with a panel discussion in which we will consider the feasibility and scope of reinforcement learning as a theoretical framework for understanding motor skill learning in

humans and animals, potential underlying learning mechanisms, and challenges associated with learning complex repertoires of skills through reinforcement learning.

10:30 – 12:10 Session 6, Individual II

O2.1 - Network features underlying motor learning and skill generalization in marmosets

Samantha Johnson [1], Jeffrey Walker [2], Nicholas Hatsopoulos [1]
[1] *University of Chicago,* [2] *Yale University*
Presenting Author: **Samantha Johnson**

Motor skill learning occurs across multiple timescales, yet most studies focus on short-term adaptations within single-session learning paradigms. Consequently, the network-level mechanisms underlying long-term skill acquisition remain poorly characterized. Emerging rodent work suggests that connectivity dynamics may pass through distinct phases during extended learning periods but has not been extensively examined with primates. Moreover, it is unclear how these network dynamics support generalization, the process by which previously acquired skills are adapted to new but related task contexts. The neural basis of generalization, especially across multiple interconnected sensorimotor areas, remains largely unknown.In this study, we trained marmosets on two sequential motor tasks requiring similar behavioral profiles. In the first task, animals performed a reach–grasp–carry movement toward a static food reward, reaching asymptotic performance over two weeks of daily exposure. We then introduced a more complex version of the task in which the target moved dynamically, requiring animals to generalize previously acquired movement strategies to a new context. Faster learning in the dynamic as compared to the static version of the task provided behavioral evidence of generalization. Throughout both tasks, we wirelessly recorded neural activity from chronically implanted Utah arrays spanning dorsal premotor, primary motor, and somatosensory cortices in unrestrained animals. Using spike timing of simultaneously recorded single units, we constructed functional networks to capture changes in sensorimotor connectivity over learning and generalization.We found that functional networks exhibited structured, biphasic changes across weeks of learning. Trial-to-trial network variability started high, consistent with exploration, decreased during the early stages of initial skill acquisition, and then increased as the skill consolidated. When animals transitioned to the dynamic task, we saw a return to variability, mirroring the early learning phase of the first task. These findings suggest that motor cortex and broader sensorimotor networks become heavily structured during the early phase of long-term learning, but may reduce their engagement after a skill becomes stable. Importantly, generalization appears to rely not on modifying an existing stable connectivity pattern but on reinstating a variability-rich network state. This indicates that generalization recruits similar neural mechanisms as initial skill acquisition rather than simple adaptation of an established motor program.Together, this work provides rare long-timescale, multi-area recordings in a primate model and reveals network-level signatures of exploration, consolidation, and generalization. These results highlight how sensorimotor connectivity reorganizes across sequentially acquired skills and motivate further comparison of functional network structure during expert phases of related behaviors.

O2.2 - Distinct premotor and motor cortical population dynamics support adaptive control in brain-machine interfaces in nonhuman primates

Alessia Sepe [1], Ophelie Saussus [1], Sofie De Schrijver [1], Irene Caprara [2], Renaud Detry [1], Pinhao Song [1], Thomas Decramer [3], Peter Janssen [1]
[1] Katholieke Universiteit Leuven, [2]Massachusetts General Hospital, [3] Universitair Ziekenhuis Leuven
Presenting Author: **Alessia Sepe**

Motor brain-machine interfaces (BMIs) translate cortical activity into device control, offering a platform not only for restoring movement but also for investigating the neural principles underlying motor behavior. Although natural action requires rapid adjustments to changing environmental conditions, most BMI paradigms rely on simple, unperturbed movements, leaving the neural basis of adaptive control unsolved and limiting the development of more flexible motor BMIs. Here we recorded neural activity from primary motor cortex (M1), ventral premotor cortex (PMv), and dorsal premotor cortex (PMd) using three 96-channel Utah arrays in three macaques performing BMI-control in a 3D virtual environment in Unity. Monkeys guided a sphere toward one of five distant targets using the neural activity of all three areas, with trials occasionally including two environmental perturbations, obstacle appearance and target displacement. In obstacle appearance trials, an obstacle appeared unpredictably in half of the trials, midway between the starting point and the target location, and the monkeys had to move the sphere around this obstacle to reach the target. In target displacement trials, the target changed location in half of the trials when the sphere was at one third of the distance to the target. We quantified firing rates and across-unit variance within the subpopulation of units directly used by the BMI decoder (based on Preferential Subspace Identification) to determine how each area contributes to online corrective control. M1 activity was largely unaffected by the presence or type of perturbation. By contrast, both PMv and PMd exhibited marked reductions in across-unit variance early after the perturbation, indicating increased population-level coherence during adaptive control. Notably, PMv responses decreased for both perturbation types, whereas PMd showed enhanced responses selectively in target displacement trials.These findings demonstrate that adaptive visuomotor control in BMIs relies predominantly on premotor circuits, with PMd playing a specialized role in updating movement plans when goal locations shift. M1 contributes minimally to early perturbation processing, consistent with a division of labor in which premotor areas compute corrective commands that M1 implements downstream. This framework provides a foundation for designing BMIs tailored to flexible, real-world motor behavior.

O2.3 - Linking neural control and muscle mechanics: Feedforward and feedback contributions in healthy and neuropathic balance control

Hansol Ryu [1], Surabhi Simha [2], Gregory Sawicki [1], Lena Ting [2]
[1] Georgia Institute of Technology, [2] Georgia Institute of Technology & Emory University
Presenting Author: **Hansol Ryu**

Effective control of perturbed movement relies on the interplay between feedforward and feedback control. Computational models are needed to dissociate their respective contributions to perturbed movement control because they are difficult to separate experimentally. Standard Hill-type muscle models, though useful for steady-state force estimation, may lead to inaccurate simulated neural control strategies as they miss critical transient behaviors such as short-range stiffness (SRS). As shown previously [1], Hill-type models without SRS predict unrealistically large initial movements before corrective activity engages, limiting interpretations of neural control in health and impairments.To develop a mechanistic simulation of perturbed movement, we incorporated a 3-state cross-bridge model [2] into a closed-loop inverted pendulum system. Our muscle model under baseline activation reproduces rapid, history-dependent force rise observed in single fibers during stretch [3], but its implications for perturbed movement control have not been explored. We coupled agonist-antagonist muscle pair to an inverted pendulum and simulated responses to sudden translational perturbations. Both muscles were controlled with feedforward tonic activation, modulated by fiber length, velocity, and acceleration feedback with delays.Cross-bridge mechanics markedly reduces initial displacement compared to Hill-type models due to SRS. Simulations reproduce the rapid, SRS-driven rise in joint torque at perturbation onset, followed by a distinct initial burst and plateau in muscle activation from sensorimotor feedback, as observed in cats and humans [4,5]. The model also captures sensory neuropathy signatures: removing velocity and acceleration feedback causes loss of balance, as in acute neuropathy, while restoring partial feedback yields large excursions, diminished initial bursts and increased co-contraction, consistent with chronic neuropathy in cats [5].Our novel biophysical muscle model in a closed-loop simulation dissociates feedforward and feedback contributions to perturbed balance control, incorporating SRS tuned by feedforward co-contraction. Because SRS naturally emerges from cross-bridge dynamics under baseline activation rather than being phenomenologically imposed, the model can be applied to different tasks such as reaching and walking. This framework allows for better understanding of muscle–neural interactions in perturbed movement control and may help generate hypotheses about how movement is controlled in health and altered in conditions like neuropathy, aging, fatigue, or disease. [1] De Groote F, Allen JL, Ting LH. (2017) J. Biomech. [2] Campbell KS. (2014) J. Gen. Physiol. [3] Horslen, BC., et al. (2023) J. Exp. Biol. [4] Jakubowski, KL, et al. (2025) J. Neurophysiol. [5] Lockhart, DB., Ting, L. H. (2007) Nat. Neurosci.

O2.4 - Cerebellar signals to the motor cortex link preparation to execution of voluntary movements

Nirvik Sinha [1], Ora Ben Harosh [1], Henn Kramer [1], Ran Harel [2], Julius Dewald [3], Jonathan Kadmon [1], Yifat Prut [1]

[1] Hebrew University of Jerusalem, [2] Tel Aviv University, [3] Northwestern University

Presenting Author: **Nirvik Sinha**

Performing rapid, coordinated, and accurate voluntary movements relies on predictions that guide movements before sensory feedback can be used. The cerebellum is essential for calculating these predictive signals based on efferent copies of motor commands and a forward internal model. Although this view emphasizes the role of the cerebellum in the initial phase of movements, recent studies have

shown cerebello-thalamo-cortical interactions as early as the movement preparation period. This suggests that cerebellar predictions may already shape emerging motor commands during planning. To test this hypothesis, we trained two monkeys to perform center-out delayed reaching movements on a vertical touchscreen. During task performance, we reversibly disrupted cerebellar output using high-frequency (130 Hz) stimulation of the superior cerebellar peduncle while recording muscle and neural activity. Neurons were sampled using high-density linear probes inserted into the task-related regions of the primary motor (M1) and premotor (PM) cortices. Blocking the cerebellar outflow altered motor behavior, leading to delayed onset ($p<0.001$), diminished peak speed ($p=0.013$) and increased variability in hand position ($p<0.001$). At the neural level, cerebellar block produced changes in the structure of preparatory activity, including a rotation of the preparatory subspace away from the control condition (45% alignment, $p< 0.001$) and an increase in its dimensionality ($p<0.001$). These results indicate an impaired pattern of inter-neuron coordination, with effects emerging earlier in PM than in M1. Next, we examined changes in the predictive power of the preparatory state under these conditions. To this end, we used reduced rank regression on the single-trial data to identify the low dimensional linear mapping linking the neural activity during preparation to that of execution. Cerebellar block increased the dimensionality of this mapping (quantified as the minimum rank needed to reach the R^2 asymptote of the full rank regression, $p=0.021$) even though its capacity to predict the execution-related activity was reduced (i.e., lower R2, $p = 0.004$), indicating a less efficient transformation of the preparatory state into movement-related activity. Consistent with this impaired mapping at the neural level, cerebellar block markedly reduced the ability of preparatory activity to predict movement kinematics (peak speed and hand position; $p < 0.001$), whereas the prediction of these parameters from execution-related activity was unchanged ($p = 0.286$; $p = 0.979$). This indicates that cerebellar signals primarily support the transformation of preparatory neural states into accurate movement plans rather than their execution. Taken together, our findings show that cerebellar predictive signals relayed through motor thalamus play a dual role in controlling voluntary movements. First, these signals are necessary for organizing the structure of preparatory dynamics in the motor cortex. Second, these signals play a critical role in sustaining the mapping that links preparation to execution and carries kinematic information essential for accurate and timely multi-joint reaching.

O2.5 - Cereballar circuits anticipate dopamine rewards

Benjamin Filio [1], Mark Wagner [2]
[1] *National Institute of Neurological Disorders and Stroke,* [2] *National Institutes of Health*
Presenting Author: **Benjamin Filio**

Theories of motor control, especially skill acquisition and reward-driven motor learning, place heavy emphasis on the role of cortical and striatal circuits, while the cerebellum is most famous for motor adaptation and refining movements. Extensive evidence demonstrates that the cerebellum is functionally interconnected with cortical and striatal circuits, highlighting a need to update brain-wide computational frameworks. The cerebellum is also causally involved in functions traditionally ascribed to forebrain and midbrain, one of these functions being reward-based motor learning. Cerebellar circuits

can predict rewards such as food and water, but it is unclear whether the cerebellum also encodes reward outside of conditions where (1) the reward satisfies homeostatic craving and (2) when a physical action is required to consume the reward. Here, we developed a reward-driven operant task where mice pushed a lever to receive dopamine (DA) self-stimulation, which was either optogenetic activation of DA neurons in the ventral tegmental area or electrical activation of the medial forebrain bundle. This satisfies the requirements to answer our questions: first, the mice did not need to physically consume a reward, disentangling neural representations of reward from consummatory movements. Second, the reward was temporally delayed, allowing us to separate reward predictive signals from neural representations of action. Third, the stimulation paradigm was surgically, genetically, and optically compatible with two-photon cerebellar imaging. Mice performed robustly for both types of DA reward. In expert mice, 22% of GrC continually ramped up activity for a 1-s delay between push and expected DA reward. Further, 65% of CFs spiked with short latency when DA stimulation occurred. When we subsequently trained mice on a 2-s delay, we observed 31% of individual GrCs "stretched" their activity profiles to match the expected time of DA release. When we trained mice sequentially with water reward either preceding or following DA reward, both rewards elicited similar population GrC and CF representations. Individually, 32% of GrCs had significantly correlated activity between water and DA, while 33% of CFs activated similarly for water and DA. Causally, mice learned operant reinforcement to push for CF optogenetic activation, with GrCs anticipating the predicted self-stimulation. Finally, inhibiting GrC activity in the delay period between push and DA reduced operant task performance, push quality, and motivation compared to control mice. We detail that previously characterized GrC-CF computations for homeostatic reward also extends to direct mesolimbic dopamine stimulation, displaying the cerebellum uses a general computation to link motor programs to expected rewards. This broadens the involvement of cerebellum in brain-wide computational networks involved in sensorimotor behavior and motor control.

15:00 – 17:00 Session 8, Panel III

Hierarchical control of pattern generation: A comparative perspective

Arkarup Banerjee [1], Britton Sauerbrei [2], Daniela Vallentin [3], Gregg Castellucci [4]
[1] Cold Spring Harbor Laboratory, [2] Case Western Reserve University School of Medicine, [3] Max Planck Institute for Biological Intelligence, Germany, [4] University of Rochester
Discussant: Andrew Pruszynski

The control of voluntary movements (e.g., reaching) is modeled as a top-down process in which cortical commands are filtered through spinal networks to determine motor output. Behaviors like speech, singing, and locomotion, however, require bidirectional coordination between higher brain areas and subcortical circuits which can generate motor patterns independently. In this session, we explore such coordination in a range of vertebrate species and behaviors.

Arkarup Banerjee, using the singing mouse, will discuss how motor cortex hierarchically interacts with brainstem pattern-generator circuits to control vocal production. Using circuit perturbations, electrophysiological data, and computational modeling, he will show that motor cortex activity adjusts song duration, while downstream circuits determine note-level features. These findings outline a systems-level framework illustrating how higher-level cortical controllers shape lower-level pattern generators to flexibly adapt behavior—a challenge shared by natural and artificial agents.

Daniela Vallentin, using the nightingale, will reveal a hierarchical mechanism by which temporal and spectral features are integrated during vocal matching. Wild nightingales show real-time pitch matching, and manipulating syllable duration shifts their own whistle durations toward the presented structure. When exposed to unnatural pitch–duration pairings, they flexibly trade off spectral and temporal imitation. A computational model formalizes this hierarchy, showing that syllable duration provides the temporal scaffold for pitch adjustments and shapes real-time matching behavior.

Gregg Castellucci will introduce a conceptual model of multi-effector action that places behaviors along a continuum from multitasking (simultaneous, competing actions) to unitary whole-body movements aimed at a single goal. He will discuss how sequential multi-effector behaviors across species—including speech and gesture in humans and wingspread displays in cowbirds—fit within this framework, and how different levels of the motor hierarchy and biomechanical factors contribute to their coordination. Finally, he will show how the kinematics of multi-effector actions can be used to infer their underlying planning and control strategies and illuminate their neural basis.

Britton Sauerbrei will discuss coordination between neural dynamics in motor cortex and the spinal central pattern generator (CPG) in mice performing an obstacle traversal task. Cortical dynamics consist of a large preparatory transient as the animal nears the barrier, oscillations driven by an efference copy from the CPG, and small, muscle-like signals resembling corticospinal commands. A simple model is then proposed which transforms inputs conveying obstacle proximity and locomotor phase into motor commands. These results reveal a regime in which higher brain areas must sculpt an ongoing, spinally-generated program to flexibly control behavior.

Thursday, April 23, 2026

08:00 – 10:00 Session 9, Panel IV

Motor abstraction in mind and brain: How abstract motor representations are learned, modified, and reused

Zekun Sun [1], Katja Kornysheva [2], Lucas Tian [3], Yuto Makino [4]
[1] Yale University, [2] University of Birmingham, [3] Rockefeller University, [4] National Institute of Information and Communications Technology
Discussant: Samuel McDougle

A violinist can move between instruments with only minor adjustment, a tennis player can switch rackets with little effort, and a child can draw the same shape using crayons, markers, or finger paint.

Our ability to generalize motor skills so efficiently suggests that the mind can encode actions in an abstract format — one that preserves their essential structure while freeing them from the constraints of specific muscle commands and contexts. This panel will present recent theoretical advances and empirical findings that significantly modify and extend beyond traditional accounts of motor abstraction.

First, Zekun Sun will present behavioral evidence showing that motor abstractions support novel skill learning at the very earliest stages of acquisition. Using a novel handwriting paradigm, Sun will show that the motor system recruits genuinely motoric, high-level representations that generalize across substantial kinematic variation.

Building on this theme of generalization, Yuto Makino will then introduce a new theoretical framework for how the motor system retrieves and applies learned skills across contexts. Makino shows that motor learning is best explained by representations organized around the relative phase of a movement, rather than absolute state or timing parameters.

Transitioning from behavioral to neural mechanisms, Katja Kornysheva will examine how skilled actions are constructed in real time. Kornysheva argues that behavioral fusion in memory-guided sequences cannot be taken as a proxy for neural fusion of sequential elements, but that skilled actions are dynamically assembled from coordinated interactions between motor, premotor, parietal, and hippocampal systems. This perspective highlights a flexible, distributed control architecture that can rapidly reorganize skilled actions as task demands evolve.

Finally, Lucas Tian will address how the brain represents and manipulates the symbolic building blocks of action. Using a compositional drawing task paired with large-scale neural recordings in macaques, Tian identifies neural populations that encode discrete, recombinable action symbols in premotor cortex, and neurons in preSMA that represent variables in grammatical rules. The structured population geometry of these signals explains macaques' capacity to generalize learned grammars.

Together, these four perspectives converge on a new understanding of motor abstraction as a transferable, flexible, dynamic, and generative phenomenon. Rather than relying on rigid templates or invariant schemata, the motor system appears to build actions from flexible symbolic units, modular neural components, and phase-based representations that support rapid learning, adaptive recombination, and robust generalization. This panel highlights how behavioral experiments, neural analyses, and computational modeling are reshaping foundational theories of how the brain constructs and generalizes skilled actions.

10:30 – 12:10 Session 10, Individual III

O3.1 - Understanding strategic sensorimotor adaptation as a process of hypothesis testing

Anjuli Niyogi [1], Elizabeth Cisneros [2], Wei Ding [3], Richard Ivry [4], Jonathan Tsay [1]
[1] Carnegie Mellon University, [2] University of California, Berkeley, [3] Tsinghua University, [4] University of California
Presenting author: **Anjuli Niyogi**

Picture a surgeon, mid-procedure, suddenly forced to switch from a trusted instrument to an unfamiliar one. In that moment, success—or catastrophe—hinges on the ability to rapidly adapt to the new tool's weight and dynamics. This capacity for motor adaptation is fundamental to human competence, allowing us to adjust to changes in our bodies (e.g., injury) and environments (e.g., novel tools). Indeed, motor adaptation emerges from multiple learning processes—some implicit and automatic, others explicit and strategic—that jointly enable flexible, goal-directed behavior.

For decades, motor learning research has largely revolved around the mechanisms supporting implicit adaptation. The dominant computational account, the error reduction model, casts adaptation as a gradual, trial-by-trial minimization of motor error. This framework has captured many core phenomena of implicit motor adaptation and has guided extensive work identifying the cerebellum as its core neural substrate.

However, the processes underlying strategic motor adaptation remain largely unknown. To close this gap, we developed a psychophysical paradigm that isolates strategic adaptation and measures the full two-dimensional structure of participants' movements (via an unconstrained x–y workspace). This approach uncovers a striking pattern: although group-averaged behavior looks gradual, individuals produce large, diverse, and highly structured errors before a sudden insight that brings performance into a stable solution space. These idiosyncratic learning functions contradict the smooth, incremental learning predicted by Error Reduction, pointing to a qualitatively different process.

We propose a new computational account in which strategic adaptation arises from learners generating, evaluating, and revising causal explanations for their motor errors (e.g., rotation, translation, reflection), and devising strategies to counteract the inferred perturbation. Our model accounts for a broad range of strategic phenomena across diverse perturbation types (rotations, reflections, gain changes). The model outperforms leading alternatives in the motor-learning literature (error reduction, reinforcement-learning models, win–stay/lose–shift heuristics, "moment-of-insight'') in capturing individual learning functions.

Moreover, the model reveals how uncertainty in feedback—symbolic feedback offering abstract, numeric guidance vs. sensory feedback offering precise, location-based information—attenuates strategy discovery. Additionally, it can also explain how environmental structure (e.g., target arrangement) biases learners toward specific hypotheses, producing dramatically different motor-error distributions. It also provides a mechanistic account of why strategic adaptation deteriorates in both healthy and pathological aging. Finally, we discuss how, in more complex sensorimotor tasks (e.g., riding a bicycle), the relevant hypotheses may extend beyond geometric primitives to other conceptual primitives. Altogether, these findings define a new, unifying theory of how humans discover successful sensorimotor strategies, bridging action closer to cognition.

O3.2 - Cortex-dependent motor control can be learned from subcortical demonstration

Jason Keller [1], Joshua Dudman [2]
[1] *HHMI Janelia Research Campus,* [2] *Howard Hughes Medical Institute*
Presenting Author: **Jason Keller**

Motor control in mammals is traditionally viewed as hierarchical, with the frontal cortex at the top. This framework suggests that cortex learns to control subcortical circuits through trial-and-error, a process that is both inefficient and inconsistent with the rapid contextual learning observed with innate behaviors. To address this, we studied cortical and subcortical interactions as head-fixed mice learned contextual control of a hindlimb extension motor primitive. Naïve mice performed reactive extensions to a cold air stimulus within seconds and, using predictive cues, learned to avoid the stimulus altogether in tens of trials. Using 3D kinematic tracking, we show that while extension movements were remarkably consistent across avoidance learning, predictive avoid extensions were subtly slower than reactive ones, reminiscent of cortically-controlled motor preparation. We thus examined the cortical dependence of hindlimb extension using intermittent local optoinhibition of the frontal cortex and found that it prevented avoid but not react extensions. However, mice with such inhibition on every trial easily adapted to this perturbation, suggesting distributed cortical control of the contextual, predictive extensions. To test this, we also inhibited the majority of the dorsal cortex using a novel “acute optogenetic decortication” and found that this perturbation could indeed inhibit all avoid extensions when applied on every trial, but still left reactive extensions intact with only minor posture changes. Surprisingly, though, when we released mice from this decortication on every trial, we observed an immediate appearance of avoid trials, indicating that mice can “covertly” learn to use predictive cues to elicit avoid extensions, even in the absence of any prior cortically-mediated avoidance experience. Simultaneous Neuropixels recordings in several brain areas confirmed the extent of optogenetic inhibition and were consistent with distributed control of hindlimb extension movements and widespread motor corollary activity. Furthermore, they revealed that avoid extensions were marked by persistent cue activity in the frontal cortex that was linearly separable from movement-related activity. These findings support a distributed cortical-subcortical, heterarchical control logic in which the frontal cortex can learn contextual, predictive motor control from subcortical demonstration of innate motor primitives.

O3.3 - Coordinated spinal locomotor network dynamics emerge from cell-type-specific connectivity patterns

Frank Wandler [1], Benjamin Lemberger [1], James Murray [1], David Mclean [2]
[1] University of Oregon, [2] University of Edinburgh
Presenting Author: **Frank Wandler**

Vertebrate locomotion is accomplished by rhythmic muscle activity that is generated and precisely coordinated by a dedicated neural circuit in the spinal cord, called the locomotor central pattern generator (CPG). Despite decades of research, how this rhythmic activity emerges from the locomotor CPG remains incompletely understood. Existing models tend to rely on local (often single-cell) oscillators to generate rhythmic activity, which is then patterned by network-level mechanisms. However, such models have not fully accounted for recent experimental results in zebrafish and other organisms that point to the importance of cell-type-specific intersegmental connectivity patterns and recruitment of speed-selective subpopulations of interneurons. To address these limitations, we develop a hierarchy of increasingly detailed models of the locomotor CPG in larval zebrafish that iteratively incorporate these observations. Surprisingly, in these models, rhythmogenesis occurs at the network level, without the need for local oscillators. In particular, we find that coordinated locomotion emerges in an inhibition-dominated network in which connectivity is determined by intersegmental phase relationships among interneurons and variable-speed control is implemented by recruitment of speed-selective subpopulations. Further, while structured excitatory connections are not necessary for rhythmogenesis,

they are useful for increasing peak locomotion frequency, albeit at the cost of smooth interpolation between frequencies, suggesting a basic computational trade-off between speed and control. We verify these network-level mechanisms for rhythmogenesis by reproducing our results in a spiking model. Finally, by training the weights in the model using gradient descent, we find that hierarchical and modular connectivity motifs emerge as a solution to reproduce experimentally observed dynamics from intracellular recordings from various cell types. Our results establish a novel mechanistic understanding of rhythm generation and control in CPGs based on biologically-motivated connectivity motifs.

O3.4 - Cortico-subcortical dynamics underlying adaptive locomotion

Martin Esparza [1], Ioana Lazar [1], Catia Fortunato [1], Mostafa Safaie [1], Juan Gallego [2]
[1] *Imperial College London,* [2] *Champalimaud Foundation*
Presenting Author: **Martin Esparza**

Locomotion is a fundamental behaviour common to all animal species. As such, its neural underpinnings have been extensively characterized, with particular emphasis on spinal and brainstem circuits during stereotyped locomotion. Yet, the neural processes mediating adaptive locomotion, which likely involve higher-order cortical and subcortical areas, remain elusive.

To address this gap, we designed a task based on delivering rapid, unpredictable mechanical perturbations to head-fixed mice running on a spherical treadmill using 12 evenly distributed actuators. This allowed us to elicit a broad range of behavioural corrections, determined by the actuator's location and the animals' ongoing gait cycle. We recorded from sensorimotor cortices, downstream basal ganglia projections, and relay centres in the motor thalamus, while also collecting whole-body 3D kinematics.

To investigate the role of each region during adaptive locomotion, we projected their firing rates onto the dominant patterns of covariation to obtain region-specific latent dynamics. Linear decoders trained on these latent dynamics were able to classify the perturbation direction from all regions as well as from the kinematics. Yet, the peak decoding time was variable across brain regions, with the primary motor and somatosensory cortices leading downstream regions. Additionally, perturbations selectively increased inter-region interaction strength when compared to unperturbed running, with interaction peaks happening at different time shifts, suggesting "information flow" from primary motor to somatosensory cortex and then basal ganglia and thalamus.

To disentangle how sensory responses and motor corrections contributed to these results, we trained linear regressors to predict latent dynamics from kinematics (sensory encoding) and vice-versa (motor decoding). Primary motor cortex presented both the best encoding and decoding of limb kinematics in absolute terms. Although both types of predictions improved across all regions following a perturbation, the magnitude of this increase was region-specific. Particularly, motor cortex showed the largest improvement in predictive accuracy when encoding kinematics, while the downstream dorsolateral striatum and thalamus showed the largest increase in decoding kinematics.

Finally, as animals engaged in perturbed trials, decoding accuracy of kinematics from latent dynamics increased compared to a ~10 min pre-perturbation period. This marked improvement was accompanied by a region-specific change in the leading covariation patterns across neurons, which spanned directions nearly orthogonal in between these two periods. These observations suggest a shift in "control mode",

where adaptive locomotion recruits higher-order regions when facing unpredictable perturbations. Ongoing pharmacological manipulations will causally define these regions' contributions, shedding light on how sensorimotor cortical and subcortical interactions enable adaptive locomotion.

O3.5 - Dynamic whole-body fetal sensorimotor behavior captured by 4D Cine-MRI and musculoskeletal model

Hoshinori Kanazawa [1], Seiichi Morokuma [2], Yukiyo Shimada [2], Koji Sagiyama [2], Tatsuhiro Wada [3], Chiaki Tokunaga [3], Kei Nisikawa [3], Yuya Saito [3], Yasuo Kuniyoshi [1]
[1] The University of Tokyo, [2] Kyushu University, [3] Kyushu University Hospital
Presenting Author: **Hoshinori Kanazawa**

Spontaneous movements during the fetal period generate sensory feedback that is thought to contribute to the earliest organization of the human sensorimotor system. Animal studies demonstrate that twitch-like limb and body movements reliably trigger structured neuronal events in spinal and cortical circuits, shaping somatotopic organization and early coordination. However, in humans, the absence of methods for capturing whole-body dynamics has limited our understanding of how fetal movements give rise to structured sensorimotor interactions. Here, we developed an imaging–modeling framework that reconstructs dynamic whole-body fetal behavior from 4D Cine-MRI and quantifies the resulting patterns of joint motion, posture transitions, and multimodal sensory feedback.

We acquired multi-slice 4D Cine-MRI from third-trimester fetuses and spatially and temporally concatenated the volumes to generate continuous motion sequences. Manual annotation of approximately 1% of frames provided fetal body and uterine boundaries, and automated segmentation propagated these labels across the full dataset. A subject-specific musculoskeletal fetal model was fitted to the segmented surfaces using robust Chamfer-distance–based registration, enabling estimation of 3D joint angles, posture trajectories, dynamic skin contacts, and changes in muscle–tendon lengths used to infer proprioceptive input.

This approach successfully reconstructed coordinated, spontaneous whole-body movements—including rolling, limb extension, flexion–extension cycles, and gradual postural adjustments—together with their associated sensory consequences. Contact mapping revealed rich, spatially distributed tactile input generated by interactions between moving fetal limbs and the uterine environment. Proprioceptive estimates fluctuated with major phases of movement, indicating tight temporal coupling between motor output and sensory feedback. These findings demonstrate that human fetal behavior exhibits structured sensorimotor patterns, consistent with early forms of organization observed in neonatal animal models and in early infancy. In parallel with postnatal “sensorimotor wandering” described in infants, fetal movements already display coherent spatiotemporal organization that may serve as a foundation for later coordination.

Together, these results provide the first non-invasive, quantitative description of whole-body human fetal sensorimotor interactions. By capturing multi-joint kinematics, tactile interactions, and proprioceptive dynamics within the fetal environment, this framework offers new empirical access to the developmental origins of sensorimotor organization well before birth. The method establishes a basis for linking early fetal sensorimotor experience to postnatal motor development, and it may

contribute to understanding how early disruptions in movement or sensory feedback influence atypical developmental trajectories.

Friday, April 24, 2026

08:00 – 10:00 Session 12, Panel V

Divergent pathways, convergent function: New physiological, anatomical, and theoretical perspectives on sensory-driven and top-down control of rapid eye movements

Mayu Takahashi [1], Ziad Hafed [2], Jeffrey Schall [3], Martin Bohlen [4]
[1] Tohoku University, [2] Centre for Integrative Neuroscience, [3] York University, [4] Duke University
Discussant: Neeraj Gandhi

Rapid eye movements (saccades) are among the most elementary and time-critical motor actions performed by the nervous system. Such eye movements are under a perpetual influence of endogenous cognitive demands as well as exogenous sensory drives, and this is reflected in decades of research largely investigating these two classes of oculomotor system influences in isolation. However, even simple retrospection reveals that exogenous sensory inputs, arriving asynchronously with respect to internal brain state, must compete with endogenous processes to drive behavior. This symposium will highlight novel perspectives on the enduring tension between peripheral sensory drives and top-down control of eye movements. Using recent advances in anatomical, physiological, and theoretical approaches, we address a fundamental question in systems neuroscience: how distinct pathways—direct retinal projections to midbrain and brainstem circuits, and cortical sensory and decision networks—interact, and potentially even compete, to govern rapid sensorimotor decisions. Starting from the final gate for allowing saccade generation to proceed, the brainstem omnipause neurons, we will show how feature-tuned sensory modulations of these neurons' activity jumpstart a highly reflexive and precise coordination between exogenous sensory events and endogenous motor plans; remarkably, these sensory-driven ocular reflexes depend entirely on the geniculostriate pathway (Hafed). This dominance of the geniculostriate pathway starkly contrasts with novel and compelling tracing and high-density electrophysiology evidence revealing diverse direct projections from the retina to the superior colliculus in primates (Bohlen), raising essential questions about when sensory pathways that bypass the geniculostriate system are functionally engaged. Upstream of the omnipause neurons, we will address the question of how the decision to initiate, suppress, or interrupt an eye movement requires top-down impacts from parietal and frontal cortical areas on the brainstem, and ultimately the omnipause neurons (Schall). Theoretically, similar coordination principles to those involved in sensory-driven modulations of omnipause neurons emerge, but with clearly distinct functions and time scales. These distinctions are further elucidated by integrated physiological and anatomical evidence defining the connectivity among the frontal eye field, superior colliculus, and omnipause neurons (Takahashi), revealing a shared brainstem switching mechanism through which fixation and saccade initiation are implemented. By aligning bottom-up, intermediate, and top-down perspectives on rapid eye-movement control, this session will redefine and sharpen classic questions in oculomotor neuroscience and highlight where the next major conceptual breakthroughs are likely to arise.

10:30 – 12:10 Session 13, Individual IV

O4.1 - Dual descending pathways drive the initiation of skilled movements

Yutaka Yoshida [1], Akimasa Ishida [1], Esther Lai [1], Teruko Danjo [2], Fumiyasu Imai [2], Jay Bikoff [3], Samuel Sober [4], Amanda Jacob [4], Matthew Williams [4], Kyle Thomas [4]
[1 2] Okinawa Institute of Science and Technology, [2] Weill Cornell, [3] St. Jude, [4] Emory
Presenting Author: **Yutaka Yoshida**

The initiation of skilled movements is regulated by descending neurons in the sensorimotor cortex and brainstem projecting to the spinal cord. However, the mechanisms by which these pathways convey initiation signals remain unclear. This uncertainty arises from two key previous observations. First, inhibition of each descending pathway does not abolish the initiation of skilled movements such as reach–grasp behaviors. Second, brief stimulation of descending neurons fails to evoke the sequence of these movements. In this study, we demonstrate that combined inhibition of corticospinal neurons (CSNs) in the rostral forelimb area (rCSNs) and reticulospinal neurons (ReSNs) in the reticular formation effectively blocks the initiation of skilled reaching behaviors. Conversely, simultaneous brief activation of both rCSNs and ReSNs is sufficient to not only initiate reaching, but also to evoke sequential, naturalistic reach–grasp movements. These findings suggest that rCSNs and ReSNs converge on a "reach–grasp generator" located in the cervical spinal cord. Supporting this, we find that both rCSNs and ReSNs are activated prior to movement initiation, and that these two descending circuits synergistically operate, with no apparent crosstalk in the central nervous system. Together, these findings reveal a cooperative mechanism by which two parallel descending pathways drive the initiation and execution of skilled motor sequences in mammals.

O4.2 - The influence of using finger-extending exoskeletons on proprioceptive and tactile localization

Dominika Radziun [1], Siebe Geurts [1], Valeria Peviani [1], Luke Miller [1]
[1] Donders Institute for Brain, Cognition and Behaviour, Radboud University
Presenting Author: **Dominika Radziun**

Humans show a remarkable ability to incorporate tools and artificial extensions into their sensorimotor control loops. Yet the perceptual and computational consequences of such integration remain poorly understood. We investigated how finger-extending exoskeletons reshape proprioceptive and tactile localization, providing a controlled test case for probing the flexibility of somatosensory body maps during technological augmentation. In the first experiment, twenty participants completed a high-density proprioceptive mapping task across four phases: before wearing the exoskeleton, after donning it, after active use, and after device removal. We identified three dynamic phases of plasticity. Wearing the device initially contracted the perceived length of the biological finger. After active use, both biological and exoskeletal fingers exhibited significant representational stretching, an effect absent in a non-augmenting control condition. Finally, a post-removal aftereffect persisted on the biological finger. In the second experiment, seventeen adults performed tactile localization on their index and middle

fingers before and after 45 minutes of training with 10-cm finger-extending exoskeletons. Using a probabilistic model of tactile localization, we isolated changes in sensory processing, decision variables, and body representation. Exoskeleton use selectively altered the spatial remapping between mechanoreceptor and physical space, producing a ~24% stretch in tactile maps accompanied by a proportional increase in localization uncertainty. All other sensory and decisional parameters remained stable. These results show that wearable augmentations drive structured updates to somatosensory representations rather than simple spatial shifts, revealing principled computational rules governing representational expansion. Together, these findings demonstrate that tactile and proprioceptive maps rapidly adapt to artificial extensions, with changes governed by structured probabilistic computations and shaped by both the structural and functional properties of the device. This work highlights the flexibility of the sensorimotor system in accommodating technological augmentations and provides a computational framework for understanding how artificial extensions become integrated into the body representation.

O4.3 - Spatially independent and temporally robust somatosensory hand representations in expert pianists

Masato Hirano [1], Sachiko Shiotani [2], Shinichi Furuya [1]
[1] *Sony Computer Science Laboratories, Inc.,* [2] *NeuroPiano Institute*
Presenting Author: **Masato Hirano**

In the sensorimotor system, population neural activity is constrained by the physical structure of the musculoskeletal system and its kinematics. A seminal study has shown that the geometry of hand representation, the covariation structure across fingers, mirrors the covariation patterns of finger use in daily life (Ejaz et al. 2015), suggesting that long-term usage or training can reorganize hand representations. Classical studies in musicians suggested that long-term instrumental practice increases the spatial independence of cortical motor and somatosensory hand representations (Elbert et al., 1995). However, recent fMRI work has challenged this view, claiming no clear expansion and even reduced representational distances between fingers in musicians (Ogawa et al., 2019), and preserved somatosensory maps after amputation (Schone et al., 2025). The controversy raises the question of whether long-term training of dexterous finger movements reorganizes somatosensory hand representations.An additional open question is whether structured somatosensory mappings are preserved or distorted when multiple fingers are moved in rapid succession, as in musical performance. In such situations, somatosensory signals from different fingers arrive close in time, requiring the nervous system to separate temporally overlapping inputs while maintaining a segregated mapping of which finger moved and how. This challenge is particularly pronounced in expert pianists who, through years of practice, execute rapid sequences of multi-finger movements. Pianists therefore provide a unique model to elucidate how extensive training overcomes such a challenge through adaptation of somatosensory hand representations.Here we tested these ideas by comparing expert pianists with matched nonmusicians. EEG was recorded while a custom-made hand exoskeleton robot delivered precisely controlled passive flexion/extension movements to individual fingers and to multiple fingers in

rapid succession. By systematically varying movement tempo, we characterized both the spatial organization and temporal robustness of somatosensory hand representations by using multivariate pattern analyses of evoked responses. When the robot delivered isolated passive movements to individual fingers, nonmusicians exhibited a characteristic representational geometry, with shared activity patterns between the middle, ring, and little fingers. In contrast, expert pianists showed a more differentiated spatial geometry with increased separation across these digits. When multiple fingers were moved in rapid succession, nonmusicians showed a distortion of this structure, with finger- and motion-specific representational patterns largely collapsing. However, pianists maintained clear finger- and motion-specific geometry during rapid multi-finger movements. These findings suggest that long-term piano training induces somatosensory hand representations that are both spatially more independent and temporally robust, supporting accurate processing of proprioceptive inputs during high-speed sequential actions.

O4.4 - Setting the gains: Neural and behavioral evidence for pre-movement feedback controller configuration

Dominique Delisle-Godin [1], Pierre-Michel Bernier [1]
[1] *Université de Sherbrooke*
Presenting Author: **Dominique Delisle-Godin**

Humans routinely perform skilled actions that involve automatic, context-appropriate adjustments to movement, such as reaching for a cup of coffee while reading this abstract and seamlessly correcting the hand's trajectory if bumped by a co-worker. These rapid feedback corrections are thought to rely on the engagement of controllers whose feedback gains are tuned to the specific demands of the task. For instance, previous work using mechanical perturbations has shown that feedback gains scale with accuracy requirements, yielding stronger long-latency (LL) muscle responses when targets are narrower. Despite the contention that these controllers are set up before movement, the neural evidence for such preparatory configuration remains limited because prior studies have predominantly focussed on movement execution. Here, we tested whether neural activity preceding movement reflects the preparation of a feedback controller with increased feedback gains. A secondary objective was to test whether the availability of online visual feedback influences preparatory neural activity. Twenty-eight healthy adults performed a delayed, goal-directed reaching task toward either a narrow (2.5 cm) or wide (80 cm) target. On a subset of trials, mechanical perturbations (±12 N) were applied to probe feedback responses. To assess the role of vision, blocks of trials were performed both with and without online visual feedback of the cursor. Surface electromyography (EMG) and electroencephalography (EEG) were recorded simultaneously to characterize muscle and neural activity. We hypothesized that preparing a controller with increased feedback gains (narrow target) would be accompanied by stronger beta-band (13–30 Hz) event-related desynchronization (ERD) during the delay period, reflecting greater investment of neural resources in motor preparation. As previously reported, LL responses were significantly larger for the narrow compared to the wide target for both +12 N and -12 N perturbations ($p < 0.001$), confirming the modulation of feedback gains by accuracy demands. Critically, and consistent with our

predictions, EEG analyses revealed a frontoparietal cluster showing significantly stronger beta ERD in the later portion of the delay period for the narrow target condition ($p < 0.01$). Interestingly, the same qualitative pattern of EMG and EEG results held true irrespective of the vision condition, indicating that similar controllers were engaged with or without visual feedback. By linking pre-movement neural activity to feedback responses during movement, this work provides evidence that feedback controllers are configured prior to movement and identifies beta ERD as a marker of preparing a high-gain controller.

O4.5 - Hierarchical and Context-Dependent Population Codes for Intended and Observed Actions in Human Parietal and Motor Cortex

Celia Bougou [1], Jorge Gamez [2], Emily Rosario [3], Charles Liu [4], Kelsie Pejsa [1], Ausaf Bari [5], Richard Andersen[2]
[1] California Institute of Technology, [2] Division of Biology and Biological Engineering, California Institute of Technology, [3] Casa Colina Hospital and Centers for Healthcare, [4] Keck School of Medicine of USC, [5] University of California, Los Angeles
Presenting Author: **Celia Bougou**

How the human brain represents actions across intention and observation remains unknown, largely because direct intracortical comparisons across cortical levels have been exceptionally rare. We addressed this gap by recording neural activity from Utah arrays implanted in motor cortex (MC) and posterior parietal cortex (PPC) of two individuals with tetraplegia participating in an ongoing brain–machine interface study. Across five implants, we obtained more than 4,500 single units, providing an unprecedented opportunity to examine how action features are encoded across cognitive formats and cortical hierarchies. Participants either internally generated or passively viewed the same set of actions in a fully crossed design manipulating hand, action type, and movement direction. We identified a clear functional dissociation between areas. MC robustly encoded internally generated actions yet exhibited only sparse and unreliable tuning during observation, offering the first direct human evidence that single-unit mirroring in MC is minimal. However, population analyses revealed a latent overlap between intention and observation: observed actions occupied a weak but geometrically aligned subspace of the intention manifold, reconciling the sparse responses at the single-unit level with longstanding imaging reports of MC activity during action observation. PPC showed a contrasting profile. Single-unit selectivity and population activity both demonstrated that action identity was represented invariantly across intention and observation. Representational similarity analysis, cross-format decoding, and low-dimensional trajectory alignment all converged on a shared, generalizable code for action features in PPC, suggesting that it supports an abstract representation of actions. To examine how these representations behave when observed and intended actions occur simultaneously, one participant performed a dissociation paradigm in which the viewed action and the instructed action were presented simultaneously and could be either congruent or incongruent. When the participant simply intended an action while observing another, PPC predominantly encoded the internal motor plan, with the observed action largely suppressed. However, when the task required the participant to intend an action, observe

a potentially conflicting action, and subsequently report the observed one, PPC represented both the intended and the observed action. MC, in contrast, encoded only the instructed action in all conditions. These findings provide the first single-unit evidence in humans that the posterior parietal cortex flexibly regulates visual–motor coupling based on behavioral relevance and together support a hierarchical framework in which motor and parietal cortices occupy distinct and complementary roles in action encoding.

15:00 – 17:00 Session 15, Panel VI

How do distributed motor circuits reorganize to support the execution of learned actions?

Naama Kadmon Harpaz [1], Alice Mosberger [2], Vivek Athalye [3], Karunesh Ganguly [4], Michael Long[5]
[1] Harvard University, [2] NYU Langone Health, [3] Allen Institute, [4] University of California, San Francisco, [5] New York University Langone Medical Center
Discussant: Alice Mosberger

Animals can expand their behavioral repertoire by flexibly combining and sequencing existing motor elements into novel actions. Such behavioral versatility is essential for adapting to a changing environment and new conditions. However, only with practice, an initially slow, discontinuous, and variable sequence of movements is transformed into a fast, smooth, and stereotyped skilled behavior. These behavioral changes are thought to arise from plasticity within motor circuits and the reorganization of neural dynamics and cross-area interactions. This raises a central question: How and when do neural circuits reorganize during learning to support a new action composed of a sequence of motor elements, and how does this learning alter the representation of those elements themselves?

This panel will bring together work addressing these questions across diverse model organisms, including non-human primates, mice, rats, and parrots. We will examine how interactions among premotor and primary motor cortical regions and subcortical structures such as the striatum support the acquisition and execution of learned actions. The panel will also highlight recent methodological advances that allow manipulation and tracking of the activity of single neurons during learning. Together, we will explore circuit-level mechanisms that may be shared across species and that enable animals to expand their behavioral repertoire.

First, Athalye will discuss how movements are encoded in the striatum, a key region for learning and controlling skilled actions. He will show that the minimal movements required for an isometric push–pull task in mice - opposing muscle contractions - are represented in striatal neurons even prior to learning, providing a substrate upon which learning can build to support more complex actions.

Ganguly will then focus on mechanisms of circuit reorganization that stabilize a newly learned action composed of multiple motor elements. He will demonstrate how cross-area reactivation during NREM sleep drives cortico-striatal plasticity in mice and non-human primates practicing a reach-to-grasp task and discuss a specific NREM rhythm spanning cortex and striatum that causally contributes to the emergence of skilled performance.

Next, Kadmon Harpaz will discuss how animals learn and execute multiple actions composed of partially overlapping motor sequences. She will present work tracking behavioral changes in rats learning several lever-press sequences and the accompanying reorganization of the cortico-striatal circuit.

Finally, Long will explore how motor regions interact to generate multiple learned vocalization sequences in the budgerigar, a parrot species with a versatile vocal repertoire. He will describe how neurons in a premotor region generate temporally structured activity that is relayed to a motor output region, forming a hierarchical model that supports the acquisition and execution of versatile vocal behaviors.

17:00 – 18:00 Distinguished Career Award Presentation and Talk

Evolving thoughts on motor cortex

Stephen Scott, *Queens's University*

How does the human motor system produce goal-directed movements given multiple feedback pathways: spinal, subcortical, and cortical? This question occupied much of my career. Early on, as a graduate student studying cat locomotion, I viewed motor control through the traditional Jackson/Sherrington hierarchical framework, where supraspinal regions influence the spinal cord, which generates muscle activity. This model is straightforward to simulate using engineering principles. However, during my postdoctoral work on voluntary control in non-human primates, this strict hierarchy seemed less convincing. Primates have corticospinal projections targeting both spinal interneurons and motoneurons, indicating more complex interactions. Later, approaching the problem with optimal feedback control theory, our research emphasized the importance of transcortical feedback for goal-directed actions, with spinal feedback playing a limited role. Still, I found it challenging to explain such shifts in feedback processing across species and behaviors. Modeling multiple parallel pathways often felt speculative, with strong but conflicting views about the dominance of each level. Our recent work offers fresh insight by making one feedback pathway trainable, allowing it to learn the contributions of the other non-trainable pathway—effectively one part of the motor system modeling another. As predicted, increased spinal feedback during mechanical disturbances corresponded with reduced motor cortex activity. This suggests that goal-directed movements arise from the combined contributions of multiple feedback pathways, with transcortical feedback providing motor commands that are the difference between *what is generated* by subcortical pathways and *what is required* for goal-directed behaviour.

Poster Abstracts

Poster Session 1

A – Control of Eye & Head Movement

P1-A-1 - Effort sensitivity shapes saccade dynamics in a gaze holding choice task

Caelan Thom [1], **Alaa Ahmed** [1]
[1] University of Colorado, Boulder

Details

Movement vigor and action selection are shaped by anticipated and experienced outcomes and their associated costs, yet the role of prospective effort in oculomotor control remains poorly understood. We investigated whether effort, operationalized as an imposed gaze hold duration at an eccentric location, modulates saccade kinematics and choice behavior.

Participants (N=18) completed an eye-movement based 2AFC task. During a learning phase of 50 trials, participants associated five visual cues with gaze hold durations of 0.5, 1.0, 1.5, 2.0, and 2.5 seconds, followed by trial blocks containing interleaved forced and choice trials. In forced trials, a single cue specified the required hold time at the target. In choice trials, two cues were presented simultaneously, allowing participants to select between the effort options. Saccade vigor, peak velocity normalized to movement amplitude, was calculated for both outgoing and return movements.

Choice behavior was heterogeneous across individuals. Logistic modeling revealed a continuous spectrum of effort sensitivity, captured by a subject-specific parameter (k), spanning effort avoidant individuals who preferred shorter gaze durations (n = 7), effort seeking who preferred longer durations (n = 2), and effort agnostic or direction driven (n=9) preferences.

For **outgoing saccades,** prospective effort influenced vigor differently depending on task context. In **forced trials,** outgoing vigor was insensitive to upcoming gaze-hold duration. During **choice trials**, outgoing vigor depended on subjective effort sensitivity. There was a significant interaction between selected effort and k ($\beta \approx 0.0065$, $p = 0.019$), indicating that individuals with greater effort sensitivity showed stronger modulation of outgoing vigor when making choices. The movements of individuals who are effort avoidant increased in vigor in response to shorter hold time options, while those of effort seekers decreased toward shorter hold times. Interestingly, baseline vigor was lower in effort-seeking individuals ($\beta \approx -0.020$, $p = 0.007$).

In contrast, **return saccades** reflected **experienced effort** rather than prospective cost. In forced and choice trials, longer gaze-hold durations reduced return vigor ($\beta \approx -0.0135$, $p < 10^{-6}$, $\beta \approx -0.0096$, $p = .094$), and in forced trials, this effect was modulated by effort sensitivity ($k \times$ effort: $\beta \approx 0.0049$, $p = 0.036$), with stronger slowing in effort-averse individuals.

Together, these findings demonstrate a dissociation between outgoing and return saccades in the presence of effortful conditions. Prospective effort alone does not influence outgoing vigor, but subjective effort sensitivity shapes outgoing vigor during voluntary choice. In contrast, experienced effort reliably modulates return vigor across individuals. This work extends value-based motor control frameworks to the oculomotor system and highlights how internally represented effort costs shape both action selection and movement execution.

P1-A-2 - Coordinated head, body and eye-movements support active sensing to reduce spatial uncertainty during navigation

Fabian Kessler [1], **Isabella Chiani** [1], **Julia Frankenstein** [1], **Constantin Rothkopf** [2]
[1] Centre of Cognitive Science TU Darmstadt, [2] Technical University of Darmstadt

Details

Navigation in the real world is fundamentally uncertain: current self-location, goal position, and landmarks must be inferred from noisy sensory cues while planning sequences of motor actions. This requires the brain to maintain and update an uncertain internal representation of self, landmarks, and goals. However, it remains unclear how eye, head, and body movements are actively coordinated to manage this spatial uncertainty. Theories of active sensing propose that agents should direct their sensors toward locations expected to reduce task-relevant uncertainty.

To test this experimentally, we combined immersive virtual reality, motion capture, and eye tracking to quantify active sensing during walking. Seventy-two participants completed the triangle completion task, which involved physically walking triangular paths in a virtual environment with three landmarks and three goal objects. On each trial, participants followed a predefined path to collect these goal objects and then navigated back to the remembered location of the first goal. Across path types, we manipulated landmark visibility so that on critical segments, viewing specific landmarks required active reorientation of head and body. For each trial, we recorded head and body orientation, landmark visibility, and gaze position across the different walking paths.

Participants who selectively fixated task-relevant landmarks at specific points along the walking paths exhibited reduced variability in walking trajectory endpoints. To interpret these behaviors, we developed a belief-space optimal control model that maintains a Bayesian belief over self-location, landmark positions, and goal location, which is updated from noisy self-motion cues and landmark observations. Sequences of motor actions are planned according to a cost function that trades off three terms: a task cost penalizing distance from the goal, a control-effort cost on locomotor and reorienting movements, and an uncertainty cost penalizing expected spatial uncertainty over self, landmarks, and goals. Closed-loop simulations of this model with different uncertainty costs reproduced the timing and position of landmark fixations and predicted behavioral variability of human participants across the different walking paths. Taken together, these results suggest that humans coordinate eye, head, and body movements to perform uncertainty-aware active sensing strategies during navigation, selecting motor actions both to reach goals and to actively reduce internal spatial uncertainty.

P1-A-3 - A direction-dependent role for complex spikes firing during the peri-saccade onset period in modulating saccade kinematics

Junya Inoue [1], **Akshay Markanday** [2], **Peter Thier** [2]
[1] University Tübingen, [2] Hertie Institute for Clinical Brain Research

Details

The cerebellum is critical for the precise timing and scaling of saccadic eye movements. Dysfunction leads to fundamental deficits, including dysmetria, reduced velocity and a loss of motor adaptation. While Purkinje cell (PC) simple spikes (SSs) are the primary output of the cerebellar cortex, their functional code is obscured by high cell-to-cell firing rate variability. We hypothesized that analysing PC activity based on the complex spike (CS) error tuning directions (CS-on) — the climbing fiber input defining the anatomical microcomplex— is essential to resolve this coding problem. We tested this approach by recording PC activity from macaque monkeys across two distinct saccadic paradigms.

We validated our idea by demonstrating that differential SS alignments (CS-on vs. CS-off direction) successfully revealed a robust, consistent bi-phasic SS population modulation across both paradigms, confirming that CS-on tuning organizes the reliable SS code.

Applying this framework, we discovered a novel and potent direction-dependent role for CS firing curing the peri-saccade onset period (-50 ms to +50 ms relative to onset). This perisaccadic CS activity actively modulates ongoing kinematics. When the CS-on direction was opposed to the saccade, CSs significantly reduced peak velocity and prolonged duration. Conversely, when CS-on was aligned, CSs firing was associated with saccade onset position closer to the target, compensated by smaller amplitude and shorter duration. We found that the CS preferred direction for encoding retinal position reversed from the fixation period to the peri-onset period, suggesting a shift from error signaling to state modulation. At the cellular level, the CS-induced SS pause was directionally symmetric in the population (increase/decrease) and its duration was dynamically temporally modulated around the saccade.
Our results demonstrate that the CS is not confined to acting as a post-movement error signal but serves as a pre-movement, direction-dependent modulator that controls saccade execution via immediate effects on PC output and motor command. This establishes the CS-driven microcomplex as the fundamental functional unit for cerebellar motor control.

P1-A-4 - Event-locked patterns of macroscopic traveling wave in visually-guided saccade task

Kuan-Ting Ho [1], **Chih-Yang Chen** [1], **Hirotaka Onoe** [1], **Tadashi Isa** [1]
[1] Kyoto University

Details

Traveling waves (TWs) of local field potential (LFP) have been identified in many brain areas and linked to various brain functions. However, macroscopic traveling waves encompassing multiple cortical areas have been less studied, and their roles remain unclear. In this study, we implanted epidural electrocorticogram arrays that cover the entire dorsal surface of a hemisphere on two marmosets. The marmosets were trained to perform a visually-guided saccade task, while LFP and eye position being recorded. We calculated the generalized phase (20-50 Hz) of the LFP and derived a graph representation (node: electrode, edge: wave flow) of TWs at each timepoint by a shift-and-match algorithm. We then assigned edge weights using average amplitude of the adjacent nodes, representing the wave strength between the two electrodes. Next, we performed independent component analysis on the edges and extracted wave components that compose the global TW pattern around saccades. Among these wave components, some are highly similar between the two marmosets. Finally, to correlate each with task event (target onset, saccade onset/offset) and behavioral variables (saccade direction, amplitude, peak velocity, latency, duration, error), we fit the component activations to a generalized linear model. The resulting model shows significant contribution of saccade parameters to the TW patterns in an event-locked manner. For example, a temporal-forward wave component time-locked to target onset prefers ipsilateral and upper target, and is stronger in short latency trials; a frontal-spreading wave component time-locked to saccade onset is stronger for fast and small saccades; an occipital-temporal wave component time-locked to saccade offset prefers contraversive and downward saccades, and is stronger if landing error is small. In conclusion, our method successfully extract the common fundamental wave components in the two marmosets. The behavioral relevance of these wave components provides hints about the functions of TWs around saccades.

P1-A-5 - Electrophysiological correlates of differential anatomical inputs to brainstem omnipause neurons during saccadic eye movements

Maria Ermolova [1], **Antimo Buonocore** [2], **Ziad Hafed** [3]
[1] Centre for Integrative Neuroscience, University of Tübingen, [2] Werner Reichardt Centre for Integrative Neuroscience, [3] Centre for Integrative Neuroscience

Details

Brainstem omnipause neurons (OPN's) fire tonically during gaze fixation and pause during saccades of all directions. As such, these neurons are thought to gate rapid eye movements, and they form an integral

component of brainstem neural circuitry implementing precise saccade control. However, questions remain about how the anatomical connectivity of OPN's, especially with the superior colliculus (SC) and brainstem burst neurons, relates to these neurons' classically observed electrophysiological discharge properties. For example, the rostral quarter of the SC projects excitatory inputs to OPN's but still drives small saccades that should be associated with OPN pauses. Similarly, there is a lateralized inhibitory connection from brainstem burst neurons to OPN's on either side of the midline, but OPN's pause equally well for saccades of all directions. Here, we studied the dynamics of OPN output spiking as well as local input activity (via analyzing local field potentials; LFP's) for a large range of saccade sizes and directions. We first analyzed the activity of 44 well-isolated single neurons (approached from the right hemisphere) during a delayed saccade task with varying saccade sizes (from microsaccades to >20 deg). OPN spiking probability reliably dropped ~4 ms before saccade onset and resumed ~17 ms before saccade end, regardless of saccade size, thus confirming the prior literature. Remarkably, however, the OPN activity pause was not as complete for small saccades (<5 deg in amplitude) as for larger ones. This resulted in a significant negative correlation between intra-saccadic spiking likelihood and saccade amplitude in 91% of the neurons, even after accounting for differences in saccade durations. In terms of LFP's, we observed a sharp pre-saccadic increase in voltage (in the final 10-20 ms before saccade onset), with a peak coincident with movement onset (~2 ms after such onset); this was immediately followed by a stronger and longer-lasting negativity, reaching a trough ~14 ms before movement end and outlasting the movement by almost 50 ms. Both the peak and trough amplitudes increased with saccade size. Remarkably, the peri-saccadic LFP peak was stronger for leftward than rightward saccades, even after matching the leftward and rightward saccade kinematics, and even though single-neuron spiking modulations were not direction-dependent. We hypothesize that increased intra-saccadic OPN spiking during small saccades reflects excitatory SC projections from the small-saccade region of that structure. Because we were approaching the OPN's from the right, we also hypothesize that the larger leftward peri-saccadic LFP peak deflections reflect inhibitory inputs from contralateral burst neurons, helping to trigger OPN pauses. Our results reconcile potentially conflicting anatomical and physiological observations about OPN's, and they also suggest that OPN's might exert finer inhibitory control over eye movements than previously assumed.

P1-A-6 - Ketamine disrupts the saccadic signature of agency in the common marmoset

Masatoshi Yoshida [1], **Daisuke Koketsu** [2], **Acer Chan-Yu Chang** [3], **Wen Wen** [4]
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Details

Introduction: The sense of agency (SoA) is the subjective experience of controlling one's own actions and their subsequent effects in the external world. While SoA in humans is predominantly studied through explicit verbal reports, objective behavioral markers are essential for translational research. We previously established a gaze-controlled paradigm in which participants interact with a visual stimulus. In both human adults and infants, we identified a distinct "agency signature": when the stimulus is fully controlled (locked) by the participant's gaze, their saccades do not merely pursue the target (0° deviation) but frequently deviate toward orthogonal (90°) or opposite (180°) directions, showing active exploration of their control over the stimulus. Here, we investigated whether this saccadic signature of agency is conserved in the common marmoset and how it is affected by ketamine, a drug widely used for a pharmacological model of schizophrenia.

Methods: We tested two marmosets in a gaze-contingent task. The target's movement was determined by a weighted mixture of the animal's current gaze vector and its own gaze vector recorded from a past trial. The mixture probability (prob) was set at 0.1, 0.5, and 0.9, representing low to high agency levels.

Using circular statistics, we calculated the angular deviation of the gaze movement relative to the target's movement vector and the resultant vector length (R), which indicates the concentration of the distribution. We compared performance before and after a sub-anesthetic dose of ketamine (0.5 mg/kg, i.m.).

Results: In the pre-ketamine (control) condition, the marmosets exhibited an agency-dependent shift in gaze patterns. At prob=0.9 (high agency), the distribution of angular deviations was broader, with increased deviations from the target direction (0°) resulting in a lower R value compared to the prob=0.1 condition. This pattern mirrors the human agency signature, suggesting that marmosets alter their motor strategy upon detecting high self-control. Preliminary analysis of post-ketamine data revealed that these probability-dependent differences were largely abolished. Specifically, the characteristic deviations from the target vector observed at prob=0.9 disappeared, suggesting that ketamine disrupted the link between the detection of agency and the generation of exploratory or strategic saccades.

Conclusion: Our findings suggest that the saccadic signature of agency is conserved across primates. Furthermore, the disruption of this signature by ketamine provides a crucial link to schizophrenia models. Given our previous report that ketamine induces schizophrenia-like gaze shifts (reduced scanpath length) in marmosets (Polyakova et al., 2022), the current results suggest that NMDA-receptor dysfunction may impair both visual saliency processing and the sense of agency. This gaze-contingent paradigm in marmosets offers a promising platform for studying the cognitive-motor deficits central to neuropsychiatric disorders.

P1-A-7 - Action possibilities contextualize motor memories

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Details

In our daily life, we often pick one action out of many options, not necessarily knowing which one to carry out from the beginning. Importantly, the available actions depend on the environment, which we refer to as action possibilities. Here, we show that the motor memory is formed based on the action possibilities, even when not all the options are actively planned.
Participants performed 8 cm centre-out reaching movement towards one of five possible targets positioned 45°apart. At the start of each trial, three potential targets, composing either the right (0°, 45°, 90°) or the left (90°, 135°, 180°) distribution appeared simultaneously (preparation period). After a delay, two of the targets disappeared, and participants were required to reach toward the single remaining one. In half of the trials, the potential targets were all presented in the same colour and the participants had to prepare for all three directions of reaching during the preparation period (multiple-plan trials). In another half of the trials, the target to be reached was highlighted in red during the preparation period, which allowed the participants to prepare for the single target without actively preparing for the other two targets (single-plan trials). After baseline trials, the right- and left-distribution conditions were each assigned a clockwise (CW) or counterclockwise (CCW) force field, and learning was assessed by evaluating force compensation levels during error-clamp trials. A critical feature of this design was that the target distributions partially overlapped, leaving the 90°target common across conditions. Participants were thus required to adapt to two opposing force fields at the overlapping direction.
In the multiple-plan trials, participants learned the force fields not only for the non-overlapping targets (0° and 45° for the right, 135° and 180° for the left), but also for the overlapping target (90°for both). This suggests that different patterns of multiple motor plans function as contexts for motor learning, which enabled simultaneous acquisition of distinctive two motor memories for opposing perturbations. Critically, significant dual learning was also observed in single-plan trials, indicating that not only the

active preparation of the targets, but the non-active options in the given environment can work as a contextual cue for motor memory. A replication experiment demonstrated that this dual adaptation effect sustains even after the termination of multiple-plan trials at the end of sessions, when the participants were required to successively perform only the single-plan trials.
Previous studies have highlighted the difference in the planning as a factor for contextualising motor memory. We suggest that not only the active plan per se, but the landscape of the possible action plans in the environment can also contribute to defining contexts in motor learning.

P1-A-8 - Skill differences in head–eye coordination during real-world tracking of an approaching ball

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Details

Visual tracking has been widely investigated using display-based 2D targets, where motion is typically restricted to a single plane, and analyses often focus primarily on eye movements. In contrast, tracking an approaching object in a real-world 3D environment imposes greater demands on gaze control that involves head movements under head-free conditions. When an object follows a slightly curved trajectory with a vertical component, as in an approaching ball that rises relative to its launch point, observers must adjust gaze, engaging coordinated vertical eye and head movements. Because gaze (eye-in-space) is formed by the combination of head movement (head-in-space) and eye movement (eye-in-head), decomposing gaze into head and eye components can reveal coordination strategies beyond gaze measures alone.The purpose of this study was to clarify whether head–eye coordination during tracking of an approaching ball differs according to ball-sport experience. Thirteen novices with no ball-sport experience and twelve experienced ball-sport players wore a wearable eye-tracking device and were instructed to track an approaching tennis ball as accurately as possible. Tennis balls were launched from a ball machine positioned 9 m in front of the participant and approached near face level. For safety and task standardization, a transparent acrylic panel was placed in front of the participant, and the approaching ball was viewed through the panel.
The analysis window was defined as the 400-ms interval from 20 to 420 ms after the end of the initial saccade, corresponding to a sustained tracking phase after gaze was aligned with the ball. We analyzed vertical gaze, head, and eye kinematics by computing mean position and mean velocity within this window. Position data were expressed as vertical angles (deg) relative to ball launch position (0°), such that larger values indicate a more upward orientation compared with launch. To quantify the relative role of the head movements in forming gaze, head position contribution was defined as the proportion of the head component within gaze position.
The results showed that the mean gaze position was higher in novices than in experienced participants. When gaze was decomposed into head and eye components, novices showed significantly larger upward head movements, whereas eye movements did not differ between groups. Accordingly, head position contribution was significantly greater in novices, suggesting that novices rely more on head movements to control gaze during approaching-ball tracking. Furthermore, across both groups, head and eye movements showed negative correlations in both position and velocity, indicating compensatory coupling between head and eye movements. Taken together, these findings suggest that skill-related differences in gaze during real-world approaching-ball tracking are expressed primarily through head movements rather than eye movements.

P1-A-9 - Different roles of the cerebellum in long-term memory of vestibulo-ocular reflex enhancement and suppression

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Details

Through repeated short-term practice in activities such as sports or musical performance, motor skills gradually improve and stored as long-term memory. Although substantial evidence has identified distributed cortical and subcortical circuits involved in motor memory storage, the precise mechanisms and loci underlying long-term motor memory for individual motor skills remain incompletely understood.

The vestibulo-ocular reflex (VOR) has served as a prominent model system for investigating the transition from short-term (hours) to long-term (days to months) motor memory. The VOR stabilizes visual images during head motion by rotating the eyes in the opposite direction at nearly the same velocity. The efficacy of VOR is quantified by its gain, defined as the ratio of eye velocity to head velocity. Repeated visual stimulation presented in the opposite or same direction as head motion induces an increase (VOR enhancement) or decrease (VOR suppression) in VOR gain measured in darkness, respectively. Previous studies have demonstrated that short-term VOR motor learning exhibits frequency selectivity, with maximal adaptation occurring at the trained frequency. Moreover, frequency-competitive VOR training results in simultaneous gain enhancement and suppression at different frequencies as distinct short-term memories. It has been shown that VOR memory is initially stored in the cerebellum (CB) during short-term training and is gradually transferred to the vestibular nuclei (VN) as long-term memory. While short-term VOR memory is frequency selective, it remains unclear whether this property is preserved in long-term memory stored in the VN, whose neuronal circuitry is considerably simpler than that of the CB.

In this study, we investigated how VOR enhancement and suppression acquired concurrently at different frequencies are consolidated into long-term memory using frequency-competitive VOR training in goldfish. Animals underwent simultaneous enhancement training at 0.5 Hz and suppression training at 0.1 Hz using sum-of-sines head rotation paired with large-field visual stimulation. The 0.1 and 0.5Hz components of the visual stimulus were presented in phase and out of phase with head motion, respectively. Training was conducted for 2 hours per day over 7 consecutive days. To evaluate the role of the CB in maintaining frequency-selective long-term memory, cerebellectomy was performed on day 7. Across the 7-day training period, VOR gain gradually increased at 0.5 Hz and decreased at 0.1 Hz, indicating that frequency-selective short-term learning accumulated into long-term memory for both VOR enhancement and suppression. Following cerebellectomy, the enhanced VOR gain at 0.5 Hz remained unchanged, whereas the suppressed VOR gain at 0.1 Hz returned to pre-training levels. These results suggest that long-term memory for VOR suppression is retained in the CB, whereas long-term memory for VOR enhancement is stored outside the CB, likely within VN.

P1-A-10 - Frontal eye field inhibition disrupts saccade reaction time, accuracy, and express saccade generation in Marmosets

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Details

The frontal eye field (FEF) is a key cortical region controlling saccadic eye movements. However, classical lesion and inactivation studies in macaques have shown only mild and transient behavioural deficits, leaving unclear how fine, temporally precise inhibition of FEF activity influences saccade generation. Recent advances in optical neuromodulation have opened new avenues for dissecting neural circuit

function. While optogenetic activation has been effectively used to modulate behaviour in non-human primates, reliable optogenetic inhibition has been substantially more challenging.
In this study, we used Jaws-mediated optogenetic inhibition in common marmosets to transiently and reversibly suppress FEF activity either during the gap period or at the time of visual target presentation in a visually guided saccade tasks. We also recorded FEF local field potential (LFP) activity simultaneously. Optogenetic inactivation reliably reduced the success rate in all directions, with a stronger effect observed for contralateral targets. Moreover, inhibition of the FEF impaired contralateral saccade kinematics, resulting in longer saccade reaction times and a change in saccade landing accuracy. We also observed a reduction in the proportion of express saccades, but only when FEF activity was suppressed during the gap period. The observed effects were fully reversible upon inhibiting the opsin expression using doxycycline.
These findings provide the first direct causal evidence in marmosets that the FEF plays a critical role in regulating saccade initiation, kinematics, and the generation of express saccades. Furthermore, this study demonstrates the successful optogenetic inhibition of the FEF in marmosets and establish a powerful approach for dissecting the causal neural mechanisms of oculomotor control.

P1-A-11 - Relating trial-to-trial variance in eye movements to variance in superior colliculus and primary visual cortex

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Details

Superior colliculus (SC) is an important sensorimotor structure for controlling eye movement. We recently found that variance in SC single neuron visual responses is correlated with variance in saccadic reaction times. Given that in primate, SC gets strong visual input from primary visual cortex (V1), here we further investigated the covariability of visual responses between these two areas. We first recorded 112 SC neurons and 251 V1 neurons when the monkeys were fixating and a Gabor pattern was displayed in the receptive fields of the neurons. From these recordings, we obtained 490 simultaneous neuron pairs, and we characterized visual response latency and strength. Within each area, simultaneous neuron pairs showed positive correlations (across trial repetitions) for both response strength and latency. In the SC, average correlation within pairs was 0.112 for visual response strength, and this was significantly stronger than in V1 (average R = 0.0721) (t-test, $p<0.0001$). Between areas, response strength and latency both still showed weak positive correlation. The correlation was stronger for response strength (average R = 0.0891) than latency (average R = 0.0294) (t-test, $p<0.0001$). Interestingly, trial-by-trial correlation of response strength was higher between SC visuomotor neurons and V1 neurons (average R = 0.1201), than in the case of purely visual SC neurons (average R = 0.0876) (t-test, $p=0.0102$). Conversely, the correlation of neurons within different V1 layers with simultaneously recorded SC neurons showed no significant effects. Thus, SC-V1 correlations likely reflect global state changes and not the influence of direct anatomical connections between SC and V1. Based on these observations, we next asked how simultaneously recorded neurons in either SC or V1 might influence motor outputs in an immediate, visually-guided saccade task. The saccade target could have 4 different contrasts (10%, 20%, 50% and 100%), either darker or brighter than the background. 26 SC sessions and 13 V1 sessions were recorded. In each session, we obtained 2 to 10 simultaneously recorded neurons. We then modeled saccadic reaction time across trials as a weighted linear combination of the visual response strengths of N simultaneously recorded neurons. R^2 values were adjusted for different predictor and observation numbers to evaluate the model predictions. Consistent with our previous work, the visual response strength of a single SC neuron was better than that of a single V1 neuron at predicting reaction time. By adding more simultaneously recorded neurons, the prediction got better in SC, but not in V1 for most of

the conditions. Only for 100% dark stimuli did V1 show an increase in prediction quality with more simultaneous neurons, which could reflect the preference of V1 for dark contrasts. These results suggest that despite qualitative similarities between SC and V1 visual responses, they serve different functions from a motor perspective.

B – Fundamentals of Motor Control

P1-B-12 - The predictive gaze: Linking eye movements to the sense of control

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Details

Understanding how humans estimate and experience control over their actions and outcomes is central to theories of sensorimotor learning and the sense of agency. This project investigates the relationship between anticipatory eye movements and the subjective sense of control in a dynamic visuomotor task. Control is manipulated through a gain parameter that alters the correspondence between finger movement and visual feedback. Participants are required to predict the outcome of their actions via anticipatory saccades and report perceived changes in control across trials. Gaze-based prediction errors—calculated as the distance between the saccade landing point and the actual visual outcome—are modeled alongside trial-wise control judgments using hierarchical logistic regression. This approach enables analysis of how control estimation evolves through learning and how prior experience with stable control conditions influences behavior under variable ones. The broader aim is to identify how basic sensorimotor signals relate to the sense of control and to use this understanding to inform models of how individuals judge their influence over the environment.

P1-B-13 - Vibrotactile stimulus detection during Fitts aiming: Implications for the use of biofeedback devices during skilled, manual tasks

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Details

Introduction: Musculoskeletal injuries are common in healthcare workers due to spinal loading and poor posture. To mitigate this, we have developed a system using sensors to assess injury risk and vibrotactile motors to deliver biofeedback. However, sensitivity to vibrotactile stimuli can vary depending on stimulus location and intensity. Tactile suppression can also occur when vibration is delivered to a moving body part. Accordingly, this study asks whether combining vibrotactile feedback with a manual task interferes with motor performance or reduces sensitivity to vibrotactile stimulation, as this could potentially make biofeedback unsafe or ineffective for practical use.
Methods: 18 participants (Mean age = 19, range 18-21; 16 women, 1 man, 1 non-binary; 16 right-handed, 2 left) performed a vibrotactile detection task, a Fitts aiming task using a digitizing tablet, and a dual task which combined the detection and aiming tasks. The study used a within-subjects design, with vibration delivered to the hand and the upper back on separate days in counterbalanced order. 50% detection thresholds (the intensity of vibration at which participants could detect the stimulus 50% of the time) were analyzed for the vibrotactile detection task and dual task, while movement time and path length were measured for the aiming task and dual task.
Results: 50% Detection thresholds for the vibrational stimuli increased on the dual-task compared to the solo vibrotactile detection task (Back = 52.83 units of stimulation intensity, Hand = 42.92, Back_Dual = 66.77, Hand_Dual = 62.77). This suppression effect was greater when the vibration was delivered to the moving hand compared to the upper back (Back = +13.87, Hand = +23.44). Movement time was slower

on the dual task compared to the solo aiming task, and was slower within the dual task when vibration was delivered to the hand compared to the back (Motor = 1.03s, Back_Dual = 1.11s, Hand_Dual = 1.21). There were no differences in path length.
Conclusion: Detection thresholds for vibrotactile stimulation are increased when performing a simultaneous, manual task. However, this suppression effect was lower when vibration was delivered to the back rather than the hand, and costs to movement time were also lower for the back. These effects are small, and in practice, vibration would be delivered at strong intensities rather than near the threshold of detection. A vibrotactile biofeedback system worn by healthcare workers on their upper back should therefore retain good sensitivity during work activities without impeding manual performance.

P1-B-14 - Refinement of movement patterns in sequential skill learning

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Details

A key goal in many motor skills is to become faster. Consider an Olympic swimmer: they constantly practice to shave off fractions of a second for a medal. To do so, however, they train at different speeds, including slower ones, to precisely refine their movement patterns, including stroke, arm and torso coordination, and head position. The underlying idea is that the refined movements under specific speed constraints will ultimately boost their competitive speed.
This aspect of skill learning, however, is not well characterized. Most previous studies have focused only on changes to the speed and accuracy of the performance with learning, ignoring how the patterns of movement change. Moreover, in most learning paradigms, speed and movement patterns change simultaneously throughout learning, making it difficult to distinguish systematic changes in movement patterns from those that simply reflect differences in execution speed.
To isolate systematic changes in movement patterns, we directly controlled movement speed during learning. We propose that if changes in movement patterns are a component of active skill learning, they should transfer across different execution speeds. To test this, participants were trained on a sequential finger-pressing task, where they learned to perform a single sequence of presses as fast as possible while maintaining accuracy. They were instructed to keep their fingers placed on a piano-like keyboard while executing the sequence. The recorded continuous contract force under each finger was used to characterize their movement patterns. After initial training, one group practiced within a constrained speed range, while the second group continued to increase their speed. Both groups were then tested at maximal speed.
The speed-constrained group showed systematic changes in their force patterns during the constrained practice phase. Crucially, when tested at maximal speed, this group showed a sudden improvement in execution speed, comparable to the speed in the unconstrained group. If changes in force patterns during the constrained-speed phase contributed to this speed boost, those patterns should transfer to the test phase. In fact, preliminary results show that the force patterns during the maximal speed test were more similar to the end of the speed-constraint phase than to the beginning, suggesting that the refined force patterns were used to achieve faster execution. Overall, our results reveal a previously underappreciated aspect of sequential skill learning: systematic refinements in movement patterns.

P1-B-15 - Exploring the effects of auditory stimuli on motor skill learning

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Details

The availability of reward improves motor skill learning and is related to dopaminergic processing. Listening to pleasurable music is also associated with the release of dopamine and may also improve aspects of motor performance. Therefore, an outstanding question is whether listening to pleasurable music can improve motor learning. Prior work from our lab found that participants who listened to their favourite music or silence, while performing a motor learning task, exhibited better skill retention than those who listened to neutral music or an audiobook. Listening to neutral music or an audiobook may have been a distraction; other studies have reported that listening to lyrical materials or words makes it harder to focus.

In this study, we aim to replicate our prior work in an *a priori* manner. We implemented the same study methodology and included an attention probe questionnaire to understand the role of distraction during motor skill learning. We hypothesize that the favourite music and silent group will show better skill retention than the neutral music and audiobook groups.

We plan to recruit 48 participants (12 per group). At present, 21 participants were randomized into one of four groups: favourite music, neutral music, audiobook, and silent (data collection ongoing). On day 1, participants listened to their group-allotted materials while performing six acquisition blocks of the sequential visual isometric pinch task (SVIPT). All groups were then tested with one block of the SVIPT performed in complete silence to evaluate skill retention at 10-minutes after block 6 (immediate retention) and 24 hours later relative to block 6 (24-hour retention). The dependent measure is Skill, a variable that accounts for movement time and error in performance.

We performed repeated-measures analysis of variance to compare skill across the different time points (blocks) between the music groups (conditions). During acquisition, there was a significant main effect of block ($F(5,85) = 3.847$, $p=0.003$); participants improved with practice regardless of group. However, there was no significant effect of condition ($F(3,17)=0.925$, $p=0.450$) and no significant interaction effect ($F(15,85)=0.544$, $p=0.908$). During immediate retention, there was no significant effect of block ($F(1,17)=0.669$, $p=0.425$) or condition ($F(3,17)=0.651$, $p=0.593$), and a trend toward an interaction effect ($F(3,17)=2.671$, $p=0.080$). The favourite music and silent groups showed better skill retention than the neutral music and audiobook groups. At 24-hour retention, there was no significant effect of block ($F(1,17)=0.848$, $p=0.370$) or condition ($F(3,17)=0.377$, $p=0.771$), and no significant interaction effect ($F(3,17)=0.655$, $p=0.591$). These preliminary results suggest that when learning a motor task, being in silence or listening to one's favourite music may lead to better short-term retention of the skill.

P1-B-16 - Motor cortical dynamics underlying coarticulated reaching sequences

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Details

Humans and animals routinely execute action sequences with striking fluency. A hallmark of this fluency is coarticulation, in which earlier movements are shaped to facilitate those that follow. Here, we investigate how the cortical motor circuit supports the preparation and execution of coarticulated reaching sequences.

We trained one macaque to perform 2-reach sequences with 50ms dwell times at each target. We manipulated the number of future targets visible to the animal (Horizon 1 or 2), thereby controlling how many future movements could be prepared before initiating the first reach. As a result of target placement and short dwell times, the animal coarticulated its movements in a biomechanically efficient

manner in the H2 condition. We recorded single-unit activity from M1 (N=2012), PMd (N=2057), and SMA (N=1968) using Neuropixels probes.
First, we examined how information about the sequence elements was distributed across the cortical motor circuit. We found that following the target onset, information about sequence elements emerged in M1, PMd, and SMA over time in the order of their execution. This information arose first in PMd, followed by SMA and M1. Interestingly, in the H2 condition, both targets explained a similar amount of variance in SMA and PMd at the end of the preparation period. In M1, however, variance was dominated by the first target, with only a small contribution from the second target.
Next, we asked whether the coarticulated sequences are prepared reach by reach or as a single long movement. To gain insight into this question, we used the condition-independent trigger signal that is part of the preparation-trigger-execution motif previously reported in single-reaches and non-coarticulated sequences (Churchland and Shenoy 2024). That is, we tested whether the trigger signal appears before each reach or only once at sequence initiation. As expected, in the H1 condition, we found that the trigger subspace was engaged two times, once per reach. In contrast, in the H2 condition, we found that the trigger subspace was engaged only once at sequence initiation. This pattern was evident in SMA, PMd, and M1. These results suggest that the cortical motor circuit prepares a single, long movement that spans multiple sequence targets.
Last, we examined when motor cortical areas begin representing a newly revealed third target during an ongoing coarticulated movement through the first two targets. To do so, we ran a second experiment with 3-reach sequences under the H2 condition. We found that none of the areas represented the third target until the first two targets had been captured, even though the third target appeared immediately after the first one was captured. This finding is consistent with the view that the animal prepares a single, long movement to capture the first two targets.
Taken together, our study provides a comprehensive view of how rapid coarticulated reaching sequences are prepared across the cortical motor circuit.

P1-B-17 - Parallel and distributed processing of value-based information during multi-attribute action decisions

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Details

Many previous studies have shown that neural activity in prefrontal areas reflects information pertinent to ongoing decisions, suggesting that decision-making is part of the frontal lobe's executive functions. However, decision-related neural modulation is also observed in sensorimotor areas. Does this imply that these areas are also causally involved in the decision processes? Or are they instead merely recipients of the final decision, which is made in the prefrontal cortex on the basis of a unified, integrated estimate of utility? In the first study, we investigated how humans make reach decisions in a multi-attribute value-based decision task. Subjects were presented with reach targets whose reward value was indicated by two attributes - its brightness ("bottom-up" feature) and its orientation ("top-down" feature). Importantly, in some cases ("conflict trials") the two attributes differed but the total value for each target was nonetheless equal. We predicted that if decisions are always made after a unified estimate of utility is calculated, the reaction time (RT) should be longer when targets differ in both attributes compared to when they only differ in one. Instead, we observed that RTs were dependent on which feature drove the subject's choice – i.e. faster when subjects chose on the basis of the bottom-up attribute even in conflict trials, as if they "jumped the gun" before fully integrating value-based information from the top-down attribute. Consistent with this, mid-reach changes-of-mind in conflict trials usually changed from the target favored by bottom-up information to the one favored by top-down information. In the second study, we investigated the role of dorsal premotor (PMd) cortex

and parietal reach region (PRR) while rhesus monkeys performed the same task. We predicted that the latency of choice-predictive activities in PMd and PRR would reflect their causal role, especially when the attributes are in conflict. A population analysis of early-tuned cells showed that both PMd and PRR predicted choices before action execution, with PMd often preceding PRR. Furthermore, conflict resolution between equally-valued choices was biased by baseline activity in PMd, but not PRR. However, a neural space analysis on the entire population showed that neural state trajectories of bottom-up choices reflected the monkey's choice earlier in PRR than in PMd, whereas the opposite was true for top-down choices. Together, these results suggest that at least in the case of choosing between concrete reach actions, value-based decisions are made at the individual attribute levels in a distributed decision network that includes PMd and PRR, as opposed to at an abstract, fully integrated value representation in prefrontal cortical areas.

P1-B-18 - Time course of corticospinal excitability during observation of anatomically and spatially variable body stimuli

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Details

Introduction: Action observation has generally been reported to modulate corticospinal excitability in the muscles involved in the observed movement. However, previous research suggests this may also be modulated by factors including the timing of stimulus presentation and the positioning of the presented muscles relative to the participant's own hand. Here we examined the influence of these factors on corticospinal excitability.

Method: Participants observed stimuli presenting a static hand, followed by an image of the endpoint of an index/little finger abduction movement. Transcranial magnetic stimulation was delivered at time points from 100-800ms after movement offset. Stimuli were presented in various orientations to study possible effects of anatomical positioning and movement direction, compared relative to the control condition of a static hand.

Results: Corticospinal excitability was lower at early timings (100-400ms) before rising to a plateau at later timings (500-800ms) that did not differ from the static hand condition. This facilitation was muscle-specific, with higher excitability for the muscle involved in the observed movement. By contrast, the relative direction of movement did not influence cortisospinal excitability.

Discussion: Although there is a modulation of corticospinal excitability induced by action observation with an increase in excitability over time, this is not consistent with facilitation as suggested in previous studies. In fact, we observed lower excitability for action trials than for static ones, which is more consistent with a phenomenon of inhibition at early timings. This suggests the need to rethink the generally accepted view of the influence of action observation on corticospinal excitability.

P1-B-19 - Contribution of GABAA(δ)R in nucleus ambiguus motor control of cardiac contraction rate

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Details

Nucleus ambiguus (NA) contains cardioinhibitory cardiac vagal motor neurons (CVNs) that decrease cardiac contraction rate through axonal projections to cardiac pacemaking cells. Despite robust evidence for the role of glutamate to regulate CVN activity, the role of the primary fast inhibitory neurotransmitter, gamma-aminobutyric acid type A receptors ($GABA_AR$), is less clear. $GABA_AR$ ligand binding and kinetic properties are determined by subunit composition. $GABA_ARs$ containing a δ-subunit ($GABA_A(\delta)Rs$) possess a high affinity for GABA with slow rates of desensitization, making them well suited

to contribute to long duration, or tonic, current. Given the critical signal integrating nature of tonic current, we hypothesized that $GABA_A$(δ)Rs contribute to CVN regulation in NA. Initial immunohistochemical analysis confirmed $GABA_A$(δ)R protein expression in CVNs. Bilateral microinjections of THIP (4,5,6,7-tetrahydro isoxazole[5,4-c]pyridin-3-ol); a GABAA(δ)R superagonist; 60nl; 10nL/s; 20uM; n=4/group) into NA produced significant tachycardia (PBS; 30.7 BPM ± 9.6; p=0.05) compared to vehicle (-1.62 BPM ± 6.12). To further isolate GABAA(δ)R contributions to CVN regulation, we utilized a unique transgenic mouse line, δ*KI, which possesses GABAA(δ)Rs insensitive to picrotoxin, a GABAAR antagonist (n=8). Disinhibition of NA with picrotoxin significantly (5.5 mM) decreased cardiac contraction rate (97.6 ± 100.7 BPM) compared to vehicle (4% DMSO in PBS; 21.2 ± 8.58 BPM; p=.0008). Sequential microinjection of gabazine (a general GABAAR antagonist; GBZ; 1 mM) further decreased HR (76.3 ± 50.4 BPM) compared to vehicle (PBS; 18.52 ± 25 BPM; p=0.042). Taken together, total GABAAR inhibition contributes to ~30% of resting cardiac contraction rate in murines with GABAA(δ)R making up ~50% of total CVN inhibition of CVNs. These results were confirmed using whole cell electrophysiology, as GABAA(δ)R-mediated currents contributed ~68% of total tonic inhibition in CVNs. To understand the plasticity of GABAA(δ)R signaling in CVNs, mice were fed high fat diet (HFD) for 15 days, where disease pathology causes a decrease in cardiac vagal motor drive through overactivation of GABAA(δ)R in CVNs. C57/Bl6J mice on HFD for 15 days had greater tachycardic responses to THIP (39.9 ± 19.9 BPM), compared to animals placed on normal fat diet (NFD; 8.9 ± 5.6 BPM; p=0.0218). δ* KI mice fed HFD had no significant changes to picrotoxin, but significantly larger bradycardias to disinhibition with gabazine (HFD; n=4, -270 ± 30.7 NFD; n=3, -68.7 ± -28.4; p= 0.0003), further implicating the role of these receptors in the pathology of HFD. Immunohistochemical and whole cell electrophysiological analysis confirmed $GABA_A$(δ)R protein and functional electrophysiological expression in CVNs in upregulated as well. Together, these data confirm GABAA(δ)R as a robust regulation of CVN plasticity.

P1-B-20 - Can finger movements be decoded from early visual cortex?

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Details

Early visual cortex (EVC) is increasingly understood as more than a mere passive recipient of retinal input. Growing evidence demonstrates that EVC activity is modulated by action planning and execution, such that upcoming effectors (e.g., hand versus eye) or action type (e.g., grasp versus point) can be decoded from visual cortical activity, even in the absence of visual input. Such findings suggest that EVC is influenced by action-related top-down signals that support visually guided behaviour. However, existing studies have primarily examined coarse effectors and broad action categories, such as grasping versus reaching. It remains unexplored whether fine-grained motor information, such as finger movements, is represented in EVC. Using sensitive decoding analyses, we tested (i) whether individual finger movements can be decoded from EVC and primary sensorimotor areas, and (ii) whether instruction modality (visual vs auditory) influences this decoding.

We asked 20 adults (27.5 ± 4.0 years; 10 female) to perform a finger-tapping task during 3 T fMRI. We used visual or auditory cues to instruct them to tap their thumb, index, middle, ring, or pinky finger, in sync with a blinking fixation cross, or to rest. Instruction modality (visual vs auditory) alternated across runs. During visual instruction runs, the finger to be tapped was presented as a word (e.g. "thumb") on the screen, whereas they were presented via headphones during the auditory runs. Importantly, the movement period was identical across conditions, with consistent visual (i.e., blinking cross) and without auditory stimuli. We assessed finger-specific information content within EVC (V1-V3) and primary sensorimotor areas (S1, M1) using classification analysis and determined group-level significance using permutation testing.

As expected, we robustly decoded finger identity in primary sensorimotor areas (both $p_{Holm}<0.001$), demonstrating that our decoding was sufficiently sensitive to detect finger identity. Interestingly, albeit weak, finger identity could also be decoded from EVC during movement execution in both the visual (mean accuracy=0.23, $p_{Holm}<0.05$) and auditory (mean accuracy=0.23, $p_{Holm}<0.05$) conditions. Notably, this effect was substantially weaker than the finger decoding in primary sensorimotor areas and above-chance decoding was present in only a subset of participants. We further found above-chance decoding of fingers in EVC during the instruction period, prior to movement onset, in both the visual (mean accuracy=0.30, $p_{Holm}<0.05$), and auditory conditions (mean accuracy=0.23, $p_{Holm}<0.05$). This suggests that EVC activity is not solely driven by retinal input and may reflect task-related or preparatory top-down influences. Together, these findings propose that motor-related influences on EVC may extend beyond coarse effectors and action categories, though further, ultra-high resolution fMRI studies are needed to investigate finger-specific information in EVC in depth.

P1-B-21 - A brain-computer interface paradigm reveals different constraints on cortical and striatal activity

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Details

Motor cortex (M1) and striatum are interconnected, anatomically distinct regions whose functional contributions to behaviour remain elusive. Some studies suggest that striatal activity primarily reflects cortical inputs, whereas others propose more sophisticated functional contributions. For example, a recent study showed that striatal neural population activity is higher-dimensional than M1 activity during the same reaching and grasping task (Fortunato et al bioRxiv, 2024).

Here, we used a Brain-Computer Interface paradigm to ask two questions about the differences between M1 and striatum: (1) Can animals volitionally modulate striatal activity, like it has been reported for M1? (e.g., Fetz, 1969) If so, (2) to what extent are the neuroanatomical and functional differences between these two areas imposing different constraints on the neural activity each of these areas can generate?

To answer these questions, we designed a BCI task where we recorded M1 and striatal activity from head-fixed mice running on a treadmill. The firing rate of 5 consecutive Neuropixel channels from either layer 5 of M1 or dorsolateral (sensorimotor) striatum was mapped to a one-dimensional visual cursor. Mice received a reward when the firing rate of the BCI channels increased beyond an adaptive threshold, which corresponded to the cursor reaching the target.

Mice (n=6) successfully increased the firing rate of the neurons from the selected BCI channels for both M1 and sensorimotor striatum. Importantly, this increase in firing rate was not reflected in the running speed or movement initiation for BCIs from either brain region. Moreover, in most sessions, mice exhibited anticipatory licking ~1s before the reward delivery, suggesting intentional control of the BCI that could not be explained by the movement of the visual cursor.

Interestingly, when the BCI channels were in M1, the increase in firing rate was reflected in neurons throughout the entire area, and occasionally even in downstream striatum. In contrast, when the BCI channels were in the striatum, the increase in firing rate was predominantly confined to neurons recorded in neighbouring channels.

This difference suggests different constraints on M1 and striatal activity, with striatum allowing for more independent activity patterns that do not need to be associated with similar changes in upstream M1. Consistent with recent studies, our data thus suggest that striatal population activity is more than a reflection of the ongoing activity in upstream M1; instead, these two areas have fundamental differences in the flexibility and constraints of their neural population activity that we are examining in ongoing work.

P1-B-22 - The effect of Reward and Punishment on the Acquisition and Consolidation of a Basketball Free-Throw Skill

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Details

Reward and punishment have been shown to differentially influence components of motor learning in laboratory tasks, including sensorimotor adaptation (Galea et al., 2011; Therrien et al., 2016; Spampinato et al., 2019), sequence learning (Sporn et al., 2022), and force modulation (Abe et al., 2011; Vassiliadis et al., 2021, 2022, 2024). Converging evidence suggests that reward plays a prominent role in the offline consolidation of motor memories, whereas punishment preferentially facilitates rapid online adjustments, particularly in adaptation tasks. While these findings have important translational implications, it remains largely unknown whether the effects of reward and punishment generalize to real-world skills beyond laboratory settings, and whether their combination might yield additional benefits.

To address these questions, we trained 4 groups of 17 participants on a basketball free-throw task under reward, punishment, mixed, or control (no-incentive) conditions, and assessed the effects of these different motivational contexts on initial acquisition (directly after training, $Post_{0day}$) and subsequent consolidation ($Post_{+1day}$ and $Post_{+3days}$) of the skill. In the training session, following a baseline block that evaluated initial performance in the absence of any motivational manipulation (Pre), participants completed 120 free throws in pairs (2-on-2) to simulate a conventional basketball free-throw setting, and points were recorded for each pair. Crucially, the reward, punishment, and mixed conditions differed only in how points were computed (bonuses vs penalties), with no monetary incentives and no additional performance feedback provided. The Control group received one point per successful free-throw exactly as in a conventional basketball setting (+2 if 2/2), the Reward group received a bonus point if both throws were successful (+3 if 2/2), the Punishment group lost one point if both throws were missed (-1 if 0/2) and the mixed group combined the bonus and penalty of the Reward and Punishment groups (+3 if 2/2 and -1 if 0/2).

Consistent with prior findings, the delivery of reward and punishment led to markedly different acquisition and consolidation dynamics. While initial performance was comparable in the four groups, free-throw accuracy improved more in the Punishment and Mixed groups compared to the Reward and Control groups at $Post_{0d}$, demonstrating enhanced skill acquisition. Interestingly, Reward markedly enhanced offline gains compared to all other groups, in which performance at $Post_{1d}$ and $Post_{3d}$ was largely maintained. Importantly, the offline benefits of the Reward group were larger than the online improvement in the Punishment group, with better free-throw accuracy 3 days after training in the Reward group. The Mixed group demonstrated a hybrid learning profile, with acquisition gains similar to those of the Punishment group and offline gains between those of the Punishment and Reward groups, suggesting competing influences of reward and punishment on motor memory consolidation.

Overall, these results show that the motivational context in which a skill is learned can shape both the acquisition and consolidation of a complex, real-world motor skill, with clear implications for rehabilitation and sport coaching practice.

P1-B-24 - Cortical mechanisms underlying human eye-hand coordination: beyond summation of saccade and reach networks

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Details

Introduction:

Eye-hand coordination supports everyday behaviours, yet its neural basis remains unclear. Most neuroimaging research has examined eye and hand movements separately (Connolly et al., 2000, *J Neurophys*; Fernandez-Ruiz et al., 2007, *Cereb Cortex*; Beurze et al., 2009, *J Neurophys*; Gallivan et al., 2011, *J Neurosci*), whereas progress on understanding human eye-hand coordination has been limited by the difficulty of recording natural reach and eye movements in the MRI environment, the need for appropriate controls, and the challenge of temporally separating the encoding of visual information from the formation of a motor plan and the execution of movement. To address these challenges, we developed a cue-separation fMRI task in which the action (eye, hand, or eye-hand) was divided into these three phases, allowing us to test whether cortical activation for eye-hand coordination is simply the sum of the activation for its effector (eye, hand) components.

Methods:

We used an event-related fMRI task with three separate phases: 1) **Encoding** phase: participants fixated while viewing the peripheral target, 2) **Planning** phase**:** a task cue was presented (look, reach, look and reach, or target colour report), and 3) **Execution** phase: a 'go' cue was presented. Behaviour was quantified using MRI-compatible eye-tracking and a custom LED-touchscreen apparatus. Each scan lasted 70 minutes, and all reaches were performed with the right (dominant) arm. We conducted nonparametric permutation testing ($p < 0.05$ FWE-corrected) to identify significant activation for each action compared with the color control condition across the distinct phases. To determine whether coordinated eye-hand behaviour engaged processes beyond the summed contributions of eye-only and hand-only movements, resultant voxel-wise maps for the combined condition were compared with the additive eye and hand maps.

Results:

20 participants were included in the following analysis. Comparisons of the statistically significant maps for task-specific activity related to the colour control revealed the following. During the **encoding** phase (before effectors were specified), bilateral temporal regions were engaged across all action tasks. During the **planning** phase, saccade activation was restricted to a small portion of the left occipital / posterior parietal cortex. In contrast, reaches engaged more extensive bilateral posterior parietal and frontal regions, with modest left-hemisphere lateralization. Combined saccade-reach actions generally activated regions intermediate between these two patterns, showing some shift relative to reach and a tendency towards left-hemisphere lateralization. During **execution**, saccade-only and reach-only actions showed the expected bilateral parietal, frontal, and subcortical activation, with partial overlap, and clear sensorimotor cortical lateralization for reach. In this case, the combined saccade-reach task generally produced more widespread activation than the individual effector activation maps, and recruited additional regions, including regions within the cingulate gyrus, occipital cortex, precuneus, and cerebellum.

Conclusions:

Together, these results demonstrate differences in the timing and spatial distribution of planning signals for saccades versus reaches, and that brain regions recruited during planning and executing eye-hand movements are not the summation of eye and hand regions. Surprisingly, the combined saccade-and-

reach task produced less activation than reach during planning, but more activation than the sum of saccade and reach activation during execution, including several additional cortical and subcortical areas. These findings point to candidate mechanisms underlying eye-hand coordination and highlight targets for future investigation into fundamental processes supporting human motor control.

P1-B-25 - Asymmetric grip forces in a bimanual peg-in-hole task

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Details

Mechanically uncoupled bimanual tasks, where each hand manipulates an object independently, present unique challenges compared to unimanual tasks. When the two objects are controlled for precise interaction, both hands must account for the combined motor noise and variability when coordinating their movements. Here, we investigated the motion, variability, and grip forces immediately prior to insertion of both hands during a simulated bimanual peg-in-hole task, where participants completed the task in both possible hand configurations for the peg and hole. Each hand grasped the end of a phantom robot instrumented with force sensors to measure grip force. Visual feedback was provided via a virtual reality system, while the robotic system was used to control the virtual objects and measure force variability at the time of insertion in each hand. Experimental feedback led to synchronized movements of the two hands by the participants. By using three different peg diameters, we introduced a range of difficulty levels to the task. Participants showed an increased trial duration and increased corrective movements as the task difficulty increased. However, we found that grip force before insertion was consistently elevated in the left hand compared to the right hand regardless of whether the left hand controlled the peg or hole object. This asymmetry is evident despite similar forces acting on each object within the simulated environment, resulting in comparable forces acting on the two hands. Overall, we found a strong asymmetry in grip force before insertion, independent of the manipulated object and symmetry of the movements.

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P1-B-27 - Influence of hand dominance and stimulus eccentricity on the StartReact effect

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Details

The StartReact paradigm is used as a probe of subcortical motor pathways, especially the reticulospinal tract (RST). Following stroke, spinal cord, or brain injury, patients may rely more on the RST to control their upper limbs. Current evidence suggests auditory startle responses are not completely symmetric; with significant response size differences in head and neck, and a trend towards asymmetry in proximal upper limb. There is also evidence to suggest responses to central visual cues are slower compared to peripheral visual cues, due to visual processing. Therefore, the purpose of this study was to investigate physiological and methodological variables influencing the StartReact paradigm by comparing responses between dominant (DOM) and non-dominant (NONDOM) hands, and central (CEN) and peripheral (PER) visual cues.

In twenty-six healthy adults (mean age = 19 ± 1 years, 21F), we measured reaction time (RT) in response to a visual cue, a visual-auditory cue, and a visual-startling-auditory cue. The visual stimuli were either CEN (0°) or PER (15°) from the fovea. EMG was recorded bilaterally from the first dorsal interosseous (FDI) and abductor polis brevis (APB) muscles during 108 bilateral, isometric pinch grip contractions. Reaction time was identified as EMG onset from stimulus, and StartReact was calculated as the difference in RT between visual-auditory and visual-startling cues.

Pairwise comparisons between DOM and NONDOM revealed no differences in RT in response to all six CEN and PER cues (all p>.5). In the APB, the StartReact was larger in NONDOM compared with DOM in CEN (34 ± 22 ms vs 27 ± 17ms, *p*<.05) and PER (42 ± 26 ms vs 39 ± 22 ms, *p*=.173). In the FDI, the StartReact was not different in NONDOM compared with DOM in CEN (31 ± 21 ms vs 29 ± 19 ms, *p*=.428) and PER (39 ± 22 ms vs 39 ± 23 ms, *p*=.819). APB RT was prolonged in CVSC compared with PVSC in DOM (131 ± 20 ms vs 128 ± 18 ms, *p*=.027) but not different in NONDOM (134 ± 17 ms vs 132 ± 16 ms, *p*=.227). FDI RT was prolonged in CVSC compared with PVSC in DOM (130 ± 16 ms vs 127 ± 16 ms, *p*=.031) but not different in NONDOM (131 ± 16 ms vs 128 ± 15 ms, *p*=.170).

There are differences in RST contribution between thumb (ABP) and finger (FDI) muscles. These results suggest a greater influence of brainstem circuits and a weaker CST dominance on thumb-related motor programs, compared to the dominant hand. Meanwhile, the absence of dominance effects in FDI reflects its consistent dependence on corticospinal control for fine motor precision of the fingers in both hands. RT to peripheral startling cues were faster compared with central startling cues, in DOM but not NONDOM, suggesting peripheral startling cues may be a better assessment of RST excitability, bypassing cortical processing. In contrast, peripheral visual and visual-auditory cues were slower compared with central visual and visual-auditory cues, likely due to initially relying on the learning of spatial contingencies.

P1-B-28 - Impact of movement repetition on physical and imagined movements

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Details

Introduction: Motor planning relies on the ability to anticipate and adapt movements based on environmental constraints. This study examined the impact of repetition on physical execution and motor imagery. The objective was to evaluate how repetition of a movement influences performance, and whether this effect transfers between real and imagined movements.

Methods: Thirty-two participants took part in this experiment (22.7 ± 3.4 years old). The task consisted of making a reaching movement from a start to an end position as quickly and accurately as possible. The start and end points were always in the same position but were surrounded by barriers with apertures that required participants to move with specific trajectories. Participants completed 240 trials requiring them to either physically execute or imagine (using visual 1st person and kinesthetic imagery) movements; manipulating the barrier orientation allowed us to study the effects of requiring trajectories that either repeated or differed from one trial to the next. Reaction times (RT) and movement times (TimeMov) were analysed.

Results: The results show a significant decrease in RT and TimeMov when the barrier orientation and condition (physical or imagined) are repeated, suggesting that repetition has a facilitating effect on motor planning and execution. This effect is also observed when the orientation is the same, but the condition is different for reaction times only.

Conclusion: These results reinforce the idea that repetition optimises motor planning and performance and confirm the validity of motor imagery as a relevant tool for studying movement planning processes.

P1-B-29 - The role of kinematic and muscular synergies in dexterous, contact-rich manipulation

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Details

The human hand is largely considered an "enabler" of human intelligence. Thanks to its biomechanical architecture – characterized by dozens of joints and muscles – the human hand enables the performance of a vast and diverse set of coordinated manipulation tasks with ease. Several research efforts have sought to understand the control mechanisms underlying the hand's complex biomechanical system. Synergies, a class of motor primitives, have emerged as a plausible framework for explaining how the nervous system manages motor coordination. Despite this, it remains debated whether the central nervous system controls all degrees of freedom in parallel or through a hierarchical, domain-based structure. Furthermore, it is especially unclear how humans coordinate joints and muscles during complex dynamic manipulation tasks that involve varying physical interaction. Because these coordination modalities are typically analyzed separately, their interaction is poorly understood. Together, these gaps underline the need to study multi-domain coordination. We hypothesize the existence of two distinct controllers for task coordination: one that manages kinematic constraints and another that governs kinetic or dynamic interactions. We further propose that these controllers become more apparent during complex manipulation tasks. To test these ideas, we conducted a research study in which human subjects were tasked to perform two complex manipulation tasks, with different finger individuation requirements: prism in-hand re-orientation and piano playing. To examine how task dynamics influence performance, we varied the prism's weight in the re-orientation task and the required key-press intensities in the piano-playing task. Through the lenses of both kinematic and muscular synergies, we quantified task coordination complexity, and observed distinct behaviors during higher-force production, involving both greater joint individuation and intrinsic hand muscle coordination. Using a newly developed metric (VAF-CI) capable of quantifying motor coordination, we (i) verify VAF-CI's ability to quantify coordination complexity in muscle space, as was previously shown in kinematic space; (ii) use this metric to elucidate differences in motor coordination in both kinematic and muscle spaces during complex manipulation; and (iii) use it to demonstrate that coordination in the kinematic space varies with hand dominance. Our findings emphasize the importance of personalization in motor control, and in assistive and rehabilitative applications, and will guide the improvement of technological aids for hand impairments, such as bionic hands and exoskeletal devices.

P1-B-30 - Judging action-outcome intensifies motor preparation: Evidence from readiness potentials and β-band desynchronisation

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Details

Motor preparation can be tracked in scalp EEG by the readiness potential (RP)—a slow pre-movement negativity—and by β-band event-related desynchronisation (β-ERD, 13–30 Hz) over sensorimotor cortex. Previous studies have shown that anticipating an action's consequence can modulate the RP. However, whether motor-preparatory activity changes further when the consequence must be explicitly evaluated rather than merely anticipated remains not answered. We addressed this question using a virtual-reality Libet-clock paradigm that presented stimuli at near and far viewing distances to examine spatial-proximity effects. EEG was recorded while participants completed right-hand key-press tasks. One of the tasks involved no consequence after the keypress (Active-only), another involved the mere presence of a consequence (No-report-outcome), and the last involved reporting the timing of the outcome (Report-outcome). A graded pattern emerged from the preliminary analysis. The Report-outcome task produced

the largest early and late RP amplitudes, the steepest RP slope, and the deepest β-ERD. The No-report-outcome task was intermediate; Active-only was smaller. Thus, the largest RP and β-ERD emerged when participants were required to judge the timing of the tone caused by their key-press. Because greater action-outcome precision is thought to heighten the sense of agency over an action's consequence, the convergent RP + β-ERD pattern could constitute a neural signature of the prospective agency. These findings support precision-weighted, hierarchical models of motor control and highlight neural markers that could guide feedback-based rehabilitation and improve intent detection in brain-computer interfaces.

P1-B-31 - Toward an integrated view of the role of multi-region networks in locomotor control

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Details

Locomotion is a fundamental behaviour that in mammals engages circuitry from the cortex down to the spinal cord. Initiation and termination are thought to be controlled by brainstem hubs, such as the pedunculopontine and cuneiform nuclei in the mesencephalic locomotor region, while goal-directed steering is suggested to recruit forebrain structures, such as the basal ganglia and motor cortex.

While the field has developed an understanding of how individual regions and subpopulations of cells contribute to specific aspects of locomotion, these insights have often been achieved by studying regions in isolation, and/or focusing on a single aspect of locomotor control. What is lacking is an integrated understanding of how these multi-region networks work together to control various components of locomotion, and what enables the animal to transition from internally-generated, spontaneous locomotion to externally-driven, goal-directed behaviour.

To approach this problem, we developed a locomotor task requiring head-fixed mice to keep track of the progression of an audiovisual cue to a target, and use this information to guide the initiation and termination of running. After mice acquired the task, we collected multi-region Neuropixels recordings during performance of both the cue-driven task and periods of spontaneous running. Furthermore, in a subset of these animals we performed region-specific inactivations to test for their causal contributions to the task.

Using this dataset, we are characterizing how within-region population dynamics and inter-region coordination changes across the initiation, maintenance, and termination of locomotion, and how these features differ between spontaneous and cue-driven locomotion. Together, this combined experimental and analytical approach provides an integrated account of how multi-region networks support locomotor control from spontaneous to goal-directed behavior.

P1-B-32 - 'Automatic and selective inhibition in the brain: A MEG and selective stop task study'

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Details

The aim of our work is to better characterize the neural markers of automatic (task-unrelated) and selective (task-related) inhibition, and to validate the tools used to detect them.

Currently, the stop-signal reaction time (SSRT) is widely used to quantify action inhibition in manual and saccadic tasks. However, it is criticized for its limited reliability (Hedge et al., 2018), its dependency on visual and motor delays (Statham et al., in preparation), and the fact it is a compound measure, reflecting not only the speed of inhibition but also the likelihood of inhibition being triggered (Matzke et al., 2017). Still, many neurophysiological studies rely on SSRT to identify neural markers of inhibition such as increased or earlier P300 and N100 event-related potential (ERP) components (e.g., Huster et al.,

2020).
The selective stopping task has participants give speeded responses to lateralized dots on go trials, withhold responses when a stop signal appears, or respond when an ignore signal appears. The time of divergence between go and signal-present trial distributions reflects the minimum estimate of visual and motor delays, termed visuomotor deadtime (VMDT , Bompas et al., 2024). The time of divergence between stop and ignore distributions reflects the selective stopping time, i.e., the earliest time that top-down, instruction-relevant signals can influence action. Additionally, peak partial response electromyography (prEMG) latencies can be used to index the timing of inhibition as they reflect when an initiated muscle response has been interrupted before the recording of a full response (Raud et al., 2022, eLife).
We will outline the study, analysis, and preliminary results of a manual selective stopping task in MEG. Similar work has been done before (Schaum et al,. 2021), although the analyses relied on time windows derived from SSRT, used too few trials to reliably extract VMDT or selective stopping time, and did not ensure that trial types being compared had comparable temporal histories e.g., by equating the distributions of SOAs.
Our aim is to use physiological and more mechanistically precise behavioural markers, rather than SSRT, to constrain analysis windows. Within these windows, we should be able to make targeted comparisons between trial-types (stop, go, and ignore) to isolate the neural mechanisms of automatic and selective inhibition. For each process, we will identify 1) trials where the process has most likely occurred, and 2) comparable control trials where it hasn't. To do so, we will use trial types and their behavioural/ physiological outcomes (button press response times and EMG latencies in relation to key landmarks: VMDT and selective stopping time). We will compare the oscillatory power across trials to identify when in a trial and where in the brain differences occur. We will also extract traditional markers (P300 and N100 onset) and compare their latencies with those of the markers identified using our methods.

P1-B-33 - Salient and latent neural motor representations for whole body movements

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Details

Intracortical brain–computer interfaces (iBCIs) enable individuals with paralysis to control external devices by decoding attempted movement by harnessing neural signals from the precentral gyrus. In practice, however, iBCI systems are limited to one or two cortical implants covering limited territory. A fundamental open question is therefore how much whole body movement information—particularly directional information—can be extracted from a subregion of the precentral gyrus. Classical studies of motor cortex emphasize spatially segregated somatotopy, which would predict limited access to movements outside the dominant body-part representation. More recent studies suggest a broader, graded organization with overlapping body-part representations, but have not examined directional tuning across body parts, leaving the richness of this latent information unclear. Here, we quantify how much body-part identity and directional movement information is available within a single region of the precentral gyrus. We conducted experiments with two individuals with cervical spinal cord injury enrolled in an ongoing iBCI clinical trial under an FDA Investigational Device Exemption. Prior to implantation, participants underwent functional MRI to map body representations. Guided by these maps, each participant was implanted with two pairs of intracortical microelectrode arrays in the hand/arm region of the pre- and post-central gyri. Following implantation, participants performed a whole-body motor mapping task involving directional attempted movements (up, down, left, right) of 12 body parts, including contralateral and ipsilateral fingers, wrist, arm, leg, ankle, and eye and tongue movements. Neural recordings were collected simultaneously with eye-tracking and marker-based

motion capture. Neural activity was significantly modulated relative to rest for all movement conditions in both participants. Factor analysis revealed a low-dimensional neural state space in which both directional (within-) and identity (between-body-part) information was significantly greater than zero across all movements, with higher separability for the contralateral index finger, wrist, and arm. Decoding analyses showed above-chance classification of body-part identity and movement direction for every body part. Finally, when classifiers trained on movement direction for one body part were tested on another, decoding performance dropped to near chance, with generalization observed only for a subset of pairs: typically somatotopically related (e.g. ankle–leg) or contralateral–ipsilateral effectors. While directional structure is robust within each body part, it is not shared globally across the motor map. Together, these results show that directional information extends beyond the strict somatotopic organization predicted by classical motor maps, yet remains structured within a graded somatotopic hierarchy, defining key constraints and potential for future multi–body-part iBCI control.

P1-B-34 - Reconciling cell and network effects of 5-HT1ARs on motor cortex excitability

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Details

Serotonin (5-hydroxytryptamine; 5-HT) exerts robust effects on neocortical excitability that may be leveraged for neuromodulation therapy following acquired brain insults. Canonically, 5-HT receptors of subtype 1A (5-HT1ARs) are expressed in multiple neural structures and signal transduce via G protein-gated inward rectifying potassium (GIRK) channels, and Gi-protein GPCR intracellular signaling, to reduce excitability of cells that express them (Polter & Li, 2010). Non-canonically, our laboratory and others have observed activation of 5-HT1ARs as strong pro-excitatory signals in neocortex (Lamb et al., 2000; Puig et al., 2010; Kruglikov & Bernardo, 2008; Lladó-Pelfort et al., 2012; Scullion et al., 2013). Reconciling mechanistic differences in 5-HT1AR cell and network effects is a critical step towards implementing these receptors as a therapeutic target. As a possible explanation for pro-excitatory effects of 5-HT1ARs, this study tested the hypothesis that 5-HT1AR expression in motor cortex is restricted to inhibitory gamma-aminobutyric acid (GABA)-releasing interneurons and results in network disinhibition when 5-HT1ARs are active. Htr1a-IRES2-Cre-D mice (5HT1AR-Cre) (Daigle et al., 2018) were crossed with Ai14 (TdTomato reporter) mice (Madisen et al., 2010) and resulting endogenous red fluorescent 5-HT1AR+ cells were tested for co-label with markers of cell identity. Contrary to the hypothesis, separate populations of 5-HT1AR+ cells co-label with either GABAergic (inhibitory) or glutamatergic (excitatory) markers implying network effects of 5-HT1ARs are a combination of distinct cell responses in motor cortex. Corticospinal (CST) cells, traced by adeno-associated virus of retrograde serotype (AAVrg), exhibit less than 5% overlap with 5-HT1AR+ cells indicating these receptors affect motor cortex upstream of this CST cell population. Ongoing experiments are testing how 5-HT1ARs shape excitability of CST cells and GABAergic cells in motor cortex layer 2/3 and 5 using pharmacology and whole cell patch-clamp recording techniques. Preliminary results suggest differential effects of 5-HT1ARs on excitability of these cell types that include layer-specific differences of GABAergic cells. The laboratory is completing a novel floxed 5-HT1AR mouse model to provide genetic knock-out targeting of these cell populations. Understanding cell and network determinants of 5-HT1ARs, on motor cortex excitability, supports their development as interventional targets during long-term recovery from brain insult.

P1-B-35 - Subcortical control of object interception in the real-world

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Details

Extremely rapid interactions with moving objects are fundamental to human behaviour in many real-world settings, yet our understanding of the underlying neural mechanisms remains largely based on theories derived from highly constrained laboratory virtual reaching tasks. Express sensorimotor responses (ESRs) are brief bursts of muscle activity occurring ~70–120 ms after visual target onset and are thought to reflect a primitive subcortical pathway involving the superior colliculus and brainstem reticular formation. Although ESRs have been well characterised in seated subjects reaching to virtual visual targets, they are usually too small to overcome inertia and initiate limb motion. We predicted that ESRs would be larger and more prevalent in natural tasks with extreme time constraints, such as catching a fast-moving object.

We examined ESRs during standing, bimanual catching of a high-speed tennis ball to simulate real-world interception demands. Twenty-one healthy, physically active young adults attempted to catch balls projected unpredictably to the left or right at velocities of 45–50 $km \cdot h^{-1}$ from ~4 m, allowing less than 350ms to intercept. Surface electromyography (EMG) was recorded from posterior deltoid (prime mover) and pectoralis major. ESRs were identified as direction-specific EMG onsets at 70-120ms after target onset. Reaction times (RTs) were estimated from hand acceleration data.

Participants exhibited extremely short movement latencies (RTs = 127ms [95% CI: 119 – 135]). Error rates were below 5% despite unpredictable target direction, ruling out anticipatory strategies. The observed RTs are much faster than those typically observed in earlier studies using virtual reaching tasks optimised to encourage ESRs (i.e., ~180 ms). ESRs were detected in the posterior deltoid on 98% (95-99%) of trials and in pectoralis major on 79% (66-88%), compared to ~50% with virtual targets. Some hand acceleration onsets at <100ms preceded shoulder muscle activation, implying that muscles in the trunk and/or legs drove the first phase of the catching response. These data suggest that transformations of target location in visual space to whole body musculoskeletal dynamics can be performed by subcortical circuits responsible for the ESR.

The high-speed catching task clearly promotes exceptionally strong recruitment of the ESR system, presumably because the task cannot be accomplished without it. These results beg the question of what these known, but often overlooked, subcortical circuits might contribute to musculoskeletal coordination of all human motor behaviour. The current work is consistent with a unified theory of targeted sensorimotor control across appendages (e.g. arm, leg, head, eyes) and among vertebrate species, in which cortex provides context and motivation, but subcortical systems compute musculoskeletal dynamics based on sensory target information. The current work is consistent with a unified theory of targeted sensorimotor control across appendages (e.g. arm, leg, head, eyes) and among vertebrate species, in which cortex provides context and motivation, but subcortical systems compute musculoskeletal dynamics based on sensory target information.

P1-B-36 - Virtual brush illusion paradigm reveals importance of disembodiment in multisensory integration

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Details

Our sense of touch guides our physical interactions with the outside world more than any other sense. For example, when our fingers go numb on a cold day, a task as simple as tying one's shoes becomes

incredibly difficult. Similarly, the loss of proprioception can make everyday tasks such as walking impossible. To compensate for the loss of tactile (haptic) feedback, our bodies integrate information from multiple senses to improve dexterous control. Noninvasive methods utilizing haptic illusions have leveraged our reliance on multisensory integration and have been employed to restore body ownership and haptic salience in individuals with limb loss or sensorimotor impairments, as seen through interventions such as mirror therapy. Here, the mirror causes a proprioceptive drift of the injured limb towards the unaffected, healthy limb. These methods suggest that haptic illusions can enhance these individuals' sensation and motor control. Haptic illusions arise in multisensory situations where visuo-haptic and audio-haptic conflicts generate illusory haptic percepts. Virtual reality (VR) offers accessible, repeatable, and cost-effective means to deliver a variety of sensory modalities that would otherwise be limited in the real world, and therefore creates a valuable platform for these haptic illusions. However, how these sensory modalities combine in VR to generate specific percepts and their implications on user embodiment is not well understood. Haptic illusions in virtual reality are useful for addressing these limitations, because they allow us to explore how the user generates internal body representations and haptic percepts in multisensory virtual environments. Thus, we were inspired to develop a VR illusion similar to mirror therapy, but here we add actuated brushes where congruent and incongruent visuo-tactile stimuli of brushstrokes are presented in both the real and virtual worlds. We hypothesized that the visual stimuli would override the conflicting real-world haptic stimuli due to embodiment of the virtual hands, creating an illusory tactile percept. However, we found that embodiment of the virtual hands alone is insufficient to generate this illusory haptic percept. Instead, it appears that strong embodiment of the virtual limb along with strong disembodiment of the real limb may be necessary to induce the illusion. As embodiment is critical for sensorimotor control, achieving strong embodiment in VR is necessary for the development of sensorimotor therapies. These findings present novel evidence that visual dominance in humans does not always outcompete haptic sensation, and suggests the importance of sensory input that will promote disembodiment of injured limbs in immersive VR sensorimotor therapies. Strengthening immersion can improve haptic illusions that could restore haptic sensation by leveraging multisensory integration, and emphasizes the use of VR as a valuable tool for rehabilitation of sensorimotor control.

P1-B-37 - The roles of the posterior parietal and motor cortices in grasp and object processing in three humans with tetraplegia

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Details

The act of grasping requires creating a goal, planning, then executing the movement. To accomplish these, we rely on the brain's sensorimotor processing ability. The posterior parietal cortex (PPC) is known as an integration hub and is involved in early stages of movement planning. Specific subregions within PPC play crucial roles in grasp and object processing, such as the supramarginal gyrus (SMG) and the anterior intraparietal cortex (AIP). These subregions, along with the primary motor cortex (M1) make up the cortical grasping network (CGN). The primary somatosensory cortex (S1) completes this sensorimotor network. Here, we use human electrophysiology to reveal how grasps and object properties are encoded in SMG, AIP, M1, and S1.

Three tetraplegic participants were implanted with microelectrode arrays: S2 in SMG and S1; S3 and S4 in SMG, AIP, M1, and S1. Single-unit neural activity was recorded during a motor imagery task, where participants were asked to imagine grasping unique objects. Three variations of this task were

performed, each asking a unique question. Task 1 asked if grasp was encoded in these regions and if the grasp representation differed depending on object involvement. In previous literature, the presence of an object has been shown to decrease the effectiveness of a grasp BMI. We used static images of 4 grasp types, each paired with a unique object and cued using 1) only the grasp, 2) only the object, or 3) the hand grasping the object. In Task 2, we asked whether altering the object's size would affect our ability to decode grasp and whether size was encoded. Task 3 aimed to disentangle the pairing between each grasp type and unique object to determine the encoding of object shape separate from grasp type. This was accomplished by participants imagining grasping each object with each grasp type.
We identified the roles of the CGN throughout Planning (cued static image) and Action (imagined grasping) phases of all tasks. Grasp type is encoded in PPC and M1 during Planning and strongly in SMG and M1 during Action. Size differences can be classified in SMG during Planning, and M1 during Action. Our data implies that these regions encode unique features of grasps, such as number of fingers involved in grasp in SMG or thumb involvement in M1. Encoding of the object shape is seen strongly in PPC during Planning, and very little in M1. We see reciprocal firing in S1 after M1 activity during Action, suggesting an anticipatory effect. While our findings in SMG align with literature regarding tool use, putative AIP regions in non-human primates have largely encoded object properties, including size; in contrast, human AIP exhibited more variable object-related encoding, ranging from chance levels to levels comparable with grasp representation depending on task demands. As expected, single units in M1 strongly encoded motor execution; however, there was also strong tuning during cue presentation, suggesting plan-related activity. Our data suggests integrating grasp and object information from the CGN will enhance grasp BMIs.

P1-B-38 - The impact of task instructions on finger motor sequence learning

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Details

Individuals are continuously engaged in sequential skill learning to solve emerging problems and achieve goal-directed behavior. A substantial body of literature has investigated both behavioral and neurophysiological components of sequential learning, including the order of execution (Yokoi et al., 2017), neural representations and repetition effects (Dash et al., 2024; Ariani et al., 2020), and movement preparation processes (Ariani & Diedrichsen, 2019), among others.
The present study examined how motor skill learning is influenced by the initial instructional framework. The experiment involved 38 healthy participants (19 F; mean age = 25.69 ys), randomly assigned to two equal groups. Each participant completed four experimental sessions within the same week. The first three involved repeated practice of the task under the same instruction, whereas the last one—conducted after a one-day break—was performed using the untrained instruction.
Each session comprised a total of 480 trials, subdivided into 80 PRE assessment trials, 320 training trials, and 80 POST assessment trials. The task consisted of the presentation of a neutral cue followed by a sequence of five distinct numbers, which participants were required to reproduce within an external keypad connected to a computer. Trial-by-trial feedback on performance was provided.
Two instructional conditions were employed. In the ORD condition, participants were instructed to reproduce the numerical sequence from left to right. In the SPA condition, participants were instructed to reproduce the sequence according to ascending numerical order from 1 to 5. Two types of sequences were used: one in which both instructional conditions required identical inputs and motor outputs, and another in which the input differed across conditions while the motor output remained identical. Consequently, across sessions, participants executed the same movements an equal number of times.
Results revealed distinct learning trajectories for the two instructional conditions across nearly all performance measures. In the ORD condition, performance improved consistently across the first three

sessions and remained stable following the instructional switch. In contrast, the SPA condition exhibited a marked deterioration in performance during the final session. This pattern was further supported by the within-session learning index computed as the difference between PRE and POST assessment trials. A comparable trend was observed for errors. Participants in the SPA group committed fewer invalid sequences on average, except during the session in which the instructional switch occurred. Conversely, unfinished sequences had a greater impact during sessions conducted under the ORD instruction. Overall, the present study highlights the critical role of instructional context in motor skill learning. The findings suggest that employing multiple instructional modalities may be particularly beneficial in educational settings, facilitating more effective knowledge transmission and skill acquisition. As demonstrated by the results, identical motor behaviors can be acquired through different instructional frameworks, leading to distinct learning pathways.
Future research should investigate how the brain reorganizes under different instructional demands and how such mechanisms operate in special populations, thereby further elucidating the interaction between instruction, learning, and neural plasticity.

P1-B-39 - Sex-specific associations between motor unit remodeling and pinch force in older adultsc associations between motor unit remodeling and pinch force in older adults

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Details

Introduction

Motor units are the final common pathway of the motor system and consist of a single motor neuron and muscle fibers it innervates. With aging, motor unit number decreases and reinnervation occurs (motor unit remodeling), but the extent of this remodeling varies widely among individuals. Progression of motor unit remodeling has been reported to potentially contribute to muscle strength decline through muscle fiber loss, changes in muscle fiber composition, and reduced motor unit activation efficiency. Therefore, the extent of motor unit remodeling may serve as a biomarker to explain inter-individual differences in muscle function among older adults. This study aimed to investigate the relationship between several parameters reflecting motor unit remodeling and muscle function in older adults. Considering sex differences in the progression of muscle strength decline and motor unit remodeling, analyses were performed separately for males and females.

Methods

Pinch force of the non-dominant hand was measured in 49 healthy older adults (25 males, 24 females). Motor unit parameters were obtained from the abductor pollicis brevis using the MScanFit2 facility in Qtrac software (Digitimer Ltd., UK). The following parameters were calculated: motor unit number estimation (MUNE); N50, defined as the number of motor units contributing to 50% of the maximum compound muscle action potential (CMAP) amplitude; A50, defined as motor unit size at the 50% cumulative CMAP amplitude expressed as a percentage; and the largest surface motor unit potential (Largest SMUP), expressed as a percentage of CMAP amplitude. Associations between motor unit parameters and pinch force were examined separately by sex. Because pinch force was moderately correlated with body weight, partial correlation analyses were performed with body weight as a covariate.

Results

In males, pinch force showed moderate positive correlations with MUNE ($r=0.456$, $p=0.025$) and N50 ($r=0.557$, $p=0.005$), and a negative correlation with Largest SMUP ($r=-0.491$, $p=0.015$). No correlation was observed between A50 and pinch force ($r=-0.396$, $p=0.056$). In contrast, no correlations were observed between pinch force and any of the motor unit parameters in female.

Discussion

The results of this study indicate that age-related muscle strength decline in older males is associated with a reduction in motor unit number and an increase in motor unit size due to reinnervation. In contrast, no significant association was observed between motor unit remodeling and muscle strength in older females. The result of the present study suggest that the determinants of muscle strength may differ between older males and females. At least in older males, indices reflecting motor unit remodeling may serve as biomarkers to explain individual differences in muscle function.

P1-B-40 - Motor cortical dynamics during long sequences of reaching movements

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Details

Movements in everyday life typically follow each other in quick succession, forming coordinated sequences. Behavioral studies show the brain uses sequence information to rapidly plan future actions and to coarticulate movements for global sequence optimization. Although core motor areas (primary and premotor cortices) are known to prepare future movements during ongoing execution, the neural mechanisms that give rise to coarticulation (i.e., kinematic changes in the current movement dependent on the next) remain unknown. We addressed this by training two macaques to perform sequences of seven reaches in a 2D exoskeleton robot. The task varied the available sequence information: in each trial, monkeys saw one (Horizon 1), two (H2), or three (H3) future targets. Behaviorally, performance varied by Horizon: as expected, H1 yielded no sequence effects as movements were prepared one-by-one; H2 resulted in faster movements without coarticulation; and H3 yielded both speed-up and coarticulation.

Using Neuropixels probes, we recorded single-unit activity across a distributed network known to be engaged during reaching actions. In Monkey M, we recorded from M1 (N=811) and PMd (N=691). In Monkey P, we recorded from M1 (N=757), PMd (N=831), SMA (N=559), pre-SMA (N=584), dlPFC (N=499), and GPi (N=774). Neural recordings revealed that highly similar preparation and trigger dimensions were used for reaches in the sequence, across all Horizons. In the neural state-space of M1 and PMd, the condition-independent signal (CIS)—associated with single movement production—repeated for each of the seven reaches. Although the CIS shape was conserved across Horizons, CISs for different Horizons were separated in different dimensions. This pattern held for all areas in Monkey P, with the exception of pre-SMA, which displayed amplitude scaling where larger Horizons evoked larger CIS signals.

To understand the behavioral differences between H2 and H3, we analyzed the arrival time of next-target information. In H2, information about the next target arrived in PMd and M1 only near the end of the ongoing movement. In H3, however, next-target information was present even before the current reach was initiated, potentially enabling the trajectory optimization observed behaviorally by adjusting the preparation of the current reach. In Monkey P, this future information appeared across all recorded areas with remarkably similar onsets (though PMd slightly led dlPFC and SMA). This synchrony suggests a parallel architecture where all areas receive sequence information from a common upstream node, rather than a strict serial hierarchy among the recorded regions.

Together, our results reconcile distinct preparation processes for individual movements with continuous coarticulation of movement during sequence production: movements are prepared individually, but when future information is available early enough, it modulates the preparation of the current movement to optimize the sequence.

P1-B-41 - Error correction strategies in a redundant hand-foot reaching task

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Details

Although previous research in motor control has focused on goal-directed upper-limb movements, humans often perform whole-body actions that require the coordination of the upper and lower limbs, such as drumming. When errors arise during redundant whole-body movements, the motor system must attribute the error to either the upper or lower limbs. However, how errors are assigned across limbs during whole-body movements remains poorly understood. Because the upper and lower limbs differ in their neuromechanical properties and functional role in daily life (Winter, 2009; Moriyama et al., 2024), limb-specific constraints can involve error attribution across the upper and lower limbs. Therefore, this study aimed to examine contributions of the upper and lower limbs to error corrections during coordinated hand-foot movements.

Twenty right-handed healthy adults (10 females) participated in this study. We developed a redundant hand-foot reaching task, in which participants performed simultaneous reaching movements of the dominant hand and foot in the horizontal plane while seated. A monitor placed in front of the participants showed a target and a cursor. Before the main session, participants completed single-limb conditions, in which they moved the cursor toward a target using the dominant hand or foot (30 trials each). Following the single-limb conditions, participants performed the hand–foot reaching task. In this task, the cursor position was defined as the spatial average of the hand and foot in the horizontal plane. Participants repeatedly performed a block consisting of one to three null trials, followed by one perturbation trial and one catch trial. During perturbation trials, a visuomotor rotation ranging from −30° to 30° in 10° increments was applied to the cursor, with seven trials performed for each rotation angle. In the hand-foot task, we observed that directional errors induced by perturbation were predominantly corrected by the lower limb. To quantify asymmetries in corrective responses between the upper and lower limbs, we calculated the asymmetry index (White and Diedrichsen, 2010). The asymmetry index was significantly smaller than 0.5 ($p = 0.03$), indicating greater reliance on the lower limb for error correction. To further examine factors underlying the assignment of corrective responses between limbs, we calculated asymmetry indices for movement accuracy in the single-limb conditions and movement initiation timing in the hand-foot task. Movement accuracy tended to be higher in the upper limb ($p = 0.07$), and movement initiation occurred significantly earlier in the upper limb than in the lower limb ($p = 0.03$), suggesting the error correction is assigned to the limb most likely to have caused the error, rather than to the limbs with greater accuracy or faster movement initiation. Taken together, these findings demonstrate a systematic bias toward the lower-limb error correction in redundant whole-body actions.

P1-B-42 - The contributions of natural and artificial touch to motor cortex and their implications in BCI control

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Details

Somatosensory feedback is crucial for the planning and execution of dexterous manual behavior. This is evidenced behaviorally by cases where feedback is missing, such as in patients with neuropathies who struggle to perform basic tasks such as buttoning a shirt, or in amputees using prosthetic devices. Additional evidence for the importance of sensory feedback in manual behavior comes from users of brain computer interfaces (BCI), who have electrode arrays implanted into motor and somatosensory cortex in order to restore movement and sensation respectively. While movement can be restored using recordings from motor cortex alone, the use of intracortical microstimulation (ICMS) of somatosensory cortex to provide sensory feedback during BCI control has been shown to improve movement control

and execution. However, ICMS modulates activity in motor cortex, making it more difficult to decode motor intent from motor cortical recordings. Here, we characterize the responses of motor cortex to both ICMS and tactile stimulation in participants with tetraplegia who have Utah arrays implanted into both motor and somatosensory cortices and retain some residual sensation. Specifically, we delivered mechanical stimuli to the contralateral hand and ICMS to somatosensory cortex, both while the participants were at rest, and when they were engaged in covert and overt motor tasks. Analyzing the evoked responses in motor cortex, we find that intensity related information is well represented in motor cortex for both stimulus modalities. Additionally, we can create somatotopic maps using the evoked activity in motor cortex at the resolution of individual digits and find that the maps for natural stimuli and ICMS stimuli are very similar. Moreover, we show that the impact of ICMS sensory feedback on M1 is task dependent but exists within a distinct subspace from that of movement intent. This separation in cortical representation may allow us to create motor decoders that are less disrupted by ICMS-based feedback. This study was approved by the institutional review boards at the University of Chicago and the University of Pittsburgh (Pittsburgh, PA, USA) and was carried out under an investigation device exemption (IDE) from the FDA.

P1-B-43 - A markerless tracking setup for examining a large variety of grasping movements in macaque monkeys and humans

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Details

Understanding the neural mechanisms underlying movement generation is a fundamental goal in systems neuroscience. Grasping, a critical function for interacting with the environment, involves a diverse range of complex hand movements. However, most studies have explored only a limited subset of grasp types, raising concerns that significant movement dynamics may remain undiscovered. Previous research suggests that neural activity during grasping can be explained by a small number of latent dimensions; yet, it remains unclear whether this low dimensionality is a fundamental principle of brain dynamics or merely an artifact of constrained experimental designs.

To address this, we developed a novel experimental setup enabling the recording and classification of an unprecedented number of grasping movements in both non-human primates and humans. The setup utilizes a conveyor belt system to present a diverse set of objects in randomized order, ensuring a broad exploration of grasp types. To capture the full kinematic complexity of grasping, we employ a markerless tracking method (Jarvis), enabling precise motion tracking via multiple video cameras without interfering with natural behavior.The recorded kinematic data is analyzed using Uniform Manifold Approximation and Projection (UMAP) and Louvain clustering to categorize distinct grasping poses. This approach allows for a detailed classification of hand movements and provides insights into the diversity of grasping strategies across species.

The analysis reveals a complex motor pattern: we have identified a large number of different clusters of movement parameters, which are sometimes connected by smooth transitions. Surprisingly, the structure of this kinematic space does not merely mirror the object space; instead, distinct kinematic clusters frequently encompass a mix of different objects**.** We will further extend this analysis to humans using a larger object set. Finally, we plan to perform a direct cross-species comparison to determine whether the fundamental organization of grasping strategies is conserved, or if the human repertoire exhibits a higher degree of clustering and complexity.

P1-B-44 - Distinct neural control of alpha motor neurons in individual finger contraction and pinch task

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Details

BACKGROUND: Understanding how the central nervous system generates coordinated muscle activity from motor units is a fundamental challenge in motor control. Precision tip pinch, an essential motor task to daily object manipulation, demands coordination of the first dorsal interosseous (FDI) and thenar motor units to stabilize thumb-index contact [1,2]. Despite extensive study of single-muscle/-task control [2,3], the neural control underlying the intra- and intermuscular coordination in dexterous tasks remains less understood. Specifically: (Q1) Do synergistic intrinsic hand muscles use similar rate coding strategies to scale force output? (Q2) Does task context (isolated vs. synergistic) alter neural oscillations coordinating alpha motor neurons within the same muscle? This study analyzed rate coding across force levels and common oscillations of FDI and thenar motor units during individual finger contractions and pinch tasks.

METHODS: Seventeen healthy adults performed force-controlled finger tasks using a custom manipulandum with the index finger and thumb attached to load cells. Participants performed 10%, 20%, and 30% of their maximum voluntary isometric contractions (MVC) following trapezoidal force profiles (i.e., ramp-up at 3% MVC/s, 30s plateau, and ramp-down). Two tasks were tested for each force level: isometric finger flexion and tip pinch. High-density surface electromyograms (HDsEMG) were recorded from the FDI and thenar muscle. Motor unit spike trains were decomposed and matched across force levels (Q1) and tasks (Q2) [4]. Mean discharge rate (MDR) and recruitment threshold were analyzed in both muscles. Coherence and non-linear network interactions were analyzed in FDI [5].

RESULTS: MDR increased with force in both muscles. FDI showed steeper slopes than thenar muscle at 10-20% (FDI:0.38±0.24; thenar: 0.23±0.15) than 20%-30% MVC (FDI:0.31±0.19; thenar: 0.21±0.17pps/%MVC; $p<0.001$). FDI also showed lower recruitment thresholds and higher MDR than thenar. Task-dependent differences were observed in the FDI, with higher MDR during pinch (17±4pps) than isolated contraction (15±4pps; $p=0.002$). Coherence analysis revealed no task-related differences in FDI, while network-information analysis showed increased weighted network density during pinch (0.18±0.07) compared to isolated finger flexion (0.13±0.05; $p=0.004$).

CONCLUSION: Task- and muscle-specific control strategies were observed. During pinch, FDI modulated force via rate coding of active motor units, reflecting its role as the initiating muscle, whereas the thenar relied more on motor unit recruitment. The absence of linear coupling changes but presence of increased non-linear network connectivity in FDI during pinch suggests that precision pinch demands higher-order interactions, which indicates that common inputs are stronger in the synergistic task.

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P1-B-45 - Demedicalizing individual longitudinal follow-up and frailty detection

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Details

Introduction

Frailty prevention requires earlier, scalable detection strategies that can be deployed outside specialist settings to identify pre-frailty and guide timely interventions in aging populations. This study aimed to develop and evaluate a portable sensors–based platform, combining wearable inertial measurement unit (IMU), force-plate balance assessment, grip strength, and standardized questionnaires, to support demedicalized, longitudinal frailty monitoring and to compare its outputs with clinical and self-reported assessments in community-dwelling older adults.

Research objectives and methods

A prospective observational cohort study was conducted in southern Réunion Island between 2021 and 2024 among retired adults aged 65 years and older recruited in general practice. protocol comprised five steps: (1) baseline general practitioner (GP) hetero-assessment and detailed frailty work-up including Fried's phenotype and ICOPE Step 1, (2) telephone-based evaluation of social vulnerability, mental health, self-rated health, and quality of life, (3) ambulatory assessment using instrumented gait (inertial measurement units), static balance on a force platform, and additional ICOPE Step 2 measures, (4) monthly fall surveillance over six months, and (5) repeat instrumented gait and balance assessment at six months.

Results

Among 145 included participants (mean age 71 ± 5 years), 98.5% showed impairment in at least one intrinsic capacity domain at baseline, with frequent vision (77.7%), locomotion (53.1%), hearing (52.5%), and psychological (27.3%) problems, and 77% reporting predominantly sedentary behavior. Correlation analyses demonstrated a significant relationship between expert-assigned frailty scores and Fried's phenotype, but weaker and often non-significant associations with self-rated health. Machine-learning models indicated that sensor data alone had limited ability to reproduce Fried-defined frailty compared with multimodal models incorporating subjective and clinical variables. Kinesiotherapy and regular physical activity were associated with improvements in center-of-pressure metrics and mediolateral sway over six months, although effects on gait speed were modest, and depressive symptoms were present in approximately one quarter of participants.

Conclusions

These findings show that an IoT-based platform integrating quantitative gait, balance, and grip strength measurements with targeted questionnaires can generate frailty estimates broadly concordant with GP evaluations while remaining portable and potentially operable by trained non-medical personnel. The results also underline that subjective input from clinicians and older adults remains indispensable to capture psychological and multidimensional aspects of frailty that are not fully reflected in sensor signals. We found also that rehabilitation and physical activity may preferentially affect postural control rather than walking speed over short follow-up. In conclusion, this work supports the feasibility of demedicalized, community-based frailty screening and longitudinal monitoring. It points toward next steps, including scaling the platform to larger samplesoperate by non-medical personnels, strengthening

psychological frailty assessment, and progressively embedding the system within digital-twin–inspired, precision prevention pathways beginning from midlife.

P1-B-46 - Modality-selective onset timing of sensory gating in primate motor cortex during preparation for voluntary movement

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Details

During voluntary movement, the central nervous system suppresses self-generated sensory signals, a phenomenon termed sensory gating, to facilitate efficient motor control. Previous studies established that sensory gating occurs at multiple neuraxis levels and that cortical suppression begins hundreds of milliseconds before movement onset. However, whether this preparatory suppression differs in temporal onset between cortical regions (primary motor cortex, M1 vs. primary somatosensory cortex, S1) and sensory modalities (cutaneous vs. proprioceptive) remains unknown. Here, we addressed this by comparing suppression onset timing for cutaneous and proprioceptive input at identical recording sites in M1 and S1.

We analyzed local field potential recordings from M1 and S1 in a rhesus macaque performing a visually guided wrist task. Somatosensory evoked potentials (SEPs) were elicited at 2 Hz by stimulating the superficial radial nerve (SR; cutaneous afferents) and deep radial nerve (DR; proprioceptive afferents) via implanted cuff electrodes. We restricted analyses to sites where both SR- and DR-evoked SEPs were recorded in separate sessions (M1: 47 sites; S1: 20 sites). SEP peak amplitudes were normalized to rest-period mean and smoothed using a moving average (200-ms window, 20-ms step) from -600 to +400 ms relative to movement onset. Suppression onset was defined as the earliest time bin where normalized SEP amplitude was significantly negative (t-test vs. rest, $p < 0.05$) and persisted for at least three consecutive bins. A two-way mixed ANOVA (Region × Modality) was applied, followed by simple main effects analyses.

Suppression onset was detected at all sites, predominantly preceding movement onset. In M1, cutaneous suppression began significantly earlier (mean: -380 ms, SD: 107 ms) than proprioceptive suppression (mean: -318 ms, SD: 81 ms; $t(46) = -3.3$, $p = 0.002$, Cohen's $dz = -0.48$). In contrast, S1 showed no significant modality difference (SR: -214 ms, SD: 88 ms; DR: -231 ms, SD: 93 ms; $t(19) = 0.68$, $p = 0.504$). The ANOVA confirmed significant main effects of Region and Modality (both $p < 0.001$) and, critically, a significant Region × Modality interaction ($F(1,65) = 37.08$, $p < 0.001$).

These findings demonstrate that M1 exhibits modality-selective sensory gating during motor preparation, suppressing cutaneous input earlier than proprioceptive input, while S1 does not show such selectivity. This dissociation suggests that M1 actively gates sensory information based on its relevance to the upcoming movement. The earlier suppression of cutaneous input may reflect prioritization of neural resources for processing proprioceptive signals, which are more critical for precise movement control. In contrast, S1 may implement more generalized suppression. These results advance our understanding of the distinct roles of M1 and S1 in sensorimotor integration during voluntary movement preparation.

P1-B-47 - Timing of target motion affects target choice

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Details

If you're in a crowd and want a friend to notice you, you might wave your hand to get their attention. Conversely, if you don't want your friend to notice you, you should stay still and avoid being spotted. The human brain does not process all sensory input equally; it prioritizes some input and uses it for perception of the external world and control our behaviour efficiently. The human visual system is exceptionally sensitive to changes in motion, which drives changes in spatial attention and could affect decisions. However, visual motion also affects online control during reaching, with shifts in target location producing robust involuntary feedback responses to correct the hand motion. Here we investigate how human participants detect, choose and move to one target amongst two possible options and many distractors. We specifically test how target motion influences our decision of which target to choose, how it influences our reaction time and whether it can elicit changes of mind. Through changing the time of the target motion, we can examine the evolution by which the motion affects each of the features in a reaching task. Twelve healthy human participants grasped a robotic manipulandum and made reaching movement to one of two presented targets as quickly as possible, without overshoot. Before each movement, a total of 12 objects in the same colour were shown evenly spaced in a 10 cm radius circle around the start position, where two of the objects were circular targets and the rest were square distractors. In this task, fast decision making was required to detect and choose a target to make a centre-out reaching movement. On most trials, one of the two targets was jumped by 1.74 cm at one of 11 different times (0-500 ms) after the presentation of the targets, either in an outwards, inwards, counterclockwise or clockwise direction. Participants exhibited very different responses to the targets depending on the timing and direction of the target motion, showing that their online control strategies depended on these factors. In general, participants preferred to choose targets away or towards the body regardless of target motion. However, when target motion occurred within the first 150 ms after target presentation, it strongly biased choices towards the moving target – particularly for inward motion. Later motion of the target elicited strong visuomotor feedback responses. In addition, target motion also elicited changes of mind, with these predominantly occurring towards targets with lower metabolic cost. Overall, we show that the timing and direction of target motion affects target choice, with differential effects evolving over time to incorporate motor cost in the decision making.

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P1-B-48 - Neural population dynamics during bimanual finger control

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Details

Erroneous behavior during fine motor control has been consistently observed across diverse motor contexts, including force regulation (e.g., pinching), serial movements (e.g., typing), and continuous ballistic actions. The anti-phase bimanual finger-tapping task robustly induces spontaneous transitions to in-phase tapping and is widely used as a standard paradigm to investigate involuntary phase transitions (Haken, Kelso, and Bunz, 1985). We previously demonstrated that pre-movement neural synchrony between bilateral primary motor cortices reflects preparatory neural dynamics that determine the duration of the anti-phase period (Iwama et al., 2022). However, it remains unclear how neural dynamics during motor preparation evolve after movement initiation and which whole-brain spectral parameters are associated with spontaneous phase transitions. Here, we investigated large-scale sensorimotor dynamics during the anti-phase tapping task using high-density electroencephalographic recordings from 63 healthy participants combined with data-driven temporal modeling of neural time-series data. EEG

signals were acquired using a high-density scalp electroencephalogram system (EGI NetAmp GES400) and were subjected to source reconstruction using standardized low-resolution brain electromagnetic tomography (sLORETA; Pascual-Marqui, 2002). Source-space signals from 27 cortical regions were then extracted and analyzed using a time-delay embedded hidden Markov model (TDE-HMM) implemented in the osl-dynamics toolbox (Gohil et al., 2023). We found that state transition dynamics were systematically modulated prior to spontaneous phase transitions in finger tapping (permutation test, $p < 0.05$), indicating that whole-brain neural dynamics became unstable before error events. Moreover, key states visited around transitions were characterized by significant modulation of bilateral sensorimotor activity and phase coupling. Results suggest that sustained anti-phase tapping is supported by optimal whole-brain neural dynamics and that preparatory activity contributes to maintaining phase coupling between bilateral motor cortices, thereby preventing them from interference of motor commands.

P1-B-49 - Intrinsic motor representation in congenitally and acquired blindness

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Details

Movements can be represented in extrinsic Cartesian coordinates or intrinsic joint-angle coordinates. In sighted individuals, both reference frames contribute to motor representation (Brayanov et al. 2012). Still, it is unclear how movements are represented in blind individuals, and whether congenitally and acquired blind individuals differ. We addressed these questions by examining the generalization of sensorimotor learning with auditory error feedback in blind individuals.

Participants, divided into three groups (congenitally blind, acquired blind, blindfolded sighted, n = 15 each), performed a reaching task by controlling a cursor on a screen with the right hand. Movement endpoint error was provided via auditory feedback: sound pitch indicated left-right directions of error, and sound duration indicated its magnitude. After baseline, participants adapted to a rotated mapping between the cursor and hand movements, gradually increasing up to 30° while reaching for a training target with feedback. Then, they reached without feedback toward three untrained targets from a new arm posture to assess generalization. These targets included an extrinsically matched target (same hand displacement as the training target) and an intrinsically matched target (same joint-angle changes), allowing us to quantify the relative contributions of extrinsic and intrinsic components to motor representation. Finally, retention was tested by reaching again at the training target without feedback.

All groups achieved similar adaptation levels. However, generalization patterns differed across groups: both blind groups showed stronger intrinsic components ($p < 0.005$ for both), whereas the sighted group showed comparable intrinsic and extrinsic contributions ($p = 0.07$), suggesting a greater reliance on intrinsic coordinates in blind individuals. Retention, however, differed between blind groups: despite similar generalization, retention was robust in the acquired blind group ($p = 0.20$), whereas the congenitally blind group showed rapid decay ($p = 0.003$), suggesting differences in memory stability related to visual experience. In the baseline, the acquired blind group exhibited straight trajectories, like the sighted group, but the congenitally blind group showed more curved movements ($p = 0.005$), which may be related to reduced robustness of external spatial representations (Gori et al. 2014).

These results indicate that motor memory in blind individuals is more weighted toward intrinsic coordinates. However, only acquired blind individuals exhibited stable retention, whereas memory decayed rapidly in congenitally blind individuals. This dissociation suggests that visual experience contributes not to sensorimotor adaptation itself, but to the formation of durable motor memory and stable representations of external space for action. These findings provide new insight into how visual experience shapes the coordinate frames to form and retain motor memories.

P1-B-50 - Medullary and intersegmental cervical networks underlying mammalian forelimb movement control

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Details

Traditional models of motor control posit that goal-directed upper limb movements are primarily mediated by frontal cortical regions via the corticospinal tract, whereas posture and balance are governed by brainstem nuclei and spinal interneurons. While the corticospinal pathway is essential for skilled and dexterous movements, brainstem reticulospinal circuits and intersegmental spinal interneurons have been viewed largely as modulators of posture and reflexive behavior. Emerging evidence from animal studies challenges this dichotomy, demonstrating that brainstem motor circuits, including the medullary reticular formation, as well as cervical propriospinal neurons at C3–C4, actively contribute to goal-directed forelimb movements. Whether these findings extend to humans, who possess a more elaborated corticospinal system, is not yet clear.

Here, we characterized the brain-wide functional organization of medullary and spinal circuits involved in forelimb force control using functional magnetic resonance imaging in humans and mice performing unilateral hand or forepaw force tasks. In humans, we employed simultaneous brain–spinal cord fMRI to map activations and functional connectivity across the neuraxis. In mice, we developed an awake fMRI platform enabling whole-brain imaging while head-fixed animals performed a forepaw force control task inside an ultra-high field 11.1 T scanner.

Across species, we identified two medullary regions, the caudal medulla (CaudM) and lateral rostral medulla (Lat-RM), that were selectively engaged during force regulation. Sensorimotor cortex exhibited the strongest functional connectivity with CaudM, followed by Lat-RM, with minimal engagement of the medial rostral medulla (M-RM). In mice, cortico-medullary coupling within CaudM and Lat-RM followed a ventro-medio-dorsal gradient, with strongest connectivity to primary motor and premotor cortices. In humans, by contrast, higher-order sensorimotor regions, including anterior cingulate cortex, insula, and secondary somatosensory cortex, showed the strongest coupling with CaudM and lateral Lat-RM. Moreover, we observed robust force-related activation at the C3–C4 cervical spinal level in humans, with ventral regions preferentially connected to medullary nuclei and dorsal regions linking to lower cervical segments.

Together, these findings identify a conserved cortico-medullary network supporting forelimb force control across species, while revealing species-specific differences in cortical engagement. They further support the existence of an indirect motor pathway involving reticulospinal and C3–C4 propriospinal circuits that contributes to fine hand motor control in the mammalian brain.

P1-B-51 - Causal involvement of the M1-parietal area 5 pathway in movement-related sensory suppression and fine hand motor control

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Details

Anatomical projections from the primary motor cortex (M1) to posterior parietal Area 5 are thought to convey motor-related information involved in sensory prediction and state estimation. During voluntary movement, sensory responses are suppressed, a phenomenon commonly attributed to predictive mechanisms based on efference copy of motor commands. However, the neural pathways implementing this movement-related sensory suppression, and their contribution to fine hand motor control, remain unclear. Given the role of Area 5 in sensorimotor integration, the M1-Area 5 pathway represents a plausible circuit underlying these processes.

In macaque monkey, we selectively suppressed the projection from the primary motor cortex (M1) to posterior parietal Area 5 using a chemogenetic approach. An inhibitory DREADD receptor (hM4Di) was expressed in M1 neurons via an adeno-associated viral vector (AAV2.1 CaMKII-hM4Di), and the ligand deschloroclozapine (DCZ) was locally injected into Area 5 to inhibit M1-derived inputs. Somatosensory evoked potentials (SEPs) elicited by peripheral nerve stimulation were recorded before and after DCZ administration. Fine hand motor function was assessed using a precision grip task. Phosphate-buffered saline (PBS) injections served as control conditions.
Selective chemogenetic suppression of M1-derived inputs to Area 5 induced clear changes in sensory and motor function. Local injection of DCZ into Area 5 significantly altered SEPs elicited by median nerve stimulation compared with the pre-injection condition. Importantly, the movement-related suppression of sensory responses was markedly attenuated following inhibition of the M1-Area 5 pathway. These effects were not observed after PBS injections, indicating pathway-specific modulation. In parallel, suppression of this pathway led to a significant impairment in precision grip performance, reflecting reduced fine finger dexterity, while gross limb movements were largely preserved.
These findings provide causal evidence that motor command-related signals from M1 are transmitted to Area 5, where it contributes to movement-related modulation of sensory input. Disruption of the M1-Area 5 pathway attenuated sensory suppression during movement and impaired fine hand motor control, indicating that this circuit supports the integration of motor and sensory information necessary for precise motor behavior by changing the gain of somatosensory input. Together, the results highlight Area 5 as a critical node in sensorimotor integration, linking motor commands to sensory processing and dexterous hand control.

P1-B-52 - Functional ultrasound imaging of goal-directed reaching in awake infants

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Details

The first year of life is characterized by rapid brain development that supports lifelong motor and cognitive abilities. Yet, most studies of infant motor behavior rely primarily on behavioral experiments, leaving the neural mechanisms underlying motor control poorly understood. Existing functional neuroimaging methods face major challenges in awake infants due to motion artifacts and compliance constraints, leading to high exclusion rates and relatively few studies of early motor systems. Functional ultrasound imaging (fUSI) is an emerging neuroimaging technology that addresses these limitations by providing high sensitivity, broad spatial coverage, and exceptional spatiotemporal resolution (~100 µm at <1 Hz). Importantly, fUSI can leverage the infant fontanelle as a natural acoustic window, enabling noninvasive brain imaging that is more tolerant to motion than existing techniques.Here, we report the first acquisition of fUSI recordings in awake infants performing upper-limb motor tasks. Infants (6–8 months old) participated in a single experimental session structured into alternating blocks of 30 seconds of rest followed by 60 seconds of goal-directed reaching. Infants were seated either in a high chair or on a parent's lap to ensure trunk stability and comfort. During rest blocks, age-appropriate videos were presented to maintain engagement while minimizing movement. During reaching blocks, objects were presented at the body midline to elicit goal-directed reaches. A custom-designed headset positioned the fUSI probe over the anterior fontanelle and aligned it with the superior sagittal sinus to acquire functional neuroimaging data. EMG and inertial sensors were attached to the limbs to record muscle activity and limb acceleration, respectively, while multi-view video recordings enabled detailed annotation of reaching events and movement-free periods. This study represents an important step in

infant neuroimaging by demonstrating the feasibility of acquiring functional neuroimaging data in awake, behaving infants and producing robust multimodal datasets. Preliminary evidence suggests that we can differentiate reaching from non-reaching movements using these recordings. Ongoing work focuses on improving the mechanical stability of the ultrasound holder and developing new analysis algorithms capable of handling fUSI data affected by motion artifacts inherent to awake and behaving experiments. Continued data collection and analysis aim to identify localized changes in cerebral blood volume within expected sensorimotor cortical areas during movement and to characterize their temporal alignment with reaching behavior, EMG activity, and kinematic signals.

P1-B-53 - The subthalamic nucleus in the regulation of motor variability

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Details

Motor skills underlie much of what we do, from tying our shoes to serving a volleyball. A hallmark of skill learning is a gradual transition from highly variable, exploratory behavior to precise and stereotyped movement patterns. However, when challenged by changed conditions, even highly stereotyped skills can become flexible again, allowing for renewed exploration and adaptation of learned movements. This suggests that motor variability must be flexibly, but tightly regulated: while it may impair peak performance, it is necessary to explore the motor space to find rewarded solutions in de novo learning and adaptation. However, despite insights into motor variability regulation in songbirds, the underlying circuits and mechanisms in the mammalian brain remain largely unclear. Inspired by the songbird and the regulation of the exploration/exploitation balance in decision-making, the basal ganglia have been implicated in variability regulation. Notably, in rodents, a transition from dorsomedial striatum (DMS), mediating variable behavior, to dorsolateral striatum (DLS), driving stereotyped movement patterns, correlates with the progressive variability decrease during learning. However, how the DMS-DLS balance itself is regulated and whether it indeed underlies motor variability regulation remains unclear.

Here, based on our work in rats, we suggest a novel mechanism which contributes to the regulation of the DMS-DLS balance and thereby of motor variability during skill learning and execution. The subthalamic nucleus (STN), an indirect basal ganglia pathway node, sends largely unexplored feedback connections to the striatum: directly to the DLS and indirectly to the DMS via the anterior thalamic nuclei (ATN). STN also receives broad cortical and subcortical input, allowing an integration of striatal signals with internal and external state information. Based on this, STN may modulate the DMS-DLS balance, thereby dynamically regulating motor variability. Indeed, chronic, selective silencing of the STN-DLS projection in rats impairs, while silencing of the STN-ATN or ATN-DMS projections accelerates the development of kinematic stereotypy and overall skill learning. However, silencing of the latter pathway also reduces behavioral flexibility, impairing the adaptation of learned skills upon changes in task conditions. Finally, consistent with a balance shift from DMS to DLS, STN-ATN silencing in experts has no effect, while STN-DLS silencing disrupts learned stereotypies. Our results suggest novel roles for STN in regulating motor variability, likely by modulating the DMS-DLS interplay, as well as unappreciated complexity in the basal ganglia circuitry.

P1-B-54 - Neuron population correlations cycle over fast timescales

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Details

The presence of low-dimensional latent states embedded in neuron population activity has become a tenet of systems neuroscience. Despite the stability of these latent representations and their associated

behaviors over time, the underlying activity of individual neurons is known to gradually drift across days. Meanwhile, less attention has been devoted to changes in neuron correlations over short timescales, particularly under conditions where networks must adapt quickly (e.g., after injury). Here, patterns of neuron contributions to latent state dimensions in motor cortex were tracked over repeated blocks of reaching trials. The number of identified encoding patterns was consistently less than the typical dimensionality reported for the motor cortex of large animals. Although population state dynamics were effectively conserved, these underlying encoding patterns changed in two ways: slow modifications over time and fast switches in their rank. To explore whether the two drift timescales share a physiological mechanism, small electrical currents were passed through two recording electrodes, causing neuron loss that evoked fast- and slow-timescale changes. These results revealed two independent timescales of representational drift, which could help guide the discovery of the cellular and network mechanisms responsible for the maintenance, (re)learning, and recovery of low-dimensional structure in neuron populations.

P1-B-55 - The effect of gravitational force on path selection in 3D obstacle-avoidance reaching

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Details

We investigated whether the central nervous system (CNS) exploits gravity when planning three-dimensional upper-limb reaching movements. Previous studies have suggested that the CNS may “use” gravitational forces in reaching movements to reduce muscle effort. However, it remains unclear whether the CNS takes gravity into account during path selection, thereby strategically exploiting gravitational dynamics. To address this question, we conducted three behavioral experiments using obstacle-avoidance reaching tasks in a vertical plane.

Across all experiments, participants performed single-degree-of-freedom shoulder rotations to move a cursor around an obstacle. In Experiment 1 (N = 28), participants freely chose between two possible paths: passing above (Upward) or below (Downward) a circular obstacle. Obstacle *distance* (Near, Mid, Far) and obstacle *height* were manipulated. For each condition, we computed the probability of selecting the Upward path (P(Upward)). Assuming that freely chosen paths reflect underlying cost-minimizing planning, we predicted that P(Upward) would be lower when obstacles were Near (where anti-gravity torque is costly early in the movement) and higher when obstacles were Far. Consistent with this prediction, P(Upward) increased as obstacle distance increased.

In Experiment 2 (N = 21), participants were *forced* to follow one of the two paths (Upward or Downward) by the experimenter. This was achieved by modifying the obstacle shape from a circle to a vertical bar extending to the upper or lower edge of the monitor. Reaching performance was quantified using a composite speed-accuracy trade-off (SAT) index combining movement time and endpoint error. If the upward bias observed in Experiment 1 reflected cost-minimizing planning, performance should favor the Upward path for Far obstacles. Consistent with this prediction, the SAT index indicated better performance for the Upward than for the Downward path when obstacles were Mid or Far, but not when they were Near.

In Experiment 3 (N = 20), we tested whether increasing the effect of gravity would strengthen the upward bias observed in Experiment 1. Participants performed the same free-choice task while wearing a 300 g wrist load. Contrary to the prediction, the upward bias did not increase with load; instead, it disappeared in the Far condition while remaining in the Near condition. Importantly, the added weight did not negatively affect reaching performance (movement time or endpoint error). Taken together, these results suggest that path selection in three-dimensional reaching is influenced by gravity-related movement dynamics, but not necessarily in a way that minimizes motor costs. In particular, the dissociation between preserved reaching performance and altered path bias with added load suggests

that compensation for increased gravitational effects does not automatically translate into gravity-utilizing path selection.

P1-B-56 - Motor-evoked modules elicited by transcranial magnetic stimulation

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Details

Transcranial magnetic stimulation (TMS) has been a noninvasive method to probe the motor system, providing valuable insights through motor-evoked potentials (MEPs). Given overlapping muscle representations in the motor cortex, TMS over the motor cortex often elicits non-negligible MEPs in multiple muscles (i.e., multimuscle MEPs). In the present study, we applied a factorization approach to multimuscle MEPs to quantify a pattern-level structure of corticospinal outputs beyond conventional per-muscle amplitude measures. To evaluate this approach, we analyzed multimuscle MEP datasets from three experiments in healthy young adults focusing on different stimulus parameters: stimulus intensity (experiment 1: n = 40), motor mapping size (experiment 2: n = 35), and intracortical circuits assessed by a paired-pulse TMS paradigm (experiment 3: n = 20). We extracted the pattern of covariation in multimuscle MEPs as motor-evoked modules (MEMs) using non-negative matrix factorization (NMF) and compared them across different stimulus conditions. Because NMF is invariant to uniform scaling, global excitability shifts do not, in principle, alter the pattern-level structure of corticospinal outputs, Comparisons of MEM therefore capture the pattern-level changes in corticospinal outputs beyond changes in amplitude measures. Amplitude-based analyses could fail to detect potentially meaningful physiological changes even when alternations manifest in the underlying multimuscle corticospinal recruitment. Thus, the present framework complements the well-established single-muscle MEP analyses. Our findings demonstrated that MEM diversity was greater at low intensities and decreased at higher intensities. Varying motor mapping size had only a minor impact on MEMs, suggesting that the pattern-level structure of corticospinal outputs elicited by TMS was stable across mapping extents. MEMs derived under short-interval intracortical inhibition (SICI) differed from those with single-pulse TMS. These results suggest that intracortical inhibition can shape corticospinal output patterns in a non-uniform manner across different muscles. Importantly, individual differences in motor cortex anatomy accounted for MEM diversity, and possible crosstalk had minimal influence on our findings. The present framework allows us to characterize the pattern-level structure of corticospinal outputs beyond per-muscle single-muscle MEPs; thus, MEMs obtained from TMS complement well-established MEP analyses and offer a novel perspective for investigating the motor system.

P1-B-57 - Development of an experimental system for analyzing redundancy in multi-person cooperative movements

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Details

What mechanisms underlie the cooperative physical movements that shape human cultural and social behavior? Situations in which multiple individuals cooperatively achieve a single goal exhibit a redundant structure, in which more people than strictly necessary contribute to task performance and each individual's contribution varies flexibly (Hochman & Rodgers, 1969). In such redundant systems, control variables can be decomposed into task-relevant dimensions, which directly affect task success, and task-irrelevant dimensions, which do not. Recent studies have suggested that movement variability in task-irrelevant dimensions reflects latent adaptive capacities that support flexible motor control and learning

(Latash, 2012). For example, individuals who exhibit rapid visuomotor learning in reaching tasks show greater variability in arm joint angles—dimensions that do not affect hand position—during the pre-learning phase (Singh et al., 2016). However, whether variability in task-irrelevant dimensions similarly relates to adaptability in multi-person cooperative movements remains unclear, as does whether a common redundancy-based mechanism for flexible motor control exists at both individual and group levels.

In this study, we developed a novel cooperative motor task in which multiple participants jointly exert force to manipulate a single visual cursor. The experimental apparatus consisted of a circular display surrounded by three force sensors. Each participant pinched one sensor and applied force in the forward and backward directions to control cursor motion. Because each participant's force contribution affected the cursor along only a single dimension, coordinated force production by three participants was required to reach a target position. As the dimensionality of the control variables exceeded that of the task objective, the resulting force patterns were not uniquely determined. In a preliminary experiment (N = 36), participants performed reaching movements toward targets in 12 directions. We quantified variability in task-irrelevant dimensions from force output patterns during baseline reaching and examined its relationship to group-level learning. Baseline task-irrelevant variability at movement offset was not a reliable predictor of group-level learning speed. One possible explanation is that force profiles during reaching showed strategic, explicit force modulation, suggesting that measurements taken only at movement offset may not fully capture within-trial control processes. Consequently, further investigation will be required to reach robust conclusions about the role of redundancy-related variability in group learning.

P1-B-58 - Current direction determines neural recruitment patterns in magnetic spinal stimulation

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Details

Transcranial magnetic stimulation activates various neural elements in the primary motor cortex, each of which can be preferentially activated depending on the eddy current direction. In contrast, although magnetic spinal stimulation is assumed to activate neural elements surrounding the spinal cord, it remains unclear how the current direction influences neural activation around spinal circuits. Here, we show that magnetic spinal stimulation activates different neural elements surrounding the human cervical spinal circuits in a current direction–dependent manner. Using a figure-eight coil, we delivered pairs of monophasic magnetic pulses over a cervical intervertebral region. Muscle responses evoked by the second pulse were significantly suppressed relative to ones evoked by the first pulse, and the magnitude of suppression depended on the direction of the induced eddy current. Suppression became more pronounced when the directions of eddy currents flowed laterally, crossing the rostral-caudal axis of the spinal cord in the coronal plane. This pattern indicates that muscle responses in these current directions were largely mediated by transsynaptic inputs. In contrast, suppression was minimal when current was directed from caudal to rostral, indicating that the responses primarily originated from the activation of peripheral motor axons. Conditioning electrical peripheral stimulation to evoke H-reflex demonstrated that magnetic spinal stimulation recruited either group Ia sensory afferents or motor axons, depending on the current direction. These results indicate that the magnetic stimulation targeting around the spinal cord activates cervical spinal motor circuits, with the direction of the induced eddy current serving as a key determinant of neural element activation.

P1-B-59 - A paired-pulse TMS method to measure cortico-reticulo-spinal responsiveness in humans

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Details

Recent data suggest that a cortico-fugal pathway involving the reticulospinal tract likely contributes to the later portion of TMS-induced Motor Evoked Potentials (MEPs) in muscles required for balance (e.g., gastrocnemius) (Shemmell et al., *J. Neurophysiol*, 2024). The evidence for this is drawn from a paired TMS paradigm in which a suprathreshold conditioning stimulus is delivered 50-80ms before a test stimulus, such that the resulting test MEP occurs within the silent period of a preceding conditioning stimulus. It is presumed that the conditioning stimulus inhibits the motor cortex, which in turn releases inhibition from the reticular formation, thus ultimately allowing for stronger transmission via the reticulospinal tract from the test stimulus. A cortico-reticulospinal contribution to these effects is suggested by an increase in the later portion of the MEP that coincides with the cortico-reticulospinal transmission delays (~10ms) typically seen when TMS is delivered to the ipsilateral motor cortex. However, the underlying mechanisms contributing to these responses are not yet fully understood. One challenge to reveal distinct circuit contributions under this paradigm is the need for strong reticulospinal inputs to the muscle, which are mostly associated with axial muscles or those required for posture stabilisation that have medial cortical representations, making it difficult to distinguish whether the effects of TMS are due to activation of the contralateral or ipsilateral motor cortex, or requires bilateral stimulation.

While common paired-pulse paradigms typically produce responses consistent with standard corticospinal transmission (i.e., a common shape and duration), the current TMS paradigm exhibits changes more likely to be produced by the cortico-reticulospinal pathway. The purpose of this study was to examine whether a cortico-reticulospinal pathway contributes to the conditioned MEP response produced in proximal upper limb muscles, and whether the release of brainstem inhibition is produced by a contralateral or ipsilateral cortical projection. This study had four conditions for paired-pulse TMS (50ms ISI): 1) bilateral stimulation, 2) contralateral stimulation, 3) ipsilateral stimulation, and 4) ipsilateral (conditioning) followed by contralateral (test) stimulation. Our preliminary findings revealed an increase in the later portion of the conditioned MEP amplitude and an onset latency shift (~6-10ms) in proximal upper limb muscles, consistent with observed responses in the lower limb. These findings suggest that a similar cortico-fugal pathway contributes to the conditioned MEPs produced in proximal upper limb muscles (i.e., pectoralis). These effects were observed for bilateral stimulation, contralateral stimulation, and inter-hemisphere stimulation, suggesting that both hemispheres may be capable of releasing brainstem inhibition. This method appears viable to examine cortico-reticulospinal contributions to motor control.

P1-B-60 - Striatal ensembles specify and control granular forelimb actions

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Details

The ability of the brain to control specific fine actions is crucial for survival. The striatum is a critical brain center for both movement and learning, and its dysfunction underlies numerous movement disorders. Whereas activity in the striatum has been classically viewed as invigorating and reinforcing movements, recent studies suggest that striatal activity encodes specific movements. However, it is not known how granular this activity is, and if it indeed controls specific ongoing movements. We designed a task where mice performed two minimally-different forelimb actions, consisting of a push or pull isometric force on

an immobile joystick, and imaged the activity of medium spiny neurons (MSNs) in the dorsolateral striatum using 2-photon microscopy. We observed that striatal activity encoded both the preparation and execution of specific actions, even when those actions were not reinforced. Furthermore, both populations of D1 and D2-MSNs - classically viewed as promoting versus inhibiting movement - equally encoded action identity. We developed a closed-loop system to model and stimulate action-specific neural ensembles deep in the brain, using holographic optogenetics through a GRIN lens. Stimulation of action-specific ensembles of both D1- and D2-MSNs increased the force of ongoing actions, but only when the ensemble stimulated was congruent with the ongoing action. These results reveal that specific ensembles of both D1- and D2-MSNs causally control specific ongoing actions, as granular as different muscle co-contractions of the same forelimb. Such granularity provides a mechanistic framework for understanding how striatal dysfunction can produce highly specific movement impairments in Huntington's disease and dystonia.

P1-B-61 - The brain's internal rhythm generator: Understanding the behavioral traits and neural functional correlates of spontaneous motor tempo

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Details

Background

Rhythmicity is a fundamental property of human motor behavior, supporting actions such as walking, speaking, and reading. Disruptions of intrinsic motor rhythm typically reflect dysfunction of the central nervous system rather than peripheral motor limitations, as seen in Parkinson's disease, where basal ganglia impairment produces characteristic abnormalities in spontaneous rhythmicity, including resting tremor and festination. In healthy individuals, spontaneous finger tapping provides a reliable behavioral index of intrinsic motor tempo (SMT), which shows robust individual differences. However, the behavioral traits that define SMT and the neural functional significance underlying these rhythmic tendencies remain poorly understood.

Objectives

This study aims to characterize both the behavioral traits and the neural functional correlates of spontaneous motor tempo. From a behavioral perspective, SMT was quantified using four theoretically grounded dimensions:

(1) Speed: the mean frequency of an individual's natural motor tempo;

(2) Variability: fluctuations around the individual's mean tempo;

(3) Uniqueness: the distinctiveness of each person's tempo profile;

(4) Reliability: the temporal stability across days and contexts.

From a neural perspective, we investigated how individual SMT profiles are reflected in intrinsic spontaneous brain activity and functional connectivity patterns measured with resting-state functional MRI, focusing on the functional neural significance of internally generated motor rhythm.

Methods

Thirty healthy adults completed an 8-minute eye-closed resting-state fMRI scan and a T1-weighted structural scan. SMT was recorded during relaxed, cue-free finger tapping (2 min × 2 trials) on Day 1, Day 7, and Day 30 using a custom iPad application. Resting-state data were preprocessed using standard pipelines. Thirty AAL-defined regions relevant to timing, basal ganglia circuits, sensorimotor integration,

limbic modulation, and prefrontal control were selected as seeds. For each seed, seed-to-whole-brain functional connectivity (FC) maps were generated. A global coupling measure—mean FC strength within a 90% group gray-matter mask—was extracted as a summary index of each seed's large-scale intrinsic connectivity. Seed-wise FC–behavior associations were tested using Pearson correlation with False Discovery Rate (FDR) correction. The top seed was then examined using voxel-wise FC-behavior regression with Gaussian Random Field (GRF) correction (voxel $p < 0.001$, cluster $p < 0.05$).

Behavioral Results

SMT showed marked individual differences in speed (0.2–4.8 Hz). Variability was inversely related to speed ($r = –0.3999$, $p = 0.039$), indicating lower rhythmic variability in faster tappers. SMT demonstrated strong uniqueness, with distinct tempo profiles across individuals. Reliability was excellent across one month (Day1–Day7: $r = 0.89$; Day1–Day30: $r = 0.87$; Day7–Day30: $r = 0.93$; all $p < 0.0001$; ICC = 0.92), and mean tempo did not differ across sessions (ANOVA $p = 0.67$).

Neural Results

Across 30 seeds, only the left putamen showed a significant relationship between global coupling and SMT ($r = 0.385$, FDR-corrected $p = 0.036$). Voxel-wise analysis revealed two GRF-corrected clusters: one in the right occipital cortex (BA18/19), implicated in perceptual timing processes, and one in the left insula/Rolandic operculum, reflecting sensorimotor integration. Together, these findings indicate that individual SMT is supported by a putamen-centered intrinsic network extending into perceptual and sensorimotor timing systems.

Conclusion and Implications

SMT is a stable and distinctive motor rhythm, and its individual differences are supported by putamen-centered functional systems extending into perceptual and sensorimotor timing networks. SMT provides a reliable window into the brain's internal rhythm generator, with potential applications in motor rehabilitation, early detection of basal ganglia dysfunction, and personalized rhythm-based interventions.

P1-B-62 - Mapping the motor control of skin pigment cells in cuttlefish

Xuqing Feng [1], **Xitong Liang** [1]

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Details

Cephalopods are known for the ability to rapidly change body patterns within hundreds of milliseconds through direct neural control of millions of pigment cells across the skin(chromatophores). Given the scale and speed, it is unlikely that individual chromatophores are controlled independently, implying the necessity of dimensionality reduction in the motor control system. Early behavioral observations of recurring pattern components favored a component-based strategy, in which complex patterns are generated by combining stereotyped groups of co-activated chromatophores. However, recent cellular-resolution analyses of cuttlefish camouflage indicates that individual chromatophores are not constrained to participate in stereotyped components. This flexibility motivates consideration of control architectures that do not rely on fixed modules, such as spatially organized, body-map–like representations. To test whether the chromatophore system employs body-map representations, we performed both anatomical tracing and functional mapping in the pharaoh cuttlefish (*Acanthosepion pharaonis*). In cuttlefish, motor neurons in the posterior chromatophore lobe (PCL) project through the pallial nerve (PN) to innervate skin chromatophores. We first charactered the spatial organization of PN projections. By stimulating individual PN branches, we revealed a topographic relationship between the orientation of nerve branches and the spatial distribution of activated chromatophore fields. By retrograde tracing from distinct PN branches back to PCL in the brain, we found internal axes in the PCL that correspond to the anterior–posterior and mediolateral axes of the mantle skin. We then performed functional mapping by combining focal electrical stimulation and two-photon calcium imaging in PCL,

with simultaneous imaging of skin chromatophore activity. Evoked neural activity and chromatophore activity displayed consistent topographic correspondence across multiple individuals. Furthermore, we found that the soma layer of PCL is laminated, with different neuronal layers exhibiting the same somatotopic maps. Together, these results support a spatially organized mapping from PCL to the skin. Our findings uncovered a somatotopic organization in the cuttlefish chromatophore system, a feature that is rare in invertebrates. This architecture may provide the continuity needed to generate both stereotyped signaling patterns and flexible camouflage patterns. Furthermore, it might facilitate the maintenance of a stable projection pattern across developmental stages. As a parallel of retinotopic representations in sensory systems, a body map has the potential of functioning as a generative space for pattern composition rather than a collection of fixed motor modules.

P1-B-63 - Spatiotemporal modulation of lower limb spinal reflexes by combined transcranial magnetic and transcutaneous spinal cord stimulation

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Details

Spinal reflexes play a central role in postural control and locomotion and have traditionally been assessed using the H-reflex. Although subthreshold transcranial magnetic stimulation (TMS) has been shown to modulate the soleus H-reflex, it remains unclear whether similar modulatory effects occur across other lower-limb muscles because the H-reflex can only be reliably elicited in a limited subset of muscles (e.g., soleus). Transcutaneous spinal cord stimulation (tSCS), by contrast, can evoke spinal reflexes in multiple muscles by activating spinal dorsal roots and thereby recruiting afferent pathways similar to those engaged in the H-reflex. This study therefore examined how subthreshold TMS applied over the primary motor cortex modulates tSCS-evoked reflexes across the lower limb, with a particular focus on the timing-dependent interaction between descending input evoked by TMS and afferent volleys induced by tSCS. In addition, to investigate the mechanisms underlying reflex modulation by combined stimulation, intramuscle activation patterns elicited by each stimulation (TMS-only, tSCS-only, and combined) were assessed using high-density surface EMG (HDsEMG) and visualized with heatmaps. Ten healthy males (25 ± 4 years) received combined TMS and tSCS across eight interstimulus interval (ISI) conditions defined relative to each participant's central conduction time (CCT): CCT−10, −5, 0, +5, +10, +15, +20, and TMS+100 ms. CCT was calculated as the latency difference between the TMS-evoked motor evoked potential (MEP) and the tSCS-evoked spinal reflex in the right tibialis anterior (TA). During combined stimulation, TMS was delivered at 80% of the resting motor threshold (rMT), and tSCS intensity was set to the ascending phase of the recruitment curve. Bipolar EMG was recorded from TA, medial gastrocnemius (MG), rectus femoris (RF), and biceps femoris (BF) bilaterally to assess the global effects of TMS conditioning on spinal reflexes. HDsEMG was additionally recorded from the right TA to evaluate the spatial patterns of intramuscle spinal reflex modulation.

Results showed that spinal reflex amplitudes in most muscles were facilitated at ISI corresponding to or later than each participant's CCT, with unilateral facilitation observed from CCT to CCT+20ms and bilateral facilitation emerging at TMS+100ms. These results indicate a timing-dependent spinal modulation, whereby descending input induced by TMS modulates spinal reflex excitability when it arrives in close temporal proximity to the tSCS-evoked afferent volley. HDsEMG heatmap further revealed that the spatial activation patterns of TMS-evoked MEPs differed from those of the tSCS-evoked spinal reflexes, and that TMS conditioning appeared to modulate tSCS-evoked reflexes by overlaying its spatial pattern onto that of tSCS. In conclusion, these findings demonstrated that subthreshold descending input can robustly modulate spinal reflex in a timing- and spatially specific manner.

C – Posture and Gait

Poster Cluster (P1-C-64 & P1-C-65)

P1-C-64 - The effects of globus pallidus internus deep brain stimulation on locomotor adaptation in Parkinson's Disease

Anjela Gurrala [1], **Joshua Wong** [1], **Julia Choi** [1]
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Details

The globus pallidus internus (GPi) is a common target for deep brain stimulation (DBS) in Parkinson's disease (PD). Anatomically, the GPi is positioned to modulate gait through direct connections to both thalamocortical circuits and brainstem locomotor regions. While DBS can improve gait speed and variability in PD, its effects on locomotor adaptation in PD remains unknown. Understanding how DBS affects the ability to adjust step length and step timing is important, especially in PD with freezing of gait (FoG) who show greater deficits in locomotor adaptation.

12 PD patients with FoG participated in a crossover study assessing the effects of DBS on locomotor adaptation. All participants had bilateral GPi-DBS and completed DBS ON and DBS OFF sessions, in randomized order. Testing was performed in the off-medication state following a 12-hour overnight dopamine washout. Changes in step length and step time asymmetry were measured across Epochs (A1 = 1-30, A2 = 31-60, A3 = 61-90, A4 = 91-120, A5 = last 30 strides) during split-belt walking, where the belts moved at a 2:1 speed ratio.

Repeated-measures ANOVA showed a significant main effect of Epoch for both step length ($p < 0.001$) and step time asymmetry ($p < 0.001$). There were no significant main effects of DBS on step length or step time asymmetry, and no significant DBS x Epoch interaction effects (all $p > 0.05$).

This is the first study to examine GPi-DBS effects on split-belt adaptation in PD with FoG. Our preliminary results showed that GPi-DBS did not significantly alter symmetry-based adaptation measures in PD with FoG. Understanding the neurophysiology of locomotor adaptation in PD is essential for developing treatments to more effectively improve gait adaptation.

P1-C-65 - Pallidal beta oscillations underlying locomotor adaptation in Parkinson's Disease

Julia Choi [1], **Anjela Gurrala** [1], **Coralie De Hemptinne** [1], **Joshua Wong** [1]
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Details

Locomotor adaptation is essential for adjusting walking patterns to environmental changes. This study investigated oscillatory activity in the globus pallidus internus (GPi), a major output nucleus of the basal ganglia, underlying locomotor adaptation in people with Parkinson's Disease (PD). We hypothesized that elevated GPi beta oscillations are associated with reduced locomotor adaptability in PD. Twelve patients with idiopathic PD with GPi deep brain stimulation (DBS) (eleven bilateral and one unilateral implantation) were included. Seven subjects also had freezing of gait (7/12 "freezers"). Local field potentials (LFPs) were recorded from DBS electrodes during split-belt treadmill walking. Step length adaptation was absent in five patients ("non-adapters", 5/12), including 4/7 freezers and 1/5 non-freezer. The remaining seven patients ("adapters", 7/12) showed preserved adaptation, reducing step length asymmetry over the adaptation period. We demonstrated that low beta (13–20 Hz) oscillations during walking distinguished freezers from non-freezers, whereas high beta (20–30 Hz) activity during split-belt walking differed between adapters and non-adapters. These findings provide novel insights into the neural signatures of gait dysfunction in PD. Low- and high-beta oscillations may reflect separate neural mechanisms underlying freezing of gait and gait adaptation deficits, respectively. These results have

important implications for the development of DBS targeting specific gait impairments, which remain challenging to treat clinically.

P1-C-66 - Modulation of broadband EEG during walking in younger and older adults

Charlotte Devol [1], **Chang Liu** [2], **Jacob Salminen** [1], **Erika Pliner** [3], **Arkaprava Roy** [1], **Chris Hass** [1], **David Clark** [4], **Todd Manini** [1], **Rachael Seidler** [1], **Daniel Ferris** [1]

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Details

Mobility declines with age, to the extent that walking speed is often considered a vital sign and predictive of physical well-being. Electroencephalography (EEG) may provide insight into neural factors contributing to age-related mobility decline. Recent work shows that aperiodic EEG (i.e., broadband power from the EEG power spectrum) differs across age groups, cognitive abilities, and neurological populations, possibly serving as a biomarker of brain health. However, it remains unclear whether aperiodic EEG is modulated by mobility tasks or whether age- and task-related effects differ across brain regions. The purpose of this study was to compare aperiodic EEG activity in healthy younger and older adults during rest and walking. We hypothesized that older adults would exhibit lower aperiodic exponents than younger adults during both rest and walking.

We recorded EEG in 31 younger adults (24 ± 4 years) and 59 older adults (74 ± 6 years) with no known cognitive or neuromuscular impairments while they sat at rest and walked on a treadmill at a comfortable walking speed. We recorded EEG using a high-density, custom dual-layer cap with 120 electrodes and used independent component analysis and source localization to isolate neural sources. We then separated power spectral densities into periodic and aperiodic components and used linear mixed-effects models to examine aperiodic exponent, with fixed effects (β) for age (old v. young), task (walk v. rest), and their interaction, and a random intercept for participant.

Older adults exhibited lower aperiodic exponents in the bilateral sensorimotor cortex (right: $\beta = -0.208 \pm 0.070$, $p = 0.039$; left: $\beta = -0.142 \pm 0.044$, $p = 0.003$), bilateral posterior parietal cortex (right: $\beta = -0.238 \pm 0.072$, $p = 0.003$; left: $\beta = -0.169 \pm 0.066$, $p = 0.012$), and right premotor cortex ($\beta = -0.194 \pm 0.065$, $p = 0.008$), indicating age differences in aperiodic EEG are region-specific. Across both age groups, aperiodic exponent increased during walking relative to rest in the left sensorimotor ($\beta = 0.057 \pm 0.018$; $p = 0.003$), left presupplementary ($\beta = 0.067 \pm 0.023$; $p = 0.005$), right premotor ($\beta = 0.062 \pm 0.024$; $p = 0.012$), and right posterior parietal areas ($\beta = 0.057 \pm 0.025$; $p = 0.027$). A significant age-by-task interaction was observed only in the occipital cortex, where only older adults showed higher aperiodic exponents during walking compared to rest ($\beta = 0.162 \pm 0.037$, $p < 0.001$). Given established evidence that older adults rely more on visual information while walking, this occipital interaction may indicate related task-dependent changes are observable in aperiodic EEG. Together, these findings demonstrate that aperiodic EEG is modulated between rest and walking tasks in a region- and age-dependent manner. Future work should examine whether task-related modulation of aperiodic EEG is associated with individual differences in mobility during healthy aging.

P1-C-67 - Improving propulsion in stroke survivors with haptic stance time instruction

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Details

Introduction: Temporal asymmetry and propulsion are key issues in the gait of stroke survivors [1,2]. The paretic limb having a shorter stance time than the nonparetic [1] may lead to the propulsive deficits seen

in the paretic limb [2]. We aimed to evaluate the relationship between stance time and propulsive features in the gait of healthy and stroke survivor participants. We demonstrate a simple haptic biofeedback strategy for increasing stance time and, consequently, propulsive features in healthy and chronic stroke individuals. Additionally, we propose a mechanistic relationship between stance time and trailing limb angle (TLA), supported by a simple geometric model that aligns with healthy subjects when following the biofeedback.

Methods: 7 healthy subjects and 3 chronic stroke survivors walked with the biofeedback. Healthy subjects walked at 1.0m/s, while stroke survivors walked at their preferred speed. The feedback was applied to the feet and instructed subjects to end their stance at the timing of vibration onset. We set a 20% stance time increase target for healthy subjects and an individualized target for the paretic limb of stroke survivors. This paretic target was adjusted based on how much they could increase their paretic stance time. The feedback was controlled using motion capture [3]. A geometric model based on a rimless wheel [4] was used to support the relationship between stance time and TLA of healthy participants. We adjusted the model based on the subject's leg and foot lengths. A linear mixed-effects model analyzed the feedback effects for the healthy data ($\alpha = 0.05$), while percentage changes was used for stroke survivors. Finally, we assessed the accuracy of the geometric model with the R^2.

Results & Discussion: Healthy subjects significantly increased stance time by 25.0±3.7% with feedback (0.21±0.03 sec, $p<0.001$), resulting in significant increases to TLA 50.8±8.2% (8.84±1.13deg, $p<0.001$) and propulsive impulse 102.6±19.0% (2.78±0.55%BW*sec, $p=0.001$). Feedback also increased the stance time and TLA in stroke survivors. The geometric model predicted TLA of healthy subjects with an R^2 of 0.65 across subjects. This study shows that simple stance time instruction results in increases to TLA values and propulsive impulses in healthy and stroke survivor participants. Our geometric model demonstrates that this is done through passive mechanics. Further analysis involving more stroke survivors may help determine a mechanistic link between stance time and paretic limb propulsion.

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P1-C-68 - Discovering feedback pathways for human walking with a structured neural controller

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Details

Physics-based simulation of the human musculoskeletal system provides unique in-silico experiments for examining how multiple feedback pathways contribute to and interact during locomotion. Existing neural controller models, however, rely either on hand-crafted models or on opaque deep reinforcement learning (DRL) policies [1], limiting insight into distinct contributions of feedforward and feedback control in walking [2]. This study develops a neural controller that explicitly separates feedforward and feedback components while maintaining the flexibility of DRL. The framework can reveal feedback pathways that are functionally necessary for stable walking and support physiological and mechanical interpretation through comparison with experimental findings.

The feedback component of the controller is inspired by the circuitry of Song and Geyer [3], which consists of 40-50 predefined linear feedback pathways, each representing a reflex arc. This structure was generalized as a linear mapping $a = Gs$, where the muscle excitation vector a is computed from a feedback gain matrix G and a state vector s containing muscle fiber length and velocity, tendon force, muscle activation, and trunk lean angles. The feedforward component is a multilayer perceptron (MLP) with one-dimensional gait-phase input variable, which is estimated from the full body state using a separate MLP. To reflect physiological delays, trunk lean angles and the estimated phase are delayed by

150 ms, whereas peripheral muscle variables are delayed by 20 ms. All parameters are optimized jointly using proximal policy optimization, with reference motion tracking [4] and activation minimization rewards. The gain matrix is initialized as fully connected, linking all state variables to all muscle excitations. The iterative weight pruning is applied to identify effective feedback pathways by removing connections with minimal contribution [5].
The proposed neural controller generated stable walking in a human model with 14 degrees of freedom and 22 Hill-type muscles on the lower body using 33 feedback pathways. The learned gain matrix exhibited positive muscle-length feedback in the vasti, gastrocnemius, and soleus, consistent with experimental evidence that stretch reflexes contribute to human walking [6]. Unlike conventional model-based approaches, our approach generalizes to larger models; it also enabled stable walking of a model with 31 degrees of freedom and 150 Hill-type muscles. These results demonstrate optimizing neural control structure in computational human models can reveal functionally significant feedback pathways.
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P1-C-69 - Resting-state and task-related cortical signatures of static balance inform the predictive efficacy of tDCS

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Details

Introduction: Postural control is a complex sensorimotor task relying on multisensory integration via cortical and subcortical pathways. Aging impairs balance, especially under sensory conflict, altering both behavioural performance and neural mechanisms of postural regulation. We characterized cortical activity during static balance tasks and evaluated resting-state EEG as a predictor of individual tDCS effects on dynamic balance training performance. **Method:** Eighteen older adults (60–80 years) and forty-seven (18-30 years) performed three randomized static balance conditions on a fixed Wii Balance Board: Eyes Open, Eyes Closed, and One-Leg stand. Each condition consisted of 14 trials (30 seconds each). Resting-state EEG was recorded before the tasks, and task-related EEG was recorded concurrently. Following the static tasks, participants underwent a 20-minute dynamic balance training session on a movable platform, accompanied by tDCS. **Results:** I will present results of three empirical studies where we show the critical role of pre-existing cortical resting-state activities as potential predictive biomarkers for tDCS success. Specifically, resting-state alpha power has been shown to be associated with stronger tDCS-induced facilitation of dynamic balance training outcomes. Our research shows spectral characteristics of the resting brain and the cortical activity required during task performance. While in younger adults, resting-state theta and beta power predicted stronger practice effect, in older adults, alpha power was found central to task-related changes and can be identified as a key predictor of tDCS efficacy. By characterizing both the predictive state and the task-driven state, these results directly inform the design of future personalized neuromodulation protocols aiming to maximize the beneficial effects of anodal tDCS on dynamic balance training in older adults. Findings demonstrate that the effectiveness of anodal tDCS is highly dependent on not only the stimulation target region and also the individual's baseline brain oscillatory activity. Rather than applying a one-size-fits-all approach, future studies should focus on identifying EEG-based predictive biomarkers to determine the optimal stimulation target for each individual. This personalized strategy would ensure that tDCS effectively

enhances motor learning by engaging the appropriate cortical networks, such as those involved in top-down executive control or motor execution, according to each person's baseline processing dynamics. Results demonstrate that EEG relative power is strongly modulated by the complexity of static balance tasks, with increased Delta, Theta, and Beta power—particularly in posterior and occipital regions—reflecting heightened sensory integration demands under more challenging conditions such as eyes closed and one-leg stance. These task-specific cortical patterns highlight the neural mechanisms through which older adults adapt to degraded or conflicting sensory inputs.
Conclusion: Postural control in older adults relies on dynamic interactions between baseline cortical activity and task-specific neural engagement. Pre-existing cortical state and real-time task-driven activity determine postural performance and motor learning in aging populations.
Keywords: Postural control; Static balance; Alpha power; tDCS; Personalized neuromodulation; Sensorimotor integration

P1-C-70 - Digital twin of human upright stance: identifying neural control disruptions in Parkinson's disease via Bayesian parameter inference

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Details

Intermittent control of upright stance is a strategy that optimizes the trade-off between minimizing postural deviation and minimizing control effort. While the intermittent control model can replicate quiet stance sway, translating this into clinical applications remains challenging. In this study, we constructed a Digital Twin (DT) of quiet stance using postural sway time-series from healthy elderly individuals and patients with Parkinson's disease (PD).
The DT framework integrates four elements: (1) Bayesian inference of posterior distributions for model parameters (μ), enabling the generation of synthetic data indistinguishable from individual real sway; (2) Characterization of sway metrics through latent variable (z) clustering for both real and synthetic data; (3) An approximate bijective mapping (via neural network) between the control strategy (μ) and the observed sway phenotype (z); (4) Classification of PD severity based on these identified clusters.
Traditional statistical analysis of clinical datasets is often hindered by the diversity of sway phenotypes—such as the paradoxical conflict between enlarged and reduced sway areas in PD. Our DT framework overcomes phenotypic complexity by leveraging mechanistic parameter inference. By tracing the disruption of control strategies within the parameter space, we disentangle complex clinical phenotypes into identifiable neural controller deficits. Causal relationship between the identified neural controllers and the corresponding sway patterns can be made clearer by augmenting the dataset with high-fidelity synthetic data, resolving the "small data" limitation. In this way, unlike "black-box" machine learning approaches common in Evidence-Based Medicine, our DT offers a transparent diagnostic logic grounded in control theory.
Furthermore, we demonstrate that aging- and disease-related changes in postural sway can be interpreted as bifurcations within the intermittent control model as a nonlinear dynamical system. These bifurcation diagrams provide a roadmap for detecting pre-symptomatic states and determining personalized interventions to improve postural function. Our results offer a comprehensive understanding of how neural control disruptions manifest as clinical variability in PD.

P1-C-71 - The difference of motor modules during the anticipatory phase between static-dynamic and dynamic-dynamic motion transition

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Details

Motor transitions, which are shifts from one movement to another, involve movements in daily life and sports competitions. Preceding the voluntary motor transition, anticipatory muscle patterns provide biomechanical conditions that support both postural stability and effective motor execution. For example, in a squat jump task, which is involved in the motor transition from a quiet stance to a thrust motion, the inhibition of the agonist muscle (soleus) and the activation of the antagonist muscle (tibialis anterior) are observed preceding the thrust motion. This muscle coordination induces a backward shift of the center of pressure, which increases the stability margin and leads to a more effective forward-upward push during takeoff. However, only a few studies have focused on motor transition involving a shift from one action to another. Although voluntary movements involving preparatory actions, such as jumping with steps, are generally known to enhance performance, the role of anticipatory motor control in such motion transitions remains uncertain. Therefore, we attempted to verify the difference of motor modules during the anticipatory phase of vertical jumps performed from a stationary posture without a step (static-dynamic: s-d) and with preceding steps (dynamic-dynamic: d-d). Muscle synergy patterns were extracted using non-negative matrix factorization (NMF). Twelve participants were asked to perform 10 trials of each condition, while kinematic, electromyography (EMG), and ground reaction force (GRF) data were acquired. The onset of the main movement (t0) was defined as the next data point following the minimum value in the z-axis (vertical component) displacement data of the center of mass (COM). Subsequently, the NMF technique was applied to the pooled datasets of all trials within each condition, and motor modules were extracted from the anticipatory phase, defined as the 500-ms window preceding t0. Moreover, the modified NMF algorithm proposed by Cheung et al. (2005) was applied to the pooled dataset of all trials within both conditions, and shared and unique (condition-specific) motor modules were extracted from the same phase. Our results showed that the number of motor modules identified in the d-d condition was greater than that in the s-d condition, and several unique modules specific to the d-d condition were extracted exclusively. Furthermore, the recruitment coefficient of the shared module was significantly lower in the d-d condition compared with the s-d condition. These findings suggest a more complex anticipatory motor control during dynamic–dynamic motor transition. Specifically, the presence of pre-steps may require the recruitment of unique modules that facilitate the transitions of horizontal energy into vertical propulsion. Concurrently, the temporal recruitment of shared modules responsible for actively generating propulsive energy may be decreased, reflecting more efficient utilization of incoming momentum.

P1-C-72 - Time-locked spinal neurons transform descending drive into locomotor rhythms

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Details

Spinal circuits are thought to contain a central pattern generator (CPG) that autonomously produces rhythmic locomotor output under tonic descending drive from the brain. The CPG is believed to be implemented by networks of spinal interneurons. However, the network dynamics of the CPG during

locomotion have remained elusive due to technical difficulties in large-scale recordings of spinal activity. Here, we performed multi-electrode recordings of spinal neuronal populations in the cat, a classical model organism for CPG studies, to elucidate how tonic descending drive is transformed into locomotor rhythms.
Experiments were conducted in decerebrate, paralyzed cats. After head fixation in a stereotaxic frame, a multi-electrode probe (Neuropixels 1.0) was inserted into the lumbar spinal cord (L3–L6). Electrical stimulation (30 Hz, ~40 sec) was delivered to the mesencephalic locomotor region (MLR) in the brainstem to evoke fictive locomotion. L7 ventral-root activity was also recorded to assess rhythmic motor output and its coupling to spinal population activity. All procedures were approved by the Animal Care and Use Committee of Asahikawa Medical University. Spike sorting was applied to extract spike trains of individual spinal neurons.
We first constructed stimulus-triggered PSTHs aligned to MLR stimulation and quantified time-locked responses of recorded spinal neurons. We identified two neuronal groups: one showing a sharp short-latency component immediately after stimulation (excitatory peaks and/or inhibitory troughs), and another with delayed, broad activation. These patterns likely reflect responses driven by relatively direct and indirect pathways downstream of MLR drive, respectively. Notably, when fictive locomotor rhythms were clearly expressed, the early-response groups exhibited more robust, less jittered responses, indicating enhanced excitability.
These findings suggest a hierarchical circuitry within the spinal cord that progressively transforms descending drive into locomotor rhythms. Specifically, early-response neurons may function upstream within the rhythm-generation network. Ongoing analyses include principal component analysis (PCA) to quantify how stimulus responses relate to contributions to the locomotion rhythm, and these results will be presented at the meeting. By bringing high-density multi-electrode recordings to the classical cat fictive locomotion preparation, this study is expected to advance our structural and functional understanding of CPG networks.

P1-C-73 - Adding platform and visual perturbations significantly increased postural responses

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Details

Postural sway evoked by pseudorandom platform perturbations (Peterka, 2002) has strong potential to predict fall risk (Maki, 1994). To advance understanding of multidimensional postural control, novel two-dimensional (2D) platform motions were recently developed (Wagner, 2024). However, no prior study has characterized postural responses when 3D platform and 3D visual perturbations are delivered simultaneously—an essential step toward understanding how the nervous system weights vestibular, proprioceptive, and visual cues. This study quantified postural responses evoked by (a) three platform perturbations—two tilts aligned with the vertical semicircular canal planes, Right Anterior–Left Posterior (RALP) and Left Anterior–Right Posterior (LARP), plus an earth-vertical translation; (b) three visual perturbations in RALP, LARP, and yaw; and (c) combined platform + visual perturbations. We hypothesized that platform perturbations would amplify visual-evoked responses and that RALP/LARP visual stimuli would interact with corresponding platform stimuli due to shared anatomical directions. Each of six sum-of-sines (SoS) trajectories was constructed by summing five distinct frequencies (0.04–1.55 Hz), enabling spectrally separated stimulation across six dimensions using a motion platform (Virtualis Motion VR) and VR headset (HTC Vive). Postural responses of 20 healthy adults (32.3 ± 13.1 years) were recorded at the head, hips, and feet via an AMTI AccuSway-Optimized forceplate. Participants completed five randomized trials: platform-only (two), vision-only (one), and combined (two).

Spectral analyses showed independent postural responses at each stimulus frequency. Yaw head rotations evoked by visual yaw perturbations, for instance, were distinct from those evoked by RALP or LARP stimuli. A three-way repeated-measures MANOVA revealed that adding platform perturbations significantly increased postural responses at RALP/LARP visual-perturbation frequencies compared with vision alone ($p < 0.016$). Combined perturbations elicited 1.5× larger pitch rotations and 2× larger roll and yaw rotations. Similarly, adding visual perturbations significantly amplified postural responses at RALP/LARP platform-perturbation frequencies ($p < 0.006$) compared with platform-only; head translations increased by 18% in the medial–lateral direction and 12% in the anterior–posterior direction.

These findings demonstrate that SoS trajectories can isolate postural responses across six perturbation dimensions even when platform and visual stimuli are delivered simultaneously. Combined 3D platform + 3D visual perturbations produced substantially larger postural responses than either modality alone, suggesting that visual perturbations may upweight proprioceptive contributions and that platform perturbations may increase visual reliance. This work establishes the feasibility of expanding the paradigm to 6D platform + 6D visual, enabling more naturalistic motions to assess fall risk.

P1-C-74 - Sequential movement patterns during the transition from standing to independent walking: A longitudinal analysis

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Details

The transition from standing to independent walking represents a critical developmental milestone in infancy. Traditional approaches have focused primarily on the description of this transition by counting discrete behaviors such as standing, crawling, walking, and falling; however, the sequential organization of movement patterns can offer greater insight into developmental trajectories. To examine this temporal ordering and behavioral transitions, we conducted a longitudinal study of infants from the onset of independent standing (10 seconds) to the achievement of independent walking (10 steps). Typically developing infants were observed biweekly during four-hour naturalistic play sessions and these videos were coded frame-by-frame using Datavyu. Sequential behavior was quantified by examining the probability of a subsequent behavior given the occurrence of a specific behavior. Sequential patterns were analyzed across two timepoints: standing onset (~11 mo) and walking onset (~13 mo). We found two striking patterns in the sequential behaviors at these timepoints. (i) At standing onset, falling was very common, occurring at the end of every walking bout, but also frequently after standing; moreover, the recovery behavior after falling was prolonged and less directed (i.e., they did not return specifically to any particular behavior). (ii) At walking onset, falling rate dropped significantly, with infants being able to remain standing after walking; furthermore, when falling occurred, there was a quicker recovery to resume walking, indicating a greater 'confidence' in their ability to walk. These findings suggest that the temporal structure of movement provides a deeper window into the mechanisms of learning to walk than mere frequency counts. The occurrence of these specific transitions identified here could potentially serve as behavioral biomarkers of walking development. Mapping these transitional dynamics offers a new framework for identifying typical development and may serve as a critical tool for the early detection of motor delays.

P1-C-75 - Gait-combined transcranial alternating current stimulation around gait cycle frequency over cerebral motor areas modulates spatiotemporal gait variabilities

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Details

Neural control of human gait depends on the integrated neural activations of the supraspinal and spinal systems, in which cerebral motor areas such as primary motor cortex (M1), supplementary motor area (SMA), and premotor cortex (PM) especially contribute in the supraspinal level. These cerebral motor areas are rhythmically activated within the gait cycle, and transcranial alternating current stimulation (tACS) at the gait cycle frequency over the M1 entrains the gait rhythm. However, whether modulating the tACS frequency to be slower or faster than the normal gait cycle frequency alters the gait rhythms remains unclear; therefore, we aimed to investigate the effects of different tACS frequencies, around the gait cycle frequency, applied over the M1 (Experiment 1) and the SMA and PM (Experiment 2) on spatiotemporal gait parameters, in 30 healthy young adults. Each experiment involved treadmill gait measurements with 5-min tACS under the following stimulation frequency conditions: normal gait cycle frequency (100% rhythm), slower and faster gait cycle frequencies (90% and 110% rhythms, respectively), and sham stimulation. Spatiotemporal gait parameters (gait cycle time, stance time, swing time, and stride length) were measured using optical sensors in each tACS condition. In Experiment 1, applying gait-combined tACS over the M1 in the 110% rhythm frequency condition (at faster frequency than the normal gait cycle frequency) significantly decreased the change in the coefficient of variation (CV) of the swing time (temporal gait parameter) during 5-min stimulation compared to the 90% rhythm frequency (at slower frequency than the normal gait cycle frequency) and sham stimulation conditions. In Experiment 2, applying gait-combined tACS over the SMA and PM in the 100% rhythm frequency condition (at natural gait cycle frequency) significantly decreased the change in the CV of the stride length (spatial gait parameter) during 5-min stimulation compared to the sham stimulation condition. Therefore, gait-combined tACS at natural or faster frequencies than the normal gait cycle frequency over the cerebral motor areas decreased the variability of spatiotemporal gait parameters.

P1-C-76 - Light fingertip touch stabilizes gait and alters vestibulomotor coupling during stochastic vestibular stimulation

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Details

When vestibular function is disrupted, individuals may compensate by relying on external cues for stability, such as light touch from a stable surface. Work in standing balance has shown that light touch reduces postural instability and alters the weighting of vestibular inputs. However, it is unclear if the benefits of light touch extend to the more dynamic demands of walking. The purpose of our study was to examine the effects of light touch on gait stability and sensorimotor reweighting during walking with vestibular disruption. Twenty participants walked on a treadmill (1.0 $m \cdot s^{-1}$) with and without stochastic electrical vestibular stimulation (EVS) while touching stationary surfaces bilaterally with prescribed (<2 N) or self-selected (<10 N) fingertip forces, or unilaterally with a prescribed force (<2 N). Control conditions included natural walking and walking while hovering the fingertips bilaterally over the touch surfaces. We hypothesized that EVS would induce instability-related gait changes, including greater step variability and increased residual head variance (V_{res}), and that light touch would mitigate these effects. We assessed vestibular weighting using coherence and gain between EVS and mediolateral ground reaction forces. We hypothesized that light touch would induce a reweighting of noisy vestibular inputs, potentially upweighting them through vestibular-cutaneous interactions. As a secondary analysis, we

recorded electromyography from the gastrocnemius and tibialis anterior muscles, along with metabolic cost, expecting that both would increase with EVS and be attenuated by touch. As expected, EVS led to gait instability, increased muscle activation, and increased metabolic cost. Prescribed and self-selected light touch reduced instability-related metrics but did not reduce activation or cost. Importantly, coherence increased during touch conditions, whereas gain remained unchanged or decreased, which may reflect sensorimotor upweighting of vestibular inputs via vestibular-cutaneous interactions, the engagement of cutaneous reflex pathways triggered by fingertip contact, or reductions in non-stimulus-related motor variability. Overall, our findings highlight that light touch can stabilize gait under vestibular disruption, possibly through vestibular-cutaneous interactions, though it does not alleviate neuromuscular or energetic demands.

P1-C-77 - Age-related differences in startle-like responses and reactive postural stiffening during unexpected external perturbations

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Details

Background:

The startle reflex is an involuntary, whole-body response to sudden external stimuli. While the flexed posture in the startle reflex serves as a protective mechanism, the accompanying pronounced postural stiffening often compromises subsequent compensatory balance by restricting movement flexibility. Especially, modulating this excessive stiffening is essential for maintaining adaptive postural stability in older adults. We investigated the effects age on startle-like responses and compensatory postural adjustment following unpredicted external perturbations.

Methods: Nine healthy young adults (average age=21.8 y) and fifteen healthy older adults (average age=70.5 y) participated. After a standardized 5-minute warm-up, participants were positioned on a motor-driven platform and strictly required to recover balance without compensatory stepping or grasping the safety handrail during unpredicted perturbations as possible. Muscle activities of the sternocleidomastoid (SCM), tibialis anterior (TA), and medial gastrocnemius (GA) on the dominant side were recorded via surface electromyography (sEMG) and normalized to maximum voluntary isometric contraction (MVIC). To identify the occurrence of a startle-like response, the activation of the SCM was monitored as a reliable physiological marker. Furthermore, changes in postural control strategies were quantified using the co-contraction index (CCI) between the TA and GA. The CCI was calculated to evaluate the degree of reactive stiffening in the lower limb following the perturbation. To compare between groups, the Fisher's exact test and Mann-Whitney U test. All significance levels were set at $p < 0.05$.

Results: There was no significant difference in the occurrence rate of the startle-like response (SCM activation) between the groups ($p=0.092$, $\phi= 0.393$). Although no significant differences were observed in either the startle-like response or the subsequent compensatory postural metrics between the groups, the CCI in the older group was significantly higher than that in the younger group following the compensatory postural adjustment ($p<0.01$).

Discussion: Our results suggest that the impact of aging on reactive postural control varies depending on the phase of the response. Regarding the initial startle-like response, although the occurrence rate did not show a statistically significant difference between groups, the moderate effect size and the trend toward significance suggest a potential age-related shift in neural excitability within the brainstem-mediated postural circuits. In contrast, the subsequent postural stabilization following the compensatory phase was significantly influenced by aging, as evidenced by the markedly higher CCI values in older adults. Furthermore, our results support the findings of Sanders et al. (2019), who reported high CCI

values in older adults.We have extended this knowledge with the new insight that this control strategy, characterized as a stiffening strategy with high CCI, continues even after the compensatory postural adjustment has ended. Consequently, while the initial startle-like response and the primary compensatory adjustment appear similar across age groups, the long-term effect on postural stabilization in older adults differs fundamentally from that in younger adults.
Conclusion: In conclusion, while the initial startle-like response is relatively preserved in older adults, the subsequent postural stabilization following the compensatory phase is significantly influenced by age-related increases in joint stiffness. This highlights the importance of analyzing late-phase postural integration to understand fall risks in older populations.

P1-C-78 - Post-stroke reorganisation of gait-related functional muscle networks

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Details

Altered muscle coordination patterns during walking are observed in patients with post-stroke gait. Muscle synergy analysis offers a neurocomputational framework for investigating the mechanisms governing human movement through low-dimensional modules. In this study, we used partial information decomposition (PID) to characterize how multiple muscles contribute to gait progression through redundant (functionally-similar), synergistic (complementary), and independent (unique) information components (O'Reilly et al., Exp Brain Res, 2024). Post-stroke gait is often characterized by excessive co-contraction, reduced motor selectivity, and compensatory control strategies. We hypothesized that post-stroke gait would be characterized by increased redundant information and decreased synergistic information among muscles, along with reduced unique information.
Thirty healthy individuals and thirty-five patients with stroke walked along a 10-m walkway at a self-selected speed. Muscle activity and joint kinematics were recorded using electromyography from eight muscles of the paretic lower limb, together with inertial sensors attached to the lower limbs and trunk. The information shared across muscles about joint angles was decomposed into redundant, independent, and synergistic components using PID. To extract low-dimensional muscle coordination networks corresponding to each information component that were common across subjects, a projective non-negative matrix factorization approach was applied. Associations between muscle coordination networks, motor paralysis assessed using the Fugl–Meyer Assessment for the lower extremity, and gait-related variables derived from inertial sensors were assessed using correlation analyses.
Stroke patients exhibited a significant increase in redundant information and a decrease in independent information compared with healthy individuals ($p<0.05$). Redundant information was negatively correlated with lower-limb motor paralysis ($p=0.017$, $\rho=-0.43$), whereas independent information showed a positive correlation ($p=0.028$, $\rho=0.40$). Information-specific muscle coordination analysis revealed stroke-specific modules with low similarity to those of healthy individuals across redundant, independent, and synergistic information components. In both redundant and synergistic components, these modules were significantly associated with motor paralysis, walking speed, and stance-time asymmetry ($p<0.05$).
Increased reliance on redundant information may reflect a compensatory strategy to stabilize movement in the presence of impaired independent and synergistic control, while stroke-specific muscle coordination modules capture clinically relevant features of motor paralysis and gait dysfunction. These results suggest that post-stroke gait control is characterized not simply by impaired coordination, but by a reorganization of information sharing and segregation among muscles.

P1-C-79 - Distortion of internal heading representation reflected in vestibular reflexes and gaze direction

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Details

When humans attempt to walk straight without visual cues, their walking trajectory often veers leftward or rightward (Souman et al., 2009), suggesting that the heading direction is not accurately estimated from non-visual sensory information alone. Specifically, walking deviation may reflect inaccuracies in vestibular-based estimation of head-body rotation, as heading direction during locomotion depends on yaw head-body rotations generated during stepping. However, how vestibular-based estimation of head-body rotation contributes to veering trajectories in the absence of visual cues remains unclear because both heading representation and vestibular-based estimation are internal neural states that cannot be directly observed. Vestibular-based estimation may be indirectly assessed through vestibular reflexes, namely the vestibulo-ocular reflex (VOR) and vestibulocollic reflex (VCR). During locomotion, the VOR stabilizes vision by generating compensatory eye movements opposite to yaw head rotation, whereas the VCR stabilizes head orientation relative to yaw body rotation. The gains of these reflexes reflect the fidelity of vestibular processing underlying head-body motion estimation. If inaccurate estimation of head-body rotation contributes to walking deviation, VOR and VCR gains would be expected to exhibit left-right asymmetries, with the lower-gain direction corresponding to the direction of walking deviation. To test this hypothesis, we assessed VOR and VCR while participants attempted to walk straight in a virtual reality (VR) environment. Eleven participants walked toward a distant goal under two conditions: with a goal (w/g) and without a goal (w/o). In the w/g condition, walking trajectory remained straight in all participants, while in the w/o condition the trajectory systematically veered leftward or rightward in an individual-specific manner. VOR and VCR gains, calculated as the ratio of eye velocity to head velocity and of head velocity to body rotation velocity, respectively, exhibited significant left-right asymmetries only in the w/o condition, and the side with lower gain consistently matched the direction of walking deviation. We also recorded gaze direction as an indicator of heading representation (Hollands et al., 2002; Lakshminarasimhan et al., 2020). Gaze direction at each step predicted the heading direction of the subsequent step. Multiple mediation analysis further revealed that VOR and VCR performance shifted the gaze direction, and walking trajectory subsequently deviated toward the gaze direction. Together, these findings suggest that asymmetric vestibular-based estimation of head-body rotation distorts the internal representation of heading direction and contributes to systematic veering during navigation when visual landmarks are unavailable.

P1-C-80 - Relationship between avoidance patterns and the direction of center of mass motion during walking following unexpected obstacle recognition

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Details

Background

When an obstacle is recognized late during walking, individuals must execute an avoidance maneuver within a limited time. Obstacle-avoidance patterns are generally classified as parallel steps and cross steps. However, it remains unclear whether these patterns are primarily shaped by the timing of obstacle recognition (i.e., temporal constraints) or by the direction of center of mass (CoM) motion at avoidance onset.

Methods

Fourteen healthy adults participated in this study. Participants performed an obstacle-avoidance walking task in which a black circular obstacle (radius: 25 cm) was suddenly projected onto the walking path during gait. The distance between the participant and the obstacle was kept constant (1.3 times step length), while the obstacle appearance timing (OAT) relative to the swing phase was varied.
The support foot at which the mediolateral deviation of the extrapolated center of mass (XCoM) exceeded a predefined threshold was defined as the turning foot. Avoidance patterns were classified as a cross step when the subsequent support foot landed lateral to the turning foot and as a parallel step when it landed medial to the turning foot. The direction of CoM motion at avoidance onset was quantified using the mediolateral angular component of the XCoM ($\sin\theta$), calculated at heel contact of the turning foot, with the axis defined from the CoM toward the turning foot. Probability distributions of OAT and the XCoM angular component were compared between avoidance patterns using kernel density estimation.
Results
A total of 999 trials were analyzed. The distributions of OAT largely overlapped between parallel and cross steps, indicating that avoidance patterns could not be clearly distinguished based solely on OAT. In contrast, although the distributions of the XCoM angular component overlapped, cross steps showed relatively larger outward components compared with parallel steps. The median [interquartile range] of the XCoM angular component was −0.245 [−0.34 to −0.13] for parallel steps and −0.09 [−0.14 to −0.05] for cross steps.
Conclusion
Avoidance patterns during walking following unexpected obstacle recognition are not uniquely determined by OAT alone. Instead, they are associated with the direction of CoM motion at avoidance onset, suggesting that avoidance strategies emerge in relation to the mechanical state of the body at that moment.

P1-C-81 - Human sensory-musculoskeletal modeling and control of whole-body movements

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Details

Coordinated human movement depends on the integration of multisensory inputs, sensorimotor transformation, and motor execution, as well as sensory feedback resulting from human-environment interaction. Building dynamic models of the sensory-musculoskeletal system is essential for understanding movement control and investigating human behaviors. Here, we report a human sensory-musculoskeletal model that integrates precise anatomical representations of bones, joints, and muscle-tendon units with multimodal sensory inputs. A stage-wise hierarchical deep reinforcement learning framework was developed to address the inherent challenges of high-dimensional motor control with integrated multisensory information. The model achieved three representative movement tasks, showing a close resemblance between natural and simulated human motor behavior with musculoskeletal dynamics that could not be directly measured. This work sheds deeper insights into the sensorimotor dynamics of human movements, facilitates quantitative understanding of human behaviors in interactive contexts, and informs the design of systems with embodied intelligence.

D – Integrative Control of Movement

P1-D-82 - Dynamic and selective interactions in the motor system during naturalistic reach-to-grasp

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Details

When grabbing an object, we reach while preparing and executing a grasp. It remains unclear how distinct streams of action-relevant information (where to reach and how to shape the hand) are shared across brain areas and how these interareal interactions reorganize across different phases of movement. To investigate, we trained a rhesus macaque to perform a naturalistic reach-grasp-lift task, manipulating reach direction and object size while simultaneously recording from dorsal premotor (PMd), ventral premotor (PMv), and primary motor cortex (M1) with Utah arrays. We applied multi-population delayed latents across groups (mDLAG, Gokcen et al. 2023) to identify signals shared between areas and their optimal interareal lags. Separately, we performed decoding analyses to identify when each area expressed task-relevant information. Together, these approaches allowed us to test how interareal interactions changed as a function of (1) movement epoch, and (2) type of information.

First, to study how shared signals changed as a function of movement epoch, we split the reach-grasp-lift movement into two epochs: movement initiation and lift, split around the time of object contact. We fit separate mDLAG models for each epoch and analyzed the lag-lead structure of shared signals. During movement initiation, we found that PMd led for most shared signals and that M1 led least often. Conversely, no particular area led more than the others during lift. This indicates that interareal signal flow is dynamic over the course of movement.

Second, to assess how different streams of information were shared, we compared the lag-lead structures of latent variables that carried task-informative signals. We focused on the movement initiation epoch, when both object direction and size information are relevant for action. We quantified three types of information: condition-invariant, reach direction, and object size. Within each session, condition-invariant signals were primarily captured by 2 latents which were close to synchronous between areas (median lag: 8 ms). Conversely, direction tended to be explained by 1 latent that went PMd→M1→PMv (49 ms, 77 ms), and size was explained by 1 latent that went PMd→PMv→M1 (145 ms, 112 ms). When we analyzed the timing of decodable information in each area, PMd and M1 were best correlated in the timing of when they exhibited direction information; for size information, PMv and M1 were more similar. These results together illustrate different types of movement information being coupled and shared between different areas at different times, demonstrating selective flow of interareal information.

Our combined findings support the notion that dynamic and selective interactions between motor cortical areas underlie naturalistic reach-to-grasp behavior: while PMd, PMv, and M1 all encode reach and grasp information, the timing and content of interareal signals reflect structured differences aligned with potentially specialized roles.

P1-D-83 - Selective gain modulation of different spinal reflex pathways for movement execution as revealed by optogenetic manipulation of primary afferent activity

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Details

Peripheral sensory feedback is dynamically modulated during voluntary movement, which is known as sensory gating. In the spinal reflex research, this phenomenon has been proposed as the attenuation of reflex gains that are irrelevant to or interfering with ongoing movement. However, it remains unclear whether these gains are uniformly attenuated or selectively regulated according to the task demand. Here, we developed a primate-compatible sensory optogenetic strategy to causally examine the modulation of spinal reflex pathways.

First, we established a gene transduction strategy that enables selective manipulation of large-diameter primary afferents associated with tactile and proprioceptive sensations in common marmosets. Intravenous injection of a capsid variant of serotype-9 adeno-associated virus (AAV) vector (AAV-PHP.B) selectively transduced channelrhodopsin 2 (ChR2) into the primary afferents. This allowed us to causally manipulate peripheral sensory feedback in non-human primates.

Next, we tested the effect of optical stimulation on spinal reflex pathways. After training two animals to perform a reaching task toward an LED target, we transduced ChR2 into the primary afferents. Then, we applied transdermal optical stimulation to the afferent nerves innervating the wrist flexor muscles (i.e., the median and ulnar nerves). Since the task does not explicitly require wrist movement, spinal reflexes arising from these afferents are not directly relevant to task performance. As expected, short-latency excitatory reflexes in the homonymous wrist flexor muscles (e.g. stretch reflexes) induced by the optical stimulation were absent during movement, although they were observed at rest. This indicates that the task-irrelevant reflex pathways are suppressed only during the task performance.

Interestingly, the animals exhibited undershot reaching and failed to reach the target exclusively during the optical stimulation. Further analysis revealed that this undershooting was caused by reduced activity of the agonist muscle, triceps brachii, which was due to the recruitment of heteronymous inhibitory reflex pathways (e.g., reciprocal Ia inhibition) induced by the stimulation. The results suggest that these inhibitory reflex pathways may interfere with task execution. In addition, the magnitude of inhibition was significantly larger during the deceleration phase of reaching movement than during the acceleration phase. This phase-dependent modulation implies that the inhibitory reflexes specifically upregulate during movement deceleration, which may contribute to the termination of movement.

Taken together, the present study provides a novel insight into sensory gating. While task-irrelevant reflex pathways are tonically suppressed, reflexes that can be relevant to task performance are not eliminated even though they may interfere with task execution. The gains of such reflexes are likely adjusted during the task performance to support successful completion.

P1-D-84 - Combined representation of grasping and body posture in premotor neurons of freely moving monkeys

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Details

Manual grasping is one of the most flexible and distinctive abilities of primates, both human and non-human, and requires complex, integrated control of the hand and fingers in coordination with other, more proximal body parts. Indeed, the hand is rarely used in isolation, as the same type of prehension - such as precision grip or whole-hand prehension - can be performed across markedly different whole-body postures, from sitting to standing. Nevertheless, almost all studies on the neural basis of hand-grip representation in the cortical motor system have so far been carried out in head-restrained non-human primates seated in a primate chair, where proximal body posture is fixed, making it impossible to assess the potential influence of body configuration on the distal components of hand-grasp representations. In this study, we addressed this issue by wirelessly recording premotor neuron activity from two freely moving rhesus macaques performing a reach-and-grasp task on identical objects - a small and a large sphere - across multiple spatial locations that naturally afforded distinct whole-body postures: standing, upright sitting facing forward, upright sitting facing downward, or crouching. Thus, the same grip type, determined by the object (i.e. precision or whole-hand grip), had to be executed across different body postures. We recorded a total of 347 neurons, of which only 5.2 % (18/347) showed consistent modulation across all body postures, and only 1.7 % (6/347) preserved grip selectivity when body configuration changed, suggesting that both hand grasping and grip type are coupled to whole-body posture rather than being represented independently. Population-level analyses showed that distinct body postures could be robustly decoded from the pre-movement period and throughout the action execution phase. Cross-temporal decoding further revealed a transition from temporally stable body-posture representations during behaviorally static periods to increasingly dynamic coding of body posture and grip type during movement preparation and execution. Notably, grip-type coding emerged exclusively during the hand-object interaction phase and remained largely constrained within each body posture. Together, our findings reveal that grip encoding in the premotor cortex is strongly combined with the associated whole-body posture, at both the single-neuron and population levels. These results support a synergistic cortical control of axio-proximal and distal motor components underlying the representation of grasping actions during unconstrained, natural behavior.

P1-D-85 - Alpha and beta cortico-motor phase dynamics index hasty and cautious control in human visuomotor loops

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Details

Adaptive behavior often requires responses that are both fast and accurate, especially when confronted with sudden, unpredictable events. Achieving this level of performance relies on the dynamic integration of sensory and motor signals across multiple spatial and temporal scales. While sensorimotor integration has been extensively modeled at the computational level, how these processes unfold at the neural level remains poorly understood. Here, we leverage cortico-motor synchronization as a window into sensorimotor loop dynamics, revealing its selective role in fine-tuning visuomotor control on a moment-to-moment basis. We examined the ongoing relationship between motor output (force) and brain activity, measured with electroencephalography (EEG), as human participants (n = 30) performed an isometric visuomotor tracking task with their right (dominant) hand. Participants exerted a constant level of force by pulling an isometric joystick via wrist abduction. This force controlled the angular velocity of a

cursor used to track a target moving at constant speed along a circular trajectory. During continuous tracking, the target occasionally underwent brief, unpredictable accelerations, requiring rapid motor adjustments to counteract the visual perturbation. We identify temporally and spectrally specific patterns of cortico-motor phase synchronization that differentially predict behavioral performance along two key dimensions: speed and accuracy. Immediately preceding the visuomotor perturbation, stronger alpha-band (~10 Hz) synchronization predicts faster responses (shorter reaction times), whereas stronger beta-band (~25 Hz) synchronization predicts greater response accuracy, which was in turn associated with reward. The behavioral relevance of cortico-motor phase synchronization is further supported by single-trial analyses demonstrating predictive power independent of local oscillatory amplitude dynamics. Together with control analyses, these findings rule out alternative explanations such as attentional confounds. These results suggest that beta-band synchronization reflects a cautious, reward-oriented control strategy, expanding upon recent accounts of beta activity as involved in functional inhibitory control. In contrast, alpha-band synchronization facilitates quicker, though not necessarily more efficient, motor responses, indexing a more hasty control policy. This interpretation is consistent with recent findings from our group showing that alpha-band cortico-motor synchronization is associated with increased visual detection rates, indicative of heightened neural excitability that may promote more liberal and rapid decisions. This study provides insights into the closed-loop neural dynamics governing effective sensory-to-motor transformations, suggesting that the interplay between alpha and beta cortico-motor synchronization orchestrates complementary (hasty vs. cautious) sensorimotor control policies. This dynamic interplay may represent a fundamental mechanism supporting adaptive behavior in real-world contexts.

P1-D-86 - Dissociable neurocognitive dynamics characterize Kinesthetic and Visual Motor Imagery of a complex motor sequence

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Details

Motor Imagery (MI) relies on internal forward models to simulate sensory consequences without overt execution. While single target movements have been extensively studied in MI research, neural dynamics underpinning complex, multi-stage motor sequences remain under-investigated. This study leverages the consolidated motor skills of elite basketball athletes to characterize the spatiotemporal evolution of neural activity during Kinesthetic (KMI) and Visual (VMI) imagery of a sport-related motor sequence, dissecting the interplay between top-down neurocognitive functions and sensorimotor simulation.

Twenty elite junior basketball players (>3 years high-level competitive experience) participated. High-density EEG (64ch, 512Hz) was recorded during randomized 8-9s trials of either KMI (proprioceptive focus) or VMI (3rd-person visualization) of the free throw. Event-Related Desynchronization/Synchronization (ERD/ERS) maps were calculated relative to a resting baseline in Theta (4-7Hz), Alpha (8-13Hz), and Beta (15-30Hz) bands to analyze the temporal progression of cortical activity in 1-second epochs of interest.

Time-resolved spectral analysis revealed distinct profiles reflecting different neurocognitive strategies. In the Theta band, a clear topological dissociation emerged. KMI showed stable, high-amplitude ERS over frontal and prefrontal regions (0-6s) coupled with robust left centro-parietal ERD, suggesting continuous top-down executive regulation for sensorimotor simulation. Conversely, VMI exhibited a dynamic anterior-to-posterior shift: early frontal ERS migrated towards centro-parietal and occipital regions (3-7s), indicating a transition from executive planning to visuospatial maintenance. In the Alpha band, modality-specific gating was observed. VMI displayed a functional trade-off: focal occipital ERD (visual

processing) occurred concurrently with marked central ERS, suggesting active suppression of the sensorimotor cortex to privilege visual imagery. In contrast, KMI showed widespread initial ERS followed by focal left parietal ERD, reflecting active engagement of proprioceptive internal models. Finally, both conditions showed frontoparietal Beta ERD, with KMI displaying a more confined ERD in contralateral motor areas compared to the diffused VMI pattern.
Present findings indicate that VMI and KMI recruit distinct neurocognitive networks with unique temporal signatures. Crucially, KMI appears to be an effortful, top-down process where executive functions (frontal Theta) actively drive sensorimotor activation, whereas VMI relies on a transition to posterior visuospatial maintenance while actively suppressing motor output (central Alpha ERS). Thus, "thinking about moving" and "watching oneself move" engage internal models through fundamentally different control loops, influencing how mental training should be tailored for motor learning and rehabilitation.

P1-D-87 - Reaching under (visually) inferred wind forces

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Details

Wind is a ubiquitous force in our physical world. In virtually every outdoor moment, humans have to spontaneously adapt their motor plans to accommodate varying wind forces. What sensory cues drive such a process? Existing research has exclusively focused on wind that is experienced through the *tactile* modality (e.g., airflow felt on the skin), and on motor adaptation under actually felt forces. But what about perceptually *inferred* forces?
The present study investigated how we modify motor plans in response to *visually* perceived wind. In such contexts, crucially, participants do not receive any tactile information on airflow, and experience no actual physical force perturbations on their hands. Instead, participants were shown displays that spontaneously yielded compelling impressions of wind (e.g., a field of moving dots that look like leaves being blown across the scene). Participants were asked to reach from the center of a workspace screen to a cued target location. Importantly, throughout the experiment, participants were not given any form of feedback on how accurate their reaches were, and their hand positions were entirely occluded. As such, any adjustment to movement kinematics would reflect their internal representation of an inferred force field (i.e., wind), rather than error-based learning.
Results showed that participants' reaching movements 'pushed against' the visually inferred wind forces. That is, when wind appeared to blow from left to right, participants' reaches exhibited a spontaneous and automatic leftward bias, and vice versa for perceived wind moving in the opposite direction. This suggests that merely *seeing* a force field – without any accompanying physical force – spontaneously drives the motor system to alter its plans. Thus, visual cues alone are sufficient to engage motor compensation to inferred environmental dynamics, even in the absence of direct sensory or mechanical consequences.

P1-D-88 - Effect of task difficulty and auditory warning stimulus on plantar flexion position task and its subjective psychological states

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Details

With the polarization of children's exercise habits and presence of exercise aversion being pointed out in Japan or other countries, the importance of physical education classes for future exercise habits have been recognized. Contents or program in physical education classes would be influential for psychological responses and teachers or instructors should have more appropriate choice. Task difficulty

is an important variable influencing success rates and can be controlled by teachers or instructors. An increase in difficulty decreases success rates and could also decrease sense of achievement, fun, and motivation to continue the exercise. However, appropriate difficulty would enhance positive feeling in these psychological responses. Furthermore, psychological responses to the given task would be influenced by the surrounding environment, as the feeling of being evaluated from others or audiences.

The purpose of this study was to examine the effects of task difficulty and an evaluated environment on task accuracy and psychological states.

Twenty-four healthy adults performed ankle plantar flexion control tasks using a car-driving pedal. Task difficulty was set to three levels (low, medium, and high) by changing the target width of the trajectory. Additionally, an evaluated environment was simulated by using auditory warning stimulus to task failure. The task accuracy and psychological states were assessed from the time of task failure and subjective psychological states including sense of achievement, fun, sense of being evaluated, stress, and motivation to continue the exercise by a Visual Analog Scale (VAS).

The task accuracy significantly decreased as task difficulty increased ($p<0.001$). Scores for sense of achievement, fun, and motivation to continue the exercise were significantly higher in the medium and high difficulty levels compared to low level ($p<0.01$). While the auditory warning stimulus did not significantly affect the task accuracy at either medium or high levels, it significantly increased the sense of being evaluated and stress ($p<0.05$).

Setting a moderate difficulty level can be an effective means of inducing a flow state and positive affect, such as sense of achievement, fun, and motivation to continue the exercise. However, it was revealed that an evaluated environment increased psychological load without affecting success rates.

P1-D-89 - Motor cortex encodes subjective value

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Details

How much we value an action influences not only what we do but also how we do it. Crossing a street can be more vigorous if a friend awaits, more cautious if the café may be closed, or slower when you must climb uphill, and it can unfold entirely differently if the destination is your office rather than a cafe with friends. What computational architecture might allow for value attributes to influence action? A plausible architecture would distill value into a single readout that can modulate action. In this study, we found that motor cortex arranges value attributes along a single axis in population activity space, representing how much the individual values a planned action. This may provide a compact and convenient representation of subjective value that can shape the quality of our actions.

We found this single axis representation of subjective value in motor cortex of two rhesus monkeys as they performed three task variants (two reaching tasks and one isometric force task) with visual cues indicating reward and/or effort cost. Across tasks, the cue set differed: each task varied a distinct subset of value attributes (reward magnitude, reward type, reward probability, or motor effort), manipulated independently on a trial-by-trial basis. To test for a shared representation across value attributes, we projected the pre-movement neural population activity onto a low-dimensional latent space, which revealed that value attribute signals aligned to a common dimension. Along this axis, certain targets with equal expected value (magnitude x probability) had unequal projections along this axis. We hypothesized that these inequalities reflect differences in the cues' subjective value. To test this hypothesis, we ran a separate choice task in which monkeys chose between cue pairs. From these

choices, we fit a maximum-likelihood choice model to estimate each cue's subjective value. These choice-derived values were strongly correlated with neural projections onto the shared value axis. Beyond capturing these cue-specific values, this projection predicted day-by-day shifts in the monkeys' preferences between reward pairs with equal objective expected value but different reward risk. Together, these results help close the gap between decision-making and movement by placing choice-grounded subjective values directly within motor preparatory population activity. This axis is readily available for downstream readout, predicts preference shifts, and renders otherwise idiosyncratic variability interpretable in terms of value.

P1-D-90 - Visuospatial context and task performance are encoded in Ventrolateral Prefrontal Cortex LFP activity during a head-unrestrained, memory-guided reach task

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Details

The purpose of the current study was to understand how prefrontal local field potential (LFP) signals encode visual landmark information during a memory-guided reach task, and how this is modulated by performance (i.e., correct vs. incorrect trials) and spatial variables. We implanted a 128-channel Plexon Array over the posterior ventrolateral prefrontal cortex (pVLPFC). Single unit activity, LFPs and behavioral (eye, head, hand) signals were recorded simultaneously in a female Rhesus monkey trained to perform a memory guided reach task. In this task, the hand was initially placed at a waist-level LED bar while gaze fixated centrally, and a landmark (four dots forming a virtual square) was presented at one of 15 locations on a touchscreen. A visual target then appeared transiently at a variable location within or outside this virtual square, followed by a visual mask. After the mask, the landmark either reappeared at the same location (stable landmark condition) or shifted by 8 degrees in one of 8 directions (landmark shift condition). The fixation light then extinguished, signaling a reach to the target. Controls were the same, but without the landmark. Preliminary analysis of time-power plots revealed frequency band-specific decreases in power during the delay period before reach, followed by increases in power peaking near movement onset across all trials. Correct stable landmark trials (which tend to be more accurate than no-landmark controls) and landmark shift trials showed additional band-specific decreases and increases in power prior to movement onset, plus a second power peak between acquisition and reward. However, the latter landmark-specific changes appeared to be suppressed during error trials where the animal touched the wrong location. Furthermore, low-frequency LFP power exhibited spatial tuning. Increases in power prior to movement onset were stronger for targets located ipsilateral to the recording site, whereas initial hand position had a weaker and more uniform effect. These preliminary findings suggest that prefrontal LFP signals reflect task-relevant spatial information and performance-dependent modulation during memory-guided reaching.

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P1-D-91 - Pupil size reflects physical effort but not motor fatigability during a sustained motor task

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Details

Introduction

Pupil dilation is widely used as an index of a variety of bodily states and cognitive processes.

While it has been shown to be linked to physical effort, its link to motor fatigability is unclear. In our previous work, sustained maximal tapping induced motor slowing (MOS), a subtype of motor fatigability, which is characterised by a decrease in movement speed over time and associated with increased muscle coactivation. Pupil initially dilated and then gradually decreased over time. However, whether this decrease in pupil size is merely part of the typical effort-evoked pupil response or also reflects the accumulation of motor fatigability remains unclear. Since MOS is speed-dependent, systematically varying tapping speed provides a way to dissociate effort from motor fatigability. Here, we test whether pupil size only scales with effort or also reflects the build-up of motor fatigability.

Methods

35 healthy participants (24±2 y; 17 females) completed two wrist tapping tasks. In Task 1, participants tapped at maximal voluntary speed for 30s across 10 trials, which we used to derive individual target speeds (FAST, MEDIUM, SLOW). In Task 2, participants tapped at these paced speeds for 30s, with 10 trials per condition in a pseudorandomized order. Tapping frequency, tapping force, pupil size, wrist flexor and extensor activity were measured. Temporal changes (0-10s, 10-20s, 20-30s) and, in Task 2, differences between pacing conditions (FAST, MEDIUM, SLOW), were analysed with preregistered linear mixed-effects models (osf.io/rkavw).

Results

During maximal tapping (Task 1), movement speed and force declined, whereas muscle activity and coactivation per tap increased (all: $p<.001$), showing that fatigability-related motor slowing was induced. Pupil size increased at movement onset and subsequently decreased over time ($p<.001$). Pacing in Task 2 produced distinct movement speeds ($p<.001$). MOS emerged only in the FAST condition, whereas speed remained unchanged or slightly increased over time in the slower conditions (Time x Condition $p<.001$). Tapping force was highest in the FAST condition ($p<.001$) but declined over time in all conditions ($p<.001$). Flexor and extensor muscle activity per tap increased with speed ($p\leq.033$) but also over time ($p<.001$) and antagonistic coactivation per tap rose in the FAST and MEDIUM but not the SLOW condition (Time × Condition $p=.042$). Pupil dilation scaled with tapping speed, with larger responses at faster speeds ($p<.001$). However, pupil showed no Time × Condition interaction, indicating similar temporal changes across pacing conditions.

Conclusion

Pupil dilation scaled with motor effort level (operationalised as the required tapping speed) but we found no evidence that it reflected the accumulation of motor fatigability. Our findings suggest that it is unlikely that MOS results from a lack of effort investment.

P1-D-92 - Neural mechanisms underlying action-based predictions and visual false percepts

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Details

In a world full of ambiguous sensory stimuli, there is a necessity to determine which information should be deemed salient or regarded merely as sensory noise. Action is a method that aids us in distinguishing which information is more important. Specifically, action creates predictions of the sensory consequences of our movements through the efference copy mechanism. These predictions are then used to suppress the sensory information generated by said movements, enabling us to focus on unexpected information in the external environment. While this suppression effect has often been observed across the auditory and tactile modalities, the relationship between action in the visual modality is arguably more varied.

Additionally, the efference copy mechanism has been implicated in the formation of hallucinations. When dysfunctional, the suppression of self-generated sensory consequences is reduced. Thus, internal sensory events are more likely to be misattributed to the external environment, potentially causing

hallucinations. However, the direct relationship between action-based predictions and hallucinations remains elusive. To investigate this, in a previous study we employed a signal detection task wherein stimuli were either self-generated via a button press (active condition) or externally generated (passive condition). We found that action led to increased false alarm rates, driven by a more liberal response bias. In addition, we found that visual false alarms (i.e., false percepts) positively correlated with schizotypy scores. This current study aimed to explore the neural mechanisms underlying these effects. We collected schizotypy scores from an online sample (N=279) and invited those participants with scores falling in the upper and lower quartiles to an fMRI experiment. The experiment involved a signal detection task in which participants had to detect a vertical grating embedded in dynamic white noise. In the active condition, participants had to generate the stimuli themselves via a button press. Conversely, the passive condition consisted of trials where the stimuli were automatically presented. Preliminary results from our univariate analysis showed that during trials where stimuli were self-generated, activity was increased in the visual cortex, cerebellum, and insula. We also found a trend of increased activity in the visual cortex for false percepts compared to correct rejections, despite both containing identical noise stimuli. These initial results suggest that action can enhance neural activity in the visual cortex under noisy conditions, which may explain increased false percepts in the active condition. Additional analyses directly contrasting active versus passive false alarms are ongoing, as well as comparisons between high and low schizotypy groups, which will allow us to understand how this neural enhancement may relate to hallucination-proneness.

P1-D-93 - Mechanistic principles underlying flexible control in dynamic pursuit

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Details

Biological agents exhibit a remarkable capacity to adaptively control their behavior as goals, constraints, and environmental structures dynamically evolve. Yet, the interactive nature of agent-environment interaction has rendered the underlying cognitive architecture a fundamental challenge to identify. Here, we propose that flexible control is grounded in three cognitive constructs: spotlight attention, relational structure, and affordance computation. First, biased competition frameworks suggest efficient action emerges by stabilizing focus on a target and committing to a plan. Second, relational theories predict that inter-entity structure enables abstraction and combinatorial generalization across layouts or configurations. Finally, embodied accounts argue that reward value alone does not capture action possibilities; instead, they posit that affordance computation is central to achieving biological similarity and flexible control. We hypothesized that (1) spotlight attention supports scaling across many competing options, (2) relational structure enables abstraction over inter-entity relations and combinatorial generalization across layouts or configurations, and (3) explicit affordance computation is critical for producing biologically similar pursuit behavior. To evaluate these ideas, we developed a multi-module graph convolutional network in which each subnetwork implements one of these functional roles. The model was tested on a dynamic pursuit task matching the structure of a nonhuman primate pursuit paradigm requiring generalization to novel physical dynamics and target behaviors without additional training. Robust transfer emerged only when all three modules were present; removing any components impaired flexibility. The model also produced emergent change-of-mind behavior – a hallmark of continuous flexible control by biological agents – driven by continuous evaluation of affordances. Finally, we compared the model's internal representations to neural activity in the primate dorsal anterior cingulate cortex (dACC) to validate these mechanistic cognitive constructs. We found that dACC populations maintain low-dimensional dynamics predicted by our spotlight attention mechanism, show equivariant encoding characteristic of relational structure, and synthesize reward with physical constraints to encode affordances. Together, these results provide a computational basis for how flexible

control is implemented through specific neural substrates to navigate the complexities of the natural world.

P1-D-94 - Layer Va neurons, as major presynaptic partners of corticospinal neurons, play critical roles in skilled movements

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Details

Corticospinal neurons (CSNs) are located in the cortex and projecting into the spinal cord. The activation of CSNs, which is associated with skilled motor behaviors, induces the activation of interneurons in the spinal cord. Eventually, motor neuron activation is induced by corticospinal circuits to coordinate muscle activation. Therefore, elucidating how the activation of CSNs in the brain is regulated is necessary for understanding the roles of CSNs in skilled motor behaviors. However, the presynaptic partners of CSNs in the brain remain to be identified. Here, we performed transsynaptic rabies virus-mediated brain-wide mapping to identify presynaptic partners of CSNs (pre-CSNs). We found that pre-CSNs are located in all cortical layers, but major pre-CSNs are located in layer Va. A small population of pre-CSNs are also located outside the cortex, such as in the thalamus. Inactivation of layer Va neurons in *Tlx3-Cre* mice results in deficits in skilled reaching and grasping behaviors, suggesting that, similar to CSNs, layer Va neurons are critical for skilled movements.

Finally, we examined whether the connectivity of CSNs is altered after spinal cord injury (SCI). We found that unlike connections between CNSs and postsynaptic neurons, connections between pre-CSNs and CSNs do not change after SCI.

P1-D-95 - State-dependent gain control and spinal–cortical coupling during motor imagery revealed by simultaneous EEG–fMRI

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Details

Motor imagery (MI) enables internal simulation of actions without overt movement and plays an important role in motor learning and rehabilitation. Although MI has traditionally been conceptualized as a cortical process, recent work suggests that subcortical and spinal circuits may also contribute to imagery-related sensorimotor processing. However, how imagery-related internal states are associated with spinal activity, and how this activity relates to cortical dynamics, remains unclear. Using simultaneous EEG–fMRI covering both the brain and cervical spinal cord, we examined whether MI is accompanied by spinal–cortical interactions consistent with state-dependent gain control.

In Experiment 1, participants performed hand motor execution and kinesthetic motor imagery while EEG mu rhythms and BOLD signals were recorded concurrently. Motor execution and preparation reproduced established activation patterns across cortical, subcortical, and spinal levels. Execution engaged both dorsal and ventral regions of the cervical spinal cord (C5–C7), whereas preparation preferentially recruited the intermediate zone. In contrast, motor imagery elicited significant activity that was spatially confined to the dorsal region of the ipsilateral cervical spinal cord (C6–C7). Direct comparisons confirmed greater dorsal than ventral spinal activation during imagery, and imagery-related spinal activity was distinct from that observed during execution or preparation, despite identical motor

intentions. At the cortical level, imagery recruited canonical motor imagery networks, including premotor cortex, supramarginal gyrus (SMG), and primary somatosensory cortex (S1), while sparing ascending somatosensory relay structures such as the cuneate nucleus and thalamic VPL. Voxel-wise analyses further revealed that activity in the dorsal spinal cord tracked the temporal dynamics of mu-event-related desynchronization (mu-ERD). Spatial overlap between imagery-evoked and ERD-related clusters was particularly strong in the dorsal cervical spinal cord and in S1/SMG, and spinal ERD-related activity predicted interindividual variability in mu-ERD amplitude. Psychophysiological interaction analyses demonstrated imagery-dependent functional coupling between the dorsal spinal cord and both afferent-sensitive (S1, thalamic VL, SMG) and afferent-insensitive (premotor and cerebellar) components of the imagery network. Stronger coupling within sensory–motor convergence and sensory-contingent modulation nodes was associated with larger mu-ERD magnitude.
In Experiment 2, we examined how peripheral sensory input interacts with imagery-related spinal and cortical activity using a factorial design combining MI and cutaneous stimulation. Cutaneous stimulation alone engaged the canonical dorsal column–medial lemniscal pathway. Critically, when stimulation was combined with imagery, mu-ERD was significantly enhanced, and superadditive activity emerged within dorsal cervical spinal regions and cortical imagery-related areas, including S1, SMG, and thalamic VL. Spatial overlap analyses showed that stimulation-responsive regions were embedded within imagery-evoked and ERD-related clusters, and that superadditive responses arose predominantly from within imagery-related circuits rather than forming an independent sensory-driven component.
These findings indicate that motor imagery is associated with coordinated spinal–cortical interactions characterized by selective recruitment of the dorsal spinal cord and state-dependent amplification of imagery-related networks. Within a gain control framework, spinal dorsal circuits may act as an integrative substrate where imagery-related internal states and peripheral sensory input jointly shape sensorimotor network excitability. This perspective provides a mechanistic basis for individual differences in motor imagery engagement and for the variable efficacy of imagery-based and sensory-assisted rehabilitation strategies.

P1-D-96 - The effect of attentional focus on countermovement jumps

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Details

Instructions that direct focus of attention during a movement have been shown to influence performance. Previous studies have indicated that focusing on the movement effect on the environment (i.e., adopting an external focus – EF) results in superior performance as compared to focusing attention on the movement itself (i.e., adopting an internal focus – IF). However, most studies adopt an IF instruction focused on a single joint (i.e., internal focus specific; IF-S). Joint specific instructions could constrain coordination more than whole-body instructions (i.e., internal focus global; IF-G). Thus, it may be that focusing on body movement is not harmful to performance per se. Rather, the disrupted coordination brought by focusing on specific joint movements in multi-joint skills may be what explains the worse performance of IF in previous research. This study aims to investigate the effects of EF (try to touch the ball with your head), IF-S (focus on your knee extension), and IF-G (focus on the complete extension of your whole body) instructions on performance and lower-limb coordination in vertical jumping. Using a counterbalanced within-subjects design, 35 physically active college students performed maximal countermovement jumps (CMJs) under each attentional focus condition. Kinetic and kinematic variables were quantified to evaluate jump performance and coordination. Jump height served as the primary kinetic outcome. Hip, knee, and ankle kinematics were quantified to compute the relative timing of joint extension as a measure of coordination. We expected that EF and IF-G would produce superior CMJ performance and increased lower-limb coordination compared to IF-S. Preliminary

analysis of five participants, at the descriptive level, indicates that jump height tends to increase when focusing attention on the environment. Hip-knee initiation of extension (IEX) time difference showed more simultaneous movement in the EF condition, whereas knee-ankle IEX time difference was reduced in the IF conditions. Further investigation is necessary to better understand how attentional focus influences interjoint coordination. These findings will clarify whether global IF strategies can result in the benefits usually found with EF while still being applicable to coaching and rehabilitation domains where IF instructions are commonly used.

P1-D-97 - Geometry of action grammar structure in primate frontal cortex

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Details

Humans and other animals can construct varied sequences of motor and mental acts to solve new problems, even on the first attempt. This capacity to *generate novel thoughts and behaviors* has been hypothesized to rely on mechanisms for recombining units of knowledge using systems of procedural rules, or **grammars**. Hierarchical grammar-like sequencing appears widespread, from gorillas preparing nettle leaves to eat (Byrne & Russon 1998), to humans cooking (Duncan et al. 1996), to cognitive operations involved in math (Dehaene et al. 2025). Yet, whether and how the brain implements grammars remains unclear.

To address this, we designed a drawing-like visual–motor construction task in which macaque monkeys trace complex geometric figures by generating a sequence of distinctly shaped strokes, like circles or dashes. Critically, the task required them to conform to a learned hierarchical action grammar $\mathbf{A^nB^mC^k}$, meaning "repeat shape *A n* times, then repeat shape *B m* times, then repeat shape *C k* times", with *n*, *m*, and *k* varying across problems. Macaques successfully generated novel action sequences to solve new problems (i.e., images of unpracticed figures). Sequencing was (i) internally generated (no cues guiding stroke order), (ii) problem-directed (to construct a specific image), and (iii) exhibited first-trial generalization to test images—critically, even to test images more complex than training (i.e., with more shape components). These three behavioral features are hallmarks of grammar use—rather than alternative strategies of (i) memorizing solutions to each image or (ii) motor-efficient tracing.

We performed simultaneous recordings from eight frontal cortical areas previously implicated in motor control, sequencing, and rule use, but never recorded together. This included motor, premotor, prefrontal and frontal polar areas (using 16 32-channel arrays). We identified neural encoding of grammar preferentially in pre-supplementary motor area (**preSMA**). PreSMA population activity during drawing encoded latent variables of the action grammar: (i) *shape index* (A, B, C), (ii) *abstract role* (e.g., the role A, B, or C independent of specific shape), and (iii) *ordinal position* within a shape repeat. This conjunction of representations indicates a population geometry encoding hierarchical structure of the grammar. Further, it raises the hypothesis of an implementation of an internal procedure resembling a "for-loop" program: internally tracking how many repetitions remain for each shape index and switching to the next when complete—a hypothesis we are testing. Our study establishes a paradigm for studying the neural basis of grammar-guided novel behavior and identifies a dynamic representation of grammatical structure in preSMA supporting such behavior.

This finding, on action grammars, complements our finding that ventral premotor cortex (**PMv**) encodes stroke types ("action symbols") independent of grammar, which we reported at NCM 2025.

P1-D-98 - Modulation of corticospinal excitability with movement imagery

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Details

Background: Imagining performing movements (movement imagery) activates a brain network overlapping with the sensory-motor network, which can be measured as increases in corticospinal excitability through Motor Evoked Potentials (MEPs) collected via single-pulse Transcranial Magnetic Stimulation (TMS). Movement imagery also produces intracortical 'disinhibition' in the motor cortex assessed through paired-pulse TMS. However, these effects have generally been studied in limited samples (N<20-25) and heterogeneous neurophysiological protocols. Furthermore, whether these effects are specific to the effector being imagined, or reflect general changes in corticospinal excitability, which has important implications for the use of movement imagery in clinical practice, remains debated.
Methods: We are conducting the largest neurophysiological study on movement imagery to date. The study aims to collect a larger sample than prior work (N>70), which will inform interpretation of previous and future studies using movement imagery. Under single-pulse and paired-pulse (Short Interval Cortical Inhibition) protocols, 30 MEPs from a muscle involved in movement imagery ('active' imagery condition), as well as control conditions of MEPs from a muscle not involved in movement imagery ('non-active' condition) and at rest, are acquired. We determine effect sizes across the possible comparisons, in order to establish whether the effects observed are of practical relevance.
Results: Preliminary data (N=10) suggest that in single-pulse TMS, the 'active' imagery condition shows an increase in MEP amplitude specific to the effector being imagined, as compared with the 'non-active' imagery condition (Cohen's d_{rm} = 0.71 [0.29, 1.13]) and rest (d = 1.05 [-0.32, 2.42]). The 'non-active' condition shows a much weaker facilitation compared to rest (d_{rm} = 0.34 [-0.8, 1.49]). However, in paired-pulse TMS, both 'active' and 'non-active' conditions show cortical disinhibition compared to rest ('active': d_{rm} = 0.65 [-0.11, 1.31]; 'non-active': d_{rm} = 0.4 [-0.18, 0.98]), with no differences between them (d_{rm} = 0.11 [-0.19, 0.4]), suggesting a global instead of an effector-specific effect.
Conclusions: Our preliminary data suggest that movement imagery may produce concurrent effector-specific corticospinal facilitation and effector-unspecific cortical disinhibition, which should be considered in studies using TMS to prove its neural mechanisms. By the time of the NCM meeting, we expect to be able to present data from >50 participants, allowing for a more robust assessment of these effects and their consistency across individuals.

P1-D-99 - Combined action observation and motor imagery: evidence for simultaneous sensorimotor representations

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Details

Despite evidence that the motor system has capacity to simultaneously represent multiple actions (e.g., either through the observation of multiple actions or by observing an action while acting oneself), whether multiple motor simulations can co-exist within the motor system is unclear. The processes of observing someone act (action observation; AO) and imagining ourselves act (motor imagery; MI) share similar neurophysiological circuitry across premotor and parietal regions. Due to these shared properties and their potential to enhance movement, AO and MI have been of great interest across applied settings. The simultaneous engagement of AO and MI (AOMI) results in greater motor-related cortical activity and enhanced behavioral outcomes compared to its independent components. There is theoretical debate concerning what drives these motor-related activations. These theories can generally

be categorized by ideas that both AO and MI can either be simultaneously represented or not. The Dual Action Simulation Hypothesis (DASH) posits that activations are an additive effect of individual AO and MI sensorimotor representations. Also contingent on simultaneous sensorimotor representations, the Sensory Conflict Hypothesis (SCH) proposes activations are driven by conflicting kinematic information between AO and MI. By contrast, the Visual Guidance Hypothesis (VGH) suggests MI to drive sensorimotor activity alone, with AO being sensory in nature.
The current study tested these competing theories of AOMI using a within-participants functional magnetic resonance imaging (fMRI) design. Participants (N = 15) observed and imagined different actions across four conditions: observation of a vertical finger tapping action (AO), observation with a secondary counting task (AO_{count}), motor imagery of horizontally tapping their finger (MI), and observing vertical tapping while imagining horizontal tapping (AOMI). Representational similarity analysis was conducted across the ventral premotor cortex and inferior parietal lobe. Both AO and MI were present in sensorimotor regions, supporting the capacity to simultaneously represent AO and MI actions. A summative analysis, comparing AOMI to the additive effects of MI with AO (AO+MI) and with AO_{count} (AO_{count}+MI) showed significantly greater global activity for AOMI (in the superior parietal lobule, temporal pole & visual cortices). Greater activations contest predictions of DASH and VGH, but align with SCH, where the increased activation is thought to be due to the conflict caused by the dual simulations. These data evidence the capacity of the sensorimotor system to represent different actions through AO and MI. Findings align with the DASH and SCH accounts, with greater and more widespread activations providing additional evidence for the SCH. This research highlights the complexity of the human sensorimotor system and its capacity to represent multiple actions in the absence of overt movement.

P1-D-100 - The arm-mazing task: Investigating movement bias in a hierarchical cognitive motor task

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Details

Moving our body is essential for goal-directed behavior, and it has been shown that movement may bias higher-order decision making[1]. This effect has primarily been observed for brief and independent movements[2]. Contrarily, complex behavior is thought to be organized hierarchically[3], dividing overarching task goals into various sub-goals. Whether the prioritization of main goals and sub-goals interacts with movement-related decisions, is not known. We designed an experiment to investigate the interaction between movement-related decision-making biases and task-imposed cognitive goal hierarchies.
Perfect (i.e. single solution) mazes were designed from a 19x19 square grid with a super-imposed 3x3 room structure. Mazes only included 3-way junctions to ensure comparability of choices. Four maze orientations (start in each corner, finish in diagonally opposite corner) were included in each set, to allow differentiation between task- and bio-mechanical space mapping. The task is solved through continuous arm movement across a wide range of motion.
Measurements were taken from upper arm, lower arm, hand segments and shoulder-to-shoulder width, according to the ISO 7250-1 (2nd ed.). Subjects were placed in front of a touch screen, with view of their arm blocked. A separate screen in front of them showed the task. Maze size was scaled to individual maximal reaching distance to ensure uniform movement range between subjects. Subjects were instructed to find the single solution to the maze using their right index finger on the touch screen. View of maze geometry was limited to outer and room walls, and squares directly surrounding the current position. Each unique maze was shown (and solved) once.
Arm movements based on subjects arm and hand segment lengths were modeled to calculate torque (shoulder + elbow) required for a predicted fingertip trajectory along each direction out of a junction. A hierarchical Bayesian linear regression model was used to test whether individual movement effort (i.e.

motion torque) could explain choices at junctions independently from task-related factors. First-time encounters of all visited junctions were analyzed. Chosen exits were labelled as left (1) or right (0) choice, seen from the egocentric perspective. Model results show an independent effect of predicted motion torque on choices at first-time junction encounters. Angle of choice direction relative to direction of finish shows the strongest effect on choice, as expected given the task instructions. Additionally, proximity to a room exit shows a small effect, suggesting an effect of sub-goals separate from the overarching finish goal.
These findings present a hierarchical cognitive task showing behavioral effects at the movement-, sub-goal and overarching goal level. This offers new opportunities to investigate movement influences on various levels of cognitive hierarchies.
[1]Marcos et al, 2015 PLoS One 10
[2]Canaveral et al, 2024 J Neurophysiol 132
[2]Badre et al, 2018 TiCS 22

P1-D-101 - How are continuous sequential actions learned and represented?
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Details
Most ecologically important motor skills require learning which actions to select and how to execute them in sequence. Prior work has largely focused on discrete sequences (e.g., keypresses or point-to-point reaching), showing that learning is driven primarily by improvements in action selection. However, most daily skills are continuous in nature, with action selection and execution tightly coupled as movements evolve in real time.
Here we disentangled action selection and execution using a continuous tracing task that manipulated the preview of the upcoming trajectory (limited-view: 10% of the path; full-view: 100% of the path). Participants were instructed to trace the trajectory as quickly and accurately as possible. Critically, unlike prior work, the sequence was not discretized into visual landmarks but learned as a single continuous trajectory, mirroring real-world actions such as writing or driving. A single learned trajectory was interleaved with random trajectories to probe sequence-specific learning; rotated versions of the trajectory tested whether learning reflected a representation of the path's global structure rather than chunking of specific movements; memory probe trials, conducted without visual guidance, assessed participants' explicit recall of the learned trajectory.
With full visual information of the trajectory, movement times and errors decreased at a comparable rate across learned and random trajectories, revealing general, sequence-agnostic learning. By contrast, under limited visual information, performance decreased only for the learned trajectory, with little improvement for random trajectories—revealing sequence-specific learning. For both groups, learning benefited fully generalized to a rotated version of the learned trajectory, indicating that learning involved constructing a representation of the path's global structure, rather than relying on chunking of specific movements.
Comparing across conditions, movement times during early learning were significantly faster in the full-view condition than in the limited-view condition, suggesting that a substantial component of motor sequence performance reflects deciding where to go next. By the end of training, both performance and memory recall of the learned trajectory in the limited-view condition approached those of the full-view condition, indicating that participants ultimately formed sequence representations comparable to those supported by full external path information.
In summary, while continuous motor sequence learning includes general improvements in motor execution, it is dominated by improvements in action selection that rely on representations of the sequence as a global trajectory, rather than chunking of specific movements.

P1-D-102 - Motor memory embedded in relational structure of the environment

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Details

Humans skillfully perform complex action sequences in everyday environments by exploiting knowledge of how objects and locations relate to one another. For example, in the kitchen you know the refrigerator is to the left of the stove and pans are stored below it. Understanding such spatial relationships allows you to plan and smoothly coordinate a sequence of actions for cooking. This knowledge reflects a cognitive map—an internal representation of the relational structure of the environment that supports flexible planning across diverse behavioural contexts. Crucially, different steps in an action sequence require interacting with objects with distinct physical dynamics (e.g., opening a refrigerator door, twisting a gas knob, lifting a pan), which demands retrieval of appropriate motor memories. Previous research has examined cognitive maps of environmental structure and the retrieval of motor memories largely independently, overlooking the interaction between them. While earlier work has shown that motor memories can be associated with an absolute target location or future movement direction (Howard et al., 2015; Sheahan et al., 2016), it remains unknown whether the relational structure of the environment itself can cue motor memory. Here, we demonstrate that motor memories are tagged not only by target direction, but also by the relational structure among targets.

In Experiment 1, participants performed a double-step reaching task: they first moved to a central target (square or triangle), and then to one of two lateral targets (left or right) whose shape matched the central one. The first reach was paired with a velocity-dependent force-field whose direction depended on the second reach (e.g., clockwise for left, counter-clockwise for right), establishing a stable mapping between shape and movement direction. Learning was probed using occasional error-clamp channel trials by measuring force compensation under either the original mapping (Congruent) or a reversed mapping (Incongruent). If motor memory were associated solely with movement direction, compensation should not differ between conditions just by altering the spatial layout of target objects. Participants showed compensation for the force-fields depending on movement direction, replicating previous findings. Critically, compensation was significantly stronger in the Congruent than in the Incongruent condition, revealing that relational spatial layout serves as a contextual cue for motor memory retrieval. Additional experiments confirmed that this effect required stable relational structure (Exp. 2), could not be explained by visual object identity (Exp. 3), and generalized to new spatial arrangements and movement directions when the relational structure was preserved (Exp. 4–5), demonstrating flexibility characteristic of map-like representations.

These findings reveal a previously unrecognized link between relational environmental structure and motor learning. The brain does not simply store motor memories tied to absolute target locations, but organizes them within a relational map of the environment, allowing rapid selection of appropriate motor memories in context. We propose that motor memories are not isolated from the environment; rather, they are embedded within stable relational structure, integrating *what is where* with *how to act*.

P1-D-103 - Closed-loop perturbations reveal how shared-control modulates iBCI innovation dynamics

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Details

Adaptive control in brain–computer interfaces (BCIs) relies on closed-loop integration of neural intent with continuously changing sensory feedback. In shared-control BCIs, discrepancies between decoded

neural commands and visually driven task dynamics may arise both from execution-level variability and from ambiguity about the intended goal. Here, we use perturbation-evoked neural dynamics to examine how shared control modulates neural–behavioral alignment in a macaque intracortical BCI navigation task.

Monkeys navigated a virtual environment using a velocity-based BCI, either with or without AI assistance. We analyzed two perturbation types with distinct implications for visual feedback processing: appearing obstacles, which require rapid corrective responses while preserving the same goal, and respawn events, which invalidate the current movement plan and require selection of a new goal. To characterize closed-loop neural–control alignment, we quantified the Kalman filter innovation as a time-resolved measure of mismatch between predicted and observed neural activity following perturbations. Across perturbation types and control conditions, innovation exhibited a robust increase immediately following perturbation onset, reflecting sensitivity to unexpected changes in visual feedback. At longer timescales, innovation dynamics varied across perturbation types and trial outcomes. For appearing obstacles, innovation showed predominantly transient dynamics consistent with corrective responses under ongoing visual guidance. In contrast, during respawn events, innovation often remained elevated beyond the initial perturbation, indicating prolonged mismatch during goal reorganization, particularly in trials with ambiguous goal selection.

Comparing shared-control and BCI-only conditions revealed similar early innovation responses following perturbation onset, indicating preserved sensitivity to unexpected changes in visual feedback. At later timescales, innovation dynamics diverged across conditions. During respawn events under BCI-only control, incorrect trials often showed sustained innovation despite relatively stable decoded velocity, consistent with prolonged mismatch between predicted and observed neural activity when the inferred goal was incorrect. Under shared control, this persistence of post-perturbation innovation was reduced during goal-changing events.

Together, these results show that perturbation-evoked innovation dynamics provide a principled window into closed-loop BCI control, capturing neural–control mismatch not directly expressed in the decoded output, and clarifying how shared control reshapes closed-loop interactions without disrupting rapid neural responsiveness.

P1-D-104 - Applying drift diffusion modeling to unravel contextual information integration in split-second handball penalty decisions

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Details

In soccer and handball penalties, goalkeepers use both kinematic cues from a penalty-taker‘s movements as well as contextual information to anticipate and decide when and where to intercept the ball. Previous studies examining the effect of contextual information on these decisions, however, have almost exclusively analyzed mean reaction times and accuracy scores averaged across individuals and trials. Yet, this approach is at least incomplete as it neither allows to elucidate the processes underlying evidence accumulation within a single decision nor how context may be involved in shaping such processes.

Therefore, we applied a drift-diffusion modeling approach (DDM) to examine the temporal evolution of penalty saving decisions in handball. DDM allows to identify (i) the speed of evidence accumulation (i.e., the drift rate [v]), (ii) the perceptual encoding and motor execution preceding and following the decision (i.e., the non-decision time [t]), and (iii) bias towards one of two decision boundaries (e.g., shift of the starting point [z]). Here we present three experiments in which we applied DDM to unravel information integration in handball penalty decisions.

Exp. 1 validated the suitability of DDM in a handball penalty task. Participants watched temporally occluded handball penalty videos and predicted the outcome (i.e., shot to the left vs. right) by either pointing or swiping their index finger to the left or right target area on a touchscreen. Replicating previous research, results showed that drift rates did not differ between modalities, while non-decision times were longer in the pointing than the swiping trials. Both drift-rates and non-decision times were positively correlated across modalities. These findings confirmed that DDM analyses are applicable to our decision-making paradigm.
In Exp. 2, we examined whether finger tracking may offer equally valid and reliable insights into the temporal evolution of the decision-making progress when compared to DDM. To this end, we replicated the Exp. 1, but additionally kinematically tracked the finger movements in the pointing task. The DDM results reproduced both the predicted differences between pointing and swiping trials in the non-decision times and the consistent correlations between response modalities. However, as concerns the finger tracking parameters (e.g., area under the curve, velocity, x-flips, entropy) neither did the parameters clearly reflect the response modality manipulation nor did the results show consistent correlations of these parameters between pointing and swiping trials. It follows that when compared to finger tracking DDM seemed a more reliable approach to ultimately address how contextual information modulates the DDM parameters in Exp. 3.
While the experimental set-up was almost identical to Exp. 1 and 2, in Exp. 3 participants were provided with contextual information (i.e., likelihoods) concerning the shot direction in half of the trials. Results showed that contextual information led to faster evidence accumulation in congruent trials, but slower evidence accumulation in incongruent trials. Non-decision times were longer if contextual information was present as opposed to when it was not. Taken together, our experiments (i) demonstrate that DDM is a reliable tool to examine decision-making processes in sport-specific, highly time-constrained tasks, and (ii) revealed that and how contextual information modulates evidence accumulation in such tasks.

P1-D-105 - Kinematic adaptation to expected sensory feedback during uni- and bimanual motor sequences

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Details

Actions are typically seen as a means to manipulate the environment and achieve intended outcomes. However, emerging evidence highlights a dynamic interplay, where anticipated sensory outcomes actively shape the kinetics of motor execution – even when these kinetics do not directly affect outcome properties. For example, examining the force profile of a simple act of pressing a button shows that participants apply less force when the button is (vs. is not) associated with an auditory outcome. Nevertheless, what attributes of expected action outcome are embedded in action kinetics and how, is not well understood. In the current set of studies, we characterize how expected attributes of action outcome shape the kinetics of uni- and bimanual action sequences in healthy adult participants.
We used a force-sensitive plate to measure the force profiles of presses performed with the index finger while the contingency between presses and auditory outcome was manipulated. We find an inverse relationship such that participants applied more force when the expected amplitude of the outcome was low (vs. high). Importantly, when the amplitude of sound outcome was not known in advance, no amplitude-dependent modulation of press force was found. Furthermore, such modulation of press force was related to agentic control and flipping the temporal order between action and sound abolishes sound amplitude-dependent force differences. In other words, when participants tap in response to sounds (instead of generating them), participants applied similar force levels across preceding sound amplitudes. The results of these studies show that action kinetics are sensitive to agentic control and expectancy of sensory outcome.

We further examined whether such expectations affect only the kinetics of the last movement component that is coupled with the outcome or earlier movement components. To this end, participants performed single or double taps which generated (or not) a sound immediately following the last tap in the sequence. Surprisingly, we find sound-dependent modulations in the force profile of the first tap in the double-tap sequence. In other words, the applied force in the first (silent) tap was lower when the second tap in the sequence was associated with a sound compared to when it was not. Moreover, this was true even when the initial tap of a double-tap sequence was performed with the opposite hand. For example, in a left-to-right hand tap sequence, we find that left hand force profiles are modulated by the association of sound to the right-hand tap (and similar right hand modulations were found for right to left hand tap sequences). Thus, even though the first tap is temporally and causally separate from the actual sound event, and controlled by the opposite hemisphere, it is still modulated by expectation of future sensory outcome.
Taken together, our results demonstrate that prediction of future action-outcome attributes shapes action kinetics in early stages of movement and such prediction signals are shared across hemispheres.

P1-D-106 - Theta dynamics as a marker of stress resilience in threat-related movement

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Details

Stress is a natural response to situations requiring attention or action. While stress is helpful for navigating immediate threats, excessive or prolonged stress is associated with poor health outcomes. Moreover, the ability to tolerate and adapt to stress, termed resilience, is highly variable among individuals. Biological mechanisms underlying this variability remain poorly understood, limiting effective clinical management of chronic stress-related disorders. To address this knowledge gap, we investigated behavioural and neuro-electrophysiologic responses in a rodent model of acute stress exposure. Telemetric transmitters and electrodes were implanted in the basolateral amygdala (BA), medial pre-frontal cortex (mPFC), ventral hippocampus (vH), and nucleus accumbens (NA) of male Sprague-Dawley rats to facilitate electrocorticography (ECoG). Rats were then subjected to unpredictable chronic mild stress to induce core symptoms of depressive-like behaviors. An acute stress protocol consisting of controlled exposure to predator-scent (cat urine) was performed under continuous video and ECoG recording. At the start and conclusion of experimental protocols, rats underwent a behavioral assessment battery comprising the sucrose preference test (SPT), elevated plus maze (EPM), and open field test (OFT) to derive anxiety index (AI). Rats exhibiting a positive change in AI (ΔAI) were classified as susceptible, whereas those with a negative ΔAI were classified as resilient. Across all rats, marked behavioural changes were evident within the first two minutes of predator-scent exposure, characterized by reduced rearing and grooming and increased thigmotaxis. This coincided with robust elevations in total power across the stress circuit, including the BLA, mPFC, vH, and NA. Within the first 30 seconds of exposure, a clear behavioural divergence emerged: resilient rats showed increased investigation of the stimulus, whereas susceptible rats exhibited greater scanning behaviour, consistent with heightened threat monitoring. Susceptible rats also demonstrated larger increases in total power across the stress circuit. In contrast, resilient rats exhibited enhanced theta-phase spectral density in the NA, a pattern not observed in susceptible rats. Moreover, resilient rats exhibited increased theta synchrony, most prominently between BLA and NA, with no comparable changes in susceptible rats. Collectively, this suggests that resilience and exploration in response to acute stress is associated with rapid engagement of coordinated theta-band activity within limbic-striatal circuits, whereas stress susceptibility is characterized by heightened, nonspecific increases in network power and sustained threat monitoring. Together, these results advance our understanding of the neural circuitry coupling stress processing to

movement and behavioural output. Further investigation is warranted to determine whether these patterns generalize across sexes and species.

P1-D-107 - Fronto-parietal LFP signatures of inter-individual motor coordination in primates

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Details

Social interactions are pervasive in everyday life, yet the neural mechanisms underlying motor control during inter-individual coordination remain poorly understood. From a motor control perspective, coordinating with a partner requires shaping one's motor plan by integrating the partner's contribution to achieve a common goal. We previously demonstrated that non-human primates provide a powerful model to investigate the behavioral and neural dynamics of cooperation, showing that macaques, like humans, rely on a "we-representation" and identifying a class of neurons in dorsal premotor cortex (PMd) preferentially active during dyadic actions. However, local field potential (LFP) activity during social motor interactions has not yet been examined. From an evolutionary perspective, LFPs bridge the gap between single-neuron recordings in monkeys and fMRI signals in humans, offering insight into whether motor interactions rely on shared neural architectures across primates. To address this issue, we simultaneously recorded LFPs from two pairs of macaques engaged in a center-out joint action task, collecting signals from both PMd and posterior parietal cortex (PPC). Monkeys, seated side by side, controlled cursors displayed on a shared screen via isometric joysticks to reach one of eight peripheral targets to obtain a reward, either individually (SOLO) or jointly (JOINT). In the SOLO condition one animal was required to reach independently the appearing target, while the partner had to stay in the central target to gain the same amount of reward (OBSsolo). In the JOINT condition, the dyad had to coordinate in space and time to achieve the common target while maintaining the inter-cursor distance (ICD) below a predefined threshold (5 DVA). Behavioral results showed that monkeys proactively adjusted their motor planning to their partner's behavior, reducing inter-individual kinematic differences across temporal and spatial domains. These adaptations occurred on a trial-by-trial basis to enhance coordination, as indexed by the inter-cursor distance. Decoding analysis of LFP revealed that premotor activity predicted both the action context (SOLO or JOINT) and the goodness of inter-individual coordination during JOINT trials. We previously showed the role of PMd neurons during action planning in dyadic interactions, here we extend this evidence to low-frequency PMd LFPs (1-12 Hz). Cross-temporal decoding revealed sequential processing in PMd, with action context represented during motor planning and coordination level emerging around movement onset. Parietal low-frequency LFP showed a significant modulation by joint action context, particularly during movement execution, as well as by the level of inter-individual coordination. Together, our results identify low-frequency premotor and parietal LFP dynamics as key neural signatures of dyadic motor interactions in primates.

P1-D-108 - Action controllability shapes the sense of agency during continuous BCI-controlled avatar gait

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Details

The sense of agency—the subjective experience of controlling one's own actions—is commonly explained by the congruency between motor commands, predicted sensory consequences, and actual sensory feedback. Although this framework has been conceptually applied to brain-computer interfaces (BCIs), BCIs fundamentally alter the sensorimotor loop by decoding motor intentions from neural activity and translating them into external actions, often in the absence of somatosensory feedback. As a result,

it remains unclear how the sense of agency is shaped during continuous BCI control, in which action controllability unfolds over time.
Here, we tested the hypothesis that action controllability, defined as the successful execution of intended actions, plays a central role in shaping the sense of agency when somatosensory input is absent. To examine this hypothesis under continuous, goal-directed behavior, we developed a multimodal BCI to control avatar gait in virtual environments. By experimentally manipulating the correspondence between participants' intentions and the avatar's actions, we examined how distinct aspects of action controllability modulate the sense of agency during continuous avatar locomotion.
In Experiment 1, thirty-two participants performed motor imagery of marching in place to maintain continuous walking. In Experiment 2, twenty-four participants terminated imagery to voluntarily stop walking. In Experiment 3, twenty-four participants directed their eye gaze toward the intended direction at an intersection to walk along the optimal route. The sense of agency toward the avatar was assessed using subjective questionnaires and auditory evoked potentials (AEPs). AEPs were elicited by tones presented as the avatar passed through gates. These responses were used as candidate neural markers reflecting processes involved in the updating of the sense of agency, based on their sensitivity to action–effect prediction.
Across experiments, AEP amplitudes were consistently higher during active control via BCI or a gaming controller than passive observation, paralleling subjective ratings of agency. Moreover, AEP amplitudes were enhanced when participants successfully stopped and restarted the avatar compared with when they failed stopping. Similarly, AEP amplitudes were enhanced when participants successfully selected the intended route compared with when they proceeded in an unintended direction.

Together, these results suggest that the sense of agency during continuous action is closely associated with action controllability, rather than being determined by somatosensory feedback alone. Using BCI-controlled avatar gait, this study shows that agency-related neural responses are enhanced when intentions are successfully translated into ongoing motor outcomes, providing insight into the dynamic modulation of the sense of agency in a continuous action context.

P1-D-109 - Express sensorimotor responses to visual and auditory stimuli

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Details

Recent work shows that certain visuomotor reaching tasks can yield extremely rapid, "express", target-directed muscle activations that appear as brief bursts of electromyographic (EMG) activity at a narrow set of onset times locked to target appearance (~70-120ms). The early and consistent onset latencies of express responses (ERs) occurs irrespective of the latency of subsequent EMG bursts or mechanical reaction times (RTs), suggesting that two distinct control signals reach the muscle. The short latency and automatic nature of these ERs are consistent with a generator in the subcortical, tectoreticulospinal pathway. This study examined whether muscle ERs are also present for auditory stimuli, and whether there are multisensory interactions between targets of different modalities. We examined stimulus-directed movements of the arm and the associated EMG responses of the pectoralis major muscle to brief visual, auditory and audiovisual stimuli (experiment 1), and the nature of interaction between visual and auditory stimuli when both were presented together or in spatial conflict (experiment 2). In experiment 1, adult participants (n=11) sat in front of an array of speakers and co-located LEDs and moved their right arm to point to brief (8-ms) visual, auditory and (spatially congruent) audiovisual targets, presented either 210 mm to the left or right of midline. Movement of the hand was recorded with an accelerometer and EMG was recorded from the right pectoralis major muscle. Auditory stimuli were at least as effective as visual stimuli in eliciting EMG ERs, with similar EMG onsets, ER prevalence,

and EMG magnitudes in the ER window. Modelling suggests that the integration of visual and auditory EMG ERs was additive. The robust prevalence (around 50%) of auditory ERs implies that the express response control system can be accessed to acquire targets, and is consistent with a role in ecological reach to visual and auditory stimuli.
In experiment 2, we examined the interaction of auditory and visual stimuli in eliciting ERs when they were placed either on the same side (congruent) or on the opposite sides (incongruent). Participants (n=13) were instructed to point to either the visual or the auditory target in separate blocks. When audiovisual stimuli were co-located, selection of the visual target resulted in earlier EMG onsets, more prevalent ERs, and larger EMG magnitudes in the ER window than when selecting the auditory target. Presenting stimuli on opposite sides slowed EMG DTs and onsets, as well as reducing the prevalence of ERs and the magnitude of the EMG in the ER window.
The data show that express sensorimotor responses can contribute to acquisition of auditory targets in humans and that multisensory integration occurs for the earliest component of the response to bimodal targets in interpersonal space. This pattern is consistent with integration of early-stage signals in multisensory pathways such as the superior colliculus.

P1-D-110 - Neural signatures of perceptual decision-making and action selection under uncertainty

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Details

Background: Contextual uncertainty constrains physical activity and hinders action initiation in perceptual decision-making. The level of confidence, defined as an internal assessment of decision reliability, is known to modulate decision-making processes under uncertainty, and relevant neuroscientific insights are now beginning to emerge. Previous neuroimaging studies have identified spatial neural features indicating that several brain regions play pivotal roles in balancing confidence and decision-making for our actions. However, the neural dynamics with high temporal resolution and inter-regional interactions linking confidence to action selection remain debatable. The present study aimed to reveal neural signatures of perceptual decision-making under contextual uncertainty using multi-channel EEG recordings.
Methods: We continuously recorded 64-channel electroencephalography (EEG) from 27 healthy young participants while they performed a multi-attribute dot stimulus discrimination task. In this task, perceptual uncertainty was contextually manipulated by varying the number of stimulus attributes (one to four cues) that participants had to integrate on each trial. Confidence was assessed objectively on every trial using an opt-out paradigm, in which participants chose either to provide an answer or to forgo the given trial. To comprehensively characterize the behavioral and neural responses throughout the task, we analyzed behavioral performance, response times, EEG activity, and EEG phase-based functional connectivity.
Results: Although increased perceptual uncertainty significantly prolonged response times, accuracy and opt-out rates remained unchanged across uncertainty levels. Additionally, opt-out decisions, which serve as a proxy for low confidence, exhibited significantly longer decision latencies than answer choices. EEG analyses detected that perceptual uncertainty led to modulations of neural activity at centro-parietal and fronto-central electrodes (Pz and FCz), whereas no significant differences were observed between answer and opt-out trials. Phase-based connectivity analyses using the weighted phase lag index (wPLI), which measures the extent to which phase angle differences between time series of EEG signals across channels, revealed reduced neural synchronization between the frontal and temporal regions during opt-out trials compared with correct answer trials in the pre-choice period.
Conclusion: Our main finding suggests that confidence-dependent modulation of large-scale neural dynamics may contribute to action selection under uncertainty. This implies that fronto-temporal neural

synchronization may differentiate high- and low-confidence choices. Although the present study was exploratory research, our findings provide insight into high-temporal-resolution neural signatures of perceptual decision-making and action selection under contextual uncertainty.

P1-D-111 - Premotor and supplementary motor areas retain main-task selectivity during interruptions within a dual task

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Details

Achieving specific behavioral goals often requires retaining internal action plans against external perturbations. To examine how the brain retains such plans during interruptions, we trained monkeys on a dual task composed of a memory-guided sequential motor task (main task) and interrupting task. Experimental sessions were divided into sections based on the temporal order of the motor sequence in the main task. Each section required the animals to execute two visually guided movements chosen from four possible options (e.g., pronation or supination of either forearm). The sequence was performed twice under visual guidance, followed by two memory-guided repetitions. A visual cue then interrupted the main task, directing the monkeys to perform one of the four movements independently of the main task. Afterward, they resumed the main task and recalled the previously performed motor sequence. A correct recall advanced the task to the next section, where a new motor sequence was performed. Once recall accuracy reached ≥85%, we recorded neuronal activity from multiple premotor areas and the prefrontal cortex (PFC) during performance of the dual task.

We recently reported that neuronal activity in the dorsal premotor cortex (PMd) retains selectivity for the main task during interruptions. Here, we demonstrate that such retention also occurs in the supplementary motor area (SMA) and the pre-SMA but is limited in the PFC.

P1-D-112 - Neurons in the rat cervical spinal cord demonstrate common neural dynamics during different types of forelimb reach

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Details

Motor control relies upon the effective processing and integration of sensory afferents and descending drive within the spinal cord. While classically neural contributions to sensory and motor functions have been inferred through single-unit recordings, the advent of high-channel probes now permits for the activity of hundreds of neurons to be recorded concurrently. Patterns in the activity of the recorded neural ensemble have been used to study the constraints and intrinsic dynamical properties of these networks.

Rotational neural population dynamics have been described in the motor cortex and in the lumbar segment of the spinal cord during locomotion. The cervical spinal cord receives dense corticospinal input, and mediates skilled goal-directed behavior of the forelimb. However, owing to the technical difficulty of recording from the cervical cord, the populational-level organization of neural activity in this region remains largely unexplored.

To address this gap, we developed a preparation for performing stable high-density recordings from the rat cervical spinal cord (n=8) using Neuropixels 1.0 during two different reach-and-grasp movements. Recording stability and depth profiles recorded neural units were validated online by radial nerve stimulation.

To compare the patterns of coactivation across neurons between type of reaching, we first constructed the “recruitment map” for each movement by aligning them according to the order of their peak firing rate timing. We further performed population-level analysis across the composite neural ensemble. We have identified three key observations: 1) Neural activity during either reach type was captured within a **shared low-dimensional state space** (3 PCs >85%, 6 PCs >98% variance explained), indicating common latent factors mediating neural recruitment. However, the peak firing rates of individual neurons was only weakly correlated across reaches, suggesting a **stochastic or flexible recruitment strategy** of neurons by reaching direction. 2) Both types of reaches exhibited common **transient dynamics** during the preparatory, reaching, and grasping motor epochs. Transient trajectories diverged at the onset of movement for neurons in the ventral horn, while diverged in the premotor epoch for neurons in the dorsal horn, suggesting some preparatory modulation of spinal neurons. 3) We found common neural **rotational dynamics,** during the ballistic reaching epoch, with target direction distinguishable by the radius of rotation.
We suggest that the populational activity of cervical spinal neurons during arm movement also exhibit neural dynamics similar to those observed in the cortex and lumbar spinal cord. Future work will explore additional recording sites and causal tests (e.g., optogenetics) to expand upon how the corticospinal and spinal reflex loop share the neural dynamics subspace during distributed sensorimotor control.

P1-D-113 - Dissociation of perceived cognitive demand and physiological strain in varied modes of work-matched eccentric/concentric interval cycling: Implications for sensorimotor integration

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Details

BACKGROUND: Eccentric contractions generate high mechanical force at a low metabolic cost, presenting conflicting signals for the central regulation of effort. It remains unclear whether the Central Nervous System (CNS) prioritizes mechanical output or physiological strain when scaling subjective and cognitive load. We examined the dissociation among mechanical work, physiological responses, and perceived cognitive demand (via NASA-TLX) during work-matched cycling to determine sensory weighting strategies. **METHODS:** Nine healthy young males (age: 21.4 ± 0.9 yrs old, BMI: 24.6 ± 0.5 kg/m^2) completed three work-matched cycling exercise trials in a randomized, counter-balanced design: 1) Continuous Concentric (C; equivalent workload to CI and EI trial), 2) Concentric Interval (CI; 75%Wmax & 65%Wmax), and 3) Concentric/Eccentric Interval (C: 75%Wmax & E: 65%Wmax; concentric bouts interspersed with eccentric recovery at relatively low-intensity). Total mechanical work was strictly controlled to be identical across conditions. We assessed "perceived cost & cognitive load" using the NASA Task Load Index (NASA-TLX) and Rating of Perceived Exertion (RPE), while simultaneously monitoring "physiological cost" via Heart Rate (HR) and Blood Lactate (BLa) responses.
RESULTS: Anaerobic metabolic contribution, assessed via blood lactate accumulation, did not differ significantly across trials ($p > 0.05$), confirming comparable metabolic demand. Despite identical mechanical work and similar lactate levels, the EI condition elicited significantly lower cardiovascular drive (HR: 134 ± 17 bpm) compared to C (161 ± 13 bpm) and CI (155 ± 8 bpm) ($p < .001$). Strikingly, perceived effort became uncoupled from mechanical output: RPE was significantly lower in EI (4.3 ± 1.1) vs. C (7.9 ± 1.3) ($p < .001$). NASA-TLX component analysis further revealed that "physical demand" and "cognitive effort" were rated significantly lower in the EI condition, mirroring the reduction in cardiovascular strain rather than the sustained mechanical or anaerobic demands. **CONCLUSIONS:** These findings indicate that incorporating eccentric contractions into an acute interval exercise induces a functional dissociation between mechanical work and cognitive load. The observation that perceived effort tracked closely with cardiovascular strain (HR) rather than mechanical output or anaerobic demands suggests a specific sensory weighting strategy by the CNS. In this context, the CNS appears to

prioritize cardiovascular afferent feedback over mechanical feedback when scaling subjective workload. These results highlight eccentric cycling as a valuable model for studying sensorimotor integration and the central regulation of fatigue.

P1-D-114 - Exploring cerebellar prediction errors in statistical learning

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Details

Recent work in animal models has revealed that the cerebellum contributes to nonmotor forms of learning, in addition to its well-known role in supervised motor learning. One hypothesis is that the cerebellum might perform domain general prediction error computations that can be used for learning outside the motor domain (Sokolov et al., 2017). In line with this idea, prior research in animal models (Wagner et al., 2017; Heffley et al., 2018; Sendhilnathan, Ipata, & Goldberg, 2020) has provided initial evidence of cerebellar involvement in prediction-error based reinforcement learning (RL). Recent research in our lab revealed that nonmotor regions in the human lateral cerebellum (Crus I & II) encode reward prediction errors during RL (Trach, Ou, & McDougle, under review). In the present study, we used fMRI to further test the hypothesis that the cerebellum might be involved in domain-general error processing during learning by investigating its role in another cognitive form of learning: unsupervised (i.e., statistical) learning (SL).

During the SL task, human participants (N = 20) passively viewed sequences of novel fractal stimuli, where certain fractal-fractal transitions had a higher probability (0.75) than others (0.25). This allowed us to measure prediction error (surprise) signals across the brain by contrasting activity for high- versus low-likelihood transitions. We also manipulated the delay (0.8s and 3s) between fractal transitions to test whether cerebellar prediction error signals would be constrained to short timescales.

At the whole brain level, we found evidence of SL signals represented in the hippocampus, which showed increased activations to the less likely stimulus transitions. Using model-based fMRI analyses, we found reliable statistical prediction errors in regions of Crus I & II. These signals were sensitive to short inter-stimulus intervals, echoing temporal constraints found in supervised motor learning and RL. Together, these results suggest that the human cerebellum might perform domain general function in predictive processes and error-based learning in both motor and nonmotor domains

E – Disorders of Motor Control

Poster Cluster (P1-E-115 to P1-E-118)

P1-E-115 - Effects of costs and rewards on the flexibility of reaching control in Parkinson's disease

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Details

The basal ganglia (BG) are commonly hypothesised to play an important role in motor control, particularly in evaluating costs and rewards during motor task execution. We hypothesise that in Parkinson's disease (PD), BG dysfunction disrupts this process, thereby contributing to motor impairments such as bradykinesia - often interpreted as an increased sensitivity to these costs. Concurrently, advances in motor control research have introduced reaching paradigms that assess individuals' ability to modulate their behaviour in response to changes in task demands, typically modelled by altering the cost-function in optimal control models. This raises the question of whether individuals suffering from PD can modulate their behaviour when faced with varying task demands. Any

observed behavioural impairments may be correlated with disease progression, which is commonly linked to BG dysfunction. To investigate this, we designed two reaching tasks performed by 25 PD volunteers with mild to moderate symptoms (clinical stage evaluated with the H&Y scale: 1 to 3 over 5; mean age: 66 years; 7 female), and 24 age-matched healthy controls (HC) (mean age: 69 years; 8 female). In the first task, we varied the target shape between a large bar and a small dot to manipulate task redundancy (i.e., modify the cost associated with the final hand position). In the second task, participants were required to select among three targets aligned along an axis orthogonal to their movement path. The explicit reward associated with those targets was varied across conditions. In the first condition, all three targets yielded 5 points; in the second condition, only the central target yielded 5 points, while the lateral targets each yielded 1 point. In each task, we applied mechanical perturbations to assess participants' ability to exploit the target redundancy or the alternative targets. We found no significant difference between groups in movement time, peak velocity, or reaction time. In addition, behaviour in the face of changes in cost and reward did not show any significant differences in the exploitation of the geometry of the bar target, or in the choice of alternative target options, depending on their reward. In stark contrast, the impact of PD was obvious in the muscular activity: long-latency (LL) feedback responses (50-100ms) were significantly higher in PD volunteers than in HC. However, the modulation of these LL feedback responses due to target geometries and reward conditions was comparable between the two groups, showing a similar task-dependent modulation. While the impact of PD was evident in muscle responses, the similar behaviour observed in both groups across different cost and reward configurations suggested that neural structures beyond those primarily affected in PD may contribute to the transformation of movement costs and rewards into efficient control policies.

P1-E-116 - Graph-theoretic assessment of brain connectivity in essential tremor

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Details

Essential tremor (ET) is a prevalent motor disorder, characterised by involuntary oscillations of the upper limbs during voluntary movements. Despite the mounting evidence implicating dysfunction within the cerebello-thalamo-cortical pathway in ET, a definitive positive diagnosis remains elusive in the sense that ET is established after eliminating other potential sources of tremor. We recently hypothesised that errors in delay compensation within long-latency sensorimotor feedback pathways may give rise to tremor-like oscillations. This suggests that mean power spectral density (PSD) of limb kinematics could serve as a behavioural marker of ET.

To test this hypothesis, we investigated the relationship between mean PSD, clinical tremor severity as measured by the Fahn-Tolosa-Marin Tremor Rating Scale (FTM-TRS), and resting-state functional connectivity derived from fMRI in 19 ET patients and 19 neurologically intact (NI) controls, using the graph theoretical analysis. Region-of-interest–based graph metrics were used to assess (1) group differences in network topology and (2) correlations between graph metrics and behavioural measures, including FTM–TRS and mean PSD in ET.

Across all analyses, motor-related brain regions were consistently implicated. Group comparisons revealed widespread network alterations ranging from motor-related cortical regions to cerebellar areas. Correlations with FTM–TRS were primarily localized to temporal, basal ganglia, and cerebellar regions, whereas regions correlated with mean PSD were mainly found in motor-related cortical regions and predominantly within the cerebellum, including the dentate nucleus, which was also implicated in group differences. These findings are consistent with prior evidence of cerebello-thalamo-cortical alterations and the central role of the dentate nucleus within cerebellar motor networks in ET. Furthermore, mean PSD may serve as a potential biomarker linking sensorimotor behaviour to functional brain connectivity.

P1-E-117 - Task-dependent modulation of gait control in Parkinson's disease

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Details

Constraining gait rhythm with a metronome influences gait pattern in many different ways. While such a rhythmic cueing can improve several parameters in some clinical populations such as patients suffering from Parkinson's disease (PD), they do decrease the long-range autocorrelations (LRA) naturally present in series of stride durations. This change in LRA has been interpreted in the framework of optimal control as a result of two distinct modes of gait regulation. On the one hand, without metronome, free walking does not require tight regulation of step duration and length, allowing for statistically persistent fluctuations around the average. On the other hand, constraining the stride time with a metronome impedes the flexible regulation of these gait parameters, leading to a decrease of LRA in the series of stride durations. Cueing paradigms therefore require flexible adjustments when walking conditions change. As the basal ganglia have been associated with the representation of motor costs and reward, we hypothesized that they may contribute to the flexible adjustments of gait control across contexts.
To test this hypothesis, 27 patients suffering from PD with mild to moderate symptoms (clinical score: H&Y = [1-3]) and 26 age-matched healthy controls (HC) were asked to walk overground during two 15-minutes conditions. A metronome was activated either during the first half or during the second half of the session in order to test both transitions. Participants were explicitly asked to synchronize one foot with the metronome, set to their average spontaneous pace. We assessed the modulation of gait regulation through changes in LRA, using a sliding window on the series of stride durations to characterize its temporal evolution. Our analyses were reproduced with a computational model allowing to relate sudden changes in cost parameters to the LRA, which is typically measured over longer timescales.
Participants with PD exhibited an overall modulation comparable to that of HC, with similar changes in LRA following the addition or removal of the metronome cueing. This modulation was also consistent with previous measurements in healthy young adults (Vandamme et al., JNeurophysiol, 134(6):1939-1952, 2025). However, the temporal adaptation differed between groups. While both groups quickly recovered spontaneous levels of LRA when the metronome constraint was released, PD patients exhibited a slower decrease in LRA when the metronome was activated. In the model, all transitions could be reproduced by an instantaneous change in control policy, except for the transition involving the addition of the metronome in PD patients, which required a more gradual change in motor costs.
Together, these results indicate that the partial deterioration of the basal ganglia in the early stages of PD may have specific impact on the time course of gait modulation rather than its net amplitude across conditions.

P1-E-118 - Sensory attenuation in patients with Essential Tremor

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Details

Essential Tremor is a neurodegenerative disorder characterized by involuntary oscillations during volitional actions, primarily affecting the upper limbs. The presence of a time delay in a feedback control system can induce oscillations if the impact of the delay is not properly considered. In upper limb control, temporal delay compensation is thought to rely on long-latency feedback pathways involving

primary somatosensory areas and cerebellum. Our hypothesis is that delay compensation in long-latency feedback pathways is inaccurate in patients with ET. Simulations and experimental studies supported this hypothesis. Another aspect of internal delay processing is sensory attenuation. In healthy individuals, self-generated forces are perceived as less intense than identical, externally applied ones. This attenuation relies on tactile predictions synchronized with movement through the efference copy. Furthermore, sensory attenuation is adaptive, as healthy volunteers could learn to attenuate delayed self-generated touches after repeated exposure to a systematic delay. We examined whether sensory attenuation was preserved or impaired in patients with ET to test whether internal sensory delay processing is impaired.
We recruited 23 ET patients and age- and gender matched healthy volunteers. We conducted several blocks in which participants received two taps on their left finger: the first was self-generated, and the second was externally generated (i.e., delivered by a motor-actuated device). These blocks were preceded by a series of exposure trials during which the difference between the moment when they actively tapped and the moment when they received the second tap on the finger was 0 or 100ms. This design resulted in four experimental conditions defined by the exposure and the test delays. A control condition was included in which both taps were delivered by the device. Participants had to compare the two taps and evaluate which felt stronger. A clinical assessment was also performed for all participants, including evaluation using the Fahn–Tolosa–Marin (FTM) scale and measurements of the limb kinematics obtained from accelerometers attached to their fingertips while they maintained index to index postural position.
We observed a correlation between the FTM score and the power spectral density across all participants, consistent with previous results. No significant differences were observed between groups for resting tremor, whereas postural tremor amplitude was greater than resting tremor in patients. Regarding sensory attenuation, the presence of sensory attenuation in the [0 – 0] condition was observed in both groups. However, patients did not appear to be able to adapt to a new delay and showed reduced attenuation compared to healthy volunteers in the adaptation condition [100 – 100].
These results show preserved sensory attenuation but reduced adaptation to delayed feedback in patients compared with healthy volunteers.

P1-E-119 - Neural mechanisms of spinal hyperexcitability in children with cerebral palsy

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Details

Cerebral palsy (CP) is a spectrum of neurodevelopmental disorders caused by an early brain lesion and represents the most frequent motor disability in children. Spasticity and hypertonia are among the main contributors to disability in CP and are characterized by involuntary muscle contractions, likely resulting from hyperexcitability of the spinal circuits. Current non-invasive treatments, such as baclofen and botulinum toxin A, are often insufficient, and many children still undergo highly invasive surgical procedures, including selective dorsal rhizotomy. This highlights the need for new, effective treatments targeting spasticity in children with CP.
Although the cerebral origin of CP is well established, the mechanisms through which this lesion leads to spinal hyperexcitability producing spasticity and hypertonia remain poorly understood. In particular, the contribution of corticospinal and sensory motor pathways, and motoneuron properties in spinal hyperexcitability has yet to be determined, limiting the development of targeted therapies for children with spastic CP. Nevertheless, recent studies have shown that transcutaneous spinal cord stimulation (tSCS) can improve motor function in this population. However, its effect on spasticity has not been consistently demonstrated across studies (1-3), possibly due to the lack of understanding of the origin of spinal hyperexcitability in CP.

In this study, we investigated the contributions of motoneuron properties and corticospinal and sensory-motor pathways to spinal hyperexcitability using a set of human electrophysiological experiments. In addition, we evaluated the potential of tSCS to reduce the contribution of each of these elements to spinal hyperexcitability. Our preliminary results show that children with cerebral palsy have hyperexcitable spinal circuits, reflected by increased H-reflex responses. Using transcranial magnetic stimulation (TMS), we also observed an enhanced corticospinal drive producing increased muscle and motoneuron activation in children with CP. Importantly, tSCS applied to the lumbar spinal cord seems to normalize the aberrant responses from these pathways suggesting that tSCS could reduce spasticity and hypertonia.
Overall, these preliminary findings provide an electrophysiological characterization of spinal hyperexcitability in children with CP and show that tSCS may be a promising approach to modulate and reduce spasticity.

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P1-E-120 - Neuronal avalanche dynamics as network biomarkers of motor disorders and features for brain–computer interface classification and prediction

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Details
Neuronal avalanches are cascades of burst activations that travel across multiple brain regions, revealing how activity spreads through the network. This network view is crucial because motor imagery and motor diseases depend on coordinated system-level dynamics, not just local power changes. Traditional motor-control analyses mostly use local spectral features, which ignore transient aperiodic activity often dismissed as “noise” and largely miss interactions between regions. Avalanche-based measures address this by focusing on transient events and explicitly modelling their propagation across the brain. We first investigated whether neuronal avalanche features—such as avalanche length (how long cascades persist) and activation (total number of regional activations)—can predict BCI performance in a longitudinal EEG-based motor imagery study. These features provide a compact but expressive description of motor network propagation. They clearly distinguish rest from motor imagery, indicate whether a participant is truly performing the task, and are sensitive to learning: avalanche length and activation change across training and correlate with each user’s BCI performance. In longitudinal prediction models, they forecast future BCI success with accuracies up to 91%, allowing early identification of users likely to struggle. This is crucial in the context of “BCI inefficiency”, where 15–30% of users fail to gain good control. Neuronal avalanches thus emerge as biomarkers of individual learning trajectories, enabling personalized BCI training instead of one-size-fits-all protocols. We futher investigated our researchs by testing neuronal avalanches as decoding features for BCIs, specifically asking whether avalanche propagation patterns themselves could be used for brain-state classification.We introduced the original Avalanche Transition Matrix (o-ATM), which encodes the probability that activity in one region is followed by activity in another during an avalanche, yielding a probabilistic map of how motor imagery propagates through the network. In both sensor and source space, o-ATM–based models improve classification performance compared with Common Spatial Patterns (Sourcespace: o-ATM: 80%±8% vs CSP: 75%±14%) and show reduced inter-subject variability. Finally, we extended this framework to amyotrophic lateral sclerosis (ALS) using a refined metric, the Weighted-Stochastic Avalanche Transition Matrix (ws-ATM). Its

stochastic formulation, grounded in Markov-chain and graph theory, captures both the strength and duration of cortical transitions while down-weighting short, artifact-driven events. Ws-ATM yields reliable estimates with ~65% fewer avalanches, enabling substantially shorter recording times and robust analysis even after removing noisy segments—both crucial for disabled patients who experience pain, fatigue, or involuntary movements. In MEG data from ALS patients and healthy controls, ws-ATM detects large-scale network reorganization and correlates with clinical severity, positioning neuronal avalanches and ws-ATM as promising non-invasive biomarkers of motor neurodegeneration and as candidate tools for adaptive BCIs that track disease-related changes in brain dynamics.Taken together, these projects define a coherent research program: using neuronal avalanches to map how motor brain networks propagate activity in health, learning, and disease, and exploiting these dynamics to build better BCIs and improve clinical motor diagnosis, moving from static, local, frequency-based views to a truly network-level, dynamical description.

P1-E-121 - In vivo mapping of descending motor and ascending somatosensory pathways in the human brain

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Details

Dexterous hands are crucial for daily life. Fine finger control and grip strength rely on separate descending pathways: corticospinal (CST) and reticulospinal tracts (RST). Non-human primate studies suggest that when direct corticomotoneuronal CST fibers are damaged, indirect propriospinal CST can aid dexterity recovery (Isa, 2019). In humans, monosynaptic CST inputs originate from the anterior precentral gyrus (aCST) (Lassek & Rasmussen, 1940), while indirect CST projections originate from the ventral premotor cortex (pCST) (Pierrot-Deseilligny & Burke, 2012). Ascending somatosensory input from touch and proprioception travels via the medial lemniscus (ML) to the ventral posterolateral nucleus of the thalamus (Kamali et al, 2009) and then to the primary somatosensory cortex via thalamus-cortical (TC) pathways (Yang et al., 2009). Mapping these sensorimotor tracts can help characterize hand recovery after stroke.

Here, we investigated the feasibility of using whole-brain tractography to separate aCST, pCST, RST, TC, and ML in stroke survivors and healthy controls. Diffusion MRI(dMRI) images were collected from healthy older adults (N=9) and stroke survivors (N=11, Lesioned Hemisphere: 6R,5L) on a 3T GE scanner (Discovery MR750). We used readout-segmented echo-planar imaging with parallel imaging (Heidemann et al., 2010) and a multi-shell diffusion spectrum sequence. Images were reconstructed to MNI space using q-space diffeomorphic reconstruction (Yeh et al., 2010). Cortical ROIs for aCST and pCST were approximated using Brodmann's Area BA4 and BA6, respectively, and used to restrict and trace fibers between cortex, internal capsule, and cerebral peduncle (Verstynen et al, 2011). For RST, seeds were placed in the anterior segment of the brainstem and dorsal pons to approximate medial and lateral RSTs, respectively (Karbasforoushan et al., 2019). Sensory tracking was assisted by visual alignment to previous microdissection findings (Miranda et al., 2015; Wang et al., 2016b; Yeh et al., 2018). ROI masks generated atlas space were used to assess the tract integrity of the five pathways. Average quantitative anisotropic(QA) values of the fibers in these masks were then extracted from both healthy and stroke brains.

Lesion-related QA asymmetry was quantified relative to a null distribution derived from healthy controls using 10,000 paired-subject simulations to reveal pathway-specific deviations of stroke-related changes against the null distribution. The majority of the stroke survivors showed a large deviation from the null distributions in CST, aCST (and pCST . Whereas the stroke RST (), and sensory tracts, ML () and TC () showed less deviation from the healthy distribution. These findings highlight selective disruption of sensorimotor pathways following stroke, which may contribute to impaired motor control after injury.

P1-E-122 - Decoding face and hand gestures from intracortical activity for emotional expression

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Details

Expressing oneself – not only through speech but also through hand and facial gestures – is a fundamental aspect of human communication that shapes meaning, engagement, and social connection. However, individuals with motor impairments—such as people with amyotrophic lateral sclerosis (ALS), stroke, or spinal cord injury—are often deprived of this critical mode of self-expression. While recent advances in intracortical brain-computer interfaces (iBCIs) have enabled highly accurate speech decoding from neural activity, these systems still lack the emotional nuances of natural human communication. To reduce this limitation, we developed a multimodal approach to enrich iBCI-decoded speech with gesture expression. One participant with paralysis due to ALS (T15, BrainGate2 clinical trial NCT00912041) was instructed to attempt up to 20 facial and hand gestures that convey emotional/communicative intent (e.g., smile, frown, wink, thumbs up/down), presented as emoji cues in an open-loop instructed delay task. We recorded neural activity from chronically implanted microelectrode arrays in the ventral precentral gyrus and found that neural activity from most electrodes showed significant and separable modulation to instructed gestures. Next, we trained a convolutional–recurrent neural network (CNN–RNN) decoder to classify the attempted gestures from neural activity and achieved an average closed-loop decoding accuracy of **92%**. Finally, we integrated gesture decoding with a previously developed brain-to-text speech iBCI framework (Card et al., 2024). The participant was cued to attempt to speak nuanced sentences, with an embedded emoji indicating the intended emotional emphasis, and was instructed to attempt the corresponding facial or hand gesture at the point in the sentence where the emoji cue appeared. Speech and gestures were decoded simultaneously in real time. These results demonstrate the feasibility of decoding emotional gestures alongside speech from intracortical signals, offering a path toward more expressive and naturalistic communication for iBCI users.

P1-E-123 - Portable VR-based assessment of upper-limb motor control after stroke

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Details

After stroke, individuals often exhibit both negative and positive motor signs in the paretic upper limb. Negative signs (i.e., lost abilities) include weakness and poor dexterity, while positive signs (i.e., features not typically present) include hypertonia and loss of independent joint control (e.g., concomitant elbow flexion during shoulder abduction). Traditionally, robots have been used to quantify arm control during reaching tasks devised to capture some of these impairments. However, robotic systems are expensive and pose logistical challenges for implementation in clinical settings. To address this limitation, we have developed two virtual reality based (VR-based) kinematic reaching tasks that can be implemented using portable hardware (a head-mounted display and controller, and a laptop computer): (1) a center-out reaching task designed to assess proximal arm dexterity, and (2) a maximum distance reaching task designed to quantify loss of independent joint control. Fourteen people with chronic stroke (mean ± SD months poststroke = 176 ± 101) and with varying degrees of upper limb motor impairment (mean ± SD Fugl Meyer score = 42 ± 19) participated in two sessions separated by 1 week. For both tasks, the paretic or non-paretic arm was positioned in a frictionless sled with the hand centered at the midline. This “start position” was represented in VR as a gray circle. The VR controller was mounted to the sled (aligned with the base of the middle finger), and its position appeared in VR as a blue sphere cursor. In the center-out reaching task, participants moved the cursor as straight as possible from the start position to one of five

targets arranged radially along the upper half of a virtual circle, each located 10 cm away. This task was conducted with the arm supported on a table to minimize the effects of weakness and inter-joint coupling. Proximal arm dexterity was quantified by the path length ratio (i.e., the length of the actual trajectory relative to the ideal straight path) across all targets. In the maximum distance reaching task, participants were instructed to move the cursor as far as possible from the start position away from their body. The task was performed first with the arm supported on a table and then without support (i.e., requiring active shoulder engagement against gravity). Loss of independent joint control was quantified using the distance ratio (i.e., the maximum reach distance without support relative to that with support). As expected, the path length ratio was higher (i.e., arm dexterity was worse) in the paretic arm (1.53± 0.38) compared with the non-paretic arm (1.24 ± 0.09). Similarly, the distance ratio was lower (i.e., independent joint control was worse) in the paretic arm (0.70 ± 0.27) compared with the non-paretic arm (0.96 ± 0.13). Also, there was good between-session reliability for both measures. Our findings demonstrate that these VR-based assessments can provide stable quantitative measures of proximal upper-limb control after stroke, offering an affordable and practical approach to measure natural arm control recovery (or lack thereof) and intervention efficacy at different stages post-stroke.

P1-E-124 - Systematic quantification and comparison of upper limb tremor during adaptation to novel movement dynamics

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Details

Tremor is a rhythmical, oscillatory movement of any body part (Deuschl et al. 2001; Elble 2009; Louis 2016). Physiological tremor is typical in all healthy individuals but pathological tremor is disruptive to daily life. Essential Tremor (ET) and Parkinson's Disease (PD), the two most common movement disorders, have pathological tremor as one of their key symptoms. Characteristic tremor frequency is heterogeneous among these disorders and it is currently unclear how this tremor impacts motor learning. Here, we seek to 1) quantify pathological and physiological tremor along different stages of movement (i.e. postural hold, reaching, and stabilization) and 2) compare the ability of three groups (PD, ET, and neurologically healthy controls, HC) to adapt to novel movement dynamics (i.e., a force-field perturbation).

Methods: As a first step, we trained PD and ET patients, and age-matched HC subjects to use a robotic manipulandum to move a screen cursor between two targets, 10 cm apart . Following a baseline period, reaching arm movements were perturbed by a velocity-dependent force-field during training. On these force-field trials, the robot perturbed the hand motion with forces that were proportional in magnitude and perpendicular in direction to the velocity of hand motion. We used error clamp trials to assess the feedforward adaptive changes in motor output. Motor compensation to the force-field perturbation was quantified on these trials with an adaptation coefficient: the linear regression of the measured lateral force profile on each error clamp trial onto the ideal force profile required for full force-field compensation on that trial. Furthermore, utilizing Singular Spectrum Analysis (SSA) combined with Fast Fourier Transform (FFT) we were able to isolate and quantify the fluctuations in force that were associated with voluntary movement, tremor, and noise during postural hold, movement reach, and stabilization.

Results: We hypothesized that patients with greater frequencies and magnitudes of tremor would have lower learning rates. Instead, we found that, during the reach phase of motor adaptation to the force-field perturbation, learning rate was similar across the three groups, which corresponds to similar tremor magnitudes and frequencies. However, when we examined tremor frequency we observed differences across groups during postural hold as well as impaired stabilization in patient groups. Specifically, we found higher magnitude of tremor in patient groups compared to HCs during stabilization periods.

However, we did not see these differences in tremor magnitude during parts of training that involved reaching movements.
Discussion: Our results demonstrate that, during motor adaptation to the force-field perturbation, patients with pathological tremor (PD and ET) have similar rates of adaptive learning compared to neurologically intact controls. Impairments in movement, however, appear to manifest during aspects of movement that require stabilization, such as end-of-movement stabilization on the target and postural hold, which corresponds to greater manifestations of PD and ET tremor (i.e. greater magnitudes or frequencies). Thus, we conclude that pathological tremor in ET and PD interferes with the ability to stabilize at the beginning and end of movement reach, but this does not impair overall learning during the adaptation of movement.

P1-E-125 - Freezing and transition behaviours in people living with Parkinson's disease
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Details
People with Parkinson's disease (PwPD) can be affected by freezing, most commonly observed as freezing of gait (FOG), but also linked to upper-limb and speech movements. As noted in the literature, FOG most frequently strikes at behavioural transitions: when walking begins, at reversals, turns, or when passing through structures, like doorways. This connection to transitions suggests that it may be associated with planning skills needed to initiate, suppress, and change behaviour, and that it may affect multiple motor systems. We examined the relationship between PwPD's experience with freezing and their performance on eye-movement, reaching, and walking tasks, and their production of natural speech. Freezing was documented using the New Freezing of Gait Questionnaire (NFOG-Q). Eye-movement tasks (anti-saccade and gap test) were used to measure participants' ability to initiate and suppress eye-movements, and to benefit from the release of a fixation anchor. Walking and reaching tasks were employed to measure participants' behaviour as they performed reversal, turning, and passing-through tasks. Measures of articulation rate and voice quality were taken from samples of natural speech. Fourteen PwPD and 16 age- and sex-aligned controls completed these experimental tasks in addition to the Frontal Assessment Battery, Montreal Cognitive Assessment, and the Movement Disorders Society Unified Parkinson's Disease Rating Scale Part III. The results showed that PwPD with FOG had significantly larger gap effects than PwPD without FOG, and that the pro-saccade gap effect was significantly related to FOG severity as measured by the NFOG-Q. Measures of speech articulation rate also distinguished PwPD from controls and PwPD with FOG from PwPD without FOG. PwPD also demonstrated impaired performance, in comparison to controls, on both reaching and walking tasks. These findings strengthen the evidence that skills needed to initiate, suppress, and change behaviour are linked to freezing in PwPD.

P1-E-126 - Uncovering sleep-related barriers to motor recovery after stroke: Behavioural, neurophysiological, and structural insights
Matthew Weightman [1], **Barbara Robinson** [1], **Anna Guttesen** [1], **Teresa Simoes Steyn** [1], **Katrijn Schruers** [1], **Melanie Fleming** [1], **Heidi Johansen-Berg** [1]
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Details
Stroke remains a leading cause of long-term disability, with more than half of survivors experiencing persistent motor impairment. Although motor learning is fundamental to successful rehabilitation, a key component of this process - the consolidation of motor memories during sleep - remains under-explored in stroke recovery research. It is well established that sleep plays an active role in strengthening newly

learned motor skills by reactivating task-related neural patterns and stabilising fragile memories into more durable representations. These reactivation events are closely tied to brain rhythms that characterise non-rapid eye movement (NREM) sleep. During this stage, synchronous firing of neurons produces slow oscillations (<1Hz) and brief bursts of activity known as spindles (11-16Hz), which help coordinate communication between distributed brain regions and provide the foundation for memory stabilisation. Yet, sleep disruption is highly prevalent after stroke and consistently linked to poorer functional outcomes. If practice drives learning during the day, sleep may be essential for turning that practice into lasting gains. Thus, impaired sleep-dependent consolidation may contribute to the sub-optimal recovery seen in many patients.

Across a series of studies in sub-acute and chronic stroke survivors, we have shown that sleep-wake regularity, measured with actigraphy, is significantly reduced relative to age-matched controls (stroke: n=162, age 61 ±14yrs, 5 ±5 yrs post-stroke; controls: n=60, age 57 ±17yrs). Lower regularity was associated with worse depressive symptoms and poorer quality of life, though not with disability. Using low-density portable EEG and structural MRI in a subset of participants (stroke: n=38, age 64 ±12 yrs, 8 ±5.5yrs post-stroke), we found that neither lesion size nor overlap with a priori regions of interest (brainstem, basal ganglia, amygdala, hippocampus, thalamus) explained interindividual variability in subjective or objective sleep measures. In contrast, an exploratory data-driven lesion-network approach revealed clusters of voxels that were disconnected across several white-matter tracts. These disconnections predicted reduced sleep spindle density and amplitude, suggesting potential diminished capacity for overnight motor memory consolidation.
Finally, data from an ongoing clinical trial investigating sleep and motor memory consolidation, show that stroke survivors (n=56, age 72 ±13yrs) with more disrupted sleep in the sub-acute phase have poorer motor outcomes at the chronic stage of recovery. Preliminary analysis also reveals a significant correlation between %REM sleep during early recovery and upper-limb function. Despite this, participants retained the ability to consolidate memories overnight, exhibiting quicker average response times in an SRTT (PM-AM), though this improvement has not yet shown a significant relationship with specific NREM features.

Taken together, these multimodal findings suggest that sleep disruption is not merely a symptom of stroke but a potential mechanistic barrier to motor recovery. By linking behavioural consolidation, sleep physiology, and MRI, this work highlights sleep as an under recognised but modifiable target for improving rehabilitation outcomes. Future interventions aimed at improving sleep quality and/or enhancing NREM sleep physiology may offer a novel pathway to strengthen motor learning and promote functional gains after stroke.

P1-E-127 - Multiscale sleep-wake cycle neural perturbation accompanies motor impairment after a cortical ischemic lesion

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Details

Stroke and traumatic brain injury are leading causes of adult-onset disability, with most survivors experiencing persistent motor dysfunction despite conventional rehabilitation. While neuroprosthetic devices offer promising therapeutic potential, current approaches fail to harness the brain's intrinsic mechanisms for robust plasticity. The ultimate goal of our research is to develop a novel neuroprosthetic system that integrates sleep, a critical yet frequently neglected factor in neuroplasticity, into motor

rehabilitation technology. Here we present the first results, where we investigate the impact of a cortical ischemic lesion on sleep-related electrophysiological activity.
Animals (Controls, N = 7; Lesions, N = 6; male Long Evans rats, 250-350 g) were subjected to surgical implantation of recording and stimulation electrodes (32-channel microwire arrays) in the primary somatosensory cortex (S1) and pre-motor cortex (RFA), while focal ischemia was induced in the primary motor cortex (CFA) via endothelin-1 microinjections (Lesions). Assessment of motor impairment was conducted through cylinder-mirror, grid walking and pasta matrix tests 7 days after surgery. Six-hour-long recordings of local field potentials (LFPs) and spiking activity (Multi and Single Unit Activity, MUA and SUA) were then analyzed separately during wakefulness (WK), slow-wave sleep (SWS), and intermediate sleep (IS), following automated sleep staging based on state-space map estimation of LFP spectral content [Gervasoni et al., 2004].
We found that Lesions animals have a shorter latency to SWS than Controls and showed a significant correlation between behavioral-related indexes and stage clusters position in state maps. At the meso-level, ischemia jeopardized the temporal coordination between sleep spindles and slow oscillations. Spectrogram-computed metrics of spindles [Sitnikova et al., 2014] revealed a different spectral content between groups, in S1 during IS and in how they differ between stages after lesion. Moreover, spindle activity correlated with behavioral deficit in Lesions animals. Interestingly, micro-architecture (spikes) appeared to be resilient to the lesion, as only inter-stage differences were found significant. Units' firing properties presented a similar balance between WK and SWS across groups. In the end, the coordination between spindles and MUA showed a possible trend in the difference of modulation across stages between groups, in S1 (second-level contrast).
To conclude, sharp motor impairment following cortical ischemia coexists with disruption of sleep-related neural activity at multiple levels possibly indicating degradation of plasticity-mediated spontaneous recovery mechanisms and accompanying rehabilitation.

P1-E-128 - Flexor synergy after stroke: Magnitude, expression, and association with reaching performance

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Details

In the healthy motor system, upper extremity (UE) synergies are task-dependent movement patterns required to efficiently execute goal-directed actions. After stroke, abnormal synergies—the coactivation of muscles that leads to involuntary joint coupling—disrupt UE motor control. The canonical post-stroke synergy pattern is flexor synergy: shoulder flexion, horizontal abduction and external rotation coupled with forearm supination and elbow and wrist flexion. Post-stroke abnormal synergies are thought to result from upregulation of the reticulospinal tract, which provides non-selective control to predominantly flexor UE muscles. Such maladaptive plasticity and resulting aberrant motor control would imply restricted amounts (magnitude of abnormal joint movement) and expressions (pattern of abnormal joint movement) of flexor synergy within different tasks. This study aimed to rigorously investigate the amount and expression of flexor synergy across different isolated joint movements post-stroke. We hypothesized that (1) the amount, but not the expression, of flexor synergy would vary by task and (2) a greater amount of flexor synergy during isolated joint movements would relate to poorer functional reaching performance.

Chronic stroke patients (N=26) with UE motor impairment (UE Fugl–Meyer range: 15–55) performed individuation and functional reaching tasks recorded with 3D motion capture. Individuation tasks involved isolated movement at six UE degrees of freedom (DOFs): shoulder, elbow, and wrist

flexion/extension, shoulder horizontal abduction/adduction, shoulder internal/external rotation, and forearm supination/pronation. The range of motion (ROM) of each DOF was measured during each task and normalized to the DOF's instructed movement range. Flexor synergy amount was quantified using the joint coupling ratio, defined as the sum of normalized ROM of non-instructed DOFs divided by the sum of normalized ROM of instructed and non-instructed DOFs. Flexor synergy expression was evaluated by measuring the motion of non-instructed DOFs during each individuation task. Functional reaching performance was assessed using movement smoothness (spectral arc length).

The amount of flexor synergy varied across tasks: it was greater during in-synergy and proximal joint movements as compared to out-of-synergy and distal joint movements. The expression of flexor synergy, however, was consistent across tasks, with forearm supination dominating. In the functional reaching task, which included center, ipsilateral, and contralateral targets, greater amounts of flexor synergy during individuation were associated with reduced smoothness across all reaching directions.

Our findings show that the amount of post-stroke flexor synergy varies by joint movement and relates to deficits in functional reaching. The expression of flexor synergy, however, was conserved across individuation tasks. Together, our results provide insight into the neural control of post-stroke synergies.

P1-E-129 - Spatiotemporal desynchronization of motor units during Parkinsonian tremor by deep brain stimulation

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Details

Deep brain stimulation (DBS) is an effective treatment for tremor in advanced patients with Parkinson's disease (PD). Yet the underlying mechanism behind the effectiveness of DBS in reducing tremor activities remains unclear. Here we investigated the spatiotemporal modulation of motor unit (MU) activities with DBS leveraging the decomposition technique of high-density surface electromyography (HDsEMG). The MU behavior from 10 PD patients before and after DBS surgery was analyzed in this study. We observed that the overt characteristics of a population of pathological MUs was prominent rhythmic firing at single tremor frequency and synchronized activities among units within and cross muscles at single and double tremor frequencies. DBS was found effective in disrupting both rhythmic firing and synchrony of pathological MUs. Among the observed units, a large population of synchronized MUs were untangled successfully by DBS. Results suggested that DBS appears to modulate the bursting activities in the brain, so as to disharmonize pathological motor units spatiotemporally. This implied that DBS disrupts the pathological bursting firings in the brain, thereby reducing the degree of resonance in pathological motor units. This provided insights to the neural mechanism of DBS in treating tremor, or possibly other neurological disorders.

F – Adaptation & Plasticity in Motor Control

Poster Cluster (P1-B-130 to P1-F-133)

P1-B-130 - The impact of coaching in the visual perception of damping

Taliyah Huang [1], **Jeremy Brown** [1], **Michael West** [1]
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Details

Humans are remarkably adept at extracting latent dynamic information from purely visual cues. For example, prior work shows that people can innately estimate differences in limb stiffnesses using solely

their visual observation of movement. This is a surprising find, as it contradicts the fundamental Hooke's Law, *F=kx*, where stiffness (k) is a characteristic dependent on both motion *and* force. This suggests that components of mechanical impedance may be embedded within humans' internal predictive models of movement. We tested whether humans can similarly perceive damping, a force-velocity relationship, and whether targeted coaching can enhance this innate, visual ability. Specifically, 30 participants observed abstract two-link arm simulations with systematically varied elbow damping and rated their perceived level of damping for several trials. Participants completed two sessions separated by a brief coaching intervention: either no coaching, coaching to attend to endpoint motion, or coaching to attend to elbow-angle motion. Results reveal that (1) humans can innately perceive changes in arm damping using solely their visual observation of motion and (2) coaching further improved performance, with the elbow-angle coaching group showing the largest increase in rating accuracy. This work extends our understanding of how action-perception coupling supports inference of mechanical impedance. Our findings align with prior evidence that perception and action share neural resources, suggesting that participants were drawing on internal models shaped by their own motor control strategies to infer these latent dynamic properties from visual observation. Moreover, we demonstrated that perceptual strategies for estimating damping are malleable and can be systematically improved through coaching. We not only identified the visual cues observers relied on, but also guided them toward more classifiable features, effectively strengthening their perceptual models of limb dynamics. These insights have important implications for stroke patients affected by rigidity and spasticity. Physical therapists develop internal models of limb rigidity (stiffness) and spasticity (damping) only after years of experience with patients, making it difficult for new practitioners to quickly reach diagnostic similarity. Targeted coaching that accelerates the development of these perceptual models could help reduce the clinical learning curve and expand the number of qualified clinicians capable of making reliable, physics-informed assessments of motor impairment, ultimately improving widespread access to high-quality stroke rehabilitation.

P1-F-131 - Skill memory consolidation, not reactive inhibition, explains offline contributions to early learning of naturalistic skills

Ethan Buch [1], **Leonardo Cohen** [1], **Fumiaki Iwane** [2]
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Details

Early naturalistic skill learning typically shows rapid performance improvements—often emerging after brief rest breaks (micro-offline gains, MOGs)—followed by a plateau. Depending upon the context, MOGs may reflect recovery from reactive inhibition (RI), rapid memory consolidation (RMC), or both. In externally paced reaction-time tasks, RI likely plays a substantial role due to sustained demands on attention, stimulus–response mapping, and response inhibition (i.e., a continual game of "whack a mole"). By contrast, RMC is likely more prominent in naturalistic skill learning, where initial cue-driven responses quickly shift to memory-based generative actions (i.e. – learning to play "Hot Cross Buns" on the piano). Accordingly, the balance between fatigue-related limitations and consolidation-driven gains varies across tasks, reflecting differences in control needs rather than a single task-general mechanism. Nevertheless, a recent study[1] claimed that RT–based tasks can quantify RI-based—and, by extension, RMC-based—contributions to MOGs in a manner that generalizes to naturalistic skill learning.
Here, we directly tested the two core assumptions of this study in a large subject cohort (N=983) across 3 RI-modifying dimensions: 1) skill speed (slow, medium and fast with directly proportional RI), 2) naturalistic vs. RT-based paradigms, and 3) learning (fixed repeating sequences) vs. non-learning (speed-matched non-repeating sequences) states—yielding 12 unique skill task contexts. First, we asked whether RI—indexed by motor slowing measured outside a learning context—faithfully reflects RI during

active learning. Second, we examined whether the balance between learning-related processes and RI is preserved across task contexts.
We found that MOGs were significantly larger for all naturalistic learning-state tasks compared to speed-matched, non-repeating sequences (p=1.67e-04), but this difference was absent for RT-based tasks—highlighting the risks of extrapolating mechanisms across fundamentally different control architectures[1]. MOGs—which under an RI account should scale proportionally with execution speed—instead decreased for naturalistic tasks (p=6.98e-04). Importantly, total early learning was reduced by approximately 50% in the studied RT-based medium-(50.39%) and slow-speed (48.17%) skills [1] compared to their naturalistic task counterparts (p=2.99e-05)[2], consistent with the reduced core micro-offline effect reported by Das et al.
Together, these findings demonstrate that MOGs during early naturalistic skill learning do not reflect recovery from RI as claimed[1]. More broadly, they caution against generalizing RI-based mechanistic inferences from RT-based paradigms to naturalistic skills and highlight the need for task-appropriate frameworks when interpreting offline contributions to motor learning. **Refs**. 1. Das et al., PNAS 2025. 2. Bönstrup et al., NPJ Sci Learn 2020.

P1-F-132 - A state-space model of real-time performance dynamics for different sequential keypress skills

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Details

Skill performance fluctuates during practice and brief rest periods due to the interplay between performance-enhancing (e.g. – learning and memory consolidation) and performance-limiting (e.g. - fatigue and reactive inhibition, RI) latent factors. We recently showed that real-time skill performance dynamics are linked to learning-dependent expansions in memory capacity, and that these dynamics are strongly modulated by skill difficulty and practice schedule. For moderately difficult skills, brief interspersed rest breaks often elicit sharp post-rest performance improvements (i.e. – micro-offline gains, MOGs). MOGs account for most skill improvements during early learning, reminiscent of the "spacing effect" commonly observed over longer time periods. Despite decades of debate over whether memory consolidation or RI recovery are the primary contributors to this effect, behavioral manipulations alone have proven insufficient to dissociate these mechanisms. This impasse underscores the need for a biologically constrained theoretical framework—grounded in known neurophysiological mechanisms of learning and memory—that can generate precise group and participant-level predictions about real-time performance dynamics across different skill contexts.
Here, we introduce a state-space dynamical systems model that attempts to fill this gap. The model explicitly tracks the state of skill learning and effective skill memory capacity, which our recent empirical findings show expands as a function of learning. Performance drops were modeled as a function of both learning-state-independent RI and learning-state-dependent information processing constraints linked to the skill memory capacity. The model was fit to empirical data acquired for three naturalistic skill sequences of different difficulty (where easier sequences display faster unconstrained typing speeds than slower, more difficult ones). Participants (N=407) trained using a 10s practice/10s rest schedule across 26 trials. Learning dynamics differed systematically across skills: MOGs accounted for harder skill performance gains, while both MOGs and practice-based gains were observed for easier ones.
The model captured group-averaged dynamics with high fidelity (R^2 =0.952–0.964 vs. 0.69 for prior approaches) and explained 31–40% of real-time skill performance variance at the level of individual subjects. Critically, removing the RI term did not diminish explanatory power, indicating that intra-trial slowing is driven primarily by memory capacity-based information processing limits.

In summary, these findings show that early real-time skill learning dynamics can be parsimoniously explained by learning-dependent memory capacity expansion and consolidation. The present model framework offers a scalable link between neural mechanisms of learning and consolidation and fine-grained behavioral dynamics across skill contexts.

P1-F-133 - Multi digit synergies reorganize over rest breaks during early naturalistic skill learning

Ethan Buch [1], **Leonardo Cohen** [1], **Sven Bestmann** [2], **William Kistler** [2]
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Details

Motor skills depend on the precise orchestration of temporally ordered action sequences. Early acquisition of challenging skills unfolds across alternating epochs of practice and rest. Performance improvements observed following brief rest breaks ("micro-offline" gains) have been variously attributed to a rapid form of skill memory consolidation, recovery from reactive inhibition (RI) accumulated during practice, or a combination of both. We reasoned that understanding the relationship between early skill gains and detailed changes in finger kinematics could shed light on this issue. For example, early skill gains could arise from non-exclusive optimization of pre-existing movement patterns (e.g.- faster and smoother velocity profiles, uniform increases in coarticulation across all digits, or improved spatial accuracy) or coincide with the emergence of highly coordinated multi-digit synergies (MDSs). Furthermore, expert MDSs might rapidly form early in training or more gradually, and their reorganization could occur preferentially during brief rest breaks—paralleling micro-offline gains—or primarily during active practice.

We studied 20 adults trained on a well-characterized keypress sequence task. Digit trajectories were recorded at 120 Hz and tracked with markerless pose estimation, yielding 8-D time series (4 digits × 2 axes). These trajectories were decomposed with Morlet wavelets, embedded into two dimensions with UMAP, and clustered using HDBSCAN to identify density-defined MDSs. Training-dependent changes in synergy composition were quantified via Jensen–Shannon divergence, and MDS kinematics were recovered by projecting cluster labels back into the original feature space.

We report that initial practice (12 trials; early learning) rapidly shapes individuated keypress actions repertoire into temporally compressed, overlapping, high order expert MDSs. Four distinct synergy classes (novice, exploratory, trial initiation, and expert) characterized by unique temporal and prevalence signatures were identified over the course of training. Skill MDS maps displayed significantly greater reorganization across rest breaks than during active practice (t_{19}=7.33, $p<0.0001$) and predicted the magnitude of micro-offline skill gains during early learning (R^2=0.711, $p<0.001$), indicating a role of offline rapid skill memory consolidation processes. Furthermore, once expert MDSs emerged their expression was remarkably stable—we observed no degradation either within or across trials indicating that accumulating RI did not negatively impact the stability of expert MDSs during early learning.

In summary, expert MDSs emerge rapidly during early learning and do so predominantly across brief rest breaks. MDS stabilization closely tracks both micro-offline performance gains and overall skill acquisition and remained robust even in the presence of accumulating RI effects.

P1-F-134 - Composition and decomposition of high-dimensional complex hand motor components in De novo motor learning

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Details

Traditional motor learning research has primarily concentrated on motor adaptation (Mazzoni & Krakauer, 2006; Yang et al., 2021). These paradigms involve recalibrating existing internal models—adjusting pre-established motor patterns, such as reaching. Even these patterns are initially acquired on a trial-and-error basis, guided by reinforcement learning (RL) over long-term experience. While recent de novo motor learning research has focused on the use of spatiotemporal error, it remains elusive how RL signals drive the organization of novel movement components into motor programs.

Four participants (3 male, 1 female; age 41.5 ± 12.3) controlled visual gauges indicating three mutually orthogonal hand postures (Pattern 1: #1, Pattern 2: #2, and Pattern 3: #3). Initially, they trained on single-gauge targets (#1, #3), each of which was maximized, and dual-gauge targets (#(1,2), #(2,3)), where both components (e.g., #1 and #2) (we described this example as #(1,2)) were simultaneously maximized via continuous gauge feedback. Notably, the dual-gauge displayed the combined scores of these two components, so that participants did not directly train the hand postures corresponding to each individual component. After sufficient training, we investigated performance without gauge feedback for three new conditions.

First, a new #(1,3) dual-gauge target was designed to investigate compositional transfer from single-gauge training of #1 and #3. We quantified vector composition of their scores (X1 for #1 and X2 for #3) to that of the composed target (X* for #(1,3)) as X* = w1X1 + w2X2. One-tailed one-sample *t*-tests against zero revealed that the untrained #(1,3) was successfully reconstructed by significantly positive weights for both #1 (w1 = 0.35±0.11, Mean ± SEM, $p = 0.0229$) and #3 (w2 = 0.70±0.09, $p = 0.0021$).

Second, in contrast, a new #2 single-gauge target was designed to investigate decompositional transfer. We quantified vector decomposition from the dual-gauge training (X1 for #(1,2) or #(2,3)) to the unnecessary component (X2 for #1 or #3) to obtain the decomposed target (X* for #2). In #(1,2)-#1 transfer, w1 was 1.19±0.76 and w2 was -0.69±0.87, and then in #(2,3)-#3 transfer, w1 was 1.89±2.71 and w2 was -1.37±2.86. While these weights did not reach statistical significance ($p > 0.10$) due to individual variability, the directional consistency—positive w1, negative w2—indicates a nascent ability to isolate components.

Together, these findings demonstrate that the CNS can acquire high-dimensional integrated patterns and modular components via RL, and flexibly compose or decompose these motor programs. This supports a compositional architecture for de novo motor learning in redundant systems, where newly built programs can be reconfigured to expand the motor repertoire. This modular flexibility allows the CNS to adaptively reorganize motor components, facilitating the acquisition of a versatile movement library from limited initial experience.

P1-F-135 - Acquisition and interference of a novel visuomotor map formed through De novo motor learning

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Details

Traditional motor learning research has primarily focused on how we adapt existing motor repertoires, such as reaching movements, to external perturbations (Shadmehr et al., 2010). These reaching movements are guided by a visuomotor map that transforms visual target locations into appropriate motor commands (Hayashi et al., 2016). In these well-established systems, learning a new mapping often suffers from anterograde interference, where a previously learned internal model hinders the acquisition

of a conflicting one. Mirror reversal tasks, in particular, are known to be highly challenging in reaching movements because they require the brain to counteract skilled visuomotor maps (Telgen et al., 2014; Kasuga et al., 2015). However, it remains unclear whether a newly acquired ("de novo") visuomotor map, formed over a short experimental period, exhibits similar interference dynamics to those seen in such lifelong visuomotor maps. In this study, we investigated the acquisition and interference of a de novo visuomotor map from hand posture to cursor position using a continuous target-hitting task. A screen cursor was controlled through hand postures, with the second and third principal components (PC2 and PC3) of American Sign Language postures mapped to the cursor's x and y coordinates. The underlying transformation was initially unknown to the participants (18 male and 12 female, age 21–58), who had to discover the mapping rules through exploration and practice. During each 2-minute block, they aimed to hit as many targets as possible, with the target jumping to a new location immediately upon each hit. The experiment consisted of a 16-block baseline phase to learn the novel map, followed by a 12-block mirror phase where one axis was flipped (either x or y). During the baseline phase, the number of target hits significantly increased from 14.13 ± 2.53 (Block 1, mean ± s.e.m.) to 74.93 ± 5.03 (Block 16). Upon introducing the mirror reversal, performance dropped sharply to 26.47 ± 3.78 hits and showed a markedly slower recovery compared to the initial learning phase. To compare learning rates, we fitted an exponential function to the hit counts for each participant. The results indicated that the learning rate in the mirror phase (time constants: 0.11 ± 0.03) was significantly slower than in the baseline phase (0.27 ± 0.06; $t(29) = 2.71$, $p = 0.0112$). These findings demonstrate that even short-term de novo learning leads to significant anterograde interference in subsequent adaptation. Crucially, the presence of such interference serves as evidence that the brain has newly acquired a robust and stable visuomotor map, which acts as a fundamental foundation for implicit motor control and adaptation (Hayashi et al., 2016).

P1-F-136 - Consolidation fails to protect motor memories from interference during implicit learning

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Details

Adapting to a new visuomotor rotation can disrupt the memory of a previously acquired one, particularly when competing actions are learned close together in time (i.e., within the same session). The term "interference" refers to this reduced retention of a previously learned motor mapping following learning of a competing mapping and is often attributed to insufficient consolidation. Introducing a temporal gap between adapting to opposing sensorimotor mappings, particularly a 24-hour delay, is commonly assumed to stabilize the initial memory and reduce interference. It is possible that consolidation through time passage can protect motor memories against interference.

Here, we tested whether a 24-hour consolidation interval is sufficient to prevent interference when competing motor memories are acquired through protocols that emphasize different learning mechanisms. Participants performed an ABA visuomotor adaptation paradigm in which an initial abrupt 30° visuomotor rotation (A) was learned, followed 24-hours later by an opposing rotation (B), and then retested on A after a further 24-hour delay. Learning during B was manipulated across groups to emphasize either explicit or implicit processes. In one group, B was learned using delayed visual-feedback to promote explicit, strategy-based compensation. In a second group, B was learned using an error-clamped paradigm designed to emphasize implicit recalibration. A third control group learned A twice with a 48-hour interval and no intervening B learning.

Despite the 24-hour gap between A and B, robust interference was observed when B was acquired implicitly. Participants in the error-clamped group showed no benefit from prior learning when retested on A, with performance resembling naïve adaptation. In contrast, when B was learned explicitly through delayed-feedback, performance during relearning of A was preserved, indicating retention of the original motor memory. The control group, which learned A twice without intervening B learning, showed clear

retention upon relearning, confirming that the observed interference could not be attributed to memory decay alone.
These findings demonstrate that consolidation time alone is insufficient to protect motor memories from interference. Instead, susceptibility to interference depends on how competing motor memories are acquired. Implicit recalibration appears to interfere with existing sensorimotor mappings even after extended consolidation, whereas recalibrations acquired with explicit strategies coexist without disrupting previously learned mappings. Together, these results challenge the assumption that temporal separation guarantees motor memory stability and suggest that interference reflects mechanism specific disruption of consolidated representations rather than a failure of consolidation itself.

P1-F-137 - Prior experience regulates error sensitivity in implicit motor learning

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Details

Adaptative behavior depends on learning from sensory prediction errors and on regulating how strongly these errors drive learning over time. In visuomotor adaptation, repeated exposure to identical errors results in attenuation of implicit learning, evident as reduced adaptation magnitude and smaller aftereffects. However, the mechanism underlying this effect remains unclear. One hypothesis attributes attenuation to interference between competing action-feedback mappings, whereby learning is reduced when the same action becomes associated with discrepant sensory consequences across task phases. An alternative idea, however, is that attenuation reflects a history-dependent modulation of error sensitivity.

To distinguish between these competing frameworks, we isolated the contribution of prior error exposure from changes in action-feedback contingencies. In our first two experiments (n=20 each), subjects adapted to a 30° error-clamp and were re-exposed to the same perturbation after an intervening washout period with either delayed endpoint feedback (exp 1) or no feedback (exp 2). In experiments 3 and 4 (n=20 each), subjects completed a long baseline block either with (exp 3) or without (exp 4) feedback, followed by a single error-clamp learning block.

We observed robust attenuation during re-learning in exp 1 and 2, evident as a reduced asymptote and smaller after-effects. While the attenuation of exp 1 could be explained by interference, its persistence in exp 2 despite the absence of any discrepant action-feedback contingencies during washout indicated that interference is not required. Consistent with this idea, adaptation in exp 3 and 4 was comparable to naïve learning (of exp 1 and 2), demonstrating that prolonged exposure to veridical or absent feedback alone does not induce attenuation. In sum, attenuation was observed only after prior error-clamp exposure but not otherwise, suggesting that it is likely linked to dynamic regulation of error sensitivity rather than interference.

We formalize this idea via a minimal state-space model in which error sensitivity is globally regulated by a slower latent state that tracks cumulative exposure to error. The model accounts for the patterns observed across exp 1-4 and predicts that attenuation should generalize across error sign. We tested this idea in a fifth experiment (n=20) wherein subjects first adapted to a 30° error-clamp, then underwent no-feedback washout, and then re-adapted to an opposite clamp of the same magnitude. We again found significant attenuation despite full washout of the adapted motor state and error reversal.

Together, our findings suggest that attenuation of implicit adaptation reflects a history-dependent regulation of error sensitivity. More broadly, they suggest that adaptive learning systems regulate

plasticity based on the informational value of prediction errors, offering a candidate organizing principle for balancing flexibility and stability in learning.

P1-F-138 - Modulation of maximal motor performance by visual feedback: Effects of manipulation magnitude and explicit knowledge

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Details

Individual maximal motor performance is constrained not only by physiological but also by psychological inhibition to protect the body. This is modulated by explicit perceivable contextual manipulation such as the presence of loud noise, rewards, or other people. However, it is also modulated even when participants report little or no awareness of the manipulation. Here, by combining varied magnitude and direction of feedback manipulation, within- and between-participant designs, and knowledge about the manipulation conditions, across multiple studies, we identified when implicit feedback enhances maximal motor performance and when it fails.

Participants applied force on a pinching device with the thumb and index fingers for 5 seconds under real-time visual feedback of the applied force displayed on a screen. They exerted the maximum and 50% subjective force in 3 trials each. Each trial was assigned unwittingly to one of the three types of feedback types: control (no manipulation), upward (gradually increased in the second half), or downward (gradually decreased in the second half). We performed three studies where the slope of increase or decrease of manipulation and the information about the manipulation participants get were altered.

The average of the applied force in the last 1 second divided by the first 1 second of the trial was compared across trials by a paired t-test. In both tasks, the average force was significantly lager with the downwards feedback (average increase of 7.9%) and smaller with the upwards feedback (average decrease of 7.0%) compared to control, only when the manipulation slope was 30%/s when the average force during the first half of each trial was set to 100%. Furthermore, we found the effect diminishes when the participants are informed about feedback manipulation.

The modulations of the limit occurred significantly when participants were not aware of the manipulation, indicating that the motor performance was modulated independently of the consciousness. The results reveal the specific conditions for implicit enhancement in maximal motor performance, providing a new framework for understanding how human dynamically modulates the limit based on the reliability and awareness of sensory information. This study can contribute to the improvement of motor performance and promotion of skill acquisition, where maximizing performance without inducing mental fatigue or excessive effort is important.

P1-F-139 - Cross-cultural analysis of visuomotor adaptation in Japanese and Norwegian young adults: Effects of input devices and gaze-hand coordination

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Details

Visuomotor adaptation is a fundamental process that allows the motor system to maintain accuracy in response to environmental perturbations. In modern digitized societies, the ability to acquire new internal sensorimotor models is essential for mastering various digital tools. While the neural mechanisms of adaptation are well-documented, the interaction between device-specific motor demands—such as the spatial decoupling in mouse operations—and population-level differences

remains less understood. This study examines visuomotor learning and gaze-tracking strategies in young adults from Japan and Norway, comparing performance across standard mouse and trackball interfaces to determine how physical interface characteristics influence the acquisition and consolidation of motor programs.
Fifty-eight healthy right-handed young adults (Japan: n = 20, 21.9 ± 3.8 years; Norway: n = 38, 26.8 ± 3.6 years) participated. Participants were randomly assigned to a mouse or trackball group. A continuous tracking task with a 150˚ clockwise rotation was performed across two sessions one week apart. We calculated four learning indices: training effects (error reduction rate in the early stage of Day 1 adaptation), savings (the efficiency comparing error reduction rates between Day 1 and Day 2 early adaptation), unlearning (the rate of error increase from the final Day 1 adaptation block to the first Day 2 adaptation block), and aftereffects (the magnitude of error increase upon sudden removal of rotation). A two-way between-subjects ANOVA (device × country) was conducted for each index. Gaze behavior was recorded via Pupil Neon (Japan) and Tobii Pro Glasses 3 (Norway), with trajectories analyzed using DeepLabCut.
No significant main effects or interactions were found for training effects, savings, or unlearning ($p > 0.05$). However, aftereffects were significantly larger in the trackball group ($F(1,54) = 9.2$, $p < 0.01$, $\eta_p^2 = 0.15$) and in the Japanese group ($F(1,54) = 5.11$, $p < 0.05$, $\eta_p^2 = 0.09$). There was no significant interaction between the device type and the country ($F(1,54) = 0.11$, $p = 0.75$, $\eta_p^2 = 0.002$).
Our findings confirm that visuomotor adaptation to rotated environments robustly generalizes across Japanese and Norwegian young adult populations. However, the persistence and retrieval of motor memory, as measured by aftereffects, are significantly influenced by both the specific effector used and the population's background. This suggests that while the basic capacity for motor learning is universal, the strength of internal models is modulated by specific effectors and population backgrounds. Notably, the observed cultural differences in aftereffects are inconsistent with our previous findings (Yamada et al., 2025). We will further examine the discrepancy in the presentation. The poster will provide a comprehensive analysis of how gaze-hand coordination strategies evolve to accommodate the perturbation across different digital tools and cultural cohorts.

P1-F-140 - Distinct effects of acute and chronic achilles tendon pain on motor unit control and force-tracking learning

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Details
Pain is known to alter motor behaviour, yet its effects on motor learning and the underlying neural control strategies remain poorly understood. This study investigated the impact of experimental (acute) and chronic Achilles tendon pain on the acquisition and retention of an isometric plantar-flexion force-tracking task, while concurrently examining motor unit behaviour of the triceps surae using high-density surface electromyography (HD-sEMG).
Thirty-six participants were allocated to one of three groups: an experimental pain group (hypertonic saline injection into the Achilles tendon; $n = 12$), a chronic pain group (chronic Achilles tendinopathy; $n = 12$), or a healthy control group ($n = 12$). All participants performed an isometric plantar-flexion torque-tracking task requiring learning to match randomly varying force targets across two sessions (day 1: acquisition; day 2: retention). Motor performance was quantified using torque-tracking error, while motor unit firing properties (mean discharge rate and discharge rate variability) and pooled motor unit

coherence were derived from HD-sEMG recordings of the triceps surae muscles (gastrocnemius medialis, gastrocnemius lateralis, and soleus).
All groups demonstrated the capacity to learn the task; however, torque-tracking performance differed significantly between groups, with a significant day × trial × group interaction (p = 0.022). Individuals with chronic pain exhibited substantially greater tracking error than both healthy controls and the experimental pain group. In contrast, participants experiencing acute experimental pain showed reduced performance during the early stages of acquisition but achieved performance comparable to controls during late acquisition and retention. Notably, despite preserved behavioural performance, the experimental pain group exhibited alterations in motor unit behaviour that resembled those observed in the chronic pain group. Specifically, both pain groups demonstrated increased motor unit firing variability and elevated pooled motor unit coherence within the tremor frequency band (6–12 Hz) compared with controls.
Together, these findings indicate that motor unit firing strategies are highly sensitive to nociceptive input and are adaptively modified during acute pain to preserve task performance. However, in chronic pain, the persistence of these altered neural strategies is accompanied by substantial deficits in force-tracking performance. The maintenance of aberrant motor unit firing patterns over time may restrict available motor resources and contribute to long-term deficits in force control. These results have important implications for rehabilitation, suggesting that engaging in motor learning tasks in the presence of pain may negatively influence long-term outcomes and should be carefully considered in therapeutic practice.

P1-F-141 - Mechanisms underlying enhanced implicit recalibration and attenuated strategy use with age

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Details

Deterioration in motor control is a hallmark of aging, significantly contributing to a decline in quality of life. More controversial is the question of whether and how aging impacts motor learning. We hypothesized that the inconsistent picture observed in the current literature can be attributed to at least two factors. First, aging studies tend to be underpowered. Second, the learning assays used in experiments tend to reflect the operation of multiple learning processes, making it difficult to make inferences across studies.
We took a two-pronged approach to address these issues. We first performed a meta-analysis of the motor adaptation literature focusing on outcome measures that provide estimates of explicit and implicit components of adaptation. This analysis involving 2326 participants across 44 studies revealed a dissociation with aging: learning associated with strategy use was attenuated in older adults, whereas performance changes associated with implicit recalibration were enhanced. Motivated by these effects, we conducted a series of experiments using tasks designed to isolate implicit or explicit motor learning processes. In each experiment, we compared the performance of younger (ages 18–30) and older (ages 65–80) adults.
To isolate strategy use, we delayed endpoint feedback, a manipulation that abolishes implicit recalibration. Consistent with the meta-analysis results, we found a marked age-related impairment in strategy use. To probe the source of this impairment, we compared conditions in which learning is hypothesized to rely on stimulus-response caching (2 targets) or the implementation of an algorithm (8 targets). Surprisingly, older adults showed a selective deficit in the 2-target condition, but not the 8-target condition. This pattern suggests that aging selectively impairs response-caching, though it may also be that the 8-target condition boosts learning by providing a richer context.

To isolate implicit recalibration, we used clamped feedback, in which cursor position is independent of hand position, rendering strategy use irrelevant. Older adults showed a marked enhancement of implicit recalibration. To explain this, we turned to the Perceptual Re-alignment Hypothesis, which posits that recalibration is driven by a perceptual error, the mismatch between the perceived and desired position of the hand (i.e., the target). Recalibration would increase if this error increased due to greater weighting of visual information (the clamped feedback) as a result of reduced proprioceptive reliability. Consistent with this account, older adults exhibited increased proprioceptive variability, and greater variability was associated with stronger implicit recalibration. Together, these findings link enhanced implicit recalibration in aging to altered weighting of sensory information.
Taken together, these meta-analytic and empirical results show that aging differentially impacts the mechanisms underlying sensorimotor learning.

P1-F-142 - Redefining explicit adaptation into three phenotypes

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Details

Explicit strategies in visuomotor adaptation are commonly described as the deliberate implementation of aiming strategies (Taylor et al. 2014; McDougle et al. 2015). Strategies are thought to emerge smoothly, as an inverted exponential curve. However, individual aiming time courses differ sharply from the average pattern. Many participants show sudden changes in aiming, akin to aha!-learning (D'Amario et al. 2024), or erratic patterns, that may indicate solution exploration. Thus, exponential patterns may only result from averaging. Here, we assess how explicit strategy develops during adaptation to a visuomotor rotation.
Participants reached to targets while controlling a cursor under one of five rotations: 20°, 30°, 40°, 50°, or 60°. Explicit behaviour was measured using an arrow that participants rotated to indicate their planned movement direction before each reach. Consistent with previous work, (e.g. 't Hart et al., 2024; D'Amario et al., 2024) many learners (here: 48%) do not develop a stable strategy at all, but the percentage of people developing a stable strategy increases with rotation size from 15% to 70%. We also find that the time courses of strategy development are very heterogenous, belying the cognitive nature of strategy development. To better understand these patterns, we ran an unsupervised classification algorithm (kmeans clustering). We identify three strategy learning profiles. Participants' strategies can: 1) increase stepwise at one moment of insight (67.2%), 2) fluctuate as if the participant is exploring optimal strategies until this stabilizes (21.4%), or 3) sometimes do develop gradually (11.4%). This corresponds with manual labeling of learning styles (χ^2=24.67, p<.001). Cognitive learning may benefit from how clear the errors are, such that larger rotations may speed up strategy development. However, we find the opposite: strategies settle later in larger rotations. We do see a different mix of learning styles at different rotation sizes, with stepwise learning accounting for a stable proportion of participants, except at the lowest rotations. Exploratory learning only accounts for a small fraction of participants, but increases sharply at the largest rotation. In short, rotation size affects the probability, magnitude, stabilization time and style of explicit strategy learning. Future work should continue to test explicit strategy development at the individual level. Doing so will drive more accurate measures, understanding and models of explicit adaptation. This is necessary to isolate implicit and explicit adaptation from each other. In turn, this allows studying how these two kinds of adaptation interact. Overall, our results emphasize that incorporating individual time courses of visuomotor adaptation responses greatly enhances true understanding of the underlying processes.

P1-F-143 - Longitudinal neurofeedback training enhances voluntary control of Peripheral Beta-Band Oscillations for non-invasive motor augmentation

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Details

Non-invasive motor interfaces based on peripheral electrophysiological signals are emerging as an alternative to invasive cortical recordings. Peripheral beta band oscillations, specifically, can be reliably extracted during isometric contractions and do not interfere with force production. However, voluntary modulation of this signal remains challenging. We developed a 10-day neurofeedback protocol to test whether participants could learn to increase peripheral beta band activity and whether such training induces measurable physiological changes. The paradigm leveraged the natural rise in beta synchronization during movement cancellation to frame the signal as a two-state control variable and facilitate intuitive modulation.

Each daily session included a familiarization phase, where subjects practiced inhibiting a prepared movement in a GO/NO-GO task, followed by an autonomous control phase providing real-time feedback on beta band power during self-initiated movement cancellation. Bipolar EMG was used to extract beta band features, while behavioural performance was quantified through trial accuracy and task scores. To assess training-related physiological adaptations, participants underwent pre- and post-training sessions with concurrent EEG and HD-EMG during isometric contractions to evaluate changes in beta band power, intramuscular coherence, and corticomuscular coupling.

Over time, participants showed clear behavioural and physiological improvements in their ability to modulate peripheral β-band activity. In the familiarization phase, β-band power during movement cancellation increased significantly, without changes in α-band activity or timing and duration of the β rebound, indicating a specific enhancement of β-related synchronisation. A comparable increase in β-power was also observed during the autonomous control phase. Intramuscular coherence in the β range also rose, reflecting a strengthening of the common synaptic input to the motor neuron pool. Behaviourally, participants achieved higher daily scores over time, supported by a reduction in perceived overall effort, although mental and physical demands remained stable. These improvements were not explained by better force steadiness alone; instead, there was a day-to-day decrease in the coefficient of variation of force, suggesting that participants became more stable during inhibition. Crucially, EEG–HD-EMG recordings showed no changes in cortical β-power or corticomuscular coherence.

Overall, these results show that voluntary control of peripheral beta band oscillations can be enhanced through longitudinal training, highlighting the potential of this signal for non-invasive motor-augmentation applications. However, the improvement remains modest, and participants reported that the task continued to feel difficult. The gain in control was accompanied by an increase in peripheral beta band power, an effect that did not appear at the cortical level. This pattern suggests that training may have induced peripheral adaptations—consistent with day-to-day reduction in force coefficient of variation and the increases in beta band power and common input—or alternatively reflects a behavioural strategy that participants progressively refined over time.

P1-F-144 - Visual perspective taking in remote visuomotor control

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Details

Human interaction with the world is increasingly mediated by interfaces that control *tools* remotely: computer mice control *cursors*, levers control *drones*, and joysticks control *robots*. In these scenarios, the human and tool operate in different workspaces, and the tool performs actions on the human's behalf. A consequence of this is that there can be incongruencies between the human and tool's visual

perspective because the human remains in a fixed orientation whilst they update the orientation of the tool to complete a given task. For example, directing a robot to move forward could move it either towards or away from the human dependent upon the direction the robot is facing. To investigate the impact of the congruency between human and robot's orientation on visuomotor learning, we developed a novel control system. Participants sat on a pressure sensing mat and controlled a robot by acting as a human joystick: their lateral movements controlled the angular velocity of the robot, and their sagittal movements controlled the linear velocity of the robot. In the *Expectations Phase* we wanted to gain insight into whether participants expected the mapping function that converted their movements into those of the robot to be coded in a user-centric reference frame (robot's orientation was irrelevant) or a robot-centric reference frame (robot's orientation was relevant). Participants were informed that the robot was inactive and were asked to perform the movements they predicted would be necessary to guide the robot to the target and bring it to a stop. The location of the target was always forwards relative to the robot's orientation but in four different directions relative to the participant's orientation. In the *Navigation Phase,* we examined the impact of the robot's starting orientation on visuomotor learning, and of its momentary orientation on visuomotor control. Participants were assigned to either a congruent or incongruent starting orientation and given 10 minutes to complete as many laps of a track as possible using the now active robot. There were individual differences in participants' expectations regarding the mapping: 43% of participants expected a robot-centric mapping and 19% of participants expected a user-centric mapping. We classified 17% of participants as *half-centric* because their movements indicated a combination of both mappings. Several participants (21%) adopted idiosyncratic strategies including pointing with their arms, lifting their legs, or rotating their body. The robot's starting orientation had no effect on the time to complete the first lap or the total number of laps completed. Nevertheless, both groups took longer to complete sections of the track and made more errors when the robot's momentary orientation was incongruent to themselves. This suggests that participants struggle to take the robot's visual perspective which should be considered in the design of remote-control systems.

P1-F-145 - Express sensorimotor responses to visual and somatosensory stimuli

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Details

Humans can generate express (<100 ms), stimulus-locked responses in proximal arm muscles when reaching to visual targets. These rapid responses are thought to arise from fast visuomotor transformations conveyed via subcortical tecto-reticulospinal pathways. Because midbrain structures integrate multisensory information to orient the eyes, head, and limbs, such express responses might not be restricted to visual targets, and may also arise from somatosensory input. However, direct evidence for somatosensory-evoked express muscle responses in humans is currently lacking.
To address this, we used a rapid reaching task in which participants were seated and reached toward brief sensory targets presented on the left or right knees under visual-only and somatosensory-only conditions, or under bimodal visuo-somatosensory conditions that were either spatially congruent (both stimuli on the same knee) or incongruent (one stimulus on the left knee, the other on the right knee). All trial types were randomly intermingled and participants were instructed to reach to the first target they detected on incongruent trials. Visual targets were delivered via a light-emitting diode (12ms duration), while somatosensory targets consisted of a brief electrical pulse train (3 pulses at 250Hz) delivered to the skin surface. Surface EMG was recorded from pectoralis major muscle to quantify the prevalence, magnitude, and onset timing of express muscle responses. Receiver operating characteristic (ROC) analyses were also applied to EMG signals to estimate the earliest time at which muscle activity could

discriminate target side. The magnitude of express sensorimotor responses was defined as the RMS EMG within a 70–110ms window following stimulus onset.
We found that both visual-only and somatosensory-only stimuli elicited express muscle responses. While reaction times were faster for somatosensory (189+/-6ms) than visual targets (212+/-6ms), the prevalence, onset latency, and magnitude of muscle express responses were comparable across modalities. Congruent bimodal visuo-somatosensory stimuli produced shorter EMG onset latency and ROC-based discrimination times of the express sensorimotor response than visual-only and somatosensory-only conditions. The prevalence of express responses was similar for somatosensory-only and congruent bimodal stimuli and greater than for visual-only stimuli. EMG magnitude within the express response window was marginally larger for bimodal stimuli than either unimodal target. Congruent visuo-somatosensory trials exhibited earlier EMG onset and ROC discrimination times than incongruent trials, but express response prevalence and magnitude were similar.
Together, these findings provide the first evidence that express, stimulus-locked muscle responses can contribute to acquisition of somatosensory targets in humans. The results also show that multisensory integration and spatial congruency shape the temporal dynamics of these rapid sensorimotor processes. This pattern is consistent with integration of early-stage signals in multisensory pathways such as the superior colliculus.

P1-F-146 - Cortical beta synchronization during virtual stick balancing as a dynamical biomarker of motor learning

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Details

Stick-balancing is a typical task for studying motor control strategies, where individuals balance a stick manually to stabilize it at the upright position. In this case, the controlled object is modeled as an inverted pendulum exhibiting unstable saddle point equilibrium with stable and unstable manifolds. While neural transmission delays and sensory noise impose significant challenges to stabilization, humans can acquire well-defined control strategies to overcome these difficulties. The intermittent control is one of such promising strategies. It is energetically efficient while robust against feedback delays and motor noise, and can reproduce complexity in temporal patterns of postural sway during quiet stance and stick balancing. In the intermittent strategy, active control is switched ON to prevent the pendulum from falling and switched OFF when the state point of the pendulum is located near the stable manifold, thereby utilizing the contracting dynamics along the stable manifold to bring the state point toward the upright position.
The intermittent behavior of active intervention for stabilizing the pendulum enables epoch-based EEG analysis by segmenting EEG data into discrete ON-OFF switching of feedback control. Previous studies on quiet stance have revealed that parietal EEG exhibits beta-band event-related desynchronization (ERD) during ON-period of the control and subsequent event-related synchronization (ERS) around the onset of OFF-period of control.
In this study, we performed an experiment to examine whether beta-ERD/ERS patterns can be observed during visuo-motor virtual stick-balancing tasks as in quiet stance. During the task, subjects applied torque to the virtual stick using a joystick controlled by both hands based on the visual feedback information on the stick motion. Subjects performed many trials until ten successful trials without falls were achieved. To evaluate the effects of motor learning, subjects performed a three-phase protocol: an initial round of normal tasks, two challenging tasks with artificial delays and noise, and a final round of normal tasks. We then compared behavioral and EEG data between the initial and final rounds of normal tasks.

For data analysis, independent components of EEG were clustered based on dipole locations and moments using a Variational Bayesian Gaussian Mixture Model (VBGMM). We specifically examined clusters with dipoles located near the parietal region. We successfully identified dipole groups that showed ERSP with beta-ERD/ERS as in quiet stance. Furthermore, we found that, as learning progressed, mean and variance of distance between the state point at the onset of OFF-period and the stable manifold decreased. Crucially, a smaller distance to the stable manifold was associated with more prominent beta-ERS. These findings indicate that in the stick balancing, the brain recognizes the stable manifold and strategically exploits it for the intermittent motor control strategy.

P1-F-147 - Bilateral premotor cortical plasticity during skill acquisition of intracortical BCI typing

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Details

Introduction

In the BrainGate2 clinical trial, a participant with tetraplegia (T18) used an intracortical brain–computer interface (BCI) to perform neural typing. Typing speed improved substantially across sessions despite stable decoder performance, indicating acquisition of a new motor skill. Here, we investigated how neural population dynamics reorganized to support skill learning.

Methods

One participant with chronic cervical spinal cord injury was implanted with six 64-channel arrays in bilateral dorsal premotor cortex (area 6d; four left, two right). Thirty finger movements, defined by three gestures (up, down, in) for each finger, were mapped to keys in a QWERTY layout. The participant completed seven closed-loop sentence copy-typing sessions. Neural activity was decoded in real time using a recurrent neural network with a shared architecture across days. Offline analyses used hidden Markov model–based forced alignment to segment tokens, demixed principal component analysis (dPCA) to extract low-dimensional population representations, and canonical correlation analysis (CCA) to align activity across sessions.

Results

Across sessions, character error rate remained stable at a mean of 10.2%, while typing speed increased from a mean of 34 to 91 characters per minute (CPM). Neural activity segmented using HMM-based forced alignment was projected into the dPC1–2 plane using dPCA for hand-, finger-, and gesture-related marginalizations. The magnitude of neural trajectories changed significantly across sessions (Kruskal–Wallis test, $p < 0.001$), showing a decreasing trend overtime.

Trajectory magnitude was significantly negatively correlated with CPM, indicating more compact neuralre presentations with improved typing speed. Differences in trajectory magnitude between session pairs increased with inter-session interval, yielding a significant positive correlation.

After alignment using CCA, this correlation was abolished in right 6d, whereas in left 6d, it was eliminated for finger-related representations but persisted for hand- and gesture-related representations ($p = 0.021$ and $p < 0.001$, respectively).

Conclusion

Skill acquisition was associated with systematic compression of low-dimensional neural trajectories. Cross-session CCA alignment effectively captured activity in right 6d, but only partially accounted for activity in left 6d, indicating hemispheric differences in learning-related neural plasticity.

P1-F-148 - Somatosensory inputs paired with auditory perceptual training modulate speech motor adaptation

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Details

Sensorimotor control of speech interacts with speech perceptual system, and vice versa. Given that somatosensory feedback is fundamental in sensorimotor control and that somatosensory signals conveying articulatory movement information can modify speech perception, the somatosensory system may play a primary role in linking speech perception and production. We hypothesized that receiving somatosensory inputs in conjunction with auditory inputs is critical for calibrating auditory-somatosensory representations and/or sensorimotor processing underlying both speech production and perception. The current study tested this hypothesis by examining whether and how paired auditory-somatosensory stimulation during a perceptual training affects speech sensorimotor adaptation.
The experiment consisted of a perceptual training task followed by a speech sensorimotor adaptation task. Participants were native French speakers. During perceptual training, a vowel identification test was conducted with four auditory stimuli close to the categorical boundary between the French words “taie” and “ta”. Somatosensory stimulation involving orofacial skin stretch was applied concurrently with the auditory stimuli. Two somatosensory conditions were tested, involving either upward or downward skin-stretch, in two separate groups of participants. In a subsequent speech motor adaptation task, participants repeatedly produced /ɛ/ embedded in French word “taie” across trials. The first formant (F1, the lowest peak of spectral envelop) of the produced sound was shifted upward to modify the auditory feedback toward “ta”, inducing a compensatory adaptation expected to result in a decrease in the produced F1.
We observed the expected adaptation response in both experimental groups. Comparisons between groups revealed that the upward skin-stretch group showed a significantly smaller adaptation amplitude than the downward group. In addition, somatosensory stimulation modulated categorical sensitivity over the course of the perceptual training: the upward group showed significantly higher sensitivity compared with the downward group at the end of the perceptual training. Importantly, these measures were significantly and negatively correlated, with smaller adaptation linked to greater sensitivity. We interpreted these findings as suggesting that the somatosensory inputs during prior perceptual training may have induced changes in sensory weighing during subsequent sensorimotor adaptation task. Greater weighing of the somatosensory feedback may lead to more precise categorization of the acoustically ambiguous speech sounds and decreased sensitivity to the F1 perturbation during motor adaptation, resulting in smaller adaptation. Together, these results highlight a role of the somatosensory system in linking speech production and perception. Somatosensory-based manipulation during perception may therefore open novel avenues for the development of speech learning approaches.

P1-F-149 - Temporal neural dynamics associated with cognitive flexibility in neurotypical young adults

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Details

Individuals with movement disorders often experience cognitive deficits in parallel[2,3], however current gold-standard treatments are not designed to target these cognitive impairments[4,5] due, in part, to a limited understanding of their underlying neural mechanisms. Current work investigating cognitive impairments either use coarse pen-and-paper clinical assessments that are difficult to pair with neurophysiological recordings or instrumented assessments that lack the capacity to isolate distinct cognitive functions[1]. Prior work suggests that the cortical processes underlying cognitive flexibility and

balance ability may overlap[6]. Given that Parkinson's disease (PD) impairs both functions[6–11], isolating the neural correlates specific to cognitive flexibility may reveal mechanisms underlying aberrant cognitive-motor integration in this disorder. We have designed a novel cognitive task that isolates distinct cognitive functions (i.e., visual search, motor planning, general processing speed, response inhibition, cognitive set shifting, and movement), implemented on a robotic manipulandum (KinArm End-Point Lab) with the capacity to pair with synchronized electroencephalography (EEG) recordings. In our task, participants reach from a starting target toward a second target, with the required behavior (i.e., reaching or not reaching) determined by the relationship between targets and the active rule. In the first two blocks, participants learn separate rule sets under stable conditions. In the final block, rules alternate unpredictably trial-to-trial, with switches in rule sets occurring less frequent than repetitions to enhance the salience of set-shifting demands. Preliminary behavioral results in neurotypical young adults (YA, N = 6) show increased reaction times (i.e., the time from presentation of the second target to movement onset) across blocks of increasing cognitive load and in shift trials versus non-shift trials.

We now aim to record EEG while performing the behavioral task to identify differences in brain activity as reaction times increase in YA. We hypothesize that the supplementary motor area (SMA)[12,13], a region at the intersection of cognitive and motor circuitry, and beta oscillations[14–16] (13-30 Hz) which are proposed to play a global role in the maintenance of the current set contribute to successful cognitive flexibility. We predict that an increased demand of successful cognitive flexibility in shift versus non-shift trials will coincide with SMA beta desynchronization. Once a neural biomarker for cognitive flexibility in YAs is identified, we can begin to investigate altered neural dynamics for early detection and targeted interventions in individuals with cognitive impairments such as PD.

P1-F-150 - Learning to throw against the current: Internal models of object–environment dynamics

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Details

Adaptation is typically studied using perturbations applied directly to the limb or cursor. Yet in everyday action, adaptation involves compensating for the physical impacts of inferred, but often uncertain environmental dynamics acting on manipulated objects, an aspect often overlooked in traditional sensorimotor adaptation paradigms. To examine how people learn under more realistic object–environment interactions, we designed a novel virtual reality task where participants launched a virtual ball across a dynamic, lateral water current to spatially distinct targets. The velocity of the current (2.0 m/s or 3.0 m/s) was manipulated to test how the scale of this perturbation influences learning. Because the current introduces a constant lateral force on the ball's flight, compensation depends on the non-linear interactions between launch angle and speed. This results in a spatially dependent, redundant solution space, creating a more complex control problem than standard visuomotor rotation tasks.
A physics-based simulation defined each target's solution space—the set of launch angle–speed combinations that result in a hit under each current velocity. Upstream targets exhibited narrower solution spaces due to the opposing current, whereas downstream targets had broader solution spaces and thus permitted more flexible control policies. Learning was quantified as the lateral miss distance (cm) between the projectile and target at the point of closest approach. To test whether people form an internal representation of the water current, we examined whether improvement on one set of targets would generalize to novel, adjacent targets that impose different solution spaces.
During the task, participants launched a projectile toward four targets. Targets were presented in a blocked design, starting with a Training phase (current on) with one upstream-downstream pair of targets, followed by an alternating no-current Washout phase to assess aftereffects and retention. This Training-Washout sequence was then repeated for a second, spatially shifted pair of targets. This

allowed us to measure generalization by comparing experienced participants during the second Training phase against naive performance on the same targets.
Our findings revealed that participants developed a robust internal model of the projectile–environment interaction, as evidenced by a reduction in errors and significant aftereffects during Washout across all groups. Between-group comparisons revealed that learning transferred to novel targets, whereby participants with prior experience compensating for the current showed significantly lower initial errors for novel targets compared to naive participants on the same targets. Finally, the magnitude of the environmental perturbation significantly scaled the extent of adaptation, such that adaptation was larger under the higher velocity current. Despite the differences in adaptive gain, the pattern of generalization and performance during Washout (no-current trials) remained similar.
Together, these results show that people rapidly form internal models under altered projectile–environment dynamics, and that prior experience drives spatially tuned generalization. These results provide insight into the mechanisms underlying sensorimotor adaptation for changing object–environment dynamics, suggesting the brain forms an internal model representing the physics of the environment.

P1-F-151 - A longitudinal examination of hand representation reorganization after right sensorimotor stroke

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Details

The extent and nature of sensorimotor cortical plasticity remains a subject of intense debate. While earlier findings from non-human primates and individuals with limb loss suggested large-scale reorganization in sensorimotor cortex, often used to explain phenomena such as phantom limbs, more recent evidence has challenged these accounts, demonstrating preserved cortical maps even in the absence of input. However, this debate has been primarily informed by studies of amputation. Limited work has examined these mechanisms in individuals with sensorimotor stroke, where the neural substrate itself is compromised. Furthermore, while previous research has focused heavily on local changes within sensorimotor cortex, plasticity may instead rely on recruitment of regions outside of primary sensorimotor areas.
Here, we present results from a longitudinal case study of JN, who suffered a large right hemisphere frontoparietal stroke at age 17, encompassing much of primary sensorimotor cortex. Behavioral assessment of the contralesional left hand using Semmes-Weinstein monofilaments revealed elevated detection thresholds for touch and impaired tactile localization. Interestingly, subjective sensation evolved over time: one to two years post-stroke, JN reported moving or radiating sensations in response to static suprathreshold touch; by three years post-stroke, these radiated sensations resolved, leaving only tactile mislocalization. Motor control was also affected, characterized by significantly impaired grip strength and difficulty individuating finger movements of the contralesional hand.
To examine sensorimotor reorganization, we scanned JN in two separate sessions (two and three years post-stroke). In both sessions, we utilized somatosensory localizer runs to identify active regions for tactile stimulation, alongside Representational Similarity Analysis (RSA) to examine whether somatosensory hand representations emerge in areas beyond the lesion after stroke.
In both sessions, we found expected representations of the unaffected (ipsilesional) right hand in left S1 and S2. For the affected contralesional left hand, the first session (two years post-stroke) revealed evidence of a hand representation in the intact, ipsilateral left primary and secondary somatosensory cortices. However, in the second session (three years post-stroke), this ipsilateral representation in S1 and S2 was absent. Instead, we found evidence for contralesional hand representations in left parietal cortex, right frontal cortex, and the left cerebellum. These findings suggest that post-stroke plasticity is a

dynamic, time-dependent process that may initially rely on unmasked ipsilateral pathways before settling into a distributed compensatory network.

P1-F-152 - Impact of explicitness and interference on motor memory consolidation following opposing visuomotor adaptations

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Details

Motor memory consolidation ensures that learned movements persist and resist interference. While visuomotor adaptation savings has been linked to explicit strategies, the role of explicitness in consolidation under interference remains unclear. Here, we examined how explicitness of a visuomotor perturbation and interference caused by the introduction of conflicting conditions interact to influence short- and long-term savings following two opposing visuomotor adaptations. Forty right-handed adults were assigned to four groups in a 2×2 design: (1) more implicit + more interference (ABA-Imp), (2) more explicit + more interference (ABA-Exp), (3) more implicit + less interference (AWBA-Imp), and (4) more explicit + less interference (AWBA-Exp). All groups adapted to a 24° counterclockwise rotation (A1), then learned an opposing clockwise rotation (B) either immediately without washout (more interference) or after 24 hours with washout (less interference). Readaptation to the original rotation (A2) occurred at 5 min, 1 week, and 1 month. Savings was quantified using initial directional error and learning rate. Explicitness of the perturbation had no significant effect on savings at any time point. In contrast, interference caused by the opposing conditions strongly influenced consolidation: less-interference groups exhibited significantly greater savings at 1 week and 1 month compared to more-interference groups ($p < .001$). Short-term savings (5 min) was absent across all groups, likely due to competition between neural resources during close succession learning. Long-term savings persisted only when interference was minimized, suggesting that temporal spacing and washout promote memory stabilization. Findings indicate that consolidation of motor memories following visuomotor adaptation depends on interference level, not explicitness of a perturbation. These findings challenge the prevailing view that explicit strategies enhance retention and underscore the importance of designing training protocols that reduce interference. This work advances understanding of motor memory dynamics and offers practical insights for rehabilitation scheduling and skill acquisition strategies.

P1-F-153 - Heightened arousal induced by task-relevant psychological pressure reduces learning rate in force-field adaptation

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Details

Arousal-learning interactions are fundamental to sensorimotor control and critical to performance in high-stakes contexts. Autonomic nervous system (ANS) signals such as pupil diameter and heart rate are increasingly viewed as readouts of latent internal states that gate learning (Nassar et al., 2012). In motor learning, ANS indices covary with adaptation (Nogami et al., 2025), yet causal evidence that state-dependent arousal reshapes internal-model updating remains limited (Yokoi, 2025). To probe this relationship, arousal manipulations may need to be task-relevant to effectively drive behavioral change (Hebisch et al., 2024; 2025). Here, using a consecutive-success paradigm to induce physiological arousal via psychological pressure (Yamada et al., 2025), we tested whether and how this task-relevant arousal manipulation regulates the learning rate.

Twenty participants performed a reaching task (task success: endpoint within a target) while pupil diameter and electrocardiography (ECG) were simultaneously recorded. In “Main” blocks, the participants were asked to achieve 10 consecutive successes, and velocity-dependent force-field

perturbations were applied occasionally at three pre-defined streak states: 3-6 consecutive successes (Far), 7-8 (Near), and 9 (Max). Motor adaptation was quantified on the immediately following trial (single-trial adaptation). To ensure a fixed number of Far/Near/Max events, we manipulated success/failure feedback (i.e., endpoint outcome) when necessary. “Control” blocks featured the identical perturbation schedule applied at the same streak counts, but the 10 consecutive successes were not required. The protocol was approved by the ethics committee of the National Institute of Information and Communications Technology.

The paradigm successfully manipulated arousal: pupil diameter and heart rate rose as participants approached the 10-success goal (pupil: 30.6 ± 8.2 % of light-reflex range at Max, $p < 0.001$; heart rate: 92.7 ± 11.9 bpm at Max, $p < 0.001$) in Main blocks, whereas no increase was observed in Control (pupil: 18.8 ± 7.2 % at Max, $p = 0.37$; heart rate: 77.2 ± 8.9 bpm at Max, $p = 0.38$). Perceived pressure, assessed on a 10-point scale, also increased with streak length in Main (9.6 ± 0.7 at Max, $p < 0.001$), indicating that the arousal increase reflected psychological pressure. Critically, motor adaptation assessed by the across-trial movement correction and the learning rate were reduced in Main relative to Control (correction: $p < 0.05$, learning rate: $p < 0.05$).

These results suggest a causal link between task-relevant sympathetic arousal and single-trial error-based motor learning. The findings support the broad view that internal states linked to ANS, and possibly the LC-NA system, contribute to diverse learning processes (Poe et al., 2020). The current results provide an initial step for understanding how heightened arousal deteriorates motor performance.

P1-F-154 - Emergence and stabilization of coordinated movement in large group joint action

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Details

A crucial human ability is to perform joint actions, coordinating movements with others toward a shared goal. Understanding the dynamics that arise within such multi-person coordinated movements is crucial for explaining how groups organize their social behavior and sustain stable collective performance. Joint actions in small groups suggest that coordination can be supported by a division of roles. One person can primarily lead decision-making, while another leads movement execution. However, most experimental work has focused on dyads or very small teams, so it remains unclear whether large groups can coordinate and maintain high motor performance when many individuals must share control of a single effector. Here, we address this question using a continuous circle-drawing task performed on an online experimental system that enables simultaneous joint action in groups of up to 20 geographically distributed participants. Individual mouse movements are combined into a single “average cursor” that reflects each participant’s movement equally; as group size increases, the influence of any single individual decreases. The group's goal is to move the average cursor in a circular motion without seeing the movements of other group members and relying only on the average cursor and the common task goal. In previous work with groups of 2, 5, and 8 participants, we found that, across trials, both the variability of the average cursor trajectory and the variability of each participant’s angular velocity decreased. These changes suggest that groups gradually discover coordination strategies that support stable collective performance. In the present work, we extend this paradigm to ensembles of 10 and 20 participants to test how joint action scales with group size. We quantify changes in group-level trajectory variability, individual and collective motor performance, and phase synchrony, and compare these dynamic performance measures across group sizes. We show that even in large groups, once coordination is established, it can be stably maintained, and that shared goals and shared feedback are sufficient for coordination even when individuals cannot see each other. By characterizing how

coordination emerges and persists in large groups, this study clarifies how the human motor system flexibly incorporates others' actions as part of an extended, socially embedded control system.

P1-F-155 - Adaptation-dependent modulation of coordinated muscle activities in human gait adaptation as revealed by tensor decomposition

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Details

Humans achieve stable locomotion despite substantial musculoskeletal redundancy. The muscle synergy hypothesis proposes that the nervous system reduces this redundancy by activating coordinated groups of muscles (synergies) with shared temporal commands. Although synergies have been used to describe features of gait, their relationship to motor adaptation—progressive recalibration of motor commands in a novel environment—remains unclear.

To reveal the relationship, a possible limitation is inherent in the scope of application of non-negative matrix factorization (NNMF), the most common approach to extract muscle synergies from EMG data. Because NNMF is a method to analyze two-factor data, i.e., matrix data, it is unclear how to consider three factors, i.e., 1) muscle types, 2) time, and 3) adaptation phases. A typical way to extract muscle synergies from multiple phases is to separately apply NNMF in each condition or impose assumptions such as invariant synergy structure or invariant activation profiles across phases. Consequently, it is difficult to quantitatively track how the recruitment (drive) of specific muscle synergies and their activity profiles are adjusted throughout adaptation within a single unified model.

Here, we attempted to reveal the relation between muscle synergy and motor adaptation by applying non-negative CANDECOMP/PARAFAC (CP) decomposition, a variant of tensor decomposition, which jointly models three factors—muscle type, time, and experimental condition/phase—to stride-normalized EMG recorded bilaterally from 18 lower-limb muscles during split-belt treadmill walking adaptation. Twelve healthy adults walked at seven tied-belt speeds (0.45–1.35 m/s) for baseline, adapted for 15 min to asymmetric belts (fast 1.20 m/s, slow 0.60 m/s), completed tied-belt catch trials to probe generalization across speeds, and performed a 10-min washout at 0.90 m/s. CP decomposition yielded 10 components in our case. Most synergy and timing patterns were stable across phases, but two limb-specific components showed pronounced recruitment at the onset of adaptation and declined over the adaptation period. A fast-limb module dominated by ankle plantarflexor-related muscles (peroneus longus, medial gastrocnemius) peaked during fast-limb single support and its recruitment covaried with the positive anterior–posterior ground reaction force (propulsion). A slow-limb module dominated by hip and knee extensors (gluteus maximus/medius, rectus femoris, vastus lateralis) peaked around double support and covaried with the negative anterior–posterior and vertical ground reaction forces (braking/loading). These results indicate that split-belt adaptation is accompanied by selective re-weighting of a small subset of synergy–timing modules within an otherwise stable repertoire, and demonstrate that CP decomposition can quantify phase-dependent synergy recruitment in motor adaptation.

P1-F-156 - Intrinsic motor variability determines the magnitude of implicit sensorimotor recalibration

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Details

The remarkable flexibility of human motor control relies on the brain’s ability to constantly recalibrate movements in response to errors. Implicit recalibration of the motor system has traditionally been

regarded as a slow and stereotypical process governed by cerebellum-based learning. However, recent studies have found that the magnitude of implicit recalibration is modifiable by prior exposure, learning context, and even target configuration. A principled explanation for these diverse phenomena is currently lacking. We hypothesize that intrinsic variability of the motor system determines the changing levels of implicit recalibration across behavioral domains, consistent with optimal feedback control theory. Specifically, we predict that higher intrinsic motor variability leads to faster implicit recalibration. Here, we conducted a series of experiments using an error-clamp perturbation paradigm to up- or down-regulate intrinsic motor variability. We found that down-regulation of intrinsic motor variability via baseline training without perturbations decreased implicit recalibration, whereas up-regulation via restricted reaction time increased recalibration. Furthermore, the reduction of motor variance—a proxy for intrinsic motor variability—induced by baseline training was spatially restricted with little generalization. Consequently, the decrease in implicit recalibration was also spatially specific, which readily accounts for the effect of target configuration on implicit recalibration. Capitalizing on this spatial specificity, we were able to selectively decrease implicit recalibration in specific regions of the workspace without affecting others, providing causal evidence that intrinsic motor variability determines the magnitude of implicit recalibration. These diverse behavioral findings are consistent with predictions of optimal learning instantiated by a Kalman filter model. Our study not only uncovers intrinsic motor variability as a key factor in modulating implicit recalibration but also conceptually links implicit learning to an optimization process of state estimation.

P1-F-157 - Peripersonal space reshaping in response to cooperative human-robot interaction

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Details

Peripersonal space (PPS) is a dynamic multisensory representation that links perception and action by encoding the space immediately surrounding the body. PPS plays a key role in sensorimotor control and action preparation and is known to be highly plastic. Previous studies have shown that PPS boundaries can be reshaped through tool use, social interaction, and changes in sensorimotor contingencies. However, despite the increasing presence of robots in close physical proximity to humans, PPS modulation during Human–Robot Interaction (HRI) remains poorly characterized.

Here, we investigated whether repeated cooperative interaction with a humanoid robot induces changes in PPS representation and whether such changes are accompanied by adaptations in motor behavior. Participants were seated facing the robot, with objects positioned either within their reachable space or outside their reach but accessible to the robot. A synthetic voice instructed participants to grasp objects in a random order, requiring either direct grasping or object handover from the robot. The robot executed highly predictable, biologically inspired upper-limb movements at progressively increasing speeds, allowing us to isolate the effect of repeated exposure to a robotic agent acting within near space.

PPS was assessed before and after the interaction using a multisensory integration task indexing PPS boundaries. Human motor behavior during the interaction was quantified using upper-limb kinematic analyses recorded with motion capture (Vicon). Participants also completed questionnaires assessing their subjective experience of the interaction, including perceived quality, comfort, and engagement with the robot.

Initial analyses revealed changes in PPS estimates following interaction with the robot, with a tendency for larger boundary shift in participants reporting more positive subjective experiences. In parallel, participants progressively adapted their movement kinematics to the robot's behavior. A linear mixed-effects model showed that peak velocity reliably increased across successive trials ($\beta = 7.13$, SE = 1.81, z

= 3.93, $p < 0.001$), consistent with motor adaptation. Data collection is ongoing to further quantify the stability of these effects and characterize inter-individual variability.

P1-F-158 - Dopaminergic modulation of motor sequence learning depends on music training

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Details

Background: Animal studies suggests that dopamine plays a critical role in motor sequence learning, but the effects of exogenous dopamine manipulations on healthy humans have shown inconsistent results, possibly due to baseline individual differences in motor sequence learning. One source of individual differences is musical training. We investigated whether levodopa differentially affects motor sequence learning those with musical training and those without musical training, and explored concurrent neural processing using electroencephalography (EEG).
Methods: 76 participants completed an 8-element serial reaction time task with audio-visual cues under levodopa or placebo in a double-blind design, where cues were presented in a deterministic sequence (sequence blocks) or in a random sequence (random blocks). We applied Bayesian ex-Gaussian distributional modelling to decompose reaction times into μ (motor core speed), σ (trial-to-trial variability), and τ (exponential tail). Time-frequency EEG analysis used cluster-based permutation testing at frontal and motor sites to examine learning-related changes comparing the first sequence block to the final sequence block, and comparing the final sequence block to the final random block.
Results: Behaviourally, levodopa did not affect learning rates (μ) but showed expertise-dependent effects on τ. In those with music training, levodopa uniformly reduced τ by ~8 ms across sequence blocks, consistent with a vigilance decrement; in non-musicians, levodopa compressed the vigilance decrement from ~35 ms to ~7 ms across blocks. Participants with music training who received placebo showed learning-related decreases from the first to the final sequence blocks in the theta (~4–8 Hz) and alpha (~8–12 Hz) bands at both frontal and motor electrodes, across both premovement and postmovement time windows, indicating progressively less cortical engagement to execute the learned motor patterns. Those with music training on Levodopa did not show the reduction in cortical power at the motor electrodes that characterised the Placebo group, possibly reflecting sustained attentional engagement. Those without music training showed no significant learning-related spectral changes at frontal or motor sites in either drug condition, though isolated frontal clusters emerged that did not survive cluster-level correction.
Conclusions: The ex-Gaussian decomposition reveals that behavioural effects of Levodopa in the exponential tail (τ), not mean RT. Levodopa seems to have altered motor oscillatory dynamics in those with musical training, possibly reflecting sustained attentional engagement, consistent with effects on τ. Effects of exogenous dopamine on motor sequence learning on neural oscillations might thus depend critically on baseline expertise.

P1-F-159 - Motor recovery and corticospinal plasticity promoted by repetitive transcranial magnetic stimulation after spinal cord injury in macaques

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Details

Spinal cord injury (SCI) at the cervical level leads to paralysis of the hands. Our laboratory has demonstrated that while spontaneous recovery after mid-cervical subhemisection is slow and poor in nonhuman primates, a combination of rehabilitative training and electrical stimulation of the motor

cortex via subdural electrodes can promote motor functional recovery with plastic changes in the corticospinal tract (CST) that bypasses the lesioned area (Yamaguchi et al., bioRxiv, 2023). For clinical translation, we aimed to develop a non-invasive stimulation approach using repetitive transcranial magnetic stimulation (rTMS) to achieve similar recovery outcomes in the same SCI model.
We trained three monkeys (monkey-K, -D, and -M) to perform a reach-and-grasp task to assess finger dexterity. We conducted a subhemisection at the border between the C4 and C5 segments and performed rehabilitation combined with a novel rTMS protocol (3 pulses at 20 Hz every 2 s; 4500 pulses per session at 150% rMT). The stimulation was applied to the motor cortex on either the contralateral or ipsilateral side relative to the SCI twice per week, respectively. One additional monkey (monkey-A), which served as a control, underwent subhemisection and rehabilitation without rTMS.
We found that while the success rate failed to recover in the control monkey (monkey-A), all monkeys that received rTMS showed recovery of grasping within weeks after the injury. The success rate rapidly improved to over 90%, accompanied by a reduction in grasping time. Compared to task performance during the first 1.5 months after SCI, monkey-K exhibited more precise pinching in the later period. We also recorded muscle twitches evoked by rTMS throughout the recovery process. Twitches in the distal muscles of the affected forelimb evoked by stimulation of the contralateral motor cortex were absent after the injury but reappeared in parallel with behavioral recovery. Monkey-K was sacrificed 6 months after SCI, monkey-D and -M were sacrificed at 1.5 months, and monkey-A at 3.5 months. We injected a viral tracer into the contralesional motor cortex to label the CST in each monkey. In monkeys that received rTMS, we observed labeled CST fibers in lamina IX of the ipsilesional C8 gray matter. Quantitative analysis confirmed that the relative distribution of such CST fibers in these monkeys (monkey-K, -D, and -M) was higher than that observed in the control monkey (monkey-A).
In conclusion, we successfully developed a non-invasive rTMS protocol that facilitates motor functional recovery after severe SCI in macaques. Our results suggest that in monkeys receiving rTMS, plasticity in the CST occurs after SCI and contributes to the recovery of grasping hand movements.

P1-F-160 - Sensory and motor building blocks of an extra robotic digit representation

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Details

Augmentation technologies raise fundamental questions about how the nervous system can adapt to integrate and represent extra body parts. We asked whether the neural representation of a supernumerary robotic finger (the “Third Thumb”) is exclusively dependent on the body parts controlling and sensing the device, or whether an emergent, more independent representation is observed.
The Third Thumb is controlled by pressure sensors under the big toes, and is worn on the hand, with the user ‘naturally’ receiving sensory feedback on the side of their palm during movement. Using fMRI, we asked whether the Third Thumb’s representation in more than the sum of its controller movement (the toes) and effector sensory consequences (on the hand). Following short-term training to use the device, 24 novice users performed a tapping task in the MRI scanner, wearing and actively controlling an MRI-compatible Third Thumb. In separate conditions, participants would (i) move the Third Thumb, (ii) move their toes (with no Thumb movement) and (iii) passively experience the Third Thumb moving on its own on their hand (with no toe movement). This allowed identification of the specific toe-controller and sensory-feedback activity patterns, to then explore how this information combines to represent the Third Thumb. Through a linearity analysis, we found that the Thumb is successfully represented in primary motor cortex (M1) hand area as a linear combination of toe-controller and Thumb feedback signals.

To then explore how this may change with expertise, the fMRI paradigm was repeated in a new cohort of trained Third Thumb users (n=30). Following nine days of training, in M1's hand area we found a significant increase in activity when both actively controlling the Third Thumb, and when just receiving its sensory feedback. This implies retuning to the sensory and motor components of the Thumb by the biological hand area as the Thumb becomes integrated into the participants' motor plans. When considering the components combining to produce the Third Thumb's neural representation, linearity analysis indicated that the combination of the toe-controller and Thumb feedback signals was no longer sufficient to explain the Third Thumb's multivariate pattern. These preliminary findings imply that an independent representation of the Third Thumb may be emerging following long-term training.
In sum, we found while the initial representation of a novel body part is dependent on the sensory and motor components comprising motor control, unique information beyond this simple summation becomes available with extended training, implying a novel and independent representation forms. This has implications for our understanding of how the brain learns to represent artificial limbs and integrate them with our body.

P1-F-161 - Subthalamic nucleus oscillatory dynamics during speech motor sequencing and auditory-motor learning

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Details

The basal ganglia play a central role in the neural control of movement, particularly in action selection, sequencing, and motor learning based on sensory or reward feedback. While these functions are being extensively studied for limb movements, much less is known about how the basal ganglia circuits contribute to the control of speech articulation, a highly practiced yet complex sequential motor skill executed by the orofacial effector system (jaw, tongue, lips, velum). Recent advances in sensing-enabled deep brain stimulation (DBS) technology now allow extraoperative recordings of subcortical activity during naturalistic behaviors, including speech, thereby providing new opportunities to examine basal ganglia activity during human motor behavior.
In this study, individuals with Parkinson's disease implanted with subthalamic nucleus (STN) DBS systems performed speech tasks with different sensorimotor control demands, including single syllable repetition, complex syllable sequence production, and auditory-motor adaptation with perturbed auditory feedback. Local field potentials (LFP) were recorded from the STN with stimulation ON and OFF, and time-frequency analyses were applied to characterize speech-related changes in oscillatory activity time-aligned to specific task events.
Across tasks, speech was associated with robust modulation of beta-band activity, including event-related desynchronization preceding articulation and rebound following speech completion. Preliminary analyses suggest that the magnitude and timing of beta dynamics vary with task context and sequencing demands, consistent with a broader role for STN oscillations in organizing complex motor actions. In contrast, ongoing analyses indicate that beta-band responses are less strongly modulated by auditory feedback perturbations or the resulting auditory-motor adaptation.
Overall, this work demonstrates the feasibility of using DBS sensing to investigate distinct basal ganglia contributions to speech as a model system for sequential and adaptive motor control. These findings can inform further studies of how subcortical oscillatory dynamics support movement planning, execution, and learning in skilled motor behaviors.

P1-F-162 - Articulatory effort modulates speech adaptation to auditory perturbations

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Details

Introduction. Speech sensorimotor adaptation to altered auditory feedback is typically partial, variable across individuals, and often saturates at high perturbation levels. While these properties have mainly been explained in terms of sensory or phonological constraints, the role of motor effort in shaping adaptive responses remains poorly understood. More specifically, this study investigates whether the physical effort required to produce compensatory articulatory gestures in response to increasingly altered auditory feedback constrains both the magnitude of acoustic compensation (H1) and the perturbation level at which this compensation begins to saturate (H2).

Material and methods. 36 native French speakers produced the rounded vowel /ø/ in a picture-naming task while receiving gradually increasing real-time upward shifts of the second formant (F2; 0–50%). Articulatory effort was manipulated using deformable lip tubes of different rigidity: a very flexible tube (FLT) and a more rigid tube (RLT), both allowing lip rounding but requiring different levels of force. Compensation was assessed acoustically through changes in F2 and F1, and physiologically through surface electromyography (EMG) of the orbicularis oris muscle. Mixed-effects models and piecewise regression analyses were used to quantify compensation magnitude, saturation effects, and strategy changes.

Results. F2 compensation increased with perturbation level but saturated earlier and reached a lower magnitude when lip rounding required greater effort (RLT). Lip muscle activity exhibited a similar nonlinear pattern, with saturation occurring at perturbation levels closely correlated with acoustic saturation. At higher perturbation levels, some participants reduced lip recruitment and shifted toward an alternative compensatory strategy involving tongue backing, as evidenced by concomitant increases in F1. This strategy shift occurred earlier and more frequently in the higher-effort condition.

Discussion and conclusion. These findings demonstrate that speech auditory–motor adaptation is constrained not only by sensory error correction but also by the physical cost of compensatory movements. Increased articulatory effort limits compensation magnitude, accelerates saturation, and promotes reorganization of compensatory strategies.

P1-F-163 - Adaptive changes in anticipatory postural control during implicit learning of goal-directed lower-limb movements

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Details

The lower limbs contribute not only to postural control and locomotion, but also to precise, goal-directed movements such as kicking a ball. Kicking movements require maintaining posture on one leg while voluntarily moving the kicking leg toward a target. How these high postural demands and precise lower-limb movements are simultaneously controlled remains an open question. Before voluntary movement execution, posture is implicitly controlled through anticipatory postural adjustments (APAs) to stabilize and support upcoming movements (Massion, 1992). During kicking movements, the supporting leg generates APAs prior to the initiation of the kicking-leg movement, which are modulated along with visuomotor learning of the kicking leg (Moriyama et al., 2024). However, in conventional visuomotor rotation paradigms, explicit aiming strategies can also be altered, making it unclear whether observed changes in APAs reflect implicit learning processes. Consequently, it remains unknown whether APAs are learned in parallel with implicit learning of goal-directed lower-limb movements. In this study, we investigated how APAs adapt during implicit visuomotor learning of a goal-directed kicking task.

Thirteen healthy participants performed a kicking task, aiming to reach a visual target with their right foot. Visual feedback was provided via a monitor placed in front of the participants, displaying a target and a cursor representing foot position in the horizontal plane. The experiment was conducted over two days. Participants completed practice trials for three target directions (−15°, 0°, and 15°), consisting of 180 trials on Day 1 and 60 trials at the beginning of Day 2. On Day 2, following the practice trials and a 65-trial baseline phase with veridical cursor feedback, a learning phase was performed in which the cursor trajectory was clamped at a 10° offset relative to the target direction to promote implicit learning of the kicking-foot movements. Five no-cursor trials were conducted immediately before and after the learning phase, followed by a 45-trial washout phase with veridical feedback. APAs of the kicking movements were quantified based on the center of pressure (COP) of the supporting leg measured 50 ms before the onset of the kicking-foot movement.
During the learning trials, despite instructions to ignore visual feedback and kick directly to the target, participants gradually adapted their kicking movements to compensate for the clamped visual error. Moreover, APAs preceding the kicking movements changed in parallel with the implicit learning of the kicking leg. Importantly, the magnitude of APAs in the late learning exceeded values estimated from the practice trials, suggesting that APAs are not merely passive mechanical responses but are modified through learning. Together, our results demonstrate that implicit learning of the kicking movement was accompanied by flexible control of APAs.

P1-F-164 - Perceptual and behavioural consequences of using an upper-limb assistive augmentation device

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Details

Exosuits are wearable soft exoskeleton devices designed to reduce muscle effort and delay fatigue. They hold promise for industrial applications and for assisting individuals with motor impairments. However, their effectiveness is shaped by both biomechanical benefits and their interaction with perceptual and effort-based decision-making processes.
This study investigates the influence of a bimanual elbow exosuit on weight estimation, perceptual learning, and perceived fatigue. Participants completed two sessions: exosuit ON (power assistance) and OFF (motors disabled), while surface electromyography (EMG) monitored muscle activity during three tasks. In Task 1, based on the size–weight illusion, participants lifted boxes of varying weights and volumes to estimate their weight. Results show a reduction in muscle activity and an upward shift in weight estimates overall, while inter-participant variability in weight estimates remained unchanged. This suggests that exosuit assistance induces a global shift in perceived weight rather than increasing estimation noise. Because the shift affects the larger and smaller boxes similarly, the relative relationship between weight judgements is preserved, leaving the size–weight illusion unchanged. Task 2 employed a reinforcement learning paradigm in a volatile environment, presenting participants with two boxes—one typically heavier and the other lighter—with weight contingencies that change over time. Participants indicated whether the presented box was heavier or lighter. Preliminary analyses of weight-judgement accuracy over time suggest exosuit-dependent differences in how participants adapted to changes in weight contingencies. Task 3 used a decision-making paradigm, where participants chose to lift either a low-effort, low-reward box or a high-effort box with variable, higher rewards. Exosuit assistance reduced perceived fatigue without altering choice behaviour.

Together, these findings suggest a dissociation between perception, muscle activity and behaviour. Short-term exposure to exosuit assistance alters weight estimation, reduces muscle activity and perceived fatigue, while effort-based decision-making remains unchanged.

P1-F-165 - Predictive outcome feedback counters temporal discounting in complex motor learning

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Details

Biological learning systems must continually evaluate the consequences of movement, yet the outcomes of complex actions often appear substantially delayed. Evidence from sensorimotor adaptation shows that even brief delays blunt implicit learning suggesting that the nervous system rapidly devalues temporally distant error signals. This raises a central question for naturalistic motor behavior: do delayed action outcomes limit the engagement of reinforcement mechanisms that support procedural skill acquisition?

Throwing provides a powerful testbed because its high-dimensional sensorimotor transformation resists explicit strategies and its outcome emerges only after an extended flight. To probe how reinforcement processes operate under such natural delays, we introduced an ecologically grounded manipulation: predictive outcome feedback delivered shortly after ball release. This advanced the availability of knowledge of results while preserving the unfolding task-intrinsic sensory consequences. Reinforcement-related neural signatures, including the FRN, ERN, and frontal-midline theta, provide a window into the computations sensitive to feedback timing. We therefore compared predictive versus naturally delayed feedback during a virtual throwing task to determine how outcome timing shapes motor learning and the cortical evaluation of action outcomes..

Participants practiced a semi-virtual target-throwing task in which the ball's trajectory and final hit/miss outcome were fully determined at release. Two groups received identical augmented auditory outcome feedback, but with different timing: either *predictively* at ball release (predFB) or *naturally* at the moment of impact (natFB). EEG was recorded throughout practice.

Behaviorally, predictive feedback accelerated learning. A Bayesian learning-curve model revealed steeper declines in ball–target distance for the predFB group compared to the natFB group, with posterior estimates strongly supporting the idea that advancing outcome information counteracts temporal discounting.

Neurally, predictive feedback strongly engaged canonical reinforcement-related signals. A robust FRN emerged shortly after release localized to ventral ACC, accompanied by a pronounced frontocentral theta burst in cingulate–SMA networks. Natural feedback evoked attenuated and temporally shifted versions of these responses at the actual outcome with reduced cingulate engagement. Notably, the natural-feedback group also showed an early theta burst ∼200 ms after release, an internally generated prediction-error signal arising before external outcome information was available.

Together, these findings indicate that delayed outcomes dampen and displace cortical reinforcement signals, whereas predictive feedback amplifies and advances them. Temporal discounting thus operates as a core computational principle of biological information processing, shaping both the speed of motor learning and the neural mechanisms that evaluate action outcomes.

P1-F-166 - Reversed gravity promotes acquisition of predictive eye movements in goldfish

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Details

Since animals on Earth have evolved under a 1G gravitational environment, many biological functions, particularly motor control systems, are thought to be optimized for coping with this ubiquitous gravitational force. Alterations in gravity may therefore modify the characteristics of motor control and learning. In this study, we compared the speed of motor learning, with a particular focus on the acquisition of predictive control, under reversed-gravity (-1G) and normal gravity (1G) conditions in goldfish, a species that has been used in space experiments. Motor learning was assessed using a visual training paradigm of the optokinetic response (OKR), in which a temporally periodic, constant-velocity large-field visual pattern was repeatedly presented. This paradigm is known to induce a predictive form of the OKR, characterized by an acceleration and deceleration of eye velocity preceding the initiation and termination of the visual motion, respectively, as well as by the persistence of periodic eye-velocity oscillations in darkness after stimulus offset. In addition to predictive adaptation, conventional increases in OKR gain (eye velocity amplitude divided by visual stimulus velocity amplitude) are also induced during training. Animals were comfortably fixated at the center of a white cylindrical water tank either in an upright (1G condition) or upside-down posture (-1G condition) using surgically implanted head posts. Random-dot visual stimuli were projected onto the tank wall via a planetarium. The visual pattern remained stationary for 8 s, followed by an 8 s clockwise rotation around the animal's yaw axis. This stimulus cycle was repeated for 3 h. Eleven and seventeen adult goldfish (approx. 15cm in length, both sexes) participated in the 1G and -1G conditions, respectively. Horizontal and vertical eye positions were recorded using the scleral search-coil. Horizontal eye velocity was obtained by digital differentiation. Saccadic phases were removed using a custom algorithm based on velocity and acceleration thresholds, and averaged eye velocity traces were computed for each condition. From these averaged velocity traces, three parameters were quantified for each stimulus cycle: Initiation (predictive eye velocity increase before stimulus onset), OKR gain, and Termination (predictive eye velocity decrease before stimulus offset). As the result, learning curves for OKR gains were comparable between the 1G and -1G conditions. By contrast, Termination was acquired significantly faster and reached a greater magnitude under -1G than under 1G condition. No significant difference was observed in the learning curves for Initiation. These results suggest that the acquisition of predictive oculomotor learning, specifically the prediction of stimulus termination, is facilitated under the reversed-gravity condition, whereas the acquisition of conventional OKR gain is unaffected by gravitational reversal.

P1-F-167 - Adaptive control by the primary motor cortex maintains motor output under muscular fatigue

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Details

Muscular fatigue during repeated exercise causes a progressive decline in muscle force. While spinal motoneurons adjust their firing and recruitment to compensate muscle fatigue, how the primary motor cortex (M1) sustains voluntary motor output under fatigue remain poorly understood. Here, we examined how M1 neurons contribute to maintaining force output during muscle fatigue induced by voluntary contraction (*study* 1) or electrical stimulation (*study* 2). In *study* 1, two macaque monkeys performed a force-tracking involving repeated isometric wrist extensions at 40–55% of maximal voluntary contraction (MVC) until exhaustion. During the task, we simultaneously recorded neuronal activity from the M1 wrist area, forearm electromyograms, and wrist torque. Electrically evoked twitch

decreased by 61.6 ± 28.8% after the task, confirming muscle fatigue. Torque was maintained at a constant level between the early (the first 20 trials) and late (the last 20 trials) periods within the session. Cluster analysis of firing patterns from 1,054 M1 neurons identified four groups; among them, increased-type neurons (42.3%) showed further firing increases in the late period, whereas decreased-type neurons (43.1%) exhibited further firing reductions. In *study* 2, the same task was performed with the *study* 1, before and after muscle fatigue induced by 2-min continuous electrical stimulation to extensors. Evoked twitch decreased by 71.7 ± 21.3% following fatigue. Comparable torque output was maintained between the pre- and post-fatigue tasks. The analyses of 606 M1 neurons revealed that increased-type neurons (44.2%) further elevated firing rates post-fatigue, while decreased-type neurons (46.9%) showed no significant change. These results suggest that, in response to fatigue-induced force decline, increased-type M1 neurons help sustain motor output by elevating their firing to facilitate temporal summation of force trajectory in agonist muscles, whereas decreased-type neurons likely support efficient motor output by reducing firing to suppress antagonist muscle activity that would otherwise interfere with agonist force generation.

P1-F-169 - Learning to retrain the body for robotic motor augmentation

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Details

Wearable motor augmentation robots, such as additional limbs or digits, extend human capability beyond the body's limits and enable users to accomplish challenging tasks that were previously considered impossible. Distinctively from traditional hand-held tools that occupy the users' hand, hand augmentation devices are designed to expand the user's motor repertoire by introducing new controllable degrees of freedom. Learning to exploit these new control dimensions may require reorganising habitual coordination patterns and overcoming natural motor synergies, potentially imposing learning demands that differ from traditional tool use. Therefore, it is necessary to investigate the learning mechanisms that support skilled control of human motor augmentation.

In this study, we conducted a five-day experiment using the Third Thumb (designed by Dani Clode), a wearable extra digit positioned on the side of the palm that provides additional grasping capability, and included a novel and challenging tool use task as a control condition. In both tasks, participants coordinated their biological fingers with either the tool or the augmentation device to grasp difficult objects and transfer them onto a custom stand. Performance was quantified as the number of objects transferred within a fixed time window. Kinematic data were collected concurrently using a multi-camera markerless motion capture system based on deep learning motion estimation models.

Based on the preliminary results from 125 days of data from 25 participants, we characterised learning mechanisms in motor augmentation from three perspectives: performance, exploration, and synergy. Learning rate were similar between the augmentation and tool use tasks, establishing tool use as a robust control. Despite sharing a similar learning curve, the tasks differed substantially in many other learning metrics, such as movement smoothness, learning retention, and trajectory error. Second, we decomposed the body kinematic data into finger motion, upper limb motion, and eye/head motion, and quantified exploration using measures including joint angle deviations and variance, as well as the evolution of inter-finger correlations and eye-hand coordination. During five days of training with augmentation tasks, participants explored body parts that were not directly required for task success and exhibited directional search in joint space that was absent in tool use. Finally, for synergy formation, we applied uncontrolled manifold analysis to decompose joint space variance into null space and orthogonal task space components, and identified the unique synergy organization pattern of augmentation tasks.

Together, this work uses motor augmentation as a model system to reveal how humans acquire de novo control policies and reorganise motor synergies, informing shared motor control theories as well as next-generation augmentation design.

P1-F-170 - Motor variability in task-irrelevant dimensions when learning a rapid bimanual throwing task

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Details

Bimanual coordination tasks, which involve both hands to perform a shared task, have often been used as a model to study redundancy in motor control. Recent studies have shown that, contrary to the idea that bimanual coordination is dominated by coupling between the hands, the motor system shows task-dependent modulation of coordination, with greater variability being allowed in 'task-irrelevant' dimensions. However, this flexibility has been demonstrated primarily in well-learned reaching tasks with time for feedback corrections, raising the question of how this balance between coupling and flexibility is affected in rapid movements.

To examine this question, we used a bimanual virtual shuffleboard task in which participants slid a virtual puck toward a target line displayed on the screen. Participants held the virtual puck and made a quick bimanual throwing motion using a KINARM robot. When the puck crossed a horizontal line, it was released and slid towards a target based on its speed at that instant. Critically, we manipulated the task-relevant dimension for this task by testing two groups of participants. For the Bimanual group, the speed of both hands contributed to the puck speed, whereas for the Unimanual group, only the right hand contributed to puck speed (even though the task was performed bimanually). Based on this manipulation, we examined the variability in the speed of the left hand— which was task-relevant in the Bimanual group, but task-irrelevant in the Unimanual group. Participants performed this task for 300 trials in a single day of practice.

Results showed that practice at the task resulted in reduced errors in both groups. Critically, both groups reduced variability of the left-hand speed with practice (comparable to the reduction in the right hand), even though the left-hand speed had no effect on task performance in the Unimanual group. This finding runs counter to the prediction that variability should be unaffected in task-irrelevant dimensions for bimanual tasks.

These results suggest that the balance between coupling and flexibility in bimanual coordination is strongly constrained on the time available for feedback. While slow movements could allow for flexible coordination patterns between the hands, rapid movements tend to result in stronger coupling. Overall, these results highlight the need for theories of bimanual coordination to account for pre-existing coordination tendencies when making predictions about how redundancy will be used.

P1-F-171 - Muscle-specific cortical dynamics following tendon cross-transfer in the Macaque monkey

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Details

Background:

Following tendon transfer, the CNS must adapt to altered biomechanics. Behavioral evidence suggests the motor system exploits effects like tenodesis for "**good enough**" control rather than remapping synergies. We investigate if functional connectivity, i.e., **Cortico-Muscular (CMC)** and **Cortico-Cortical Coherence (CCC)**, facilitate this transition.

Methods:
We cross-transferred EDC and FDS tendons in a macaque trained on a reach-to-grasp task. We recorded high-density EMG (16 muscles) and ECoG (16-ch arrays over M1, S1, SMA) across three phases: Pre-surgery, Early (acute), and Intermediate (recovery).
Preliminary Results:

Longitudinal analysis of LFP power spectra revealed a transient, task-dependent surge in Beta (15-30 Hz) oscillatory power within M1 immediately following surgery. This "**Beta Bump**" was most prominent in digit-related channels during the first 4-5 post-operative sessions, coinciding with the acute phase of motor adaptation. EMG analysis during the hold phase demonstrated muscle-specific recovery trajectories. The **transferred muscle (FDS)** showed a significant initial reduction in activation followed by gradual recovery. In contrast, **synergist muscles (e.g., FDP, ADP)** and the **antagonist (EDC)** exhibited an immediate post-operative increase in activity. This suggests the CNS upregulates intact, native synergies to stabilize the grasp while the transferred muscle recovers. CMC analysis revealed **differential modes of corticospinal coupling**. Intact **synergists** displayed significantly enhanced Beta-range CMC (15-30 Hz) during the early phase, a linkage absent prior to surgery. This indicates a strong **oscillatory binding** between cortex and **intact synergists** to maintain grasp stability. Conversely, the **transferred muscle** showed rising EMG amplitude *without* a parallel increase in Beta CMC, suggesting it is recruited via **direct non-oscillatory drive** rather than the coherent network.
Conclusion:
These findings suggest a **parallel control strategy** for motor recovery. The cortex transiently upregulates **Beta coherence** to **link** intact synergists (FDP, ADP) into a stable, low-energy state. This "**coherent mode**" efficiently maintains grasp stability, thereby allowing the motor system to allocate resources toward the "**direct control**" required to activate and relearn the biomechanically novel transferred muscle (FDS) independent of the oscillatory network.

P1-F-172 - Multi-hierarchical plasticity of corticofugal projections through motor recovery from spinal cord injury in macaques

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Details

Descending fibers originating from the motor cortex project to the spinal motoneurons that innervate the limb muscles to generate voluntary movements. In particular, the corticospinal tract plays a crucial role in dexterous finger movements developed in higher primates. In addition to this direct pathway, higher-order circuits, such as the cortico-basal ganglia and cortico-cerebellum loops, also work in cooperation to properly plan and execute movements. These neural mechanisms of the motor system enable us to move our bodies smoothly. Therefore, motor recovery after the spinal cord injury may require reorganization not only of the lower level motor system but also of higher order circuits.

Previous studies have shown that the lesion-spared neural pathways on the lesion side took over the function of the impaired corticospinal tract in the milder spinal cord lesion model and recovered fine hand movements in macaques. Here, we focused on a more severe lesion case and investigated the neural plasticity accompanying motor recovery. We used adult macaque monkeys with subhemisection of the middle cervical spinal cord (C4/5). Following repeated behavioral tests and bilateral cortical electrical stimulations, their coarse hand movements recovered, though the precision grip didn't recover. After saturating the functional motor recovery from the lesion, we labeled the descending neural fibers

originating from the primary motor cortex in each hemisphere by injecting anterograde viral tracers to examine the target area of their projections.

At the spinal level, many descending axons in the lesion-affected trajectory projected without crossing the midline at the pyramidal decussation, and these uncrossed axons descended toward the spinal cord on the opposite side of the lesion to cross the midline caudal to the lesion and terminated in the ipsilesional gray matter of the spinal cord, which is the original target area. These axons also exhibited increased collaterals to the gray matter both rostral and caudal to the lesion.
At the supraspinal level, projections from the lesion-affected trajectory to the non-dominant side of the putamen of the basal ganglia, the pontine nucleus of the brain stem, and the lateral reticular nucleus of the medulla were markedly increased compared with projections from the lesion-unaffected trajectory. These regions constitute the cortico-basal ganglia and the cortico-cerebellum loops, involving the ipsilesional motor cortex.
Thus, corticofugal fibers originating from the lesion-affected motor cortex exhibit extensive plasticity across multiple hierarchical levels. Such anatomical plasticity accompanied by functional recovery was not observed in a lesion model without cortical stimulation, suggesting a critical role for stimulation-induced plasticity.

P1-F-173 - Exploring the neural mechanisms of motor learning and action selection during visuomotor rotation in the presence of uncertainty

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Details

Human sensorimotor learning is frequently modeled as a Bayesian inference process, where the brain integrates noisy sensory feedback with prior experience to refine motor commands. While internal models are known to facilitate state estimation and adaptation based on sensory uncertainty, decision-making, the impact of this uncertainty on action selection and inhibition (Go/NoGo decision-making) remains poorly understood. This study investigates how internal uncertainty, refined during motor adaptation, modulates the neurophysiological correlates of motor execution and inhibition.
Ten subjects performed a visuomotor rotation task under stable and random perturbation conditions, while 32-channel EEG was recorded, in which behavioral and EEG data exhibit condition-dependent distinct patterns of motor adaptation. NoGo trials were interleaved to assess action cancellation. Subjective uncertainty was quantified using an adaptive Kalman filter model to estimate time-varying parameters from behavioral data.
Behavioral analyses validated the model, showing that estimation uncertainty significantly predicted trial-by-trial motor modifications. Neurophysiological results revealed three key mechanisms of how the belief state modulates brain activity. 1. In Go trials, post-movement beta synchronization (PMBS) correlated negatively with uncertainty in the stable condition. High confidence (low uncertainty) was accompanied by high PMBS, while high uncertainty attenuated PMBS, supporting the hypothesis that beta synchronization maintains the current motor set, while desynchronization facilitates model updating. 2. PMBS during Go-trials significantly predicted beta synchronization in NoGo trials. This indicates that the confidence established during motor execution shapes motor cortex excitability even when action inhibition is required. 3. Theta synchronization in NoGo trials was modulated by uncertainty in the stable condition; lower uncertainty predicted stronger theta synchronization. This effect was absent in the random condition, suggesting that theta synchronization represents the confidence of inhibitory commands, transitioning from efficient predictive inhibition to less efficient reactive inhibition as uncertainty increases.

In conclusion, this study showed that motor preparation and execution are reflected in the beta band, while motor inhibition is characterized by the theta band, both of which are dynamically modulated by the uncertainty of internal models.

P1-F-174 - Hand dexterity recovered in spinal cord injury Macaques by a synthetic synapse organizer

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Details

Restoring lost motor function following spinal cord injury (SCI) remains a significant challenge in regenerative medicine. Promisingly, recovered locomotion was seen in SCI mice following a single injection of a synthetic synapse organizer, CPTX (Suzuki et al., 2020). This protein was shown to physically and functionally link presynaptic neurexins with postsynaptic AMPA receptors, offering a potent strategy for treating SCI in animal models. Since certain non-human primates have evolved a hand dexterity nearly equaling that of humans, we used a sub-hemisection C6/C7 SCI model in crab-eating macaques to evaluate CPTX as a therapeutic for restoring hand function.

Eight macaques were trained to perform a reach-and-grasp task requiring precise control of the thumb and index finger to retrieve small cubes of sweet potato from inside a narrow slit. SCI was then inflicted, targeting the corticospinal tract (CST) to disrupt the descending input from the primary motor cortex (M1) to cervical motoneurons. Next, monkeys were randomized to receive a one-time blinded injection of either CPTX or buffer solution (vehicle) at five sites surrounding the lesion, targeting both the dorsal and ventral horns of the gray matter. Functional recovery was then recorded for 120 days. We found an earlier and more extensive recovery of dexterity in the CPTX-injected monkeys compared to vehicle-injected monkeys.

Quantitative analysis of the kinematics using virtual markers and the deep-learning neural network DeepLabCut (Mathis et al., 2018) suggests that CPTX-treated macaques might revert back to baseline movement patterns, indicating that CPTX might rescue already established circuits for dexterity. In contrast, vehicle-treated animals exhibited compensatory strategies to a higher extent. Additionally, viral tracer injections into the M1 revealed widespread re-routing of CST fibers at the pyramidal decussation, as well as at sites rostral and caudal to the lesion, including regions distant from the injection site. Next, we will utilize confocal imaging and single-cell RNA-sequencing to uncover the underlying mechanics to better understand our observations.

In conclusion, these results suggest that sub-acute treatment with CPTX facilitates the functional and structural reconnection of the non-human primate CST after sub-hemisection at the C6/C7 level in our translational SCI model.

P1-F-175 - Supplementary motor area facilitation enhances precision in high-speed throwing

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Details

Maintaining high accuracy during rapid, dynamic movements is a significant challenge for the central nervous system, as high-speed actions are inherently subject to a speed-accuracy trade-off. A primary driver of this phenomenon is signal-dependent noise, where neural noise increases in proportion to motor command intensity. Consequently, maintaining motor precision during high-intensity actions requires neural mechanisms—such as the supplementary motor area (SMA)—to monitor and regulate

these commands to stabilize motor output. While the SMA is known to orchestrate motor drive and variability, its causal role in maintaining precision during maximal-effort, whole-body tasks remains unclear. Furthermore, it is unknown whether SMA-mediated stabilization influences the conscious performance monitoring or operates independently.
We investigated the effect of modulating SMA activity on throwing performance in fourteen healthy adults with no competitive baseball experience. In a crossover design, participants received either facilitatory intermittent theta burst stimulation (iTBS) or inhibitory continuous TBS (cTBS) over the SMA in separate sessions. Participants performed maximal and submaximal (50% effort) throwing tasks toward a target 9 m away before and after TBS. Outcome measures included ball speed, variable error (the 95% confidence ellipse area), and absolute error from the target. Additionally, subjective ratings of perceived speed and accuracy to evaluate the relationship between objective performance and conscious awareness.
The results showed that iTBS significantly reduced the variable error of pitch location during maximal-effort throwing—where signal-dependent noise is theoretically maximized—without compromising ball speed. Specifically, the 95% confidence ellipse area showed a significant decrease following iTBS ($p = 0.023$), whereas no significant changes were observed after cTBS. Interestingly, a dissociation emerged between objective precision gains and subjective ratings. While only the iTBS condition showed improved precision, subjective ratings of accuracy increased globally over time across all conditions, suggesting that participants' perceived improvement was likely a byproduct of task familiarization rather than actual motor stabilization.
These findings demonstrate that the SMA plays a critical causal role in stabilizing motor output under high motor drive. The reduction in variable error suggests that enhanced SMA activity reinforces neural connectivity responsible for timing and coordination, thereby counteracting the noise associated with high-speed movements. Because these precision gains occurred independently of conscious awareness, it indicates that SMA-mediated stabilization operates as a subconscious neurophysiological process. This study highlights the SMA as a vital neural node for constraining variability and offers a foundation for using neuromodulation to optimize complex motor skills in sports and rehabilitation.

P1-F-176 - Speech sensorimotor adaptation using altered auditory feedback in cochlear implant users

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Details

Precise speech production depends on fine motor control that minimizes errors in the produced sound. However, this control process can be disrupted when sensory signals are degraded, such as in auditory deprivation. For deaf individuals, cochlear implants (CIs) are the most effective intervention. Although CI users can acquire speech abilities approaching those of normal-hearing individuals, earlier implantation is associated with better outcomes in both speech production and perception. It is therefore important to investigate how CI profiles influence the development of speech sensorimotor function. In the present study, we applied a laboratory-based sensorimotor adaptation paradigm using altered auditory feedback (AAF), and examined whether CI users with early implantation and long-term experience exhibit speech motor adaptation. Their responses were compared with those of deaf individuals with different CI profiles, normal-hearing controls, and normal-hearing participants tested with a CI simulator.

Participants includes seven young adult native French speakers (18–35 years) who were long-term CI users (>10 years; HI-1). For comparison, we also tested seven deaf individuals outside the target CI profile, including short-term CI users (HI-2), seven normal-hearing controls (NH-1), and seven normal-hearing participants tested with a CI simulator (NH-2). The same AAF procedure was applied across all four groups. Participants repeatedly produced the vowel /ø/ embedded in the French word *deux* ("two"

in English). During the task, the second formant (F2) of the vowel was gradually increased to shift the sound toward /e/. This perturbation was applied over 50 trials with a gradual increase, followed by an additional 50 trials during which the maximum alteration was maintained. Only in the NH-2 group was a CI simulator used, consisting of sine-vocoded speech with six frequency bands. Speech adaptation was quantified by comparing the F2 amplitude at the end of the training phase with baseline production measured before training.

We found that the HI-1 group showed clear adaptation in response to altered auditory feedback. The adaptation amplitude was comparable to that observed in the NH-1 group, indicating that cochlear implants effectively supported the detection of precise auditory errors required for sensorimotor adaptation. In contrast, adaptation was limited in the HI-2 group. A similar limitation was observed in the NH-2 group, suggesting that degraded auditory feedback restricts the effective use of auditory error signals. These results demonstrate that deaf individuals can adapt to auditory errors when such errors are reliably detected through CIs. Although CIs are effective, efficient use of auditory feedback for precise sensorimotor control may depend on implantation at an appropriate developmental stage and long-term auditory experience.

P1-F-177 - Expertise-related differences in whole-body muscle synergy organization during overarm throwing

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Details

Introduction

Throwing is a fundamental skill in sports such as baseball and requires precisely coordinated activation of muscles throughout the body. However, the neural basis supporting coordinated whole-body control during throwing remains incompletely understood, and it is unclear how such coordination is reorganized and refined with increasing expertise and sport-specific experience. Therefore, this study aimed to investigate the expertise-related differences in whole-body coordination during throwing by comparing novices and experienced baseball players using muscle synergy analysis.

Methods

Six participants with no baseball experience (NE) and eight experienced baseball players (EX) participated in this study. Each participant performed 20 throws toward a net located 18.44 m away, with instructions to throw as fast as possible. Ball speed was recorded using either a radar gun or a radar-based tracking system. Electromyographic (EMG) activities were recorded from the 16 muscles across the dominant upper limb, as well as bilateral trunk and lower limbs. To evaluate muscle coordination, muscle synergies were extracted using non-negative matrix factorization (NMF). To compare group differences, synergies from each group were clustered using k-means, and cluster consistency of synergy structure was evaluated based on cosine similarity. Clusters with cosine similarity > 0.9 were considered common synergies. For group-specific synergies, we examined the merging of muscle synergies between groups. To characterize the temporal patterns of the synergies, the centroid of activity (CoA) was calculated for each pattern, and the standard deviation of the CoA (SD of CoA) was then computed.

Results

Average ball speed in NE (75.8±9.5 km/h) was significantly lower than in EX (121.6±6.0 km/h) (independent t-test, $p<0.05$). The number of muscle synergies in NE (median [IQR]: 5 [5-6]) was significantly higher than in EX (median [IQR]: 4 [4-4.5]) (Mann–Whitney U test, $p<0.05$). K-means clustering identified ten muscle synergy clusters in NE and five in EX. Of these, three clusters were common to both groups, while seven clusters were unique to NE and two were unique to EX. Notably, all

EX-specific clusters were formed through the merging of NE-specific clusters. The SD of CoA across trials was significantly lower in EX (2.2% ± 0.4%) than in NE (5.8% ± 1.9%) (independent t-test, $p<0.05$).

Conclusion

In this study, the main findings of expertise-related differences in synergy organization were that (i) the number of extracted muscle synergies was greater in NE than EX; (ii) synergy structure were differed between-group, with 10 clusters identified in NE compared with 5 in EX, including patterns consistent with module merging; (iii) synergy activation timing was more consistent in EX. Together, these findings suggest that throwing expertise may be associated with a more integrated and temporally stable organization of whole-body muscle coordination.

G – Theoretical & Computational Motor Control

P1-G-178 - When do nonlinear control models matter in human reaching movements

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Details

Control theoretical models of human reaching movements have become increasingly important as a formalism to study the neural mechanisms underlying sensorimotor control. A recurrent limitation of many modeling works is the reliance on linear approximations, which is adequate when the modeled behavior is close enough to linear. However, it remains unclear how to determine such proximity to linearity. More specifically, there has been no systematic quantification of the range of movement parameters, such as reaching amplitude or movement speed, that require nonlinear control models. Here, we investigated two nonlinear control models applied to human reaching control of an upper limb composed of six muscle groups. This arm model also included three sources of nonlinearities: inertia that varied with joint configuration, Coriolis and centripetal effects that varied with products of joint velocities, and muscle force–length and force–velocity relationships that varied with both joint configuration and angular velocity. We then compared an established method in the field: the iterative Linear-Quadratic-Gaussian (iLQG) controller **[1]**, with an alternative candidate approach based on Feedback Linearization (FL). The FL method handled nonlinearities through an invertible change of variables that transformed the nonlinear system into an equivalent linear system to which standard stochastic linear optimal control models could be applied (LQG). To assess how well these controllers reproduced human behavior, we applied them to three standard reaching tasks: a center-out reaching task to model movements with small changes in joint configurations; a velocity-dependent force-field to assess the robustness of the controllers' structures against unexpected external forces; and movements of larger amplitude, where we expect a visible impact of nonlinearities due to large changes in joint configuration and velocity. The performances of the nonlinear controllers were then compared to an artificial, unrealistic time-varying LQG (DLQG), which linearized the dynamics around the current state during movement. This enabled a comparison between linear and nonlinear control models. Our findings established that the necessity of nonlinear control models is task-dependent and it is directly related to changes in joint configuration and velocity. Indeed, DLQG appeared sufficient only for the center-out task, showing that local linear approximations are "close enough" for this standard paradigm. In contrast, the two other tasks required nonlinear approaches, suggesting the existence of nonlinear representations in the brain for reaching movements. Both nonlinear control models showed advantages depending on the modelled task. The force-field task showed that FL was more robust to model errors as it does not rely on a predicted trajectory for linearization. However, the iLQG was better suited to replicate movements of large amplitudes, as FL produced unrealistic movement curvatures, although adding path constraints could reduce the discrepancy. Finally, the directions most affected by

nonlinearities correlated with the bimodal distribution of preferred directions in monkeys' primary motor cortex **[2]**, supporting the hypothesis that these preferences emerge from control solutions optimized for biomechanical demands.

[1] Li and Todorov, *Int. J. Control*, vol. 80, nº 9, p. 1439-1453, 2007.
[2] Lillicrap and S. H. Scott, *Neuron*, vol. 77, nº 1, p. 168-179, 2013.

P1-G-179 - Hierarchical organization of motor memories in bimanual movements

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Details

Skilled bimanual actions require the brain to manage multiple motor memories, determining when they are expressed independently or coordinated across hands. Unrelated bimanual actions (e.g., holding a teacup in one hand and a cellphone in the other) can be controlled using separate memories, whereas contextually linked actions (e.g., a cup resting on a saucer held by the other hand) require shared representations because manipulating one object affects the other. Although everyday behavior often involves such hierarchical contexts, bimanual motor learning is typically studied as isolated, hand-specific mappings. It remains unclear whether the two arms draw from independent motor memories or a shared repertoire depending on contextual alignment.

To address this question, we conducted three experiments in which participants made reaching movements with both hands, each grasping a robotic manipulandum. After learning in each experiment (see below), we selectively modified the dynamics experienced by the right hand (i.e., modified its motor memory) and assessed its influence on left-hand memory.

In the **Baseline** experiment (n=8), participants reached unimanually to either a right- or left-hand target using the corresponding hand. During training, each hand experienced a velocity-dependent viscous curl field with opposing directions across hands. Following training, we reduced the right-hand force-field strength to zero and then reinstated it (renewal), while the left hand was constrained to channel trials. We found no evidence that right-hand memory modulation influenced left-hand expression: left-hand adaptation decayed to 27% of its trained level and showed no renewal (no significant increase from the midpoint of renewal to steady phase; $p = 0.18$). This establishes that, following unimanual learning, motor memories for the two hands are independent.

In the **Match** experiment (n=8), bimanual trials were randomly interleaved with unimanual trials, with force-field directions during bimanual trials matching those during unimanual trials, creating a shared contextual structure. As in Baseline, right-hand memory was selectively modified during unimanual trials, while the left hand (and both hands during bimanual trials) was constrained to channel trials. Under these conditions, right-hand memory modulation significantly influenced left-hand expression: left-hand adaptation declined only to 64% of its trained level during the steady phase and showed renewal (35% increase from the midpoint of renewal; $p = 0.02$), indicating functional coupling of memories across hands.

Finally, to test whether this effect depended on shared contextual structure rather than the presence of bimanual trials, we performed a **Conflict** experiment (n=8), identical to Match except that force-field directions during bimanual trials conflicted with those during unimanual trials. Here, left-hand adaptation declined to 16% of its trained level during the steady phase and showed no renewal (46% decrease from the midpoint of renewal; $p = 0.02$), indicating no influence of right-hand memory modulation.

These results show that motor memories are independent across hands during unimanual actions and become functionally linked only when actions share contextual structure. Bimanual coordination alone is

insufficient to induce memory sharing; instead, shared context determines whether memories are expressed independently or drawn from a common, hierarchical repertoire.

P1-G-180 - No evidence of dual-rate learning in speech sensorimotor adaptation

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Details

Sensorimotor adaptation, driven by a mismatch between predicted and observed sensory feedback, is essential for flexible motor control in response to body or environmental changes. The dual-rate model posits that adaptation comprises two computational processes, a fast and a slow process, and has been used to account for adaptation in reaching, saccade, and walking, hinting that dual-rate adaptation may be domain-general. To date, whether speech adaptation involves the dual-rate process has never been evaluated, despite it being the most-studied motor learning process in the speech domain. On one hand, from a domain-general perspective, speech adaptation is expected to involve the dual-rate process. On the other hand, prior work studying reach adaptation to visuomotor rotations has mapped the fast/slow processes onto the explicit/implicit learning mechanisms known to contribute to reach adaptation in parallel. This mapping was supported by a recent study that isolated implicit reach adaptation and showed no evidence of dual-rate adaptation. As speech adaptation is inherently implicit without an explicit component, speech adaptation provides a further test for this hypothesized mapping.
Evidence for the dual-rate model comes most strongly from the perturbation counter-perturbation paradigm, where participants are exposed first to a perturbation (e.g. +45° rotation) for a large number of trials and then to a second, opposing perturbation (e.g. -45°) for a limited number of trials. When participants produce movements without feedback in a post-test phase, their behaviors resemble the adaptation to the first perturbation. This “rebound” supports the dual-rate process: as participants only briefly experienced the second perturbation, the fast process dominates the learning to this perturbation, while learning in the slow process in response to the first perturbation is not completely washed out, resulting in the observed rebound. Here we used a speech analog of the perturbation counter-perturbation paradigm to test our hypotheses. Participants (n = 30) repeatedly produced the target word, “bed”, while receiving auditory feedback of their speech. They were first exposed to perturbed feedback that up-shifted the first formant (F1, formants are resonances of the vocal tract that acoustically distinguish vowels), to make “bed” sound more like “bad”, then received a downward perturbation that made “bed” sound more like “bid”.
Participants adapted to both upward and downward F1 perturbations; however, there was no evidence of rebound, as the productions in the post-test did not differ significantly from those at the end of the downward perturbation phase. Aligned with behavioral results, the single-rate model provided a better fit to each participant’s data than the dual-rate model. These results suggest that speech adaptation lacks the dual-rate process, supporting the hypothesis that explicit and implicit learning constitutes the fast and slow processes.

P1-G-181 - From motor intention to control: Longitudinal neural decoding with electrocorticography

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Details

Decoding movement-related information from neural activity is a central problem in motor control and a foundation for brain–machine interfaces (BMIs) that aim to restore communication and movement. For chronic, real-world use, performance must go beyond offline accuracy benchmarks: decoders must

operate reliably online under low-latency closed-loop constraints, and researchers need principled guidance on how much longitudinal training data is required to reach and sustain target accuracy. Using chronic macaque electrocorticography (ECoG) signals, we present an end-to-end framework that links systematic offline benchmarking, online validation, and data–accuracy scaling analysis within a single long-term setting.
ECoG signals were recorded from a 32-channel array over the sensorimotor cortex (29 channels retained after quality control) at 1 kHz during a colour-cued two-choice button-press task. We focused on a motor-preparation (pre-movement) window (-500 ms to 0 ms relative to hand lift-off), with minimal preprocessing designed for low-latency deployment (common average reference and baseline correction). To ensure temporal realism in chronic data, we excluded portions of the recording timeline associated with major signal/protocol shifts and analysed a central ~10-month interval.
In Phase 1, we compared a broad set of decoding architectures under a temporally constrained nested cross-validation protocol that prevents leakage and evaluates generalisation to future recordings. Attention-based decoding (EEG-Transformer) achieved the best offline performance (83.37% ± 2.70%, variability across folds), with strong results also observed for modern convolutional models, while classical machine-learning baselines lagged.
In Phase 2, we quantified how performance scales as training data accumulates using forward-chaining (time-forward) evaluation to preserve causal ordering: models were trained on earlier days and evaluated on held-out future days (validation and test). Accuracy improved with additional training data initially, but gains plateaued once training exceeded ~5,000 samples (≈40 training days in our dataset). Beyond this point, adding more data did not show a clear improvement in accuracy.
In Phase 3, we selected OneDCNN for its accuracy–latency balance and deployed it in online closed-loop sessions. The decoder reached 84.38% online accuracy (27/32 correct), closely matching offline estimates and demonstrating strong offline-to-online transfer without additional fine-tuning.
Together, these results connect movement-intention representations in sensorimotor ECoG to practical closed-loop decoding, providing an end-to-end framework for selecting online-capable decoders and planning longitudinal data collection in chronic BMI settings. The observed plateau in data–accuracy scaling offers a principled guide for when additional data are likely to improve control and when adaptation or data-quality interventions may be more effective.

P1-G-182 - Two distinct mechanisms of temporal precision

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Details

It is known that the variability of duration estimates increases with its magnitude in a lawful manner - a phenomenon known as scalar variability or Weber's Law. How does the brain achieve accurate time estimates despite the increasing variability? Timing studies have proposed at least two mechanisms. First, when an interval estimate is subdivided into chunks, the overall precision is higher than when estimating the entire interval ballistically. This can also be derived analytically from the variance sum law. Besides this subdivision effect, recent findings suggest that the timing precision may rely on yet another mechanism - temporal scaling modulated by the speed of motor timing. Temporal scaling posits that a stereotypical movement—either the movement of body parts or the movement of neural activity along a trajectory—once established, can estimate time by temporally stretching or compressing the movement. It has been reported that by increasing the speed of that movement, the temporal precision of the estimate is increased, a phenomenon termed the speed-Weber effect. However, the subdivision effect is confounded with the speed-weber effect - increasing speed also increases the number of resets. Here, we used two different timing tasks and behavioral modeling to test whether the speed-Weber effect is an outcome of the subdivision effect. By parametrically varying the speed of mental

simulation while controlling for distance and the number of resets, we found that the speed indeed reduces timing variability independent of the subdivision effect. What is thought to be a general mechanism for keeping time in the brain (i.e., temporal scaling) can also help keep timing variability in check by simply scaling both time and space and maintaining a high neural trajectory speed. The speed-Weber effect thus makes precise neural predictions, which we are currently testing in openly available neural datasets on timing behaviour in rodents and primates.

P1-G-183 - Causal inference in action and perception supports sensorimotor learning

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Details

Implicit motor adaptation supports skilled action in the face of dynamic environments and body states. Classical theories posit the goal of adaptation as one of error minimization through state estimation of environmental perturbations. Recent models, referred to here as “perceptual-realignment” models, posit the goal of reach adaptation as one of realigning a percept of the hand with the movement goal. Here, we present a computational framework that sheds light on these questions and explains a diversity of motor and perceptual findings.

The Parsing of Internal and External Causes of Error (PIECE) model is a Bayesian causal-inference model where the ideal observer combines visual, proprioceptive, and motor predictive cues to compute a posterior regarding whether sensory feedback was perturbed or not. Adaptive motor output reflects the posterior-weighted average of the state estimate of the perturbation. Thus, in contrast to prior causal-inference models (e.g., Wei & Körding 2009), the PIECE observer utilizes the posterior on the perturbation, as opposed to the hand location, to guide future reaches.

PIECE was successfully applied to two separate adaptation experiments in which visuomotor rotations were randomized and counter-balanced across trials. Behaviorally, we observed the remarkable ability of participants to implicitly parse total movement error into internally- and externally-generated sources (i.e., motor noise vs. perturbed visual feedback, respectively), adapting only to the latter. This was observed when the range of imposed perturbations matched baseline motor variability (Exp. 1), and when it exceeded normal bounds of motor variability (Exp. 2). PIECE was the only model that correctly captured this error-parsing behavior, outperforming five competing models, including several perceptual-realignment models (e.g., Tsay et al 2022), for all 32 participants.

In Exp. 3 we investigated explicit error detection and its relationship to implicit error parsing by assessing perturbation-detection thresholds. PIECE was highly successful in characterizing the signal-detection properties of human observers, outperforming two other perceptual models in 13 out of the 16 participants who also participated in Exp. 2.

Additional simulation-based analyses showed that PIECE also provides a unified explanation for several other motor and perceptual phenomena: exponential learning curves in response to consistent visuomotor rotations, saturated adaptive responses, and reversion to baseline reaching during washout. Notably, PIECE also reproduced a recalibration of perceived hand position during adaptation, a finding that has been used to support perceptual-realignment models. Contrasting this view, our results suggest that this recalibration is a correlate, rather than a cause, of adaptation.

Combined, our work supports a normative model of implicit adaptation that unifies classical and current ideas related to prediction, perception, and error correction.

P1-G-184 - Corticospinal mechanisms underlying non-compositional motor unit recruitment during finger control

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Details

The ability to individuate and coordinate finger movements is the essence of manual dexterity, enabling behaviours that range from basic object and tool manipulation to complex, skilful actions. This ability generalises across contexts, allowing similar finger movements to be produced under varying task demands. Such flexibility has motivated the idea of compositionality, here defined as the ability to produce neural or motor outputs for combined finger movements from the activity patterns associated with individual ones. However, evidence across multiple levels of the motor system challenges a direct compositional account of finger control.

While intracortical recordings in premotor cortex reveal an approximately linear encoding of combined finger movements from individual ones, functional imaging of primary motor cortex (M1) does not support this view. Instead, M1 finger organisation reflects the frequency of finger covarying patterns during natural hand use. A similar departure from compositionality is observed at the spinal level. In extrinsic hand muscles that terminate in multiple tendons, individual and combined finger tasks recruit distinct sets of motor units (MUs) within the same muscle for mechanically similar tasks. These task-dependent recruitment patterns are inconsistent with a control scheme in which each muscle compartment is driven by a single common input that could be reused compositionally across tasks.

This organisation might reflect the fact that grasping with multiple fingers emerges earlier than individual finger movements in both evolution and human development. Neuroanatomical and physiological evidence implicates the caudal “new” M1 and its direct corticomotoneuronal (CM) projections as a critical substrate for independent finger control. However, these CM projections are weak at birth and strengthen over childhood contributing to improvements in manual dexterity. Together, these observations suggest that developmental refinement of CM projections may underlie the non-compositional MU organisation observed in extrinsic hand muscles during finger control.

Here, we address this hypothesis using a computational model that integrates modular recurrent neural networks representing M1 and spinal circuits with a biophysical model of MU recruitment and firing. We systematically probe plasticity across cortical, spinal, and descending CM projections using a learning paradigm aligned with childhood motor development, progressing from multiple finger coordination to finger individuation. Model performance is evaluated by finger force accuracy, the ability to recreate experimentally observed MU recruitment patterns during finger presses, and the associated cortical and spinal population dynamics. This mechanistic framework advances our understanding of motor control by shifting the focus of motor control models from muscles to the neural organisation of MUs.

P1-G-185 - Causal inference in closed-loop motor control

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Details

Many computational models of perceptual causal inference focus on static perceptual tasks with no temporal or motor components. However, real-world behaviour unfolds dynamically and often involves closed-loop control. Here, we introduce a general modelling framework that combines multisensory causal inference with optimal feedback control by casting the problem as inference and control in a

switching linear dynamical system (SLDS). Our framework combines approximate probabilistic inference over latent causal structures and environmental states with a mixture-of-controllers, in which each controller is optimized for a specific causal model and weighted by the approximate probability of that model. We develop our approach by generalizing from static models of multisensory perception to dynamic and action-oriented settings, where inference and control evolve over time. We simulated previously published behavioural tasks, including visuo-vestibular heading discrimination and path integration with interception. Our approach reproduces key empirical findings, such as S-shaped biases in heading estimation and motor strategies based on inferred object motion. We further demonstrate the versatility of our approach by simulating novel task extensions, including motion in depth, latent switching dynamics, and multi-objective motor control. Together, our framework provides a principled computational account of how perceptual causal inference and motor behaviour can interact in dynamic, uncertain environments.

P1-G-186 - From motor units to muscles: Evidence for synergy degeneracy in human motor control

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Details

Muscle synergies are considered a potential control strategy implemented by the central nervous system to coordinate multiple muscles during movement execution. However, some critics of synergies emphasize that synergies should instead be implemented at the motor unit level since muscles are not the basic control units. Recent advances in high-density surface electromyography (HD-sEMG) recording and motor unit decomposition algorithms have enabled the non-invasive decoding of large populations of motor units, leading to the emergence of the concept of motor neuron synergies. Unlike traditional muscle synergies that are defined at the whole-muscle level, motor neuron synergies transcend anatomical boundaries and form functional clusters across muscles. Whether these motor neuron synergies align with conventional muscle synergies remains uncertain.

To address this question, we first conducted a simulation study incorporating simulated spike trains and physiologically realistic motor unit action potentials. Ground truth synergy structures were manually defined at both the whole-muscle and motor unit levels to evaluate the performance of traditional synergy extraction algorithms, such as non-negative matrix factorization (NMF). The results demonstrated that NMF could retrieve synergy information from this non-linear system regardless of whether the underlying structure was implemented at the whole-muscle or motor unit level. Notably, the simulations suggest that different implementation types of motor unit synergies could result in the same muscle synergies, indicating degeneracy in the motor control system.

To assess whether this synergy degeneracy generalizes to actual biological systems, we then recruited twenty healthy subjects and recorded 64-channel HD-sEMG along with traditional single-channel EMGs to simultaneously extract motor unit activities and muscle synergies. Analysis across different hand tasks and force levels revealed that muscle synergies remained largely consistent. By tracking common motor units across tasks, we examined all possible two-trial and three-trial combinations to assess the relationship between motor unit and muscle synergies. Grouping motor unit synergies into stable and unstable clusters revealed that stable motor unit synergies consistently produced stable muscle synergies, whereas unstable motor unit synergies resulted in a broader range of muscle synergy similarities. These findings are consistent with the simulation results showing that different motor unit synergies can converge to the same muscle synergy output, thus revealing the many-to-one

correspondence between motor unit synergies and muscle synergies and the synergy degeneracy in the motor system.

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P1-G-187 - Standardized and automated pipeline for processing chronic sparse multielectrode array data

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Details

Chronic sparse multielectrode arrays (e.g., Utah and floating microelectrode arrays) are widely used in systems neuroscience, brain–computer interfaces (BCIs), and neuroprosthetics. However, multi-session data are often processed with manual workflows that differ across operators. This variability limits reproducibility and cross-session comparability, which undermines scalable artificial intelligence (AI) analyses and credible tracking of BCI progress across studies and iterations. It thus highlights the need for standardized data assessments, which require reproducible pipelines with transparent quality control (QC) to support comparable outcome measures. We developed a containerized and automated pipeline that standardizes data ingestion, stimulation-aware preprocessing, spike sorting, and QC for sparse multielectrode arrays. Preprocessing includes a new model for automated artifact removal and objective channel rejection. It also handles artifact-contaminated intervals using consistent rules such as masking stimulation-locked contamination. The workflow generates session-level QC reports (noise statistics, channel status, artifact indicators) and logs dataset identifiers and processing configurations to enable repeatable runs and transparent comparisons. Spike sorting is executed via SpikeInterface with Kilosort (a machine-learning–based template inference) to extract units, i.e., cluster of detected spikes originated from the same neuron. Post-sorting validation combines quality metrics (refractory and inter spike interval violations, signal-to-noise ratio, presence ratio, etc.) with task modulation and behavioral alignment to flag and exclude unreliable units from downstream analyses. Across multiple sessions (with and without stimulation), the pipeline runs reliably and produces standardized QC outputs suitable for cross-session comparison and multi-session analyses. Relative to expert-level manual workflows, automated processing suppresses artifacts more consistently and reduces the risk of discarding usable channels and units. Preliminary benchmarks show higher recovery of units and more spikes per unit, while reducing hands-on time and specialized training requirements. Overall, this work provides practical infrastructure for sparse-array electrophysiology data processing by enabling scalable and reproducible multi-session processing with standardized QC outputs. This increases reliability of downstream analyses and consistency of BCI and neuroprosthetic performance evaluation across sessions and studies.

P1-G-189 - Damage-dependent neural computation reveals opportunities for restoring spinal locomotor CPG function

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Details

Locomotor control emerges from interactions between biomechanics, sensory feedback, and intrinsic spinal circuitry. A classical representation of this intrinsic circuitry is the bilateral half-center central pattern generator (CPG), which has been successfully modeled using ordinary differential equations.

While these rate-based models capture the temporal structure of locomotor phases, they cannot represent neural damage or degradation of distributed computation. To address this limitation, we converted a validated analytical CPG model into a spiking neural network (SNN) composed of leaky integrate-and-fire neurons, trained to reproduce the same input–output ensemble relationship, transforming locomotor drive at different speeds to the appropriately modulated locomotor phases. The SNN-CPG accurately reproduced experimentally measured extensor-dominant relationships between stance and swing phases. Across simulated speeds, the model maintained symmetric left–right alternation and preserved the linear mapping between tonic drive and effective stepping speed, consistent with established neuromechanical principles.
This framework enabled controlled examination of how distributed network structure relates to function. We performed progressive simulated lesions by randomly removing a fraction of neurons from flexor, extensor, or combined populations. Lesions produced differential deficits: removing extensor neurons led to rapid degradation of phase regulation and coordination, whereas equivalent flexor lesions produced milder disruptions until a sharp transition point. These findings reflect the experimentally observed dominance of extensor-related pathways in regulating cycle structure during overground locomotion. We then tested whether increased descending drive could rescue “damaged” neural computation. Following lesion onset, gradually increasing the CPG input restored normal phase alternation and reduced error across a broad range of damage levels. This behavior parallels experimental observations in which elevated excitation from supraspinal or sensory pathways reinstates locomotor rhythms after spinal injury or during fictive locomotion.
The model provides a transparent demonstration of degraded computation within a rhythmic neural circuit; when the distributed integration that generates locomotor phase transitions becomes insufficient, but increased drive compensates for the lost computational capacity. This mechanism is illustrated by a conceptual “rusty watermill” model: reduced torque due to damage can be overcome by increased water flow, restoring rotation. These results show that (1) distinct functional identities within structurally similar CPG subnetworks can be revealed through lesion sensitivity, (2) damage produces predictable distortions of dynamic computation, and (3) tonic excitation is a potent compensatory mechanism. Because the SNN formulation is extensible, it provides a foundation for modeling pathological gait, designing rehabilitation strategies, and integrating neuromorphic controllers with robotic or prosthetic systems. The talk will illustrate the key principles of locomotor control, its damage, and potential rehabilitation strategies using neuromechanical concepts and models.

P1-G-190 - Involuntary visuomotor feedback responses reflect the competitive and collaborative context of sensorimotor interactions

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Details

From two opponents competing for gold to a physical therapist assisting a patient, competitive and collaborative contexts shape how we move with others. Past work has shown that the interactive context modifies *voluntary* movements during sensorimotor interactions. Yet it is unclear if these high-level representations of the competitive and collaborative context influence lower-level rapid feedback responses. Here we tested the idea that the nervous system uses high-level representations of a partner’s action intent to tune rapid feedback responses.
To investigate, each participant of a human pair grasped the handle of a robotic manipulandum. Each participant saw their self cursor, their partner’s cursor, and a jointly controlled cursor. They also had vision of their self target and their partner’s target. The self target and partner target were perfectly overlapped at the start of each trial. Participants were instructed to move their hand such that the

jointly controlled cursor passed through their self target. We manipulated the competitive/collaborative context by using three target jump conditions: *competitive self target jump*, *competitive partner target jump*, and *collaborative target jump*. In the *competitive self target jump*, the self target laterally jumped and the partner target did not jump. In the *competitive partner target jump*, the self target did not jump and the partner target jumped. In the *collaborative target jump*, both the self and partner target jumped. The *competitive self target jump* and *competitive partner target jump* conditions are competitive, since there was no overlap between the self and partner target. Conversely, the *collaborative target jump* condition was collaborative, since there was perfect overlap between self and partner targets. To probe feedback responses, the participant's hand was constrained to a force channel when one or both targets jumped. We measured the lateral force applied to the channel during the involuntary visuomotor feedback response epoch (180-230 ms).
Remarkably, we found significantly greater involuntary visuomotor feedback responses in the *competitive self target jump* condition compared to the *collaborative target jump* condition ($p < 0.001$). That is, despite the same self target jump, involuntary feedback responses were higher when competing against a partner compared to collaborating with a partner. Our result aligns with the idea that the nervous system forms a representation of a partner's action intent to tune involuntary visuomotor feedback responses. A differential game theory feedback controller was able to predict feedback responses by using an internal model of a partner's competitive or collaborative action intent. Collectively, our behavioural results and computational model highlight that high-level partner representations tune involuntary visuomotor feedback responses in both competitive and collaborative contexts.

P1-G-191 - Modeling fear-induced effects on postural control

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Details

Human postural control is typically modeled using low-dimensional biomechanical systems such as ankle–hip or 3-link inverted pendulum models. These models successfully capture quiet stance in neutral conditions, but they omit upper-body degrees of freedom and have not been evaluated in the context of height-induced threat, where psychological factors are known to reshape motor coordination. Understanding how threat reorganizes whole-body control is an important step towards connecting biomechanics, optimal control, and emotion–motor interactions.
In our VR experiment, participants stood in an indoor environment in which the floor disappeared both in front and behind them, creating a dual-direction height threat. Using synchronized Center of Pressure (CoP) traces, full-body kinematics, and physiological recordings, we observed a clear shift in postural behavior: threat reduced anteroposterior sway range, increased sway frequency, and shifted stance forward. Joint-level analysis revealed a dissociation in control allocation: upper-body segments showed the largest displacements overall which were systematically reduced under threat, whereas lower-limb joints remained comparatively stable. These findings show that humans actively modulate arm configuration as part of their balance strategy in both conditions—an element not represented in standard stance models. Our data therefore provide concrete empirical constraints on the structure of any computational model attempting to capture posture under threat.
Motivated by these findings, we evaluate whether existing models can account for these whole-body adaptations or whether these models need to be extended. We implement an iterative Linear–Quadratic Regulator (iLQR) controller for a 3-link inverted pendulum model and compare its optimal policies when there's no height threat to a biologically inspired multi-joint controller. This comparison allows us to test

how an optimal controller compares with the biologically inspired controller in simulating the observed behavior. We then extend the iLQR framework to a 4-link system that incorporates a shoulder/arm segment, enabling us to test its efficacy in comparison to a 3-link system.
In the future, we plan to investigate how optimal control cost-function weights differ across Ground and Height conditions, to identify which internal control objectives (e.g., error minimization, effort penalization, or movement-variability costs) shift with threat. This integrated experimental–computational program seeks to establish how fear reorganizes whole-body control and to determine whether upper-body contributions are computationally necessary for modeling postural behavior under psychological threat.

P1-G-192 - Opposite biases reveal distinct mechanisms to achieve both efficient and accurate motor planning

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Details

The motor system continuously adapts to environmental statistics to optimize control. This form of adaptation results in two phenomena that operate on different timescales: use-dependent learning, which creates an attractive bias toward repeated targets (Diedrichsen et al, 2010), and a sequential dependency effect which generates a repulsive bias away from the immediately preceding action (Wang et al, 2025). Here, we show these opposing biases reflect distinct mechanisms that collaborate to increase both the speed and the accuracy in movement planning.

Use-dependent learning is often viewed as a Bayesian optimal process where the motor system integrates current plans with an internal prior. However, by systematically manipulating the prior distribution of targets (uniform ranges of 60°, 120°, or 180°), we found that neither bias pattern nor motor variance shifted as predicted by Bayesian models across priors. Consequently, we propose an alternative account: use-dependent learning facilitates planning speed rather than accuracy. Consistent with this hypothesis, targets aligned with the prior mean elicited significantly shorter preparation times and faster movement speeds.

We quantified this idea using a computational framework that combines a circular drift-diffusion model with action-critic learning. Our model successfully reproduces the empirical bias and preparation time functions across priors. Crucially, it also replicates the bimodal distribution of motor bias (Tsay et al, 2023): short preparation times yield a high bias with habit-like movements distributed around the prior mean, while long preparation times show only small attractive bias (~5°). Our model accounts for both biases within a single process, in contrast to previous accounts that have attributed this pattern to the operation of different systems. As such, we consider use-dependent learning increasing planning speed for frequent targets at the cost of biasing infrequent ones.

If use-dependent learning sacrifices accuracy for speed, how is movement precision maintained? We propose that the repulsive sequential effect serves as a compensatory mechanism. Simulations demonstrated that this short-term bias effectively attenuates the attractive bias, thereby improving movement accuracy. The observed magnitude of repulsion was near-optimal for minimizing global error (RMSE) for all priors. Furthermore, this effect is dynamically modulated: when the temporal autocorrelation across the targets increases, the repulsive effect strengthens, cancelling the attractive bias more aggressively without boosting trial-by-trial variability.

We conclude that these two biasing processes effectively serve a homeostatic function. By prioritizing planning efficiency, a Hebbian-like accumulation mechanism generates an attractive bias, whereas a repulsive sequential mechanism restores accuracy. This dynamic interplay allows the motor system to remain both fast and precise in across different environments.

P1-G-193 - Adaptive ILC model integrating sensorimotor and reward learning

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Details

Motor learning relies on multiple interacting processes driven by distinct error signals, which are thought to differentially engage implicit and explicit learning mechanisms. Sensory prediction error is typically associated with implicit adaptation, whereas reward prediction error is associated with explicit, strategy-based learning. It has been suggested that the explicit and implicit components of learning may correspond to two interacting processes: a fast process that adapts and decays rapidly, and a slower process that adapts gradually and exhibits greater retention. This interaction has been formalized computationally in models which capture learning dynamics through distinct timescales and retention rates. However, these models do not explicitly differentiate between error signals and often rely predominantly on a single error source to explain adaptation. **Importantly,** behavioral evidence indicates that different learning processes are selectively driven by specific error signals. Therefore, computational frameworks aiming to provide a more comprehensive account of motor learning should incorporate adaptation driven by both sensory and reward prediction errors.

Here, we present a computational model of motor adaptation that integrates sensorimotor and reward-based learning within a unified control framework. We developed an adaptive iterative learning control (ILC) model where a current-iteration feedback controller is incorporated with ILC in the parallel architecture and combined with learning based on reward prediction error. Sensorimotor adaptation is driven by sensory prediction error, updating feedforward commands across trials through ILC. In parallel, an explicit reward-learning module adjusts behavior based on reward prediction error, enabling rapid strategy changes and context-dependent switching.

The model was tested in simulations replicating human reaching experiments under visuomotor and force-field perturbations. Task performance was evaluated using trajectory tracking errors that combined deviations in both position and velocity. The model captured distinct retention rates and learning dynamics associated with the two processes. It successfully reproduced key experimental findings, including differences in aftereffects, behavior in catch trials, and asymmetries in switching between perturbations. Our framework accounts for how visual cues and contextual signals differentially influence sensorimotor and reward-based learning. The results support the view that motor adaptation emerges from the integration of mechanistically distinct learning processes operating on different error signals and timescales.

By explicitly modeling both sensory and reward prediction errors within a control-theoretic framework, this work provides a computational account of how multiple learning mechanisms are coordinated during motor adaptation and offers a principled foundation for studying their interaction.

P1-G-194 - Decoding epidural ECoG signals for motor control across human and non-human primates

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Details

Epidural electrocorticography (ECoG) provides a stable and relatively safe neural recording modality for long-term motor brain-computer interface (BCI) applications, but its relatively low signal-to-noise ratio poses challenges for decoding accuracy. Many studies have applied deep learning methods to improve

ECoG decoding performance under offline conditions. However, it remains unclear how deep learning-based decoding architecture systematically shapes online neural control performance, as well as generalization and transfer across individuals and species. Here**,** we implemented online BCI control using 128-channel epidural ECoG signals with convolutional neural networks (CNNs)-based (HiLo_ResNet) and Transformer-based (HiLo_Transformer) decoders in a center-out cursor-control task. Neural control performance was evaluated in two human patients and two non-human primates implanted with electrodes over the sensorimotor cortex. We compared offline decoding accuracy, online closed-loop control performance, two-dimensional direction generalization (from four to eight targets), and cross-sessions, cross-subjects and cross-species, and transfer through fine-tuning and feature alignment based on canonical correlation analysis (CCA). Both HiLo_ResNet and HiLo_Transformer supported stable online BCI control using epidural ECoG signals. Direct comparison revealed consistently but modestly improved offline decoding (accuracy: 0.74 vs. 0.58) and online control performance (accuracy: 0.72 vs. 0.54) for HiLo_Transformer relative to HiLo_ResNet. In two-dimensional cursor control tasks, both models showed robust direction generalization, successfully extending control from four to eight directions. In transfer experiments, cross-subject and cross-species decoding performance was effectively restored via feature alignment combined with fine-tuning of the shallow network layers (e.g., cross-subject accuracy improving from 0.33 to 0.70). In contrast, under cross-session conditions, the benefits of alignment were inconsistent, whereas deeper networks maintained robust performance without additional alignment. Together, our findings provide empirical guidance for decoder selection and contextualize the roles and limits of cross-subject and cross-species transfer strategies in future epidural ECoG–based online neural control.

P1-G-195 - Motor-unit center and territory estimation in the forearm cross-section from HD-EMG for control and visual biofeedback

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Details

Assessment of motor-unit (MU) discharge timing and motor-unit action potentials (MUAPs) provides a more direct neural drive to muscle than conventional amplitude features. It makes it possible to extract the neural core signal, promising robust prosthetic control and neuromuscular assessment. In addition to the control perspective, spatially mapped EMG signals in the forearm muscle cross-section can support real-time monitoring of muscle function and enable intuitive visual biofeedback for rehabilitation. Over the last decade, EMG decomposition algorithms using high-density EMG (HD-EMG) have been proposed; however, for translating HD-EMG decomposition into clinical applications, spatial MUAP visualization by estimating an MU's center and its territory remains challenging, especially for deep and highly overlapping sources in forearm muscles relevant to hand and wrist function.

This study proposes a complete pipeline to estimate MU centers and territories in the forearm cross-section and to use their spatiotemporal activation for user-intention estimation. HD-EMG is recorded from the forearm and decomposed into MU spike trains and MUAPs. For each MU, a representative MUAP is extracted and arranged as a grid map over the electrode array. MU localization is formulated as a volume-conduction-based inverse problem over many candidate MU points within an anatomical cross-section. Each MU's center and territory are estimated by optimizing a constrained cost function that fits the observed MUAP amplitude distribution while enforcing physiologically plausible solutions via anisotropic total variation for spatial contiguity and edge preservation, and L1/L2 regularization for sparsity and stabilization.

The estimated MU centers and territories are used to visualize forearm activation in the cross-section as a 2-D streaming map. Each MU contributes within its estimated territory, and its activation amplitude is computed from the spike-train firing rate averaged in a sliding time window. These spatial activation

maps are used as features to estimate user intention during isometric tasks, targeting wrist force (flexion, extension, pronation, supination) and hand grasping force.
Validation is performed in two settings: simulated HD-EMG with full ground truth of MU centers and territories to quantify localization and territory reconstruction performance, and experiments at 30% MVC isometric wrist force to demonstrate cross-sectional activation streaming in real time. Results show that the combined 2-D spatial and temporal MU activation information supports user intention estimation of wrist and grasp force, and provides an interpretable cross-sectional representation that connects MU-level neural information to forearm muscle function.
Overall, the proposed approach provides MU-level neural information in an interpretable anatomical representation, offering a promising way toward accurate and physiologically grounded myoelectric control, visual-guided rehabilitation biofeedback, and real-time spatial assessment of forearm muscle activation.

H – Neurorehabilitation

Poster Cluster (P1-H-196 & P1-H-197)

P1-H-196 - Brain-controlled transcutaneous spinal cord stimulation enhances corticospinal excitability and lower-limb motor performance in chronic incomplete spinal cord injury

Atsushi Sasaki [1], **Rizaldi Fadli** [2], **Akiko Yuasa** [3], **Zachary Boogaart** [2], **Hiroki Saito** [4], **Hikaru Yokoyama** [5], **Matija Milosevic** [2]
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Details

Transcutaneous spinal cord stimulation (TSCS) is a promising intervention for motor recovery after spinal cord injury (SCI), yet the principles that maximize its neuromodulatory impact remain unclear. Integrating TSCS with a brain–computer interface (BCI) may enhance therapeutic effects by coupling spinal circuit activation to voluntary motor intention, thereby promoting activity-dependent plasticity across brain–spinal pathways. This study investigated whether intent-triggered TSCS (BCI-TSCS) more effectively improves lower-limb motor function and neural excitability than stimulation delivered without intention in individuals with chronic incomplete SCI.
Participants underwent two interventions on separate days: (1) BCI-TSCS, in which 5-s bursts of TSCS were delivered to the thoracolumbar region when cortical activity associated with ankle dorsiflexion motor imagery was detected; and (2) Random TSCS, in which identical 5-s TSCS bursts were delivered at random intervals while participants remained at rest without motor imagery. Each intervention lasted 30 min, allowing a within-subject comparison between intention-synchronized stimulation and an intention-free control with comparable stimulation parameters. TSCS was delivered at 30 Hz. Stimulation site and intensity were individualized by monitoring TSCS-evoked posterior root–muscle reflexes in the tibialis anterior (TA). Stimulation was applied between the T12–L3 vertebral levels, where TA reflex responses were most prominent, and intensity was set at motor threshold (minimum intensity producing visible reflex responses).
In the BCI-TSCS condition, electroencephalography was processed in real time to detect event-related desynchronization during ankle dorsiflexion motor imagery, and this neural activity was used to trigger TSCS. Motor outcomes were assessed with a lower-extremity motor coordination test, including kinematic profiles during these tasks. Corticospinal excitability was evaluated using TA motor evoked potentials (MEPs) elicited by transcranial magnetic stimulation. All assessments were performed before and immediately after each intervention to capture short-term, session-level neuromodulatory effects.

Motor performance significantly improved after BCI-TSCS ($p < 0.05$). This behavioral facilitation was accompanied by a significant increase in TA MEP amplitude immediately post-intervention ($p < 0.05$), indicating enhanced corticospinal excitability, and task kinematics were also altered immediately after BCI-TSCS. In contrast, Random TSCS produced no significant changes in motor performance or corticospinal excitability. Together, these findings suggest that synchronizing TSCS with cortical activity during motor intent transiently strengthens functional coupling between descending drive and spinal circuits, supporting the importance of intent-triggered, activity-dependent neuromodulation for optimizing TSCS-based rehabilitation strategies in incomplete SCI.

P1-H-197 - Harnessing cortical intent to drive corticospinal plasticity using brain-computer interface-controlled epidural neuromodulation after chronic Tetraplegia

Rizaldi Fadli [1], **Atsushi Sasaki** [2], **Akiko Yuasa** [3], **Zachary Boogaart** [1], **Hiroki Saito** [4], **Roberto De Freitas** [5], **Nicolo Macellari** [5], **Elvira Pirondini** [5], **James D. Guest** [1], **Marco Capogrosso** [5], **Joacir Graciolli Cordeiro** [1], **Matija Milosevic** [1]

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Details

Spinal cord injury (SCI) disrupts corticospinal pathways and impairs voluntary movement, often resulting in chronic paralysis. For individuals with cervical SCI, upper-limb motor deficits severely limit independence and remains the highest recovery priority. Epidural spinal cord stimulation (ESCS) is a neuromodulation approach to improve grasping and reaching function after SCI whose potential to promote rapid corticospinal plasticity has not been optimized. Integrating ESCS with a brain-computer interface (BCI) that decodes motor intent in real time may enhance the effectiveness of neuromodulation by aligning stimulation with volitional cortical activity. Here, we present a first-in-human study showing that an implantable BCI paired with cervical ESCS can potentiate corticospinal connectivity, leading to both immediate and sustained improvements in upper-limb motor function in an individual with chronic, motor-complete cervical SCI, who underwent BCI-ESCS therapy for <30 days.

The BCI-ESCS therapy was delivered by detecting motor imagery from electrocorticography (ECoG) signals to trigger dorsal root spinal stimulation in real time during activity-based training. When the BCI detected motor imagery (decoding success rate of 83.8±4.2%), it triggered ESCS, providing stimulation to enhance movement execution. ESCS was delivered via two percutaneous leads implanted in the right epidural space spanning C5–T1 vertebrae levels to enable spinal circuit neuromodulation that innervates multiple upper-limb muscles. BCI-ESCS effects were assessed through three distinct analyses: 1) Assistive (immediate) effects, in which BCI-ESCS resulted in greater improvement in motor function compared to no stimulation and Tonic-ESCS (continuous stimulation) condition; 2) Single-session effects, in which BCI-ESCS led to facilitated corticospinal excitability, exceeding that observed in the Tonic-ESCS condition, underscoring the importance of volitional engagement and temporally coordinated stimulation in enhancing neuromodulatory efficacy; 3) Longitudinal effects, in which the four-week BCI-ESCS therapy produced sustained potentiation of corticospinal excitability and improvements in motor function with both TRI-HFT and GRASSP scores above the minimal detectable change (MDC) in SCI individuals, highlighting the utility of BCI-ESCS as a paradigm for neuromotor recovery.

Overall, our BCI-ESCS neuromodulation approach represents a shift in the role of brain-computer interfaces from assistive prosthetic approaches to therapeutic tools that can effectively harness volitional intent to drive synaptic neural plasticity. This mechanistically distinct approach enables targeted activity-dependent neuromodulation that promotes functional recovery even in chronic complete SCI, offering a promising new direction for restorative neurorehabilitation.

P1-H-198 - EEG classification of grasp force – neural correlates of weight during object lifting

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Details

Introduction: Restoration of general motor function and arm control is the number one priority of patients with Spinal Cord Injury. Since interacting with the environment is a crucial aspect of everyday life, having an intuitive prosthetic is of the utmost importance for the quality of life. Recent studies have found promising results for decoding reaching and grasping from neural signals [1, 2], but the target object weight and the amount of pressure applied have not been investigated as much, while being an important aspect of interacting with objects.

Methods: In this study, 11 participants are tasked with grasping and lifting objects with differing weight (50 and 250 gr) and shape (spherical and cylindrical). Additionally, the expected object weight is tested by creating catch-trials where the object weight is different from the previous trial but has the same shape. We record EEG signals and identify new neural correlates by looking at Movement Related Cortical Potentials (MRCP) below 5Hz and Event Related (De)synchroization (ERD/S) in the centro and centro-parietal regions. With this EEG data we identify neural correlates for object shape, weight, known and unknown weights, catch-trials, and how the correlates change throughout the stages of a movement. Finally, we use Machine Learning methods to create multiclass decoders based on the MRCP, and apply them over different stages of the movement.

Results: The analysis revealed clear MRCPs, show a response in lower frequency ranges in response to the movement, and a strong ERD pattern in the centro and parietal regions. Clear ERDs related to the movement were found relating to the movement onset, but no significant differences between the object weights. We found evidence for the presence of Centro Parietal Positivity when participants are presented with a new object as well as after lift onset in catch-trials.
Most notable is the above chance-level decoding accuracy of object weight in the reaching stage (acc. 51.3%), which increases during the lifting stage (acc. 56.6%). Furthermore, our work shows how heavier objects can be classified more accurately than lighter objects.

Conclusion: We show the role of different well-known neurophysiological signals during grasping and lifting of objects and how object weight can be decoded from an EEG signal around the lifting stage of a grasping movement. The proposed paradigm and neural correlates discovered help gain insight into the motor cortex' contribution in grasping control, but is also useful for the development of neuroprosthetics and exoskeletons that support stroke and Spinal Cord Injury patients.

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P1-H-199 - Intracortical microstimulation modulates neurons across the cortical reach to grasp network with rapidly evolving dynamics

Brandon Ruszala [1], **David Bjånes** [1], **Kelsie Pejsa** [1], **Brian Lee** [2], **Charles Liu** [3], **Marc Schieber** [4], **Richard Andersen** [1]

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Details

Brain-machine interfaces (BMIs) aiming to restore motor function of the arm and hand recently have been advanced by becoming bidirectional, both decoding information from one cortical region (direction 1) and delivering information back to a different cortical region via electrical stimulation (direction 2). These BMIs typically decode movement intent from neurons in primary motor cortex (M1) and deliver feedback to primary somatosensory cortex (S1), though recent work is now aiming to advance them further by interfacing with additional higher-level association regions in the cortical reach-to-grasp network. While stimulation in S1 is known to modulate neural activity in M1, which can disrupt the performance of decoders trained on the activity of M1 neurons, little is known about cortico-cortical modulation effects produced by ICMS delivered in other regions of the network. As BMIs expand to interface with cortical regions across the brain, knowledge about such modulation will be essential for maintaining robust decoding from M1 (or other regions) during stimulation.

The work here investigates cortico-cortical modulation effects of intracortical microstimulation (ICMS) across the reach-to-grasp network, first in monkeys and then in humans. In monkeys, we found that S1-ICMS concurrently modulated a majority of neurons in M1 and ventral premotor cortex (PMv), both indirectly (during and after S1-ICMS trains), as well as directly (time-locked to individual pulses within those trains). Interestingly, the sign and magnitude of indirect versus direct modulation effects were largely uncorrelated, with indirect effects being responsible for disrupted decoding performance. Having observed substantial modulation effects in neurons distant from the stimulation site, we implanted monkeys across the cortical reach to grasp network including M1, S1, PMv, dorsal premotor cortex (PMd), the anterior intraparietal area (AIP), and dorsal posterior parietal cortex (dPPC). Substantial modulation was observed between nearly every combination of stimulated and recorded region with short latencies.

We further studied these effects in humans, with two participants implanted in M1, S1, AIP, PMv the supramarginal gyrus (SMG), or dorsolateral prefrontal cortex (dlPFC). We similarly observed modulation effects between multiple stimulated regions and distant recorded regions, and additionally could measure and quantify modulation effects in neurons from the same array as the stimulated electrode. Greater modulation effects were observed within the stimulated array than between distant regions. Further, the properties of direct modulation time-locked to single ICMS pulses evolved dynamically over the course of ICMS trains. When decoding movement intent from the cortical reach to grasp network, accounting for such dynamic modulation effects may further improve the ability of BMIs to incorporate information delivered with ICMS and restore functional movement.

P1-H-200 - Functional integration and segregation of brain-heart networks underlie motor imagery in health and disease

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Details

How do cardiac dynamics interact with brain networks to support embodied processes such as bodily self-perception or movement preparation? The interplay between neural and cardiac signals is thought to be fundamental for maintaining internal balance and orchestrating large-scale neural dynamics that

shape perception and action. This view shifts the focus from localized regions to distributed networks that operate in parallel with, and adapt to, visceral states.
Our recent work investigates how interoceptive mechanisms along the brain–heart axis contribute to imagining movement in health and disease. Detecting signatures of covert motor intent could advance brain–computer interfaces and support rehabilitation after stroke.
Using repeated motor imagery sessions in a brain–computer interface and non-invasive electrophysiology, we first identified how cardiac activity interacts with neural processes in healthy individuals, observing a decrease in cardiac sympathetic coupling within motor cortex connectivity. We then tested whether these mechanisms could be captured in a region-agnostic manner by examining heartbeat-linked dynamics of global brain organization—an approach motivated by the widespread neural reconfigurations caused by stroke. In stroke patients, longitudinal motor imagery sessions elicited a characteristic coupling between fluctuations in brain segregation and cardiac sympathetic activity, showing that motor imagery entrainment after motor impairment modulates the brain–heart axis.
Our results show that brain–heart coupling is differentially modulated by context, highlighting how autonomic activity co-varies with large-scale brain dynamics and offering new insight into the physiological basis of embodied mechanisms and their adaptation after stroke.

P1-H-201 - A biomimetic iBCI decoder for restoring hand function in people with spinal cord injury

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Details

Current iBCIs typically decode kinematic commands from neural activity in M1. These commands can guide a computer cursor or a robotic arm and hand, but lack the ability to control applied forces or adjust limb impedance—critical limitations for grasping and manipulating objects. To address these limitations, we are developing a biomimetic iBCI that, instead, decodes intended muscle activity (EMG). We propose to use these decoded signals to control both joint kinematics and contact forces as well as joint impedance, as happens naturally. Initially, we will use a forward musculoskeletal model of the hand to drive an anthropomorphic hand avatar in virtual reality. We hypothesize that this biomimetic iBCI will be easier to learn and outperform existing kinematic decoders for hand function tasks. A key requirement for building this EMG-based iBCI is identifying template muscle activity patterns recorded during a sequence of hand movements made by able-bodied participants, together with the corresponding M1 activity recorded as a participant with tetraplegia attempts to perform the same movements. To this end, we collected data from ten able-bodied participants performing a multi-degree-of-freedom hand posture-matching task. To improve consistency, we asked participants to mimic the movements of an avatar hand displayed in a video. We recorded extrinsic hand muscles using surface bipolar electrodes (Delsys, Boston, USA) on the forearm, along with intrinsic hand muscle activity using high-density surface electrode grids (LISiN, Torino, Italy) placed on the dorsal and palmar aspects of the hand. In some participants, we paired the surface grid signals with intramuscular recordings and confirmed that surface EMGs captured intrinsic muscle activity well enough to eliminate the need for intramuscular electrodes. While extrinsic muscle recordings alone enable reliable classification of hand postures within participants, adding intrinsic muscle activity noticeably increased accuracy, reflecting the benefit of combining both intrinsic and extrinsic EMGs to capture a more complete representation of hand posture. We next used these EMG signals as decoding templates together with M1 data recorded from a spinal cord-injured participant, implanted with microelectrode arrays (Blackrock, Salt Lake City, UT) in the arm and hand representations of M1. The paralyzed participant also watched the hand

gesture video, attempted to replicate it using their own hand. Posture classification accuracy using the M1 signals was well above significance, but below that achieved with the EMGs recorded from the able-bodied participants. We used the M1 signals in combination with the EMG templates to compute EMG decoders. EMG predicted for left-out M1 data had R^2 values ranging from 0.3 to 0.4. Although our experiments were limited to posture-matching movements, we intend to extend them to force generation and object manipulation and ask how well single decoders span this broad dynamical range. Our results represent a critical step towards using decoded EMGs to restore actual movement of a paralyzed person's hand.

P1-H-202 - Stroke and neural dynamics: Exploring recovery from focal ischemic infarcts in the latent space

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Details

Acquired brain injuries, such as stroke, are a leading cause of long-term disability worldwide. When injury occurs within primary motor cortex (M1), descending signals to the spinal cord controlling movement and the integration of somatosensory and premotor inputs are disrupted, leading to motor deficits. Although spontaneous recovery can occur and is enhanced by rehabilitative therapies, the underlying mechanisms are still under investigation. Recovery is likely supported by reorganization in spared premotor (PM) and somatosensory (S1) regions; understanding how these areas undergo neurophysiological changes following M1 injury is crucial.

Objective: To determine (1) if and how spontaneous recovery is aided by open- and closed-loop intracortical microstimulation, (2) whether neural population dynamics disrupted by M1 infarct are reconstituted within the sensorimotor network during recovery, and (3) whether between-area activity and integration are restored over 4 weeks.

Methods: Twelve Long-Evans rats were trained on a skilled pellet retrieval task and unilaterally implanted with chronic 32-channel microelectrode arrays in PM and S1. Neural data were recorded during task performance prior to and up to four weeks following a focal ischemic injury to M1. Gaussian Process Factor Analysis estimated low-dimensional neural population trajectories, while Canonical Correlation Analysis quantified PM–S1 integration. Mean firing rate and local variation of refractoriness were also computed. Beginning on Day 9 post-infarct, rats received either PM spike-triggered (ADS) or yoked, open-loop (OLS) stimulation in S1.

Results (Preliminary): The marked post-infarct disruption of task-associated latent manifolds in PM and S1 gradually reverted during recovery. By Week 2, these low-dimensional trajectories realigned, paralleling behavioral improvements on pellet retrieval. Task-associated neural modulation also gradually reappeared within and between monitored areas. Behaviorally, ADS animals achieved higher success rates, while OLS animals made more retrieval attempts.

Conclusions: Our findings suggest that recovery from M1 infarct is accompanied by re-emergence of a task-associated manifold in spared PM and S1 and stepwise restoration of cross-area coordination. ADS may further expedite behavioral improvement and network-level recovery, whereas OLS yields more modest gains.

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P1-H-203 - Spinal cord stimulation targets circuit dysfunction to improve upper-limb function in non-ambulatory adults with SMA

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Details

Pre-clinical models indicate that a hallmark feature of SMA is not only MN death but also MN dysfunction due to decreased proprioceptive inputs, leading to hyperexcitable MNs with prolonged refractory periods and paradoxically reduced firing rate. As such, along with available therapies that prevent MN death, targeting spinal sensorimotor circuitry to improve circuit and consequently MN function is necessary to treat motor deficits that persist despite SMN restoration. Since spinal cord stimulation (SCS) activates sensory afferents, we hypothesized that increased input to MNs via SCS could address this circuit dysfunction. Indeed, we previously showed in three ambulatory adults with SMA that SCS improves strength, gait quality, and endurance in only 4 weeks.Here we report a follow-up trial (STUDY21080158) building on our prior work which tested cervical SCS in three non-ambulatory adults with SMA in the absence of exercise to explore improvement of function of the upper limb. We temporarily implanted (29 days) epidural leads over the cervical spinal cord of three non ambulatory participants (SMA04: male, 56 y/o baseline RULM: 8/37, SMA05: female, 21 y/o, baseline RULM: 20/37, SMA06: male, 60 y/o, baseline RULM: 34/37). To isolate stimulation effects from exercise, SCS was delivered unilaterally, using the contralateral arm as an internal control. Participants received 2 hours/day of stimulation during strength testing and 3D reaching tasks. Despite differences in age and disease severity, all participants showed increased strength (grip: up to +184%, elbow ext: up to +190%) and improved reaching kinematics, including increased smoothness, range of motion, and movement velocity. Gains were consistently higher in the stimulated arm, indicating that exercise alone is unlikely to explain the improvements. Importantly, over the four-week study period, participants also reported meaningful functional gains in daily life, including being able to unbutton a shirt, independently open doors and open the car's gas tank door. Together, these results suggest that cervical SCS can complement SMN-based therapies by targeting spinal circuit dysfunction to improve upper-limb motor function in SMA.

P1-H-204 - Distinct mechanisms and functional efficacy of epidural versus transcutaneous spinal stimulation in complete cervical spinal cord injury

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Details

Restoration of upper limb function is consistently ranked as the highest priority for individuals with cervical spinal cord injury (SCI). While non-invasive transcutaneous spinal stimulation (TSS) is increasingly investigated as an accessible therapeutic strategy, clinical outcomes remain inconsistent, particularly in severe and motor-complete injuries. It remains unclear whether these mixed results stem from the limitations in the ability of TSS to steer electrical current toward specific neural circuitry targets. We therefore asked whether task-specific, selective engagement of individual motor pools and spinal circuitry is a prerequisite for restoring dexterous hand function and achieving meaningful functional outcomes. We hypothesized that such selectivity can be achieved using epidural spinal stimulation (ESS). Here, we report a direct within-subject comparison of the immediate neurophysiological and functional effects of ESS and TSS in two participants with chronic, motor- and sensory-complete cervical SCI. Both

participants were surgically implanted with a 32-channel paddle lead spanning the C6–T1 spinal segments. ESS configurations were compared against TSS delivered via surface electrodes positioned over the same vertebral levels. We quantified motor pool selectivity and volitional motor output using electromyography and isometric force measurements. ESS demonstrated superior motor pool selectivity, and elicited robust post-activation depression, evidenced by suppression of the R2 (the second response in a paired-pulse paradigm), consistent with recruitment of presynaptic mechanisms critical for interneuronal modulation. Crucially, these robust mechanistic effects afforded a wide therapeutic dosing window, permitting the delivery of effective stimulation intensities without discomfort. In contrast, TSS failed to elicit R2 suppression and lacked a therapeutic dosing window at tolerated stimulation intensities. This suggests that TSS, in large part, activates motor pathways, bypassing segmental interneuronal circuits that provide the substrate for volitional modulation. Consequently, the selective recruitment enabled by ESS translated into immediate functional improvements: ESS augmented volitional force production and enabled distinct hand movements that were absent at baseline and during TSS. Our findings demonstrate that restoration of dexterous hand function in complete tetraplegia requires highly selective recruitment of spinal motor pools. We conclude that the capacity to engage Ia afferent-motoneuron and polysynaptic pathways at suprathreshold intensities, enabled by the superior spatial resolution of ESS, is a critical determinant of complex upper limb motor recovery after complete tetraplegia.

P1-H-205 - Social comparison speeds up motor adaptation and increases effort during hands-on assisted gait training in artificially impaired adults

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Details

Recovery after neurologic injury depends on active practice, where rehabilitation encourages patients to generate their own motor commands, experience errors, and adapt to regain functional independence. Physical assistance from therapists or robots can make difficult movements possible, but it can also trigger a natural tendency to conserve effort rather than promote motor recovery, especially in locomotion. At the same time, when support offloads some of the mechanical demands of walking it also reduces the error signals required for the neuromotor system to stay engaged and adapt. This unconscious tendency, known as motor slacking, limits neuromotor adaptation even when people believe they are actively participating.

Psychology may offer a novel way to counter motor slacking through social comparison, in which humans naturally compare their performance to others and work harder when they see others working hard too. We tested whether this comparison effect extends to assisted walking, hypothesizing that comparing one's work contributions to the physical therapist's would increase participants' effort and reduce motor slacking during a challenging gait task. Thirty-five adults performed treadmill walking requiring a 20% increased stride length while receiving an artificial impairment of dysfunctional hamstring stimulation paired with mechanical resistance to one leg. The same therapist assisted participants' affected leg in reaching the target stride for 10 min (4 x 2.5 min blocks). Participants were randomized to either a control group, who saw net (self+therapist) mechanical work done to move their leg forward each step, or a social comparison group who saw the therapist's effort relative to their own. Results showed that compared to controls, the social comparison group worked five times harder with less help and had better task accuracy ($p <= .001$ all comparisons) and adapted at a faster rate ($p = .03$). Comparative feedback also lowered perceived competence ($p < .04$), suggesting upward social comparison was created from an increased awareness of the assistance received.

These findings show socially informed feedback counteracted motor slacking during assisted walking and promoted adaptation. This work bridges motor adaptation, energetics and social psychology in a way not previously demonstrated in locomotor rehabilitation. The results reframe slacking not as an inevitable consequence of assistance, but as a behavior malleable to social constraints, suggesting a complementary approach is needed to current adaptive systems that merely reduce assistance when slacking is detected. Modifying how assistance is perceived (not just how it is applied) has immediate implications for designing robot- and therapist-assisted rehabilitation systems that maximize exercise intensity. More broadly, this work shows social comparison is a powerful, low-cost way to enhance motor participation and potentially promote neuroplasticity in assisted rehabilitation.

P1-H-206 - Synchronized NMES–voluntary contraction coupling improves corticospinal excitability efficiency

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Details

The timing of neuromuscular electrical stimulation (NMES) relative to voluntary muscle contraction (VOL) is thought to influence corticospinal excitability, yet the efficiency of different timing paradigms remains unclear. Most prior studies have compared NMES combined with VOL to conditions in which either component is absent, making it difficult to isolate the role of temporal alignment when both inputs are present. Moreover, dissociating NMES from VOL is likely to alter total mechanical output, potentially confounding interpretation of timing effects. Here we examined whether synchronizing NMES with VOL enhances corticospinal excitability more efficiently than asynchronous coupling, while explicitly accounting for differences in force production.

Twelve healthy adults completed two experimental conditions in a randomized crossover design: synchronous and asynchronous NMES–VOL coupling. Participants performed repetitive left ankle plantarflexion at 15–20% of maximal voluntary contraction for 10 min. NMES was delivered to the soleus motor point (500 μs, 40 Hz, 80% maximum tolerable intensity). In the synchronous condition, NMES was delivered during VOL, whereas in the asynchronous condition it was delivered during rest. Corticospinal excitability was assessed using soleus motor-evoked potentials (MEPs) elicited by transcranial magnetic stimulation before and up to 60 min after each intervention. Total force production during the intervention was quantified as the torque–time integral (TTI). MEPs were first analyzed using repeated-measures ANOVA. To isolate timing effects from differences in mechanical output, MEP changes were further analyzed using a linear mixed-effects model (LMM) including condition, time, TTI, and the condition × TTI interaction.

MEP amplitudes increased significantly following both synchronous and asynchronous conditions. However, TTI was greater in the asynchronous condition. LMM analysis revealed a significant condition × TTI interaction, indicating that the effect of stimulation timing depended on force output. Post hoc analyses showed that at lower TTI levels, synchronous NMES–VOL coupling elicited greater increases in MEP amplitude than asynchronous coupling, whereas this advantage diminished at higher TTI levels. These findings demonstrate that when both NMES and voluntary drive are present, temporal alignment influences the efficiency of corticospinal facilitation beyond differences in mechanical output alone, particularly under relatively low force-output conditions.

P1-H-207 - Non-invasive stimulation of muscle receptors in order to substitute lost sensory function in anterior cruciate ligament reconstructed patients

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Details

Traditionally the anterior cruciate ligament (ACL) rupture has been considered a passive ligament injury. Increasing evidence, however, highlights the ligament's neural role, contributing critical sensory afferents that affect sensorimotor control [1]. ACL afferents mediate a reflex circuit, which facilitates hamstring activation [1], thereby limiting anterior tibial translation due to hamstring pulling forces. Although ACL reconstruction restores the mechanical knee stability, it leaves a limited re-innervation of the graft and therefore an interruption of the ACL-reflex arc, leading to persistent sensorimotor alterations and a high risk of re-injury [2].

We hypothesized that appropriate non-invasive stimulation of muscle receptors could be used to elicit hamstring activations, hence substituting the function of the lost ACL-reflex. A custom device was developed to elicit muscle spindle activity by applying precisely timed tendon vibrations at 80 Hz [3]. Initial testing involved 14 healthy subjects (CON), who performed a quiet standing task under four conditions: eyes open and closed, with and without 5 s vibrations applied to the biceps femoris (BF) and semitendinosus tendons. Vibration induced an increased perception of knee flexion ($p<.002$) in all conditions and an anterior center of pressure movement with eyes closed ($p=.01$), confirming its effects on proprioceptive activity from the stimulated muscles.

Subsequently, we recruited 14 ACL-reconstructed patients (ACLR), matched to CON ($p=.265$). All 28 participants performed gait trials with and without hamstring tendon vibration, while recording surface EMG from lower-limb muscles (2148 Hz). Vibration was applied during the stance phase, where ACL strain is high [4]. In the non-vibrated condition, ACLR exhibited lower activation of the soleus in the loading phase ($p=.044$) and BF in the push-off phase ($p=.031$) than CON. Vibrations further decreased soleus activity during loading ($p<.001$) and increased BF activity during push-off ($p=.03$) in ACLR, leading to similar BF activity to non-vibrated CON ($p=.141$).

These results suggest that targeted, non-invasive vibratory stimulation of hamstring tendons improves motor function in ACLR. By enhancing hamstring activation, vibration mimics the lost ACL-reflex and re-establishes healthy levels of BF activity in ACLR patients. This may limit anterior tibial translation, consequently unloading the ACL graft. Further work should aim to estimate ACL-strain in real time to activate vibrations at critical moments. Further, we will assess whether vibration can also be used to improve sensory function, hence increasing proprioceptive acuity in ACLR subjects. Our approach reframes ACL rupture as a sensorimotor disorder and offers potential novel rehabilitation strategies to reduce re-injury risk.

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P1-H-208 - Neurological determinants of bimanual motor control in children with unilateral cerebral palsy

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Details

Introduction:

Children with unilateral cerebral palsy (uCP) frequently show deficits in bimanual motor control (BMC; optimal collaboration of both hands), impairing their independence and self-care. Quantifying BMC and linking it to neurological factors may guide early prognosis and personalized therapy. We examined whether certain neurological factors (lesion extent/location/timing, corpus callosum morphometry, corticospinal tract wiring (CST) pattern) explain variability in quantitative BMC.

Participants/methods:

Forty-nine children with uCP (7–16 years; mean = 11.90 ± 2.87) completed various bimanual tasks using the Tyneside Pegboard test, Box-Opening Task, and Kinarm exoskeleton (for a total of 12 parameters). Neurological factors were assessed with MRI and transcranial magnetic stimulation. Using semi-quantitative scales and standard templates, we evaluated lesion extent and location. Lesion timing and the CST wiring pattern divided children in two and three groups, respectively (Predominantly white/Grey matter lesion and Typical/Atypical wiring). BMC between groups was compared using Kruskal-Wallis or ANOVA; Spearman's coefficients estimated the correlation between BMC, lesion extent an location. Backward multiple linear regression (AIC; α=0.05) calculated the predictive strength of neurological determinants on BMC.

Results:

Greater lesion extent in the more-affected hemisphere correlated with slower Tyneside peg transfers, and worse Kinarm scores (FDR < 0.05). MRICS subtypes showed no adjusted differences, whereas atypical CST wiring related to worse Box-Opening scores and slower Tyneside peg transfers. In the multiple regression, the more affected hemisphere had a consistent predictive strength on task specific BMC outcomes. Adding the corpus callosum isthmus size measured further improved the predictive strength of the model for one of the Kinarm task parameter (R^2 =30%).

P1-H-209 - Biomechanical effects of transcutaneous spinal cord stimulation amplitude on gait in children with Cerebral Palsy

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Details

Cerebral palsy (CP) is caused by a non-progressive brain injury that impacts the development of the central nervous system, posture, and movement. Damage to upper motor neurons prevents the suppression of Ia afferents, leading to an exaggerated stretch reflex and impaired reciprocal inhibition. Transcutaneous spinal cord stimulation (tSCS) is a non-invasive neuromodulation technique for CP which, when combined with locomotor training, may improve gait. Stimulation delivered to two vertebral locations at sub-motor threshold amplitudes have been shown in pilot studies to improve spasticity and gait. We theorize that tSCS primarily recruits Ia afferents, increasing spinal neuron excitability and thereby facilitating the execution of motor commands. Currently, stimulation amplitude is determined by trial-and-error and visual observation by a clinician, which limits consistency in clinical trials and delays the mechanistic understanding of how tSCS supports motor function. Thus, this study aimed to quantify the effect of stimulation amplitude on gait parameters in children with CP.

Three children with CP walked on a treadmill for 24 one-minute trials with tSCS (SCONE, Spine). Amplitudes at T11 and L1 were determined via Latin hypercube sampling, and order randomized. For each gait cycle, step length, step width, peak hip extension, peak knee flexion, and quadriceps-hamstrings co-contraction were evaluated from marker-based motion analysis and surface electromyography. These outcomes are indicative of efficient gait and commonly impacted in CP. To quantify the effects of stimulation amplitude, we trained a Bayesian additive regression tree (BART) model to evaluate the effect of T11 and L1 amplitudes on each gait feature. Time was included as a model covariate to account for fatigue. Model fit was evaluated by R^2 values and accumulated local effect (ALE) plots were used to quantify individual parameter effects.
For one participant, model fit was highest for peak hip extension (R^2=0.34) and lowest for step width (R^2=0.11). For all gait features, the direct effect of time was greater than the direct effect of T11 or L1 amplitude. T11 and L1 amplitude had the greatest influence on peak hip extension. The ALE plots indicate that peak hip extension increased as T11 amplitude increased above 40 mA and there were variable effects with L1 amplitude.
Preliminary results indicate that minor changes in stimulation amplitude can alter gait features, such as peak hip extension. We expect results from additional participants will indicate that these effects are variable due to the heterogeneity of CP. Determining whether "optimal" stimulation parameters can improve an individual's gait remains an open question that needs to be addressed to maximize intervention effectiveness. These findings may be used to develop an evidence-based protocol to identify appropriate stimulation parameters for future tSCS research, enabling consistency across sessions and institutions.

P1-H-210 - Appearance and treatment of abnormal arm muscle synergies early after Stroke

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Details

Abnormal muscle co-activation (a.k.a. abnormal muscle synergies) is an important contributor to arm and leg impairment after stroke. It has been shown that stroke survivors with severe motor impairment have abnormal co-activation between the anterior and posterior deltoid, as well as between shoulder abductors and elbow flexors. However, it is unclear exactly when these abnormal patterns appear after stroke. It is important to understand this timing in order to optimize the timing of therapies to treat this abnormal co-activation, such as our myoelectric interface for neurorehabilitation (MINT; Khorasani et al, medRxiv 2025). Here, we investigated muscle synergy patterns in the acute (within 21 days) and chronic (>6 months) periods after stroke. We recorded EMGs from nine arm muscles—brachioradialis, biceps brachii, triceps, anterior, middle, and posterior deltoid, pectoralis major, and trapezius—during point-to-point, 3D reaching tasks. We analyzed data from three groups of muscles: the unaffected arm (n=10) and affected arm (n=41) in chronic stroke participants, and the affected arms of acute stroke participants (n=21). We applied non-negative matrix factorization to the EMG envelopes to identify muscle synergies, with the number of synergies capped at three per group when variance accounted for exceeded 90%. Synergy similarity between groups was quantified via dot product similarity (threshold≥0.75).
We evaluated acute and chronic participants 10±5 days and 5.5±4.6 years post-stroke, respectively. Mean Fugl-Meyer Assessment scores were 15 and 16 in the two groups, respectively. We identified three dominant synergies in the unaffected arm: (1) elbow flexor (brachioradialis and biceps), (2) elbow extensor/shoulder abductor (triceps, medial, and posterior deltoids), and (3) shoulder flexor/adductor (anterior deltoid and pectoralis). In the affected arms of both groups, the elbow flexor synergy was preserved, but the other two synergies differed substantially from unaffected. Specifically, we found abnormal co-activation between anterior and posterior deltoids in the affected arm in both the acute and chronic periods. These results imply that abnormal synergies emerge within a few weeks after

stroke. Thus, it may be beneficial to counteract these abnormal patterns and reduce co-activation early after stroke. We are currently performing a randomized, sham-controlled trial of MINT to interrupt these co-activation patterns in the acute phase after stroke. Interim results show a trend in favor of MINT improving arm activity (Wolf Motor Function Test) more quickly than sham.

P1-H-211 - High-frequency transcranial random noise stimulation enhances motor training and neural adaptation for virtual prosthesis control

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Details

Controlling upper limb prostheses with multiple degrees of freedom (DoFs) demands significant cognitive effort, which limits their intuitive use and contributes to high abandonment rates among users. While the motor areas in amputated subjects can still control movements, prosthesis use does not fully restore the sense of agency. Increasing cortical excitability in the primary motor cortex (M1) may enhance sensorimotor encoding, strengthen the sense of agency, and reduce prosthesis abandonment. Non-invasive transcranial electrical stimulation (tES) has been shown to increase cortical excitability, enhance functional connectivity between cortical networks and improve behavioral responses. Thus, we hypothesized that an excitability-enhancing tES on M1 (high-frequency transcranial random noise stimulation, hf-tRNS), could enhance cortical responses and boost performance during training to improve virtual prosthesis use.

Eighteen healthy individuals (9 ACTIVE, 9 SHAM) underwent a 20-minute, 3-day EMG-based training in virtual reality, using an EMG-driven pattern recognition algorithm to control a 4-DoF virtual prosthesis with their non-dominant hand. Pre and post training assessments included behavioral embodiment questionnaire, motor-evoked potentials (MEPs), resting motor threshold (RMT), and resting-state EEG (rsEEG).

The morphology of MEPs was characterized by the area under the curve (AUC) in the first dorsal interosseus (FDI), flexor carpi radialis (FCR), extensor carpi radialis (ECR) and biceps (BIC) muscles, that were either trained or untrained.

EEG signals were source-localized to 19 cortical regions of interest (ROIs) using eLORETA and grouped into five canonical networks: default mode (DMN), dorsal attention (DAN), ventral attention (VAN). somatomotor (SMN) and visual network (VN). Functional connectivity was then estimated across the delta to gamma bands. Connectivity metrics quantified intra- and inter-network coupling.

Data normality was assessed using the Kolmogorov–Smirnov test, A repeated measure ANOVA with-factor:TIME (PRE vs. POST) and GROUP (SHAM vs. ACTIVE) was used corrected with false discovery rate (Benjamini–Hochberg).

Both groups showed significant motor learning across the three training days (main effect of TIME, $p = 0.0002$). Although there was no difference in overall performance or learning rate between groups, the ACTIVE hf-tRNS group exhibited significant improvement from Day 2 to Day 3 ($p < 0.01$).

In the active hf-tRNS condition there was a trend toward reduced RMT in the left FDI and FCR muscles. Significant GROUP × TIME interactions were observed for MEP AUC in the left FCR (ACTIVE > SHAM, $p = 0.033$) and left BIC (SHAM > ACTIVE, $p = 0.017$).

Resting-state EEG revealed post-training reorganization, with near-significant increases in beta-band DAN-centered connectivity ($p < 0.06$). Compared to the SHAM group, the ACTIVE group showed stronger

theta-band connectivity, with large effect sizes across DAN–DMN, SMN–DMN, VIS–DAN, and VIS–SMN network pairs.
Preliminary results from this ongoing study suggest that hf-tRNS may modulate cortical excitability and network-level dynamics during prosthetic training. This multimodal approach may help identifying neurophysiological markers of prosthetic embodiment and offers new perspectives for improving prosthesis use.

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P1-H-212 - Kinematic analysis of motor responses evoked by circumferential stimulation of the lumbar spinal cord in cats

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Details

Walking is an essential skill in everyday life, but becomes impaired in many movement disorders, such as spinal cord injury (SCI). Neuromodulation approaches, such as electrical stimulation of the spinal cord (EES), show promise in restoring leg movements after SCI. However, the walking pattern induced is artificial and functionally limited, hindering the application of this technology in clinical practice. EES has mainly been applied to the dorsal part of the spinal cord, which recruits motoneurons via reflex circuits by activating primary afferents. We hypothesize that ventral EES will allow more direct activation of motor neurons and axons located in the ventral horn and ventral roots. Here, we used a circumferential electrode that wraps around the spinal cord to investigate the effects of dorsal, lateral, and ventral EES on the generation of leg movements in anesthetized adult cats. We quantified leg movements by measuring kinematics using DeepLabCut™ (Mathis et al., 2018). Then, we characterized the direction, amplitude, and laterality of evoked movements. We associated them with stimulation parameters, including electrode localization and stimulation amplitude. Electrode localization was obtained from segmenting the post-implantation CT scan and determining electrode position and orientation relative to the spinal cord. Preliminary results were obtained by analyzing 88 stimulations. We found that the movement produced depended on electrode positioning. Rostral stimulation (L4-L5) elicited a split response, with 55% forward, and 45% backward movements of the hindlimb, while caudal stimulation (L7-S3) mostly elicited backward movements (97%). Ventral stimulation evoked more movement than dorsal stimulation with a success rate of 68% compared to 43%. It also showed greater specificity and functionality with more unilateral movements and a wider range of movement amplitudes. Our analysis also revealed that electrodes positioned ventrally to the expected location of motoneuron groups could evoke specific and functional movements at a much lower stimulation amplitude. For example, knee extension could be achieved at 1.0A when stimulating L5 ventrally, close to the expected location of left vastus lateralis motoneuron groups, while 4.0A was necessary to achieve similar results when stimulating dorsally. Our preliminary results suggest that EES of the spinal cord is highly dependent on the segment and location stimulated. Moreover, stimulating the spinal cord ventrally evokes more specific movements at a lower stimulation amplitude than equivalent dorsal stimulation. Ultimately, our goal is to find optimal stimulation parameters to reconstruct a functional walking pattern that will be tested in chronic spinal-transected cats before a trial in humans.

P1-H-213 - Using statistical models of healthy behaviour to quantify static balance impairment in Stroke

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Details

Postural instability is a hallmark of stroke impairment, yet rehabilitation practices remain informed by subjective clinical assessments based on ordinal scales. Kinematic measures offer greater objectivity in assessment but are typically analyzed through group-level comparisons between healthy and patient cohorts, preventing impairment quantification at the individual level. Our lab has previously explored using statistical models of healthy behaviour across upper-limb tasks to better quantify individual impairment in stroke. These models use large, diverse healthy datasets to estimate expected performance distributions, defining impairment as performance outside of the normal range. The goal of the present study was to extend this framework to quantify static balance impairment post-stroke.

A large cohort of healthy controls (50 ♂, 100 ♀; age (range) = 45 (18-92) years) and participants with stroke (21 ♂, 7 ♀; age (range) = 68 (41-90) years) were recorded performing a 30-second quiet standing task by eight synchronized video cameras. Raw video data were processed in Theia3D markerless motion capture software and the Centre of Mass (COM) signal of the pelvis was extracted. Five discrete parameters were computed from the COM signal to assess balance performance: RMS distance and mean velocity in the anteroposterior (AP) and mediolateral (ML) directions, plus the 95% confidence ellipse area in the AP-ML plane.

Statistical models of healthy performance for each parameter were developed following our lab's established protocol [1]. Briefly, raw healthy distributions were normalized using Box-Cox equations and adjusted for age and sex using linear regression, expressing parameters in Z-units. Parameters for each participant with stroke were then transformed into Z-units using these healthy models, with impairment defined as performance beyond the 95th percentile of the healthy distribution. Using this approach, ≥40% of participants with stroke were quantified as impaired on 4/5 of the tested parameters. Impairments were also more prevalent in the ML compared to AP direction for RMS distance (48% vs. 12%) and mean velocity (48% vs. 40%), consistent with hemiparesis in stroke predominantly affecting frontal-plane balance.

Composite Z-task scores were further produced by aggregating parameters using root-sum-squares and normalizing with Box-Cox equations. At the task level, 56% of participants with stroke were quantified as impaired. Z-task scores were also significantly negatively correlated with Berg Balance Scale scores in participants with stroke ($r = -0.78$, $p<0.05$), indicating consistency with existing clinical tools.

These findings demonstrate that statistical models of healthy behaviour enable individualized quantification of static balance impairment post-stroke. Ongoing work will extend this framework to additional tasks (e.g., gait) to quantify impairment across static and dynamic domains of balance control.

[1] Scott et al., 2023. *NNR, 37 (6).*

P1-H-214 - Impaired reward-based learning but preserved motor invigoration in chronic stroke

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Details

Reward provides a feedback signal that modulates behaviour through several mechanisms, including invigorating performance and learning of action–outcome associations to guide future choices. After stroke, the ability to utilise reward feedback can be impaired, which may limit the benefits of rehabilitation approaches that use reinforcement. One possibility is that stroke causes a global

impairment of reward processing, leading to both reduced invigoration and diminished learning from feedback. Alternatively, reward processing may be selectively disrupted, such that either invigoration or the ability to update beliefs from reward feedback is disproportionately affected.
To test these competing hypotheses, we recruited forty chronic stroke survivors and thirty age-matched healthy controls to complete a probabilistic reversal learning task with both their strong (non-paretic/dominant) and weak (paretic/non-dominant) limb. On each trial, participants reached to one of two targets associated with different reward probabilities that changed unpredictably over time, requiring continued monitoring of outcomes and adaptation of choice behaviour.
Stroke survivors showed reduced reward-based learning compared to controls, expressed as lower overall choice accuracy and a greater tendency to switch responses after rewarded trials (i.e., lower win–stay rates), particularly when using the weak upper limb. Control analyses confirmed that these selective impairments were not explained by general motor impairment or cognitive deficits. To identify the putative computations underlying these behavioural differences in reward-based learning we used an established model of hierarchical Bayesian inference, the Hierarchical Gaussian Filter (HGF). The HGF characterises learning dynamics as trial-by-trial updating of an agent's beliefs about action–outcome probabilities and their change over time (environmental volatility). Compared to healthy controls, stroke survivors were slower to update their beliefs about action–reward contingencies, an effect most pronounced for the weak upper limb, whereas updating beliefs about environmental volatility remained intact. Reward-based invigoration was also preserved: strong trial-by-trial predictions about action–reward contingencies were associated with faster movement times, with comparable slopes of this association across groups, indicating that motivational drive was maintained in patients despite overall slower performance.
This behavioural dissociation between preserved motivational invigoration but impaired probabilistic reward-based learning highlights a key translational opportunity: to leverage intact motivational pathways to enhance rehabilitation intensity and compliance, and to develop adaptive feedback strategies that compensate for impaired reward learning. Harnessing these complementary approaches could strengthen recovery outcomes and support greater long-term independence after stroke.

P1-H-215 - Explaining the dissociation between motor performance and arm use: A latent-state computational simulation model

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Details

Stroke recovery is often modeled as an interaction between observable outcome measures of motor performance and arm use, measured using clinical assessment tools or instrument-based methods. However, improvements in motor performance do not always translate into increased spontaneous use. Our recent experimental work (Kim et al., 2023) demonstrated a clear dissociation between performance and use: motor performance improved in both control and autonomy-support groups in which participants could actively modulate task difficulty, whereas arm use increased selectively under autonomy support. However, the mechanistic origin of this dissociation remains unclear.
A fundamental limitation of existing stroke recovery models of arm use is that they operate primarily at the level of observable variables, linking motor performance directly to arm use, without explicitly modeling how performance is internally estimated by the participant. In contrast, earlier theoretical frameworks emphasized that action selection depends on internal estimates rather than observable outcomes. Building on this perspective, we propose a new dynamic model in which arm use is governed by internal latent states, Q and W.

In the model, performance of the more-affected arm evolves through use-dependent learning. Arm use is determined by an internal estimation of performance (Q), rather than by observable performance itself. Willingness (W) represents a motivation-dependent latent state that modulates this internal estimation process. Successful experience of the more-affected arm updates W over time, which in turn updates Q. Under autonomy support, W gradually increases, whereas it decreases in the control condition. This bias in internal estimation leads to increased arm use, which further amplifies successful experience, forming a positive feedback loop between successful experience, internal estimation, and use.
We implemented a simulation reproducing the experimental paradigm. Population-level simulations were conducted for control and autonomy-support groups (N = 100 per group). To assess robustness, model parameters and initial conditions were perturbed to introduce inter-subject variability. The model robustly reproduces key experimental patterns: performance improves in both groups, whereas arm use selectively increases under autonomy support. Importantly, W exhibits temporal dynamics consistent with experimentally measured perseverance (continued use of the more-affected arm despite failure), which increased only in the autonomy support group, supporting its interpretation as an internal participation-related state. Importantly, removing the willingness-mediated pathway abolishes the selective increase in arm use.
These results provide a mechanistic account of how autonomy support promotes arm use without necessarily altering performance gains, by utilizing internal performance estimation rather than performance itself. The proposed framework highlights the necessity of explicitly modeling internal estimation processes to bridge the gap between motor capability and real-world behavior.

P1-H-216 - Motor correction characteristics of unilateral spatial neglect to a sudden target shift

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Details

Unilateral spatial neglect (USN) following stroke is a spatial attention disorder characterized by impaired responses to stimuli in the visual space contralateral to the affected hemisphere. Motor neuroscience has demonstrated that limb movements are subconsciously corrected in response to sudden shifts in the apparent target position. As USN is primarily considered a disorder of conscious attention or higher-order cognitive processing, such an automatic response may theoretically still be induced in individuals with USN. However, whether this response is preserved is unclear. The present study investigated visuomotor correction in participants with USN by employing a reaching task toward rapidly moving targets.

Right arm movements were recorded using the Kinarm Exoskeleton Lab in 7 participants with left-sided USN (64 ± 8 years) who were admitted to a convalescent rehabilitation ward, and 18 healthy adults (33 ± 6 years) to characterize the features of USN. In the task, a visual target was randomly presented at one of 20 spatial locations arranged in a three-row configuration (7–6–7 horizontally) covering both the left and right workspace. Participants were instructed to move their hand toward the target as quickly and straight as possible. Two sessions were conducted: a No Jump session, in which the target remained stationary, and a Jump session, in which the target either remained stationary or was shifted 2.5 cm to the left (left jump) or right (right jump) 600 ms after target onset in a randomized order.

Participants with USN achieved high reaching success rates (>90%) across all conditions, although more misses occurred on the left side of the workspace in the left jump and on the right side in the right jump. Healthy participants showed longer movement durations in both the left and right jump compared with

when the target remained stationary. In participants with USN, the mean duration increased in the left jump relative to the stationary condition, especially on the neglected left side. However, the right jump shortened the duration on the neglected left side compared with the stationary condition. The velocity profiles of healthy participants showed motor correction after target jump, resulting in prolonged duration. In participants with USN, overall movement velocity was reduced, and motor correction was not present in left jump, while in the right jump, small motor corrections were still observed.

In participants with USN, reactive characteristics differed from those of healthy participants according to the direction of a sudden target change. The results suggest that responses to rightward jumps may involve automatic correction in addition to visually guided feedback control, even under reduced visuospatial attention in USN. Such automatic corrective responses may facilitate movement execution in participants with USN.

P1-H-217 - Effectiveness of bilateral proprioceptive-motor coupling to induce muscle activity in a passively moved hand and its neural substrates

Yuki Sato [1], **Yandi Tang** [1], **Hideki Nakano** [2], **Gen Miura** [1], **Jihoon Park** [3], **Tomoyo Morita** [3], **Eiichi Naito** [3]
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Details

To restore finger motor functions of a paretic hand in patients with severe stroke, it is important to induce muscle activity of the hand. Passive movement has been traditionally used in rehabilitation, but this does not always induce muscle activity. In this study, we propose bilateral proprioceptive-motor coupling (BPMC) approach and test our hypothesis that active movement of one hand would effectively induce and facilitate muscle activity of the opposite hand that is passively moved synchronized with the active movement. This study aimed to reveal the factors essential for the effectiveness of the BMPC approach by evaluating muscle activity (electromyography; EMG) of a passively moved hand and to elucidate its underlying neural mechanisms using functional MRI in right-handed healthy young adults.
In EMG evaluation, participants wore leader/follower-type finger exoskeleton robots on both hands. They repeated In-phase (IN) task, where the robot passively extended the right fingers in sync with (with about 60 ms delay) the participant's active left finger extension. As control conditions, they also performed bilateral passive (BP) task where both fingers were passively extended simultaneously and out-of-phase (OUT) task where the right fingers were passively moved in antiphase to the active left finger extension. Changes in EMG activity of the right extensor digitorum communis were evaluated. In functional MRI experiment, brain activity was measured during the IN task, where the experimenter manually passively extended the right index finger in synchrony with participant's active left index finger extension, and during its corresponding BP and OUT tasks.
EMG activity of the right passive hand significantly increased during both the IN and OUT tasks, but not during the BP task, suggesting simultaneous bilateral proprioceptive inputs are insufficient; a motor signal is required to induce muscle activity in a passively moved hand. Only through the repetition of the IN task, the amplitude of EMG activity gradually increased and its onset became progressively earlier, suggesting bilateral proprioceptive-motor coupling progresses only when active and passive movements are bilaterally synchronized. The IN task significantly more activated the hand section of the left motor cortex when compared with the OUT task. The hand section of the right motor cortex enhanced their functional coupling with the left hand section during the IN task as compared to the OUT task. Furthermore, the right supplementary motor area enhanced its functional coupling with the left hand section during the IN task when compared to the BP task.
The results suggest that the BPMC approach can be an effective method to induce and facilitate muscle activity in a passively moved hand, and that its underlying neural mechanisms are facilitation of

functional couplings between the bilateral motor cortices and between the motor cortex and higher-order motor intention area.

Poster Session 2

A – Control of Eye & Head Movement

P2-A-1 - Multifunctional neural control of the songbird beak

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Details

The nervous system can precisely, and flexibly, coordinate muscles to produce a large repertoire of behaviors with distinct functional goals. However, little is known about how brains represent different behaviors produced by one body part, or how circuits evolve to use a body part in new behaviors. Bird beaks, often studied for their many physical adaptations, provide an exemplary model of multifunctional motor control. The beak is involved in two behaviors important for birds' survival: eating and vocalizing. Both behaviors require dexterous control of beak musculature. Birds use similar beak movements in different sequences to produce each of these distinct behaviors. Seed eating occurs in three phases where birds peck a seed, husk the seed (analogous to mammal chewing), and then swallow the seed. When vocalizing (e.g. calls and song), birds use their beaks to modulate the amplitude and frequency content of vocalizations. Evolutionary studies propose that vocal behavior evolved after jaws arose, with learned song evolving even more recently in birds. This sequence suggests calls and songs co-opted pre-existing circuits for beak motor control. Anatomical studies in bird motor cortex show a region called AiL projects to beak motor circuits in the brainstem, while region RA, found only in song learning birds, projects both to brainstem circuits for vocal control and some overlapping targets with AiL for beak movement. Do the neural dynamics of these sequentially evolved regions share motor codes for similar beak movements, or is their activity unique to beak movements during eating or vocalizing? RA neural activity during song is well studied, but no prior studies have recorded from AiL. To address our question, we combined high resolution kinematics with recordings of populations of single neurons from AiL and RA. In AiL we identified neurons with activity modulation during eating. Some neurons show similar activity modulation during pecks and husking, while other neurons show opposing modulation during pecks and husking. No AiL neurons recorded to date show vocal-related modulation relative to baseline, suggesting AiL is specialized for eating and could sequence eating behaviors. In RA, we found canonical activity showing precise firing during both calls and songs. However, preliminary data suggests the presence of eating-related modulation in RA, which traditionally was considered vocal-only. Future work will compare neural dynamics in AiL and RA with detailed kinematics of beak movements during eating and vocalizing to determine how each area contributes to precise beak motor control. If AiL and RA use different dynamics for similar beak movement, it may be that evolving new pathways, like RA, allows motor systems to expand the motor codes available to control muscles and generate new behaviors. This provides a framework for multifunctional motor control across circuits, and how circuits evolve to support novel behaviors like vocal learning.

P2-A-2 - Primary visual cortex integrity is needed for normal auditory and visually-driven pupil dynamics

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Details

Pupil diameter is widely used as a rapid and sensitive marker for internal brain states and sensory processing. Anatomically, several parallel routes link the retina to subcortical areas, such as the pretectal olivary nucleus (PON) and the superior colliculus (SC), which are involved in the pupillary light reflex and orienting responses. However, it remains unknown which of these pathways is functionally essential for driving rapid, stimulus-locked pupil modulations. Specifically, is the primary visual cortex (V1) obligatory for these responses or are pathways bypassing the geniculostriate one still sufficient? To answer this question, we performed reversible pharmacological inactivation (using muscimol) of V1 in a rhesus macaque, and we presented a small visual stimulus (black disc of 0.36 diameter) in either the experimentally-induced cortical scotoma or the opposite (intact) hemifield. We also sometimes presented a brief, non-spatially-informative auditory tone (1KHz, 50 ms duration, >70 dB), either alone or simultaneously with the visual onset. In all cases, the monkey maintained fixation on a central fixation spot, and was not required to react to either the visual or auditory stimuli. We measured pupil diameter using a video-based eye tracker, and we calculated the first derivative of pupil diameter measurements; this constituted the signal that we investigated for stimulus-driven modulations that might occur in the first few hundred milliseconds after stimulus onset. In the intact state, visual stimuli evoked a pupillary constriction pulse after ~200 ms from stimulus onset. This pulse was eliminated after V1 inactivation when the visual stimulus appeared in the experimentally-induced cortical scotoma, but it was still present in the opposite, unaffected hemifield. This result challenges the hypothesis that subcortical pathways alone are sufficient for stimulus-evoked pupil dynamics. Most surprisingly, V1 inactivation also altered the pupillary response to auditory stimuli, even when no visual stimuli were presented. Specifically, in the intact state, a pure auditory tone caused a dilation pulse slightly earlier than the above-mentioned visually-driven constriction. Whether the tone occurred in isolation or with a visual stimulus in the cortical scotoma, this dilation pulse was dramatically weakened and delayed. Additional control experiments confirmed that these deficits were spatially specific to the inactivated site's visual field location. In this study, we thus propose that spontaneous activity from V1 provides input to multi-sensory structures like the SC and inferior colliculus (IC), which then affects pupillary responses to purely auditory tones. We also suggest that in the visual modality, V1 acts as a bottleneck for visually-driven pupil responses, which is directly congruent with similar conclusions recently reached also with saccadic eye movement reflexes. Our results motivate revisiting the roles of alternative visual pathways.

P2-A-3 - Individual predictive protocols in eye–hand coordination: Modeling saccade–hand dynamics from measured behavior

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Details

Eye–hand coordination relies on predictive mechanisms that link saccadic eye movements with ongoing manual control. In previous work, we showed that the distance of each saccade during line tracing is linearly related to the pen speed at the moment the hand reaches the saccade landing position. In the present study, we developed a data-driven motor model to investigate how this predictive coupling is generated and how individual differences arise.

Seventeen participants traced 30 jerk-minimum trajectories while their gaze and pen movements were recorded simultaneously. Data mining revealed four robust linear relationships shared across all participants, involving saccade timing, gaze-lead distance, local curvature, and pen speed. Using these

relationships, we constructed a motor model that predicts saccade timing and pen-speed adjustments. Individual parameters were estimated for each participant, and simulations were performed to evaluate whether the model could reproduce human-like tracing behavior.
For several participants, the model successfully generated stable drawing trajectories resembling the measured behavior. Adding noise to the model selectively increased fixation-duration variability and, in some cases, caused breakdowns in the simulated drawing, suggesting sensitivity to internal noise in predictive control. Some participants' behavior could not be reproduced by the model, indicating that additional online feedback mechanisms or alternative control strategies may be involved.
These findings suggest that individuals combine multiple predictive strategies during tracing and that their coordination patterns can be partially captured by a linear predictive model. Further refinement of the model may help reveal how humans integrate prediction and feedback during continuous manual actions.

P2-A-4 - Functional role of eye and head movements in gaze shifts during a soccer scanning task

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Details

Scanning is a visual exploratory behavior involving rapid gaze shifts that enables soccer players to explore their surroundings and make timely and accurate situational judgments. The present study focused on gaze shifts underlying scanning behavior in soccer and aimed to clarify the functional role of eye and head movements in gaze shifts from a kinematic perspective, as well as to examine the influence of expertise on this role. Previous studies on scanning behavior have primarily used head rotation frequency as an observational indicator, while few studies have quantitatively investigated the eye and head movements that constitute gaze shifts. Furthermore, gaze control involving large visual angles in dynamic, soccer-specific contexts has rarely been examined. Therefore, the present study explicitly targeted eye–head movement components that constitute gaze shifts during scanning. Twenty male collegiate soccer players performed a task simulating a passing situation. During this task, gaze, eye, and head movements during scanning were recorded simultaneously using a wearable eye-tracking system. After visually detecting a pass delivered from the left side, participants executed a gaze shift of approximately 60° and identified the direction of an unmarked teammate based on a projected 2 vs 2 offensive–defensive video displayed on a screen, before passing the ball. Temporal constraints were manipulated by setting two conditions for the interval between pass delivery and ball contact (800 ms and 1600 ms). Gaze shifts were quantitatively defined based on the horizontal angular velocities of eye and head movements. The results showed that eye movements exhibited greater peak velocity and amplitude, as well as higher movement stability, than head movements. In contrast, the relative contribution of head movements increased progressively with increasing gaze amplitude, indicating that gaze shifts were flexibly regulated through different coordinated eye–head movements depending on task demands. Under stricter temporal constraints, eye movement characteristics were consistently preserved, whereas head movements were compensated by increasing both peak velocity and amplitude for limited time. Furthermore, analyses based on expertise revealed that, even under conditions with comparable gaze amplitude and duration, the higher-skilled group consistently demonstrated greater peak velocities of gaze and eye movements than the lower-skilled group. The present study is significant in that it decomposed soccer scanning behavior into the fundamental component of gaze shifts and clarified the kinematic structure and functional roles of eye and head movements. Moreover, our results suggest that expertise-related differences are reflected in distinct kinematic properties and coordination adjustments of gaze shifts. These findings provide fundamental insights that advance our understanding of visual exploratory behavior in soccer.

P2-A-5 - Behavioral and neural variability reveal mechanisms of saccadic fatigue and adaptation

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Details

Saccades are rapid and ballistic eye movements.This remarkable accuracy, despite the lack of visual feedback during the movements, relies on an internal model widely believed to be implemented within the cerebellum.

This study investigates the neural and behavioral mechanisms of saccadic control, specifically focusing on how the cerebellum manages non-motor fatigue during gain-changing adaptation. Recognizing that fatigue inevitably complicates the study of pure adaptation, we introduce a novel modeling approach that functionally separates these two processes. Our analysis revealed that non-motor fatigue is caused by an increase in neural noise within the motor command. This noise necessitates a reduction in peak saccadic velocity to maintain the endpoint accuracy. By decoupling these components, we isolate the source of fatigue and define the mechanisms of true, gain-changing adaptation.

Analysing the properties and variability of the post-saccadic drift (PSD) further refined our model, as the size of the PSD was modulated by adaptation. Through an inverse modeling approach, we propose a novel saccadic control model where the cerebellar output simultaneously increases the eye velocity and reduces endpoint variability, achieved using an internal model that considers both the gain and the delay inherent in the oculomotor system.

This model is strongly supported by recordings of Purkinje cells, the sole output of the cerebellar cortex. Their simple spike population activity exhibited poor encoding of kinematic information and a complex signal-to-noise ratio relationship, consistent with the model's prediction. Furthermore, complex spikes, which are implicated to update the cerebellar internal model, carry information about both gain and delay of the oculomotor system, conveyed in distinct time windows during the post-saccadic period. This work offers key insights into how the cerebellum implements and updates the internal model to robustly ensure fast and accurate movements under noisy motor command and to adapt the oculomotor system to new environments.

P2-A-6 - Neural representations of the Quiet Eye during a precision aiming task

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Details

When performing aiming tasks, experts exhibit a long-duration gaze fixation on a task-relevant landmark just before the final movement, termed the "quiet eye". Behavioral studies have provided evidence for two main hypotheses to explain why the quiet eye aids motor performance. One possibility is that the quiet eye supports the time needed to develop a precise motor plan (*programming hypothesis*). Alternatively, the quiet eye may support the necessary time to inhibit task-irrelevant distractors (*inhibition hypothesis*). However, behavioral studies alone have not been able to disentangle the extent to which each of these factors contributes to the efficacy of the quiet eye, underscoring the need to probe their underlying neural representations. Here, we use task-based fMRI to test how neural representations of task-relevant demand and task-irrelevant distractors are modulated by the extent of gaze stability during a virtual archery task. Twenty right-handed, healthy young adults completed eight blocks of trials featuring eight distinct conditions that manipulated the stability of gaze on task-relevant features (i.e., fixed/"quiet" vs. moving/"noisy" gaze), the motor planning demand (i.e., aiming at a near or far target), and the presence of task-irrelevant visual distractors (i.e., with or without a peripheral visual distraction). Bayesian pattern component modeling of GLM-derived fMRI data tested the extent to which neural representations of task-relevant demand and task-irrelevant visual stimuli are modulated

by gaze stability during the initial aiming period (i.e., the first two seconds of aiming at the target before shooting). Results showed strong evidence for distinct representations of gaze stability across the primary visual cortex (V1), superior parietal lobe (SPL), dorsal premotor area (PMd), and the primary motor cortex (M1). We observed strong evidence for distinct representations of task-irrelevant visual distractors in V1 only, and task-relevant demand features in V1 and SPL. Consistent with the two hypotheses of quiet eye, the extent of gaze stability modulated representations for both task-relevant demand (V1 and SPL) and task-irrelevant distractor (V1, SPL, PMd, and M1). Altogether, our results support both quiet eye hypotheses, albeit to different extents. While effects related to the inhibition hypothesis were widespread across visual, parietal, and motor regions, effects related to the motor programming hypothesis were localized to the visual cortex and superior parietal lobe and were absent from motor regions. This divergence of representations across regions indicates that the quiet eye engages multiple, distinct neural processes, rather than a single unified mechanism.

P2-A-7 - Countermanding model of microsaccadic inhibition suggests a preserved role for latent visual signals when primary visual cortex is impaired

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Details

We recently discovered that transient focal inactivation of the macaque primary visual cortex (V1) abolishes visually-driven microsaccadic inhibition: microsaccade rate after stimulus onset maintains its prestimulus trends as if no stimuli appeared. This discovery suggests that the geniculostriate pathway dominates the reflexive resetting of saccade generation by sensory stimuli. However, we also observed that microsaccade directions demonstrated weak but persistent biases towards the appearing visual stimulus. While this observation likely reflects residual visual signals from alternative visual pathways bypassing V1, it remains unclear why rate modulation is fully eliminated while directional biases still weakly emerge. Here, we addressed this question theoretically by developing a computational model of microsaccadic inhibition as a countermanding process, and we asked to what extent are rate and direction effects impaired with weakened visual sensory strength. In the intact model, microsaccades are constantly generated as a rise-to-threshold process, with each process' current rate drawn from a random distribution; after threshold crossing, the accumulator is rapidly reset, and a new rate is sampled for the next movement. Visual onsets countermand the accumulator: after a sensory delay (again randomly sampled), the instantaneous rate of rise is cumulatively reduced to eventually empty the accumulator. For some movements, the slowdown succeeds, and a new rise-to-threshold needs to be initiated; in others, the threshold is still crossed, causing escape movements. Microsaccade direction for each rise-to-threshold process is drawn from a random distribution centered on 180 deg from the previous microsaccade, and only the movement process associated with stimulus onset exhibits a bias towards the appearing stimulus, reflecting visual bursts in spatially organized brain structures. Running 2000 model trials revealed classic microsaccadic inhibition, and a biasing of microsaccade directions towards the visual stimulus. We then simulated an impaired visual input strength, by reducing the efficacy of the countermanding by a scale factor. Weakened countermanding was less effective in slowing down the rise-to-treshold process and led to proportionally shallower microsaccadic inhibition. More importantly, when the impairment reached ~90%, corresponding to the potential impact of the loss of the geniculostriate pathway (Perry & Cowey, 1984), the rate inhibition was abolished, but weak directional biases persisted. We further verified this observation by running 25 instantiations of the model, 2000 trials each, on different countermanding impairment levels. Thus, our model confirms that latent visual signals bypassing V1 can manifest themselves in weak directional biases even when temporal resetting is statistically unobservable. These results also motivate searching for stimulus contexts in which the impact of the latent signals can be further amplified.

P2-A-8 - The dependence of perceptual saccadic suppression on spatial frequency is dramatically different for ON-type versus OFF-type stimuli

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Details

Perceptual saccadic suppression refers to a marked reduction in visual sensitivity for brief stimuli presented peri-saccadically. Such sensitivity suppression can reflect the influences of corollary discharge associated with saccade motor commands, but it also involves a strong visual component. One example of such a component is that saccadic suppression strength is not the same for all spatial frequencies: low spatial frequencies typically undergo stronger suppression (Burr et al., 1994), although the specific visual context alters that (Idrees et al., 2020). Because of continued debates about the neural origins of low spatial frequency saccadic suppression, we hoped to provide a fresh perspective that is motivated by our recent discovery that dark stimulus contrasts are immune to saccadic suppression in the primary visual cortex (Wu et al., NCM, 2025). We designed spatial frequency stimuli that consisted of half-wave rectified luminance sine waves: ON-type stimuli consisted of only the sine wave halves that were brighter than the background, and OFF-type stimuli consisted of only the sine wave halves darker than the background. In both cases, the dominant spatial frequency was the same, and only the luminance polarity was different. We also tested regular sine wave gratings. The experiment involved nine human subjects generating a horizontal saccade of approximately 3-4 deg size (towards the center of the display). Upon online saccade detection, we presented a horizontal Gabor grating (regular, ON-type, or OFF-type; ~ 4.94 deg radius) for one display frame (~11 ms) above the line of sight by 8.7 deg, and at +/- 8.5 deg horizontally. The grating onset happened approximately 35 ms, 60 ms, or 160 ms from saccade onset, and the subjects had to indicate whether the grating appeared to the right or left of the central fixation spot that their eyes landed on. Across trials, the grating spatial frequencies varied between 0.4 and 1.71 cycles/deg. We made the amplitude of the sine wave grating luminances low enough such that performance at 160 ms, but not the shorter flash times, was near ceiling. For the regular sine wave gratings, we replicated Burr et al., 1994: perception for the shortest flash time was worst for low compared to high spatial frequencies. Remarkably, the performance patterns were dramatically different for ON- and OFF-type stimuli. For ON-type stimuli, there was very mild saccadic suppression that did not depend on spatial frequency. For OFF-type stimuli, performance at the low spatial frequencies was slightly higher than with the regular gratings, and performance at the high spatial frequencies was markedly lower (i.e. strongly band-pass); performance was highest at 0.8 cycles/deg. Our results suggest that asymmetric saccadic suppression in the primary visual cortex, coupled with resolution differences between ON and OFF early visual pathways, likely explain both Burr et al., 1994 as well as our current results.

P2-A-9 - Saccades orchestrate intraocular glucose to shape visual responses in birds

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Details

Birds exhibit remarkable vision despite lacking the typical network of blood vessels in their eyes. The characteristic poses a long-standing question about how avian retinas fulfill high energy demands necessary for sight. Here we show that natural, rhythmic eye movements, known as oscillatory saccades, orchestrate intraocular metabolic dynamics and attention-guided visual processing in pigeons. In a series of integrated experiments, we monitored eye movements along with glucose levels in the eye and neuronal activity in key brain regions receiving direct input from the retina. We found that these

saccades generate fluctuations in intraocular glucose concentrations, closely linked to changes in neuronal visual responses over timescales of seconds to minutes. Moreover, pharmacological manipulations that altered glucose availability and eliminated these oscillatory saccades resulted in corresponding shifts in neuronal responses, demonstrating a causal linkage between oscillatory saccades, metabolic regulation, and visual processing. These findings reveal a mechanism by which birds actively evoked saccades during attention-driven information gathering, propelling retinal metabolism and facilitating their vision in the absence of retinal vasculature. This study underscores the interplay among eye movements, metabolic regulation, and high-level visual performance, suggesting broader implications for how eye movements contribute to retinal health, attention, and visual function across species.

P2-A-10 - Effects of prosthesis stimulation on compensatory saccades during the En-bloc head impulse test in vestibular-impaired monkeys

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Details

Background: The vestibulo-ocular reflex plays a critical role in gaze stabilization. Patients with vestibular loss cannot maintain gaze on a target during head movements because the eyes move with the head. The head-impulse test (HIT) detects this instability by having patients fixate on a target while the head is rapidly and unpredictably rotated to stimulate the semicircular canals. Patients make two types of compensatory saccades during HIT: covert saccades, which occur during head rotation, and overt saccades, which occur after head movement stops. Patients who acquire covert saccades show improved Dizziness Handicap Inventory scores, higher visual acuity, and reduced oscillopsia, likely because retinal slip is minimized and vision is suppressed during the saccade. Learning to generate covert saccades is therefore important for quality of life. To study the neural basis of these movements, we developed a vestibular-impaired monkey model and confirmed use of a saccadic strategy during en-bloc HIT, in which head and body rotate together.
A vestibular neuroprosthesis has been used to replace missing sensory motion information. Although significant progress has been made in surgical implantation techniques and waveform optimization over the past two decades, functional restoration remains incomplete. Novel approaches are therefore needed to achieve full recovery. As a supplement to current strategies, one approach is to understand how the brain integrates and adapts to artificial stimulation delivered alongside natural neural activity, including residual vestibular function and saccades. In this study, we test whether vestibular prosthesis stimulation facilitates saccades during en-bloc HIT and assess its long-term effects.
Methods: One bilaterally vestibular-impaired monkey was tested during en-bloc HIT at a peak velocity of 100°/s. The right horizontal semicircular canal was stimulated with a vestibular prosthesis delivering biphasic pulses at 250 pps.
Results: Vestibular neuroprosthesis stimulation facilitated leftward saccades. Repeated sessions enhanced performance in both stimulation and no-stimulation conditions, and this effect persisted for several days.
Interpretations: Right-ear stimulation drives activity in the right vestibular nucleus, which in turn enhances activity in the left abducens nucleus through excitatory projections and reduces right abducens nucleus activity via inhibitions. During leftward saccades, the right abducens serves as antagonist whereas the left abducens as agonist. As stimulation depressed antagonist activity and enhanced agonist activity, the balance shifted toward easier saccade initiation. Furthermore, the long-lasting effects suggest that stimulation also induces adaptation or plastic changes in neural circuits that control gaze stabilization.

These findings indicate that vestibular prosthesis stimulation may facilitate recovery by enhancing covert saccade initiation.

B – Fundamentals of Motor Control

P2-B-11 - Steroid hormone levels significantly impact brain-network activity and cognitive-motor integration (CMI) performance in working-aged adults with persisting symptoms following concussion

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Details

In everyday life, there is an indirect mapping between the viewed goal of our action and the required movement. Such tasks require cognitive-motor integration (CMI), where visual information is translated into motor behaviour. The underlying CMI control networks may be compromised following a concussion, resulting in an inability to engage in complex movements. Previous work from our lab has found that the relationship between concussion symptomatology, functional connectivity, and visuomotor skill varies as a function of hormone levels in adults with persistent post-concussion syndrome (PPCS). However, the impact of sex, gender, and steroid hormones on the neural control of rule-based visuomotor performance remains poorly understood. Here, we aim to address a critical knowledge gap regarding the association between sex hormones and the neural control of movement in working-aged adults affected by PPCS. **Methods:** 41 working-aged adults (25 females, 47± 9.9 years old) completed two visuomotor assessment tasks, one requiring direct visual feedback with motor output, and one comprising an indirect interaction involving an element of dissociation between the visual stimulus and target of reach, requiring CMI. Persistent symptom severity and dizziness data was collected to analyze brain network function via resting state functional connectivity in CMI-related brain regions, (3T Siemens MAGNETOM PrismaFit MRI scanner). A saliva sample was collected to analyze hormone concentrations of progesterone, estrogen, and testosterone. **Results:** After controlling for age, progesterone, estrogen, and resting state network activity, testosterone was significantly predictive of early symptom severity (RPQ-3; $p<0.05$). We also observed that testosterone level explained a significant level of variability in both the somatomotor and dorsal attention resting-state network activity ($p<0.05$), networks known to be involved in visuomotor control. We also found that elevated estrogen levels were significantly predictive of poor CMI performance ($p < 0.05$), after controlling for age, and the following resting-state network activity (RS_FPCN, RS_Default, RS_Cont, RS_Limbic, RS_SalVentAttn, RS_Visual, RS_SomMot, RS_DorsAttn). **Conclusions:** We demonstrate that steroid hormone levels significantly impact relationships between movement related neural networks and cognitive-motor integration in adults with persistent post-concussion syndrome (PPCS). Thus, it is important to account for an individual's hormone status when studying the impact of brain injury on the neural control of visuomotor performance.

References: [1]Sergio et al. *Frontiers in Neurology* (2020), [2]Abstracts of the 3rd Annual Meeting of the CCN-RCC. *The Journal of head trauma rehabilitation* (2023)

Highlights:
Complex visuomotor performance is impacted by concussion symptoms in working-aged adults.
The degree of performance impairment is affected by estrogen levels.
Testosterone levels affect the motor-and attention- related brain network activity.

P2-B-12 - M1 is modulated by motor but not tactile imagery, while S1 reflects vividness of both

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Details

Background Motor imagery (MI) and tactile imagery (TI) involve internal simulation of actions and sensations without overt movement and real somatosensory perception. While neuroimaging studies show sensorimotor activation during imagery, temporal dynamics of cortical excitability remain unclear. TMS-evoked potentials (TEPs) provide millisecond-resolution measures of cortical reactivity, yet no studies have characterized TEPs during MI or TI.
Objective To investigate whether: (1) MI and TI modulate TEPs differently in primary motor (M1) and somatosensory (S1) cortices, (2) TEP components correlate with motor-evoked potentials (MEPs), and (3) TEP amplitudes reflect individual imagery vividness.
Methods 17 participants underwent TMS-EEG in two sessions targeting left M1 and S1. Each session included five conditions: MI, TI, tactile simulation (TS), and rest. Single-pulse TMS was delivered during tasks while recording 64-channel EEG. Participants provided vividness ratings after each trial and completed Tactile Imagery Vividness Questionnaires (TIVQ). We analyzed mean TEP amplitudes for components N15, P30, N45, P60, N100, P180, N280 across ROIs. MEPs were recorded from right forearm muscles (FDS, FDI, ADM). A novel preprocessing pipeline with regression-based ICA artifact removal was developed.
Results TEP responses revealed three key dissociations. First, regarding **task-dependent modulation**, M1 showed selective sensitivity to imagery type: MI significantly differed from rest, TI, and TS in late components (N100/P180/N280), whereas rest, TI, and TS did not differ from each other. In contrast, S1 showed no significant differences across any states. Second, **regional comparison** within identical tasks confirmed that M1 and S1 differ fundamentally in their late TEP components (N100/P180/N280). Third, **functional correlations** further distinguished the two regions: in M1, P60 amplitude during MI correlated with MEP amplitude ($r=0.49$, $p<0.05$), linking cortical excitability to motor output. In S1, however, correlations emerged with subjective imagery measures rather than motor output — P30 amplitude during TI correlated with TI vividness ($\rho=0.702$, $p_{FDR}=0.0017$ in C3-C1-FC3 ROI), while P60 amplitude during MI correlated with trait tactile imagery ability (TIVQ: $\rho=-0.631$, $p_{FDR}<0.01$ in CP3-CP1-C3 ROI). No such subjective correlations emerged in M1.
Conclusions We demonstrate functional dissociation between M1 and S1 during imagery: M1 shows modality-specific TEP modulation and P60-MEP coupling, while S1 responses correlate with subjective imagery experience rather than task type. These findings establish TEPs as sensitive markers of imagery-induced cortical states and individual capacity, with implications for imagery-based rehabilitation protocols. The validated preprocessing pipeline addresses reproducibility challenges in TMS-EEG research.

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P2-B-13 - Dual descending pathways control the initiation of skilled reaching movements

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Details

Multiple descending pathways have been identified as being involved in the initiation and control of upper limb dexterous movements. However, many aspects of their interactions remain to be elucidated. Here, we simultaneously manipulated multiple descending pathways during a skilled reaching task to dissect their functional interactions.

Retrograde adeno-associated viral vectors (AAVrg-CaMKIIa-stGtACR2-FusionRed or AAVrg-hSyn-ChR2-EGFP) were injected into the C6–C8 cervical spinal cord of adult mice to express inhibitory or excitatory opsins in descending motor neurons. Mice with a head chamber were trained to perform skilled reaching tasks while their heads were fixed in position. Optical fibers were implanted above the rostral and caudal motor cortex, red nucleus, and reticular MdV nucleus, enabling pathway-specific photostimulation or photoinhibition during the task. Reaching behavior was recorded with two high-speed cameras and analyzed using DeepLabCut.
Optogenetic inhibition of any single descending tract resulted in a reduction in reaching success. Kinematic analysis suggested that suppression of the rubrospinal tract primarily affected reaching distance, whereas inhibition of the caudal corticospinal and reticulospinal pathways more strongly disrupted digits movements in grasping. Notably, simultaneous inhibition of the rostral corticospinal and reticulospinal pathways impaired reaching initiation, whereas co-activation of these pathways elicited full reaching movements. The activity of both groups of neurons in these pathways exhibited an increase prior to the reaching onset, yet no substantial anatomical crosstalk between the pathways was detected. These findings indicate that individual descending pathways exert distinct yet overlapping influences on skilled motor control. Interestingly, concurrent inhibition of the rostral corticospinal and reticulospinal tracts blocked movement initiation, while joint activation drove complete reaching behavior. These results strongly suggest that multiple descending pathways may cooperatively control the initiation of reaching.

P2-B-14 - Differential coupling of motoneuron subpopulations with high-frequency common inputs

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Details

.Understanding how the nervous system controls movement requires deciphering the common synaptic inputs that project to spinal motoneurons (MNs). While the MN pool behaves as a linear system at the population level, individual MNs exhibit non-linear transformations. Common input to the MN pool is typically estimated using analyses that exploit the linearization effect emerging when pooling activity across many MNs (e.g., coherence). However, this pooling approach inevitably loses information about functionally distinct MN subpools. This limitation becomes critical for understanding how subpopulation properties affect input sampling. For example, in some motor disorders, disease progression selectively affects specific MN types, producing different MN behaviours that are masked when data are pooled across MN subpools. Here, we investigated how high-frequency common input is integrated across MN subpools with different firing rates.
We implemented computational simulations of MN pools receiving common input at varying frequencies (2-50 Hz) and characterized synchronization across MNs with different firing rates. Simulations revealed that MNs firing at rates matching the input frequency or its harmonics exhibited increased synchronization, here referred as entrainment. Analysis of the whole MN pool masked this effect for MN subpools with different firing properties. Exploiting the finding that MN firing becomes entrained with the common input frequency when this one matches their firing rate, we developed a MN-firing locked analysis using individual MN spikes as temporal triggers for peristimulus frequencygrams (PSF), allowing investigation of common input dynamics across individual MNs during sustained activity.
We validated this method using high-density surface electromyography from tibialis anterior muscle during isometric contractions in ten healthy adults. MNs grouped by firing rate into subpools showed systematic asymmetries: smaller MNs exhibited significantly larger instantaneous firing rate increases when time-locked to larger MN firings compared to the opposite situation (16.0±1.3 vs 5.9±5.5 pps, p =

0.006). These transient modulations correlated with high-frequency common input estimated through intramuscular coherence in alpha (R^2=0.38) and beta bands (R^2=0.55). These results were aligned with computational simulations, showing that high-frequency common inputs drive different firing rate dynamics across MN subpools.
Our findings demonstrate that MN firing rates determine frequency-dependent sampling of common input through entrainment, creating different responses across subpools. This reveals how subpopulation-level dynamics coexist with linear behaviour at the full pool level. The MN-firing locked method provides a framework for investigating functionally distinct MN subpools beyond whole-pool coherence analysis, offering applications for better understanding motor control and serving as a potential biomarker for motor disorders.

P2-B-15 - Multivariate fMRI reveals the representation of unimanual and bimanual reaching movements in humans

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Details

The motor regions robustly respond to and encode both the contra- and ipsilateral upper limb movements. Here we mapped these representations in the human brain using multivariate fMRI. We asked how contra- and ipsilateral information are related to each other and how they combine during bimanual movement.
Twelve participants performed unimanual wrist rotations to six target directions, as well as all 36 possible bimanual combinations. We found that unimanual movements significantly activated both the contra- and ipsilateral motor regions, including primary and premotor areas, SMA, and the anterior and posterior parts of the superior parietal lobe (SPL), with generally larger contralateral activity.
Next, using multivariate approach we were able to map movement direction encoding across the entire neocortex. Pre-motor and parietal regions in both hemispheres encoded direction information for both contra-lateral and ipsilateral hand, while M1 and S1 encoded mostly the contralateral movement.
We then asked how the contra- and ipsilateral movement representations relate to each other. We considered three possibilities. First, the activity patterns of contralateral and ipsilateral could be unrelated (i.e., independently organized). Alternatively, the ipsilateral movement representation resembles the mirror-symmetric contralateral representation (e.g., in left M1 flexion of left wrist resembles flexion of right wrist). Third, the ipsilateral movement representation could resemble the contralateral movement to the same direction (i.e., extrinsic space). Interestingly, pattern component modeling (PCM) revealed that the contra- and ipsilateral information were only mirror-symmetrically related in all regions except S1, which was independent.
Importantly, during bimanual movements, the independent ipsilateral encoding disappeared in all regions except for PMv and SMA. Instead, we found evidence for a non-linear interaction of contra- and ipsilateral movement which could be found in all regions. Part of this interaction arose from a well-known observation that incongruent bimanual movements (not moving mirror-symmetric or same direction) showed higher univariate activation. However, this simple change in univariate activation could not fully explain the interaction, specifically in superior parietal area which showed evidence for a representation of the unique bimanual combination of movements.
Overall, our study shows that during unimanual movement, motor regions constantly have access to both contra- and ipsilateral movement information. This information is primarily intrinsically organized. When bimanual movements are produced, the ipsilateral information no longer linearly coexists with the contralateral information (except for in PMv and SMA). Rather, a non-linear bimanual-specific pattern emerges along with the contralateral information.

P2-B-16 - Robotic manipulation of balance states reveals state-dependent vestibular control of standing balance

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Details

As the availability of sensory cues changes, the nervous system dynamically adjusts the importance it gives to each source of sensory information to control our movements. This process, commonly referred to sensory reweighting, has been a fundamental framework to understand the principles underlying the control of standing balance in humans. Balance response gains typically increase as sensory information decreases (e.g., standing with eyes open (EO) vs eyes closed (EC)). Alternatively, Some authors have suggested that balance control depends on state variables such as center-of-mass angle and velocity, implying gains also rise with increased variability. Because altered sensory conditions inherently increase state variability, the distinct contributions of sensory reweighting versus state variability to gain modulation remain unclear.

Here, we addressed this critical issue by first developing a protocol to match sensory states when balancing under distinct sensory conditions (EO and EC). Twelve healthy participants (5 female, age = 26.2 ± 3.1, mass = 75.3 ± 6.4 kg, height = 173.1 ± 7.9 cm) stood on a balance robot capable of manipulating the biomechanics of standing balance. Participants stood on a dual force plate robotic device, while hip and shoulder brackets moved in two dimensions, simulating inverted-pendulum dynamics scaled to each participant's mass and CoM height. We increased the range of explored states while participants balanced with their EO by optimizing (through gradient descent) the simulated negative ankle viscosity that increased postural variability to match when they balanced with their eyes closed. On average, the gradient descent algorithm converged after approximately 9 steps and identified that a -0.97±0.22N.m.s/° negative ankle viscosity was required to match the state variability of the EC condition (angle SD = 0.24±0.03°, velocity SD = 0.28±0.04°/s) when they balanced with EO (angle SD = 0.23±0.07°, velocity SD = 0.30±0.06°/s). Next, we exposed participants to subperceptual vestibular errors through electrical vestibular stimulation (EVS) delivered at 1 Hz and 0.4 mA. Participants balanced on the robot with EC, EO, and EO with states matching the EC condition. We quantified the gain of the balance responses by extracting the slope of the torque response with respect to the EVS. As expected, the normalized gain to load stiffness of the evoked balance responses to EVS increased when participants balanced with EC (0.0073 ± 0.0029 1/mA) compared to when they balanced with EO (0.0041 ± 0.0017 1/mA). Compared to the EO condition, the gain of the evoked balance responses also increased when participants balanced with EO that matched the state variability of the EC condition (0.0067 ± 0.0034 1/mA).

Our results demonstrate that we can match state variability of standing balance using our robotic device and that doing so shows that state variability contributes to the changes in balance gains typically associated with sensory reweighting. We also suggest that human standing balance is likely governed by state-dependent sensory control, although additional analyses are required to confirm this. Altogether, these results motivate the need for alternative computational frameworks for understanding how the nervous system adjusts balance control based on ongoing body state.

P2-B-17 - Evolution of object identity information in sensorimotor cortex throughout grasp

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Details

The transition from opening your hand to grasping a coffee cup happens smoothly, yet the neural systems supporting this behavior go through a significant state shift at the onset of grasp. At this

moment, the motor system begins to control contact forces and the somatosensory system receives a barrage of cutaneous signals that convey information about contact forces and the object's local features (e.g., edges, texture, and curvature). These cutaneous signals supplement the ongoing flow of proprioceptive input that encodes hand posture. It is unclear whether the neural signals representing object identity persist unchanged through this transition. In the present study, we sought to quantify the object-specific neural signals in the activity of individual neurons of the primary motor cortex (M1) and Brodmann areas 3a, 3b/1, and 2 of the somatosensory cortex in macaque monkeys. We found that, although the firing rates of individual neurons in each area declined rapidly after the object was grasped, this did not reduce the information they carried about the grasped object. On the contrary, it reflected a consolidation of object-specific information within sensorimotor cortex. The exception was proprioceptive area 3a, whose neurons were most informative right before contact and slightly less so after the object was securely held. In contrast, both individual neurons and population activity in cutaneous areas 3b and 1 carried little object-specific information before contact but became highly informative afterward. Population-level analyses further revealed that multimodal area 2, which receives both cutaneous and musculotendinous inputs, does not represent object identity stronger than areas 3b and 1. Although area 2 showed higher activity before contact, this activity lacked task-relevant information, suggesting that uninformative cutaneous inputs may have interfered with informative proprioceptive signals. Following object contact, however, area 2 became highly informative, consistent with its proposed role in haptic object perception. In contrast, only M1 and area 3a carried object-specific information before contact. However, neither region appeared to encode a generalizable object representation, indicating a likely integration of force-related signals with postural information. Together, these findings underscore the profound effects of object contact on the neural representation of object identity in sensorimotor cortex.

P2-B-18 - The role of motor timing in movement variability and the laterality of the hands and feet

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Details

Human movements are inherently variable even when we try to be as precise as possible. This variability has long been attributed to signal-dependent noise that scales with motor output, yet this does not fully explain the variability observed in human behavior. Here, we show that fluctuations in the timing of muscle activation lead to unwanted overlaps in flexor and extensor activity, contributing more to movement variability than signal-dependent noise. By measuring both the size and timing variability of muscle activity across tasks ranging from point-to-point reaching to periodic isometric force production, we demonstrate that motor timing variability better predicts position and force variability than signal-dependent noise. In one experiment, 15 right-handed participants exerted periodic shoulder forces either unimanually or bimanually. When acting with the dominant right arm alone, motor timing was precise, but the non-dominant left arm showed greater timing variability. When both arms acted symmetrically, the timing precision of the left arm improved by about 20% relative to the unimanual condition, resulting in a significant reduction in force variability. This improvement was not observed during asymmetric bimanual movements, indicating that precise motor timing in the dominant hemisphere may be shared with the non-dominant limb during symmetric actions. The reduction in force variability could not be explained by signal-dependent noise, pointing instead to a neural coupling of timing mechanisms across limbs. Building on these findings, we developed a smartphone-based assessment that measures the variability of circular arm and leg movements, tasks that require precise coordination of multiple muscles. Data from 1675 participants aged 4 to 88 years revealed a developmental decline and age-related increase in movement variability, consistent with maturation and

decline of motor control. The tool also provides a sensitive measure of handedness and footedness, detecting distinct patterns in individuals subjected to forced right-handedness, whose variability differs from both strong left-handers and strong right-handers. Together, these findings identify motor timing variability as a key determinant of movement precision, interlimb coordination, and lateralization. They suggest that the ability to regulate the timing of muscle activation is a fundamental aspect of human motor control, with implications for understanding motor development, motor learning, and clinical assessment.

P2-B-19 - Superior colliculus generates motor-performance dependent signals underlying forelimb reaching adaptation

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Details

Visual information provides spatial coordinates essential for goal-directed movements, yet the neural circuits mediating visual contributions to motor performance remain unclear. Using forelimb-reaching behavior in mice, we demonstrate that eliminating visual input disrupts limb and postural kinematics, while silencing the primary visual cortex has minimal impact. We identify narrow-field (NF) neurons in the superficial superior colliculus (SC) as critical mediators: their activity peaks before reaching initiation, and their ablation impairs reaching performance. These NF neurons preferentially target deep SC (dSC) neurons that project to the pontine reticular formation (PRF). Viral tracing reveals PRF receives sensorimotor cortical input and projects back to dSC, positioning SC to integrate visual information with feedforward motor commands. Consistent with this integrative role, dSC neurons exhibit outcome-dependent activity at movement termination during reaching behavior. Chemogenetic silencing of SC-PRF projection neurons specifically impairs within-session kinematic adaptation without affecting basic reaching ability. These findings establish SC as a critical hub for motor optimization, integrating visual input with feedforward motor signals to enable rapid motor adjustments in response to performance outcomes.

P2-B-20 - Spinal cord interneuronal population activities coordinate muscle activities through a low-dimensional communication subspace

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Details

The spinal cord integrates complex supraspinal commands to coordinate muscle activities for stable movement. To reduce the computation complexity and enable flexible motor control, the spinal cord is thought to generate voluntary movement by recruiting neuromotor modules, known as muscle synergies, encoded by spinal premotor interneurons. Recent advances in large-scale neural population recordings suggest that the low-dimensional neural manifold constructed by projecting activities of high-dimensional interconnected units onto dominant neural modes may form a fundamental neural basis for stable and efficient motor control. Despite these technical advancements, their application for stable and long-term spinal cord recordings in freely moving animals is limited. Thus, it remains unclear how spinal interneuronal populations coordinate muscle activities during natural movement.
To address these questions, we simultaneously recorded population activity from spinal interneurons using a 128-channel hyper-flexible spinal cord array and activities from multiple ipsilateral hindlimb muscles using intramuscular electrode pairs in freely walking mice. Our results showed that the spinal interneuronal population coordinates multiple muscle activities through a low-dimensional communication subspace, formed by identifying neural patterns whose projected population activities are most predictive of the recorded muscle activities. We further segmented and categorized all the

steps into three cadences: slow, medium, and fast. We found that faster cadences require more complex neural control, yet the pattern of muscle synergies identified using the rectified latent variable model remained relatively stable across different cadences.
These findings suggest that the spinal cord communicates with muscle activities through a low-dimensional neural subspace, and similar muscle synergies can be recruited by distinct neural patterns under different conditions. We argue that during locomotion, spinal interneuronal populations are dynamically coordinated to shape muscle synergies, allowing for flexible motor control across different spinal states.
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P2-B-21 - Building motor repertoires through reward and punishment contingencies

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Details

Reward and punishment are primary drivers of learning. In motor adaptation, punishment increases initial learning, but reward enhances later retention (Galea et al., 2015). At the neural level, motor regions respond robustly to reward information (Derosiere et al., 2025), underscoring a tight link between reinforcement signals and the circuits supporting motor adaptation.
Previous adaptation studies have demonstrated the influence of reward and punishment in the formation of a single memory. Here, we asked whether reward, punishment, or their combination could support the formation of multiple motor memories under conditions that normally produce complete interference. Participants experienced randomly interleaved opposing force-fields
when reaching to a target whose color indicated the field direction prior to the reach. Such target color cues are insufficient to allow learning of two memories (Howard et al., 2013). We hypothesized that linking each color to reward or punishment could enable separate memories to be learned for each field, though to different extents -- consistent with evidence that humans evaluate gains and losses asymmetrically (Kahneman \& Tversky, 1984).
Experiment 1 tested three groups in which reward or punishment were associated with the target color (and hence field direction). In the Reward group, both colors yielded positive points following an exponentially decaying function of the maximum perpendicular error (MPE). In the Punishment group, participants started with a fixed number of points and lost points on every trial according to the same function but shifted to start at zero (for MPE=0), and increasingly negative as MPE increased. In the Combined group, one color produced reward and the other punishment. Participants were informed that accumulated points would be converted to a monetary bonus. Our results revealed significant group differences (all BF>10): the Combined group showed the strongest adaptation (average of 67\% adaptation across both fields), followed by Punishment (44\%) and then Reward (11\%). All groups reached reliable non-zero learning asymptotes. These results suggest that the effectiveness of contextual cues in separating motor memories is influenced by the asymmetric evaluation of reward and punishment.
Experiment 2 assessed the role of contingency, the relation between MPE and points. In the Uncorrelated group, reward and punishment were linked to target color (as in the Combined group above) but uncorrelated with MPE (reward/punishments were the same as a Combined participant but shuffled in order). In the Combined 50% group, reward and punishment were correlated with MPE but uncorrelated with the target color (50% reward or punishment). Strikingly, the Uncorrelated group

showed no adaptation, whereas the Combined 50% group showed strong adaptation, demonstrating that contingency is necessary and sufficient to separate motor memories.
We considered these results in the framework of the COIN model (Heald et al., 2021) in which the strength with which color acts as a contextual cue depends on the history of reward, punishment, and how it relates to MPE. That is:

$P(cue_t = +1) = 1 - P(cue_t = -1) = \text{logistic}\left[(w_1 + w_2 \rho_t^r \bar{r}_t + w_3 \rho_t^p \overline{p}\overline{p}_t) H_t \right]$,
where $H_t = \{-1,+1\}$ is the target color; ρ_t^r and ρ_t^p are the MPE:log(points) correlations and $\bar{r}_t$ and $\overline{p}_t$ are the average log(points) for rewarded and punished trials, and $w_{1\text{-}3}$ are free parameters. Simulations of this modified COIN model qualitatively reproduced our findings.
Overall, our results indicate that reward and punishment can promote the formation of multiple motor memories -- memories that would otherwise interfere -- by enhancing the informativeness of (color) cues that support contextual inference.

P2-B-22 - Effect of explicit awareness on the motor and spatial representations following motor imagery practice

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Details

Motor imagery (MI) enhances motor performance and represents a promising complementary tool for rehabilitation and sport. However, evidence on its effects on motor representations (e.g., kinematic parameters) remains inconsistent[1,2]. These discrepancies may be influenced by differences in learning context across studies, specifically whether participants engaged in explicit learning (i.e., where rule-based, declarative knowledge is intentionally applied) or implicit learning (i.e., where acquisition occurs without conscious awareness of task rules).
This study examines the impact of explicit awareness on motor and spatial representations following MI practice in a pursuit-tracking task. Participants will be randomly assigned to one of four groups: 1) Implicit, 2) Explicit, and 3) Explicit-Guided groups will use MI to track a target following a repeated sequence, whereas the 4) Control group will only observe the target. Implicit and Control groups will be uninformed about the sequence, the Explicit group will be informed, and the Explicit-Guided group will receive additional directional cues.
Before and after training, and again after 24 hours, participants will complete random- and repeated-sequence tests with the trained hand in order to evaluate the sequence-specific learning. They will also perform transfer tests with the opposite hand (i.e., untrained hand), comprising a random-sequence test, a repeated-sequence test (keep the same direction sequence used by the trained hand to evaluate spatial representations), and a mirror-sequence test (keep the same muscle characteristics to evaluate motor representations). Performance accuracy was assessed using root mean square error (RMSE).
Pilot data (9 participants) revealed sequence-specific learning after training and at 24-hour retention across all practice groups. The Implicit group showed the strongest immediate sequence-specific improvement. Importantly, motor representation emerged immediately after training only in the Implicit group, whereas Explicit and Explicit-Guided groups required consolidation to reach similar levels. Spatial representations followed the same pattern, with stronger immediate transfer in the Implicit group. We suggest that explicit awareness may impose additional cognitive demands that transiently limit the effectiveness of motor imagery learning[3], highlighting the importance of minimizing explicit processing to optimize imagery-based training protocols.

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P2-B-23 - Unpaced tapping motor control is more precise during exhalation

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Details

Breathing is a rhythmic behavior initiated in the brainstem by the neuronal activity of the pre-Bötzinger complex. These neurons are known to be activated in phase with inhalation and have numerous projections that are central to the coordination of the homeostatic system. However, during nasal breathing, airflow activates the mechanoreceptors of olfactory sensory neurons, which generate a rhythmic signal locked to breathing that is then relayed to the olfactory cortex. This breath-driven rhythm propagates and has been measured in the medial prefrontal cortex and hippocampus, two areas heavily involved in cognitive information processing. In addition, prior work has shown that humans spontaneously inhale at the beginning of a task and that these inhalations alter the architecture of functional brain networks. The alteration in brain response during inhalation correlates with performance and indicates a mode of brain function processing that is dependent on the respiratory phase. Similarly, the respiratory exhalation has been linked to cortical preparation in voluntary actions associated with fluctuations in ongoing neural activity. Taken together, these results confirm the idea that the respiratory phase (inhalation or exhalation) and respiratory modality (nasal or oral) have an impact on cognitive performance. To date, no research has investigated the effects of respiratory phase on the variability of a movement.

Finger tapping tasks have been widely used to evaluate sensorimotor mechanisms of rhythm and timing. Unpaced tapping is known to recruit more importantly the basal ganglia–thalamocortical network (BGTC) which is engaged in attention-dependent evaluation of temporal intervals and self-generation of movements. Synchronizing to a metronome during paced tapping involves the preattentive encoding of event-based temporal structure and matching of movements to exogenous cues which are known to recruit mostly the cerebellar–thalamocortical (CTC) network.

Here we evaluated temporal accuracy in the production of a spontaneous tempo and the ability to maintain a paced rhythmic tempo using finger tapping tasks. Twenty-five healthy adults were tested. During paced tapping, participants were instructed to tap along to a metronome (600 ms and 750 ms inter-onset metronome interval). During unpaced tapping participants were instructed to tap at their preferred tempo or as slow as possible. In both tasks, we manipulated breathing by asking participants to breathe either through their nose or mouth. Breathing patterns were measured using a Nox respiratory inductance plethysmograph belt placed on the participants' thorax. An Arduino board processed the signals from this belt and transmitted the diaphragm motion data to a computer, allowing us to calculate the breathing phase for each point in time, within an inhalation to exhalation cycle. Motor variability was compared between various tasks using the coefficient of variation of the inter-tap interval (CV ITI). The results showed that the breathing modality had no impact on motor variability in both paced and unpaced tapping, however the breathing phase shows that exhalation was associated with more precise movement in unpaced tapping.

These findings are consistent with the idea that the modality of breathing is not driving the cortical excitability for actions. Instead, subcortical pathways in the BGTC network may be impacted by the breathing phase.

P2-B-24 - A feedback scaffold for predictive control in de novo motor learning

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Details

Skilled motor behavior relies on both corrective feedback and predictive feedforward control, yet how their contributions evolve with practice remains unclear, partly because most paradigms study learning within a single day using discrete movements, rather than tracking the continuous dynamics of control as skill develops across multiple days. In this work, we studied de novo motor skill acquisition using a novel continuous mirror-reversal visuomotor tracking task practiced over five days, allowing dissociation of control mechanisms through frequency-based analysis. We observed a robust temporal separation between learning processes: early learning was dominated by rapid online feedback corrections expressed primarily at low movement frequencies, whereas predictive feedforward control emerged gradually with extended practice and became essential for successful performance at higher frequencies where sensory feedback is intrinsically delayed and ineffective. Cursor-jump perturbations showed that feedback responses adapted early, whereas changes in initial movement direction of point-to-point reaching evolved slowly, mirroring the time course of high-frequency improvements. These results provide direct quantitative evidence for a dynamic transition from feedback-dominated to feedforward-dominated control during skill learning. A recurrent neural network model in which an adaptive feedback controller (cerebellar-like) supplies a teaching signal to a predictive policy (cortical-like) reproduced the key behavioral signatures. Together, our findings establish a behavioral dissociation between feedback and feedforward learning in a continuous task and provide a computationally grounded perspective consistent with the observed learning dynamics.

P2-B-25 - Behavioral and neural constraints on motoneuron control in humans

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Details

The spinal circuitry supporting human movement is remarkably diverse. Some spinal motoneurons innervate a single muscle, others innervate multiple muscles (including agonists and antagonists), yet others selectively target different regions within the same muscle. Additional complexity arises from spinal interneurons, whose activity distributes commands across many motoneurons. How does the nervous system coordinate these spinal circuits to generate the human movement repertoire?

To investigate how spinal circuits coordinate subpopulations of motoneurons across distinct regions of muscle, we sampled multiple compartments of hand and wrist-controlling muscles (first dorsal interosseus and flexor carpi ulnaris). To achieve this, we recorded the spiking activity of spinal motoneuron populations using ultrasound-guided high-density intramuscular EMG during isometric force generation.

Participants then performed a broad set of tasks in which we systematically varied several parameters. The goal of such manipulations was to dissociate the constraints imposed by the intrinsic connectivity of spinal circuits from those arising from the specific behavioral task. First, by manipulating force profiles, we compared motoneuron activity during stable versus dynamic force production, necessitating changes in amplitude, velocity, and frequency. Second, by altering limb posture, we changed muscle fiber length and therefore the afferent feedback sent to the spinal cord. By simultaneously recording from agonists and antagonists with shared (flexor digitorum profundus) and separate (flexor carpi radialis) innervation, we could observe how these posture-dependent feedback changes are differentially distributed across

muscle groups. Third, we manipulated the controlled variable itself. We first asked participants to track a target by modulating the firing rate of a single motoneuron, in turn producing a force profile. We then asked them to generate the same force profile directly with force. This allowed us to isolate how the task goal - controlling a single motoneuron versus producing the same output with the whole population - influences motoneuron coordination.
Finally, to examine how spinal circuits shape the direction of force generation, we leveraged the fact that the first dorsal interosseus (FDI) can produce 2D forces through index abduction and flexion. Participants generated forces across multiple angles, allowing us to estimate each motoneuron's preferred direction. By combining 3D ultrasound with intramuscular EMG, we identify which regions of FDI each motoneuron innervated - information not available from EMG alone. Linking these anatomical regions with each motoneuron's preferred direction showed how the spinal cord coordinates different parts of the muscle to produce multidirectional forces.
Across this systematically varied task space, we identify how spinal circuit architecture constrains and shapes the coordination of motoneuron populations.

P2-B-26 - Transcutaneous vagus nerve stimulation and reward shape reflex responses during reaching movements

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Details

Mechanical perturbations during reaching movements elicit short-latency (SL) and long-latency (LL) responses, occurring respectively 20–50 ms and 50–100 ms after the perturbation. The SL component is mediated by spinal circuits, whereas the LL component is likely shaped by supraspinal pathways, including cortical and cerebellar structures, which may explain its sensitivity to task requirements. Consistent with this, LL-response amplitude is greater when reaching toward narrow targets that require strict control. In contrast, wide targets demand less precision, reducing the need for corrective responses (Nashed et al. 2012). Building on these observations, the next step is to elucidate the neural mechanisms regulating LL reflex gain.
One candidate mechanism is arousal, the activation state of the central nervous system, supported by multiple neuromodulatory systems. One key component, the substantia nigra–dopaminergic (SN-DA) system, influences motor control. Reward-related dopaminergic activation invigorates movement and increases LL-responses during reaching, independently of task goals (Codol et al. 2023). More recently, we showed that another arousal component, the locus coeruleus–norepinephrine (LC-NE) system, activated via transcutaneous vagus nerve stimulation (tVNS), enhances task-dependent LL modulation. Although these systems both contribute to motor control and are anatomically interconnected, their functional interplay in rapid feedback responses has not been investigated. Here, we aim to measure their effects on LL-responses during reaching.
Eleven young, healthy, right-handed participants (of 25 planned; full sample completed by the conference) performed right-arm forward reaches toward narrow or wide targets, alternating across blocks. Each trial began with a 4 seconds (s) train of either sham or active tVNS, alternating every other block. A reward pre-cue (reward-on or reward-off, randomized) was presented for 1 s, starting 1 s after train onset; on reward-on trials, participants earned 50 cents if they successfully completed the movement. In 67% of trials, a mechanical perturbation was randomly applied left or right, eliciting reflex responses in the right Posterior Deltoid (PDelt) or Pectoralis Major (PectM), respectively. In addition to EMG, we recorded reaction time, accuracy, kinematics, and pupil size as an index of arousal, under tVNS and reward.
Preliminary analyses indicate that mechanical perturbations elicited the expected SL and LL responses in PDelt and PectM when acting as agonists, and that the LL component was larger for narrow than wide

targets in both muscles. Consistent with prior work, reward showed a trend toward increasing PDelt LL responses. In contrast, active tVNS showed a trend toward reducing this component. These preliminary observations suggest distinct influences of reward and tVNS on rapid feedback control. This pattern will need to be confirmed once the full dataset has been collected.

P2-B-27 - Phase-specific effects of reward context on motor performance, consolidation, and interlimb transfer

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Details

Reward-related feedback is common in motor practice, but its impact on distinct motor learning phases remains unclear. We investigated whether different reward contexts selectively shape performance during practice, post-practice consolidation, and interlimb transfer. Participants performed a precision shooting task with their dominant hand under one of three reward contexts: monetary, social-comparative, or no reward. Motor performance was assessed pre-practice, immediately post-practice, and one day later, using both trained and untrained hands.

All groups improved performance during practice. Monetary reward enhanced immediate post-training performance, whereas social-comparative reward promoted larger offline gains from immediate to delayed testing. Critically, only the social reward context facilitated interlimb transfer to the untrained hand at both immediate and delayed tests. Intrinsic motivation differed across reward contexts and correlated with offline gains and transfer performance, but not with immediate retention.

These findings demonstrate that reward context shapes motor behavior in a phase-specific manner, with dissociable effects on acquisition, consolidation, and interlimb generalization. Rather than uniformly enhancing learning, motivational context biases the evolution of performance across time and effectors. The results underscore the importance of considering motivation when evaluating motor skill acquisition and provide insight into neural mechanisms through which reward signals influence movement control. By highlighting how social versus monetary reward differentially affects consolidation and interlimb transfer, this work offers implications for optimizing motor training and rehabilitation protocols that target both immediate performance and long-term skill retention.

P2-B-28 - Motor cortical dynamics of broadband signal-extracted neural features across spatial electrode configurations during reaching arm movements

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Details

The interpretability of neural findings in motor control and brain-computer interfaces (BCIs) performance critically depend on the choice of neural signals, yet it remains unclear which signal features give rise to strong behavioral correlations and robust decoding performance. Moreover, neural signals vary systematically across cortical depth and spatial scale, raising questions about the generalizability of prior findings across electrode configurations. Characterizing the dynamical structure of broadband signal–derived features across contexts offers a bridge between neuroscience and engineering demands.

Here we analyzed neural recordings from the dorsal premotor cortex (PMd), primary motor cortex (M1), and dorsolateral prefrontal cortex (dlPFC) of rhesus monkeys (*Macaca mulatta*) using linear probes (64-channel S-probe) or planar arrays (96-channel Utah array). Monkeys performed delayed reaching tasks towards either static or moving targets. Neural features spanning multiple temporal scales were extracted, including spike-band power (SBP), local motor potential (LMP), and mean power of local field potential (LFP) across four frequency bands (12–25, 50–100, 100–200, and 200–400 Hz).

We report three main findings. First, behavioral decoding accuracy (R^2) using a Kalman filter-based linear state-space decoder followed a consistent ranking across neural features: SBP (Utah, 0.53 vs. S-probe, 0.40) > LMP (0.52 vs. 0.11) > high-frequency LFP power (0.18 vs. 0.07) > low-frequency LFP power (-0.07 vs. -0.19), consistent with previous studies. This trend was preserved across electrode configurations, with planar arrays yielding higher LMP decoding performance independent of sorted unit count. Second, LMP exhibited high inter-electrode correlation, low sequentiality, and a pronounced unimodal population-level preferred direction (PD), opposite to SBP. While LMP PDs differed across subjects, they were stable within individuals across brain areas and sessions, forming a subject-specific, fingerprint-like feature. Third, LFP power in the 100–200 Hz and 200–400 Hz bands showed PDs increasingly aligned with SB but lower decoding performance, likely due to reduced sequentiality that underlies quasi-oscillatory population dynamics.
By characterizing dynamical factors influencing the behavior decoding performance of field-potential-based features, the present study highlighted the critical impact of electrode configuration on neural dynamics and demonstrate that strong neural-behavioral correlations can arise from distinct underlying dynamics.

P2-B-29 - Linking single corticomotoneuron activity to population geometry in dexterous finger control

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Details

Dexterous movements, especially of the fingers, are a hallmark of humans and non-human primates, enabled by the motor cortex's ability to sculpt precise patterns of muscle activation and suppression. For finger dexterity, population-level descriptions remain incomplete and often do not specify how individual corticomotoneurons (CM), the output neurons in M1 that have monosynaptic connections to spinal motoneurons, act on their target muscles. We address this by linking the muscle-specific role of single CM neurons to population dynamics during individuated finger movements.
Two rhesus monkeys performed individuated digit movements (five digits, two directions) while we recorded CM single-unit activity ($n = 298$), forearm EMG ($m = 29$), and full digit kinematics. Spike-triggered averaging (SpikeTA) classified CM neurons by their effect on muscle activity (post-spike facilitation, PSF; post-spike suppression, PSS). For each movement, muscles were labeled as agonist, antagonist, or stabilizer. When analyzing the activity of these neurons relative to movement onset, we observed a robust temporal coordination: CM neurons producing PSS in antagonist muscles reached their peak firing rate approximately 70 ms ($p = 0.003$) earlier than CM neurons producing PSF in agonist muscles. This result identifies a unique subset of M1 output neurons that actively suppress their target muscle precisely when that muscle would oppose the intended movement.
Because these suppressive signals appear before measurable muscle activity, they seem to prepare the motor system rather than directly driving output at that moment. This raised a population-level question: where in neural state space do such signals reside, in dimensions that set up the state without producing EMG, or in dimensions that immediately drive muscles? To answer this, we modeled the relationship between neural population activity and EMG to define a potent subspace that predicts muscle activity and a complementary orthogonal null subspace. During movement, the neural-to-EMG mapping showed strong alignment, with median cross-validated $R^2 \geq 0.88$. For each neuron, we then computed two metrics. The potency index quantified a neuron's projection onto the potent subspace, and the nullity index quantified its projection onto the null subspace. Our subspace analysis suggests that this temporal lead corresponds to a specific population-level organization: in the premovement interval (-100 to 0 ms relative to onset), CM neurons producing PSS in antagonist muscles expressed

significantly larger nullity than PSF neurons (p = 0.0039), whereas no such difference was observed between PSS and PSF populations in agonist muscles (p = 0.167).

Population-level dynamics also revealed that flexion and extension occupied distinct low-dimensional trajectories with clear digit-specific separation. This separation was evident in premovement dynamics and continued during execution.

Together, these results provide a mechanistic link between the muscle-specific actions of single CM neurons and the geometry of population dynamics: suppression organizes the premovement state within null dimensions, whereas facilitation engages potent dimensions, together driving dexterous movement.

P2-B-30 - The role of individual vigor in human-human physical interaction

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Details

The speed of voluntary movements varies systematically, with some individuals moving consistently faster than others across different actions. These variations, conceptualized as vigor, reflect a time-effort-accuracy tradeoff in motor planning. How do two mechanically coupled partners with different individual vigors collaborate, e.g. to move a table together?

Here, we addressed this question by investigating dyads of subjects carrying out reaching movements while connected via a virtual elastic band. We asked 20 participants (10 dyads) to perform lone and connected, self-paced, wrist flexion-extension movements of five amplitudes. Participants were subjected to (i) three levels of effort implemented using visco-resistive force-fields with null, low and high intensity, and (ii) two levels of connection stiffness, low and high. The protocol resulted in a total of 440 solo and 600 connected movements.

After confirming that our lone movement data verify all the properties of usual self-paced reaching movements and that individual vigor could be defined as in the literature, we show that such dyads coordinate goal-directed movements with minimal interaction force, exhibiting a *dyadic vigor* with similar characteristics as individual vigor. Specifically, the results show that dyads are (i) coordinated, with (ii) higher movement performance compared to lone movements in terms of smoothness and velocity, exhibiting (iii) affine amplitude-duration relationships, (iv) higher inter-dyad than intra-dyad movement timing variability, and (v) a strong robustness of the dyadic vigor scores to different levels of effort and task settings implemented by the visco-resistive force fields and connection stiffness. The emerging dyadic motor plan is strongly influenced by the slower partner, whose vigor predicts dyadic vigor, with effects lasting beyond practice. Computational modeling with stochastic optimal control reveals the critical role of partners' movement timing's uncertainty and vigor in shaping coordination. Specifically, our model predicts all the main qualitative and quantitative characteristics of dyadic movements from individual behavior, with median timing prediction errors across 30 conditions of 30 ms and 50 ms for the low and high stiffness conditions respectively. These findings shed light on the mechanisms underlying human collaboration, and may be used in applications ranging from physical training and rehabilitation to collaborative robotics for manufacturing.

P2-B-31 - The effects of caffeine on motor unit discharge modulation and fatigue resistance in young and older adults during sustained submaximal contractions

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Details

Ageing is associated with structural and functional remodelling of the neuromuscular system, including motor neuron loss, collateral reinnervation, altered motor unit (MU) size, and reduced MU discharge rates, which may constrain neural drive modulation during sustained contractions and influence fatigue resistance. During submaximal fatiguing tasks, MU discharge rates typically decline before stabilising or increasing as task failure approaches, with the timing of this reversal associated with time to exhaustion. Caffeine is a widely consumed central nervous system stimulant that increases neural excitability via adenosine receptor antagonism and has been shown to augment MU firing rates. Therefore, this study aimed to determine whether caffeine improves fatigue resistance during a sustained submaximal upper-limb contraction in young and older adults, with MU discharge behaviour examined as a potential neural mechanism.

Twenty younger (23.6 ± 2.9 y) and twenty older (70.9 ± 5.3 y) healthy adults performed a sustained submaximal contraction of the brachioradialis at 30% of maximal voluntary contraction (MVC), involving simultaneous handgrip and elbow flexion. Participants completed the task under caffeine (3 $mg \cdot kg^{-1}$) and placebo (maltodextrin) conditions in a randomised, double-blind, crossover design. High-density surface electromyography (HD-sEMG) was recorded and decomposed to extract MU discharge characteristics. The intersection point of two regression lines (piecewise regression) was used to determine the reversal point in MU discharge rate.

Time to task failure was significantly longer with caffeine than placebo (p = 0.028; 327 ± 145 vs 287 ± 145 s), with older adults demonstrating greater fatigue resistance than younger adults across conditions (p = 0.001; 386 ± 147 vs 227 ± 91s), though no age x condition interaction was present (p = 0.875). A significant main effect of age was observed for the MU discharge rate reversal point reached during the task (p = 0.023; young: 102.03 ± 58.48 s; older: 172.72 ± 69.04 s), with older adults showing a delayed increase in discharge rate. No main effect of condition (p = 0.366) or age x condition interaction (p = 0.195) was detected.

These findings demonstrate that ageing influences fatigue-related modulation of MU discharge during sustained upper-limb contractions, while caffeine improves time to task failure without altering MU firing dynamics. This dissociation suggests that caffeine's ergogenic effects are unlikely to be mediated solely by adaptations within the MU pool and may instead reflect upstream mechanisms, such as enhanced central drive or altered cortical contributions supporting task maintenance beyond this point of maximal neural constraint. Ongoing analyses will further clarify how neural control strategies are modified with fatigue and how caffeine influences performance across different phases of the task in an ageing neuromuscular system.

P2-B-32 - Force control by human spinal motor neurons

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Details

Motor units are the basic elements of motor control, yet we do not fully understand how they are coordinated together for smooth force production within and across muscles. Alpha motor neurons in the spinal cord integrate inputs from local interneurons, sensory signals from the limb, and descending information through the spinal cord. This assortment of inputs leads to drastic variability in motor control strategies, and it is unknown if all muscles follow the same strategy or if task specialization plays a role in their respective motor unit activity. Previous work in nonhuman primates has shown that

muscle length can result in preferential recruitment of motor units, and previous human work has attempted to cluster motor units based on frequency modulations detected in the individual spike times. The goal of this work is to elucidate motor control of the quadriceps muscles at different knee flexion angles using novel Myomatrix intramuscular electrode arrays. One of the main challenges that motor unit experiments involving numerous tasks is the ability to track the activity of units as the waveform changes with muscle configuration. Here, we have overcome this by performing isometric contractions at a low force and adjusting the knee angle incrementally to successfully track motor units from one angle to the next. After motor unit decomposition, units were tracked using Principal component analysis and cross-correlation values between all detected motor units and all angles. From the four angles measured (80, 55, 40, and 25 degrees), 15 motor units were detected. After tracking, two units showed activity at all angles, and one showed activity in all but one of the angles, accounting for 73% of the detected units. Using this motor unit tracking, we have begun preliminary analyses to address which units are receiving common input signals, resulting in the frequency modulation of spike patterns between angles. This has been achieved using coherence and cross-correlation measures, and we are currently analyzing the output oscillations and fundamental coherent frequencies. This work helps to determine which neural control strategy the quadriceps muscles may use during force production at various joint angles. It could also be used as an analysis framework to examine the neural control of other muscles in the body.

P2-B-33 - Cortical dynamics underlying temporal extraction of kinematic evidence and predictive coding during observation of imminent actions

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Details

The ability to anticipate others' actions relies on predictive coding mechanisms that integrate evolving kinematic cues with internal motor representations. In high-speed sports such as tennis, these computations must occur within tens of milliseconds. Using high-density EEG and a temporal occlusion paradigm, we investigated the neural dynamics that support predictive action monitoring in 25 expert tennis players by systematically manipulating the moment at which visual information about an opponent's stroke became unavailable. Participants watched groundstroke videos occluded at six time points (−320 to +80 ms relative to ball–racket contact) and indicated the predicted landing location. Behaviorally, anticipation accuracy increased and response times decreased as occlusion approached or exceeded contact, confirming the decisive contribution of late kinematic information.

Time-frequency analyses of EEG signals showed a temporally structured engagement of large-scale cortical networks. Early in the action sequence, theta (3–5 Hz) synchronization was significantly enhanced in centro-parietal regions during observation, consistent with the recruitment of top-down predictive and attentional control processes. As the action unfolded, alpha (8-12 Hz) and beta (15-25 Hz) desynchronization emerged across sensorimotor and posterior regions, indexing progressive activation of the action observation and motor resonance systems. Critically, immediately preceding video offset, theta synchronization peaked in the +80 ms condition—i.e., when contact cues were fully available—suggesting that theta oscillations encode the integration of high-informational kinematic evidence for prediction.

During the post-video period, theta power further increased in frontal and sensorimotor sites during response preparation, and theta amplitude in this early motor-initiation window negatively correlated with the inverse efficiency score, linking stronger theta engagement to superior anticipatory performance. Beta desynchronization in sensorimotor cortices also intensified as the motor response

approached, consistent with the release of inhibitory tone and the preparation of task-specific motor plans.
Together, these findings delineate a hierarchical temporal architecture through which the brain transforms observed movement into predictive motor representations: early theta-mediated evaluative processing, mid-stage alpha/beta-mediated sensorimotor resonance, and late integrative theta bursts supporting decision formation and action selection. The results provide novel electrophysiological evidence for predictive coding mechanisms governing action anticipation in expert athletes, highlighting theta oscillations as a key neural substrate for perceptual–motor prediction in fast, open-skill environments.

P2-B-34 - Cortico-motoneuronal suppression and facilitation project onto null and potent population dynamics during dexterous movements

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Details

Dexterous movements, especially of the fingers, are a hallmark of humans and non-human primates, enabled by the primary motor cortex's (M1's) ability to sculpt precise patterns of muscle activation and suppression. For finger dexterity, population-level descriptions remain incomplete and often do not specify how individual cortico-motoneuronal neurons (CM), the output neurons in M1 that have monosynaptic connections to spinal motoneurons, act on their target muscles. We address this gap by linking the muscle-specific role of single CM neurons to population potent and null dynamics during individuated finger movements.

Two rhesus monkeys performed individuated digit movements (five digits, two directions) while we recorded CM single-unit activity ($n = 298$), forearm EMG muscle activity ($m = 29$), and full digit kinematics. Spike-triggered averaging classified CM neurons by their effect on muscle activity (post-spike facilitation, PSF; post-spike suppression, PSS). For each movement, muscles were labeled as agonist, antagonist, or stabilizer. At the single-cell level, we observed many CM neurons producing PSS in antagonist muscles became active in the premovement period, often preceding detectable EMG and movement onset. Their firing rates peaked earlier than CM neurons producing PSF in agonist muscles by approximately $30 - 80\ ms$ ($p = 0.003$). This result identifies a unique subset of M1 output neurons that become active to suppress their target muscle when that muscle would oppose movement.

Because these suppressive signals appear before measurable muscle activity, they seem to prepare the motor system rather than directly driving output at that moment. This raised a population-level question: where in neural state space do such signals reside, in dimensions that set up the state without producing EMG, or in dimensions that immediately drive muscles? To answer this, we modeled the relationship between neural population activity and EMG to define a potent subspace that predicts muscle activity and a complementary orthogonal null subspace. During movement, the neural-to-EMG mapping showed strong alignment, with median cross-validated $R^2 \geq 0.88$. For each neuron, we then computed two metrics. The potency index quantified a neuron's projection onto the potent subspace, and the nullity index quantified its projection onto the null subspace.

Three dissociations emerged. *First*, in the premovement period, CM neurons producing PSS in antagonist muscles expressed significantly larger nullity than those producing PSF, consistent with preparatory control that reshapes the neural state without producing EMG. *Second*, CM neurons producing PSF in agonist muscles showed greater potency than nullity both before and during movement, placing these

neurons within dimensions that carry movement-generating output. *Third*, flexion and extension occupied distinct low-dimensional trajectories with clear digit-specific separation. This separation was evident in premovement dynamics and continued during execution.

Together, these results provide a mechanistic link between the muscle-specific actions of single CM neurons and the geometry of population dynamics: suppression organizes the premovement state within null dimensions, whereas facilitation engages potent dimensions, together driving dexterous movement.

P2-B-35 - Context-dependent effects of grip force on dexterous force control

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Details

Dexterous object manipulation requires the coordinated control of two processes: generating sufficient grip force to stabilize an object and producing small, precisely timed force adjustments to guide manipulation. Although these components are often studied separately, everyday manual behavior requires them to operate concurrently.As a result, how increasing background force alters the ability to produce dexterous adjustments remains poorly understood.To address this gap, we developed a parametric grip-force tracking task designed to concurrently probe tonic force generation and superimposed fine force modulation.Fifteen healthy participants performed a step-wise tracking task using a high-resolution grip-force device (Izar; MindMaze).On each trial, participants generated a sustained background grip force expressed as a percentage of maximum voluntary contraction and simultaneously modulated their force around this baseline to follow a visual target as accurately as possible. Modulation amplitudes were scaled relative to the background force, allowing systematic manipulation of both overall drive and relative precision demands across 24 combinations of background loads and modulation ranges.Performance was quantified as the root mean squared error between target and produced force traces after normalization by the target force trace, allowing assessment of modulation accuracy independent of absolute force magnitude.Tracking errors increased with higher background force ($F_{3,36} = 19.29$, $p = 0.0003$) and with smaller modulation amplitudes ($F_{5,60} = 121.99$, $p < 0.0001$). Critically, we observed a robust interaction ($F_{15,180} = 16.18$, $p = 0.0012$), such that small force adjustments became disproportionately more difficult to sustain as background force increased, even when modulation magnitudes were comparable across conditions.This interaction was highly reliable across testing days.These findings reveal a context-dependent trade-off between strength and dexterity. Increasing background grip force selectively impairs the control of smaller superimposed adjustments, suggesting that the ability to express fine force modulation depends on the operating state of descending motor pathways and their spinal targets. One parsimonious neural account of this interaction is that the descending systems supporting fine, fractionated control and those supporting higher-force, synergistic output contribute differently as overall drive increases. At low background forces, precise modulation is strongly supported by corticospinal inputs that enable individuated motor unit control.As background force increases, however, force production increasingly relies on descending pathways associated with greater common synaptic drive and multi-muscle synergy, such as subcortical systems.In this regime, corticospinal inputs may approach the limits of their effective dynamic range, such that additional descending drive continues to increase overall grip force but yields diminishing gains in fine force modulation.From this perspective, precise corticospinal commands become progressively embedded within a synergistic background drive.By parametrically isolating the interaction between background grip force and fine modulation, this task provides a behavioral assay of the interaction that

occurs between processes that underlie object manipulation and may offer a sensitive tool for detecting alterations in descending motor control following neurological injury.

P2-B-36 - Internal selective attention and motor working memory

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Details

Attention plays a critical role in shaping the contents and function of working memory (WM). It not only selects what information from the external environment is encoded into WM, but it can also be directed inward to shift priority among items already stored to support goal-directed behavior. This internal selective attention mechanism has been well characterized in domains like visuospatial WM, but it remains largely unknown whether internal attention can similarly act on nonvisual motor representations maintained in WM.

To evaluate how internal selective attention affects motor WM representations, we integrated "retro-cues" into a motor WM task that has been previously used to dissociate effector-specific and effector-independent information. In this task, participants encode four nonvisual reaching movements in motor WM and are subsequently asked to recall one of the movements with either the same or the opposite arm. We reasoned that when participants recall a movement with the same arm, they are able to access both effector-specific and effector-independent representations. However, when they recall the movement with the opposite arm, only effector-independent information can inform their recall. Participants completed two sessions of this task. In the retro-cue session, a numerical cue presented after encoding indicated which movement would later be tested, allowing participants to direct attention toward a specific motor representation. In the control session, no retro-cues were shown. This design allowed us to test whether internal selective attention can be used to prioritize motor representations in WM and whether attention selectively modulates effector-specific or effector-independent information.

We found a significant decrease in reaction time when participants received a cue, with cue trials being faster by approximately 330 to 500 ms, depending on which movement was being recalled (first, second, etc.). Notably, the effect of probe position in no-cue trials was significantly lower than that of cue trials, suggesting that internal selective attention may override default primacy and recency effects. Retro-cues reduced distance error between the encoded position and the recalled position most reliably when participants switched hands, with the strongest benefits at later serial positions, especially movements 3 and 4. In contrast, cueing produced little overall reduction in error for same-hand recall, suggesting that internal attention preferentially boosts effector-independent motor codes when effector-specific information is unavailable. These results extend theories of internal attention beyond the visuospatial domain and underscore its role in the flexible control of motor behavior.

P2-B-37 - Preparing grasping movements under target size and location uncertainty

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Details

Grasping an object requires the nervous system to plan a movement that considers both where the object will be in space and its size. Respectively, each of these parameters influences the path for limb transport and the scaling of grasp size. Although grasping directed toward a single, clearly defined target has been extensively documented, considerably less is known about how the motor system prepares actions when several potential targets are available and the final target location is uncertain. Most previous work on movements under target uncertainty has focused on pointing movements, which

influence limb transport but do not provide information on how grasp size is managed by the nervous system. The purpose of the present study is to understand how the human motor system parameterizes grasping actions under target size and location uncertainty.
Using three-dimensional motion capture to record hand kinematics, participants were presented with two cylindrical objects of distinct diameters and were instructed to grasp one of them under two experimental conditions. In the *Go Before You Know* condition, participants initiated their movement before the target object was specified, with the target indicated only after movement onset. Within each condition, participants began either with their hand in a closed grasp (fingers and thumb touching) or in an open grasp (fingers and thumb apart).
The findings demonstrated that when participants started with a closed grasp, peak grip aperture increased when the non-selected object was larger than the eventual target. In contrast, grip aperture did not significantly change when the distractor object was smaller. These results provide evidence that the nervous system adopts a strategy of scaling the grasp to accommodate the largest plausible target. When participants started with an open grasp, two phases of grasping were observed: an initial partial closing of the fingers toward the thumb, followed by a peak opening (similar in timing to the closed grip condition). The results from the second peak grip opening replicated the pattern of results observed in the closed-grasp starting position. However, the initial closing phase showed that grip aperture was influenced by the non-target object for both the small and large distractor objects, becoming relatively smaller and larger, respectively. Thus, during early planning, it appears that all potential target objects influence the movement rather than the nervous system planning solely for the worst-case scenario. Such behaviour appears to reflect an adaptive mechanism through which the motor system enhances the reliability and success of grasp execution when the final target cannot be determined in advance. Later in the movement, by scaling the grasp to the largest potential object, the system ensures that the action remains viable allowing the fingers to clear all potential objects.

P2-B-38 - The role of cross-area premotor–somatosensory dynamics in reach-to-grasp control and stroke recovery

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Details

Sensorimotor function relies on a highly interconnected network involving multiple motor and sensory areas, and somatosensory–motor coordination is crucial for dexterous motor function.[1,2] Likewise, previous evidence has suggested that motor information is detectable in somatosensory areas[3–5] and *vice versa*.[6–11] Despite this, most movement-control studies focus on motor areas alone—leaving unclear how coordinated activity across sensory and motor regions supports dexterity. Recording simultaneously from dorsal premotor cortex (PMd) and primary somatosensory cortex (S1) area 2 in non-human primates performing reach-to-grasp after a primary motor cortex (M1) injury, we used DLAG to decompose population-level activity patterns of PMd and S1 into two distinct identities: activity patterns that are explicitly shared between the two regions (“cross-area”) and those that are expressly local to either region. In behaviorally recovered animals, this approach identified cross-area factors (CFs) that captured shared PMd–S1 signals that strongly covaried with reach-to-grasp kinematics. Crucially, despite accounting for a small percentage of variance, CFs predicted wrist speed better than single-area activations such as principal components and within-area DLAG factors.

Secondly, while it is known that the dexterity loss that comes with sensorimotor stroke is followed by significant changes to the system, it is unknown whether subsequent behavioral recovery is underpinned by changes local to the surviving tissue nodes or changes to inter-area communication. To uncover the differential contributions of cross-area coordination and local activity changes to stroke recovery, we used the same approach to analyze cortical activity over the course of weeks of recovery from the M1 stroke lesion. We found that as animals regained function, PMd–S1 CFs became smoother and more reliable across trials—with these improvements emerging around the time behavior returned to baseline. Importantly, changes in within-area factors, i.e. activity not shared with the other region, did not account for recovery to the same extent. Together, these findings suggest that shared latents spanning sensory and motor cortex may be key coordinators enabling dexterous upper-limb function. Lastly, since we found it surprising that these PMd–S1 CFs were more informative of subsequent kinematic state than expressly local PMd-only factors, we investigated this phenomenon across multiple species to investigate whether this is a feature inherent to sensorimotor networks. Comparing these data with those of mouse M2–M1 electrophysiology and human sensorimotor ECoG during reaching and grasping tasks, we found evidence this phenomenon may be a feature of premotor areas. Collectively, these analyses provide insight into the notions of cross-area sensorimotor communication, movement generation, and recovery of function.

P2-B-39 - Increasing task dimensionality reshapes common synaptic input to deltoid motoneurones during two-degree-of-freedom shoulder force production

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Details

BACKGROUND: Complex shoulder force production requires coordinated activation of the deltoid across multiple degrees of freedom (DoF). Interestingly, synergistic tasks have been shown to influence shared synaptic input to α-motoneurones more so than single-dimensional tasks in the lower limb [1,2]. Yet how increasing task dimensionality alters this in the deltoid remains unclear. Deciphering these adaptations is critical for providing a framework for interpreting typical motor control and neuromuscular alterations in clinical populations. Therefore, this study aimed to investigate whether task dimensionality in one- and two-DoF movements alters shared synaptic inputs to the deltoid α-motoneurones.

METHODS: Twenty-one participants (10 female) performed isometric shoulder contractions at 65° abduction under one-DoF (lateral abduction) and two-DoF (combined lateral abduction and flexion) conditions. Contractions were performed at 5%, 10%, and 20% of maximal voluntary contraction (MVC). High-density surface EMG was recorded from the deltoid using two 64-electrode arrays. Motor unit discharge times were decomposed [3] and tracked across movements and trial permutations, separately for each force (i.e., 5MVC_T1_Y to 5MVC_T1_YZ; 5MVC_T1_Y to 5MVC_T2_YZ etc.). Common synaptic inputs were quantified using motor unit–motor unit coherence in the delta (0–5 Hz), alpha (5–15 Hz), and beta (15–35 Hz) frequency bands.

RESULTS: Movement complexity altered common synaptic input to deltoid α-motoneurones in a force- and frequency-dependent manner. Compared with one-DoF, two-DoF movements indicated a reduction in delta-band coherence at low forces (5% MVC: Cohen's d = −0.88 [−1.56, −0.16]), with progressively smaller effects at higher forces (10% MVC: d = −0.51 [−1.24, 0.25]; 20% MVC: d = −0.36 [−1.03, 0.32]). Alpha-band coherence exhibited variable modulation, with small effects at 5% MVC (d = 0.20 [−0.40, 0.80]), a larger reduction at 10% MVC (d = −0.96[−0.96, 0.45]), and minimal differences at 20% MVC (d = 0.07 [−0.59, 0.72]). Beta-band coherence showed small-to-moderate increases during two-DoF tasks

across force levels (5% MVC: *d* = 0.32 [−0.30, 0.92]; 10% MVC: *d* = 0.58 [−0.19, 1.31]; 20% MVC: *d* = 0.31 [−0.37, 0.98]). These patterns indicate that increasing task dimensionality alters the structure of shared synaptic input, particularly at low-frequency oscillations.

CONCLUSIONS: Synergistic shoulder movements involving multiple DoF are associated with distinct modulation of common synaptic inputs to deltoid α-motoneurones. Preferential reductions in low-frequency coherence during low-force, multi-DoF contractions suggest reorganization of voluntary neural drive to accommodate the control of forces in different directions. These findings provide new insight into shoulder motor control and have implications for rehabilitation strategies targeting coordinated upper-limb function.

Inglis JG, et al. *J Appl Physiol* (2025)
Farina D, et al. *J Physiol* (2014)
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P2-B-40 - Compensatory reflexes for tongue posture stabilization in speech: A case study with a deafferented patient in the orofacial region

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Details

The existence of a human tongue reflex, particularly for sensorimotor control, has long been questioned due to the absence of direct behavioral evidence. Recently, this view has been challenged by experimental findings showing a reflex-like compensatory response to externally-imposed tongue stretch during steady-state vowel production. Subsequent electromyographic (EMG) experiments provided support for a reflex mechanism underlying this compensatory response. Moreover, since EMG latency was relatively short (50ms) and the response was not modified by masking auditory feedback, this compensatory response is considered to be mediated by somatosensory feedback alone.

The present study further investigates the hypothesis of a somatosensory-based tongue reflex by examining whether a quick compensatory response is also present in a patient with a congenital sensory neuropathy which is associated with severe somatosensory impairments. If the compensatory response relies solely on afferent somatosensory signals, the stretch response should be markedly altered in the deafferented patient. In addition, we investigated whether the loss of somatosensation leads to increased reliance on auditory feedback by assessing compensatory responses to formant and pitch perturbations during speech production.

The patient performed the same vowel production task with tongue stretch mechanical perturbations previously used to elicit the tongue compensatory reflex in healthy participants. Complementary tests were also administered to assess auditory–motor integration in response to pitch perturbation, passive tongue movement perception, as well as tactile sensitivity using von Frey filament and two-point discrimination.

Results indicate that the compensatory tongue reflex was absent in the deafferented patient, despite preserved voluntary compensation at longer response latencies. The additional tactile tests confirmed an impairment at the tongue, as detection thresholds were greater than controls. Unexpectedly, compensatory responses to auditory feedback perturbations were also reduced in amplitude and delayed relative to healthy controls, suggesting that congenital deafferentation may affect the proper acquisition of auditory–motor integration.

Overall, the findings provide converging evidence that reflex mechanisms for tongue posture stabilization in speech critically depend on somatosensation. The study also represents the first

experimental investigation of tongue motor control in a deafferented patient, providing critical insight into orofacial function in sensory neuropathy.

P2-B-41 - Rapid cognitive-motor algorithms in pianists

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Details

How does a pianist get from a symbol on a page to an action on the keyboard? And how does practice transform the algorithms that underpin human perceptuomotor skills? Here, we test real world pianists to examine how practice affects perceptuomotor algorithms involved in reading musical notation. We recruited pianists with 5-20 years of experience and had them respond to individual note stimuli on a digital keyboard. We tested two competing hypotheses: One possibility is that extensive practice would allow pianists to rapidly retrieve note-key associations from memory, potentially by fully parallelized processing of the notation. Alternatively, they might employ a serial, generalizable cognitive algorithm to parse the visual stimulus in stages and determine the appropriate keys to press by preparing and pruning clusters of possible actions as they process the stimulus. Using a forced-response paradigm that revealed within-trial action selection dynamics, we found evidence for the latter hypothesis, observing that pianists rapidly and sequentially processed note location, then clef, then accidental (sharp/flat), as they parse notation. Computational modeling confirmed that this hierarchical algorithm outperformed simpler, one-step models. Critically, these structured dynamics persisted across all expertise levels, though speed improved with experience even after already logging years of practice. Our results demonstrate that extensive practice refines and compresses cognitive algorithms, rather than parallelizing them or replacing them with automatic associations. These dynamics could be essential for the speed and flexibility necessary for real world skill, and have intriguing implications for neural changes associated with perceptual-motor expertise.

P2-B-42 - Effects of feedback delay duration on neural processing of valence-dependent augmented feedback during motor practice

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Details

It is well established that augmented feedback facilitates motor skill acquisition. In this context, the timing of feedback presentation and the timing of feedback processing are considered as relevant factors for motor learning. The processing of error information in both a predictive manner (based on intrinsic feedback) and a postdictive manner (based on the integration of intrinsic information and outcome feedback) is considered crucial. Theoretical accounts propose that longer feedback delays provide more favorable conditions for error detection, whereas shorter feedback delays preferentially engage processes that support reinforcement learning. Examining the underlying neural correlates of augmented feedback processing offers the possibility to confirm and supplement these findings, which to date have mostly been obtained by behavioral studies. Accordingly, specific neural correlates have been identified in association with the processing of augmented feedback. In particular, the feedback-related negativity (FRN) has been linked to implicit reinforcement learning processes, which are presumed to be facilitated by shorter feedback delays. The present study examines the fundamental neural responses to different feedback delay durations during motor practice, as indexed by event-related potentials in the EEG. To this end, 33 participants (17 women; mean age = 21.36 years) practiced a right-arm flexion–extension movement with three movement reversals across a total of 192 trials. Using a performance-adaptive bandwidth for spatial movement accuracy, participants received valence-

dependent augmented feedback after each trial, with a feedback delay of either 1500 ms or 7000 ms. Feedback delay durations alternated block-wise. EEG was recorded time-locked to feedback onset. As expected, the results revealed a significant feedback-related negativity (FRN) at the frontal FCz electrode, as a function of feedback valence. However, this finding should be interpreted with caution, as it was likely influenced by an unequal feedback distribution, which may have induced expectancy effects, as well as by differences in the informational content of the feedback displays. Furthermore, the results suggest more pronounced neural processing of augmented feedback independent of feedback valence. Specifically, FRN amplitudes were more negative following the shorter feedback delay compared to the longer delay. This pattern may indicate that implicit reinforcement learning processes are more strongly engaged under conditions of shorter feedback delays. Overall, the findings of the present study suggest that delaying augmented feedback modulates the neural processing of feedback during motor practice.

P2-B-43 - Virtual brush illusion paradigm reveals importance of disembodiment in multisensory integration

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Details

Our sense of touch guides our physical interactions with the outside world more than any other sense. For example, when our fingers go numb on a cold day, a task as simple as tying one's shoes becomes incredibly difficult. Similarly, the loss of proprioception can make everyday tasks such as walking impossible. To compensate for the loss of tactile (haptic) feedback, our bodies integrate information from multiple senses to improve dexterous control. Noninvasive methods utilizing haptic illusions have leveraged our reliance on multisensory integration and have been employed to restore body ownership and haptic salience in individuals with limb loss or sensorimotor impairments, as seen through interventions such as mirror therapy. Here, the mirror causes a proprioceptive drift of the injured limb towards the unaffected, healthy limb. These methods suggest that haptic illusions can enhance these individuals' sensation and motor control. Haptic illusions arise in multisensory situations where visuo-haptic and audio-haptic conflicts generate illusory haptic percepts. Virtual reality (VR) offers accessible, repeatable, and cost-effective means to deliver a variety of sensory modalities that would otherwise be limited in the real world, and therefore creates a valuable platform for these haptic illusions. However, how these sensory modalities combine in VR to generate specific percepts and their implications on user embodiment is not well understood. Haptic illusions in virtual reality are useful for addressing these limitations, because they allow us to explore how the user generates internal body representations and haptic percepts in multisensory virtual environments. Thus, we were inspired to develop a VR illusion similar to mirror therapy, but here we add actuated brushes where congruent and incongruent visuo-tactile stimuli of brushstrokes are presented in both the real and virtual worlds. We hypothesized that the visual stimuli would override the conflicting real-world haptic stimuli due to embodiment of the virtual hands, creating an illusory tactile percept. However, we found that embodiment of the virtual hands alone is insufficient to generate this illusory haptic percept. Instead, it appears that strong embodiment of the virtual limb along with strong disembodiment of the real limb may be necessary to induce the illusion. As embodiment is critical for sensorimotor control, achieving strong embodiment in VR is necessary for the development of sensorimotor therapies. These findings present novel evidence that visual dominance in humans does not always outcompete haptic sensation, and suggests the importance of sensory input that will promote disembodiment of injured limbs in immersive VR sensorimotor therapies. Strengthening immersion can improve haptic illusions that could restore haptic sensation by leveraging multisensory integration, and emphasizes the use of VR as a valuable tool for rehabilitation of sensorimotor control.

P2-B-44 - Sensory expectations and prediction error during feedback control in the human brain

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Details

The motor system counteracts mechanical perturbations more quickly and accurately when they are expected based on contextual cues or prior experience. Here, we investigated how sensory expectations are represented in the human brain and combined with incoming sensory information as perturbations unfold. Participants (N=14) received sudden mechanical perturbations (~3.5 N) to their ring or index finger, after being cued about the probability that either finger would be stimulated. Similar to our previous findings using flexion or extension perturbations to the elbow (Michaels et al., 2025, Nature), feedback responses were faster when the stimulated finger was cued with higher probability. Functional magnetic resonance imaging (fMRI) revealed a linear representation of sensory expectations in the blood-oxygen-level-dependent (BOLD) signal across cortical motor regions in humans, paralleling our previous findings using Neuropixels recordings from two macaque monkeys. In humans, however, the BOLD signal also showed a clear expectation representation in S1, which was noticeably absent in the spiking activity recorded in monkeys. This difference likely occurred because the BOLD signal reflects mostly the synaptic input to a region, rather than neuronal spiking. Supporting this idea, in monkeys the local field potentials (LFPs) also showed a strong expectation signal in S1. However, in contrast to M1, where expectations also bias neuronal spiking (without changing muscle activity), the expectation signal transmitted to S1 does not influence spiking activity before the perturbation.

Once the perturbation began, the expectation signal was combined additively with the incoming sensory information, leading to faster responses for correctly predicted perturbations. This was visible in the spiking activity of M1 neurons recorded in monkeys, as well as in the muscle activity recorded in humans (N=10). In contrast, the LFPs (in monkeys) and the BOLD signal (in humans) from M1 and S1 reflected a signed prediction error signal, i.e., the difference between expectations and sensory input. This is noteworthy because, from a control perspective, the nervous system does not require a prediction error signal – feedback responses could be computed from an additive combination of expectation and sensory input. However, the information about the mismatch between expectation and perturbation could support faster corrections, in line with predictive coding theories of motor control. In addition, the signed prediction error could be used for adjusting the expectations for the next trial toward the actual perturbation outcome.

In conclusion, our findings reveal that the machinery for predictive feedback control encompasses unique modulations of the synaptic input to M1 and S1 independent of the spiking activity, that are similarly observed in humans and monkeys.

P2-B-45 - Tractographic description of the course of cortico-facial fibers in healthy humans: evidence for a dorsal pathway in the brainstem

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Details

Background

The anatomical substrate of facial motor control remains a subject of significant debate. Classical neuroanatomy postulates that the human corticofacial tract (CFT) follows a strictly ventral trajectory alongside the corticospinal tract (CST) in the brainstem. However, clinical observations of central facial palsy following focal lesions in the dorsal pontine tegmentum challenge this model, suggesting the existence of non-canonical dorsal pathways essential for motor execution. We aimed to resolve this

significant anatomo-clinical discrepancy by delineating the CFT trajectory in vivo and validating it against lesion topography known to disrupt facial motor drive.

Methods

We acquired high-resolution multi-shell diffusion MRI (3T) from 57 healthy participants. To resolve complex crossing fiber architectures in the brainstem, we applied Multi-Shell Multi-Tissue Constrained Spherical Deconvolution (CSD). We utilized a probabilistic "reverse-seeding" tractography protocol between Freesurfer-derived cortical motor parcellations and custom facial nucleus seeds to reconstruct both uncrossed and crossed CFTs. To ensure high fidelity in these motor pathway reconstructions, we developed and employed TractEdit, our custom open-source software optimized for interactive virtual dissection. The anatomical plausibility of these reconstructions was validated by quantifying their spatial overlap with 16 standardized brainstem lesion ROIs associated with central facial palsy.

Results

We consistently identified a dorsal paralemniscal pathway in 100% of subjects, distinct from the ventral CST and decussating near the ponto-mesencephalic junction. This finding reclassifies this historically "aberrant" route as a systematic, canonical component of the human facial motor system. Additionally, a distinct medullary loop variant—descending caudally into the medulla before ascending to the facial nucleus—was resolved in 40.4% of participants (N=23). Quantitative analysis confirmed high anatomical validity: the reconstructed dorsal CFTs significantly overlapped with clinically relevant lesion sites, with the crossed CFT intersecting 93.7% of lesion ROIs. This intersection rate was significantly higher than that of the CST ($p < 0.0001$). Fixel-based analysis (FBA) revealed no significant microstructural differences between subjects with and without the loop, suggesting the anatomical substrate is likely universal.

Conclusion

We provide in vivo evidence in support of a redrawing of human corticofacial to include systematic dorsal components, reconciling tractography with clinical neurology. This refined anatomical model is essential for understanding the organization of facial motor control and for guiding neurosurgical decision-making

P2-B-46 - Chemogenetic activation of convergent spinal pathways augments forelimb sensorimotor performance in nonhuman primates

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Details

Motor and somatosensory deficits often co-occur after central nervous system injury, motivating strategies that can improve both domains. Because descending motor commands and somatosensory afferents converge in spinal circuits, targeting spinally projecting sensorimotor neurons may enable coordinated modulation of motor output and somatosensory processing. However, whether increasing the activity of these populations improves function remains unclear.

Here we expressed excitatory designer receptors exclusively activated by designer drugs (DREADDs) in macaque monkeys via retrograde viral delivery in neurons projecting to cervical spinal circuits, including descending motor pathway neurons and dorsal root ganglion neurons, as well as in cervical spinal cord neurons. We combined cortical recordings and electromyography with behavioral assays spanning gross motor output, fine dexterity, spinal reflexes, and sensory responsiveness. Under anesthesia, a DREADD-selective agonist increased cortical and muscle activity in a dose-dependent manner, whereas during voluntary movement cortical neurons showed bidirectional changes in firing. Animal-specific dose optima augmented reaching speed, grip strength, spinal reflexes, and thermal responsiveness, whereas higher doses impaired finger dexterity and increased sensitivity to both nociceptive and innocuous stimuli, consistent with a bounded therapeutic window. In a model with primary motor and

somatosensory cortical lesions, chemogenetic activation acutely improved multiple motor and sensory measures, although gains in fine finger dexterity remained limited.
Together, these results show that excitation of spinally projecting sensorimotor populations can be beneficial or detrimental depending on the level of activation. Spinally targeted chemogenetic modulation provides a unified approach to influence motor output and somatosensory processing after central nervous system injury and highlights the importance of individualized dosing.

P2-B-48 - Cutting out the middle man: low-dimensional invariance, stability, and drift in motor cortex
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Details
Recent work has modeled motor control, specifically in the context of voluntary reaches, using dynamical systems of latent variables. While the mapping between neural population activity and behavior is non-stationary, latent trajectories appear to populate stable, low-dimensional manifolds. In past work, unsupervised Principal Component Analysis (PCA) was used to project neural activity to a 10-dimensional latent space. This resulted in consistent latent representations that could be aligned between experimental sessions using supervised Canonical Covariates Analysis (CCA) to maintain correlations with behavior, and was used to argue that the neural circuitry underlying voluntary reaching was roughly 10-dimensional.
Here, we develop a framework for evaluating stability and drift in the relationship between neural population activity and behavior. We decompose this mapping into an encoding map (from neurons to latents) and a latent map (from latents to behavior). We show that supervised multi-class linear discriminant analysis (LDA) can identify a behaviorally relevant latent space that outperforms other common methods at an offline decoding task, even when using fewer dimensions and explaining less total neural spiking variance.
Furthermore, we show that the latent representation achieved by LDA is stable, and that a low-dimensional rotation in latent space is sufficient to align latent trajectories between experimental sessions (as opposed to past work, which used general linear mappings.) As a result, a fixed latent map consistently decodes movement parameters from latent variables over months and years of experimental sessions. We also find that this proposed method achieves similar performance (using a 2-dimensional latent space) as methods in past work for stable long-term decoding which use 10 dimensions. Finally, we show that loss of performance in an offline decoding model is strongly correlated to the geodesic distance between identified LDA subspaces, even when the latent map is retrained.
Our results indicate that representational drift occurs predominantly at the level of the encoding map, while the latent map largely remains stable over time. Moreover, the behaviorally relevant neural manifold that allows consistent decoding of movement parameters spans substantially fewer dimensions and less variance explained than previously estimated. We argue that the structure of neural manifolds is constrained by the choice of a 2-dimensional experimental task, potentially limiting the insights that properties of such manifolds reveal about underlying neural circuitry. Our findings help inform the development of new experimental and computational methods for studying the encoding of motor control.

P2-B-49 - Sex hormones differentially alter brain networks for Uni- and bimanual movement control
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Details
Introduction: While many of the movements we make throughout our day involve just one upper limb, most daily movements require a certain degree of coordination between both upper limbs. Historically,

sex differences in eye-hand coordination have been observed. There are also sex-specific differences in hemisphere symmetry, interhemispheric connectivity, and motor cortex organization. While it has been suggested that these anatomical differences may underlie sex-related differences in performance, sex differences in the functional neural correlates underlying bimanual performance have not often been investigated. In the current study, we tested the hypothesis that steroid hormone concentrations would have distinct effects in males and females on communication between brain networks for bimanual movement control. Methods: Participants underwent MRI scanning to acquire anatomical and functional brain images. During the functional runs, participants performed unimanual and bimanual coordination tasks using two button boxes. The tasks included pressing the buttons in time to an auditory cue with either their left or their right hand individually (unimanual), or with both hands simultaneously (bimanual). The bimanual task was further divided into either an in-phase (mirror/symmetrical) or anti-phase (parallel/asymmetrical) condition. Participants were trained until reliable task performance without errors was achieved. A generalized psychophysiological interaction (gPPI) analysis was implemented to examine how functional connectivity in each condition was modulated by sex hormones. Results: In support of our hypothesis, steroid hormones differentially modulated functional connectivity between males and females. In line with previous literature, females generally showed integrated cross-hemisphere connections with increasing steroid hormones, particularly in frontoparietal networks, while males had more specialized networks that were more likely to involve subcortical areas. Further, we observed task-related effects, where fewer hormone-functional connectivity relationships emerged with decreasing task complexity. Conclusions: With equivalent performance, hormone- related differences in brain connectivity were seen as a function of sex in both unimanual and bimanual movement control. Not only do these findings provide novel insight into the fundamentals of how the brain controls bimanual movements in both women and men, they also present potential clinical rehabilitation implications on how bimanual movement training – important for activities of daily living - can best be tailored to the needs of individuals.

P2-B-50 - Concurrent facilitative tDCS to primary motor cortex and right inferior parietal lobe augments kinesthetic illusory awareness

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Details

Understanding neural correlates of consciousness remains a major challenge in systems neuroscience. Bodily awareness, including the conscious experience of limb movement (kinesthesia), is a fundamental form of human consciousness. Kinesthetic illusion induced by tendon vibration of a limb provides a unique model to study the neural basis of such awareness. Previous studies have suggested the importance of the primary motor cortex (M1) that is primarily involved in kinesthetic processing and of higher-order regions of inferior parietal lobule (IPL) and inferior frontal gyrus (IFG) of the right hemisphere during illusory limb movement, yet it remains unclear whether activities in these regions are causally involved in conscious kinesthetic experience. Here, we examined whether M1, IPL and IFG causally contribute to kinesthetic awareness during illusory plantar flexion of the right foot, by conducting one functional MRI experiment (n=52) and two transcranial direct current stimulation (tDCS) experiments (n = 108, in total). The fMRI study showed that foot section of M1, right IPL and IFG (area 44) were activated and right IPL and IFG enhanced their functional coupling with the M1 foot section when the participants experienced the illusion, suggesting the importance of these regions in kinesthetic illusion. Next, we conducted a randomized, sham-controlled, double-blind tDCS study to examine whether concurrent, local facilitative tDCS to M1 foot section and right IPL or that to the M1 and right area 44 can augment strength of illusion. Twenty-one male participants who experienced the illusion

with knowledge were randomly assigned to each of L M1-R IPL, L M1-R 44, and sham groups. The study showed the prominent augmentation effect of illusion in L M1-R IPL group, but not in L M1-R 44 and sham groups. Further, we conducted another double-blind tDCS study where other 15 male participants were randomly assigned to each of L M1-R IPL, L M1 alone and R IPL alone groups (1) to clarify reproducibility of the augmentation effect by L M1-R IPL tDCS, and (2) to evaluate concurrent stimulation effect by comparing L M1-R IPL tDCS and L M1 alone tDCS or R IPL alone tDCS. In this study, similar prominent increase in strength of illusion was also observed in L M1-R IPL group, which was greater than L M1 alone or R IPL alone group, suggesting reproducibility of this effect across different groups of participants. Our findings provide compelling evidence that kinesthetic awareness can be augmented by concurrent neural facilitation between modality-specific primary kinesthetic-motor cortex (M1) and higher-order region of right IPL. The results extend the Global Neuronal Workspace hypothesis to the domain of bodily awareness. By establishing a causal link between coactivation and conscious experience, this study advances mechanistic understanding of the neural basis of kinesthetic awareness (bodily self-awareness).

P2-B-51 - Holistic planning of sequential motor actions

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Details

Humans can perform a wide range of skilled sequential motor behaviours, from whole body actions such as driving to dexterous motor tasks like handwriting. These complex actions comprise a series of separate movements which are performed in quick succession, and after extended practice can be executed with incredible speed, accuracy, and fluidity. Motor planning is critical to the effective execution of such actions; however, the question of how the brain plans such movements remains unsolved. Two primary frameworks have been proposed: serial planning, where individual movements retain their independence and are planned and executed sequentially; and holistic planning, in which discrete movements become fused into a unified 'motor primitive' and are planned as a single cohesive action. While behavioural studies have largely supported the holistic planning model, emerging electrophysiological evidence has favoured a serial mechanism. This leads to the question: does holistic planning truly exist? To investigate this, we trained participants over five days on a two-stage reaching task using two distinct target angle configurations: obtuse, which was hypothesised to promote holistic planning, and acute, which was expected to elicit serial planning. We examined this in two ways, using a stop paradigm (experiment 1) and mid-execution target switches (experiment 2). In experiment 1, on day one and day five, participants were instructed to stop as soon as possible upon hearing a tone. This tone was delivered randomly on 20% of trials so participants could not anticipate the stop. If holistic planning occurs, we predicted that participants would show an inability to stop due to an incomplete motor plan. We found an impairment in stopping performance in participants who fused, in obtuse angles compared to acute angles, suggesting that holistic planning led to an inability to stop. In experiment 2, participants performed the same movements, but we introduced target switches mid-execution, altering the second target during the initial movement. If holistic planning occurs, we predicted that participants would demonstrate impaired switching ability, moving toward the original target before adjusting their trajectory. Our findings support this: with participants moving closer to the original target in obtuse trials with increased kinematic fusion. These results provide behavioural evidence that holistic planning may underlie the execution of certain well-practiced motor sequences.

P2-B-52 - Identifying motor unit properties from high-density EMG recordings using simulation based inference

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Details

Estimating the physiological properties of motor units (MU), such as their territory (number of innervated muscle fibres), innervation zone spread, and fibre conduction velocity, provides critical insights into neural control of movement in health and disease. Alterations in these properties serve as potential biomarkers for neuromotor disorders such as amyotrophic lateral sclerosis (ALS) and age-related neuromuscular changes. However, accurately measuring motor unit properties remains challenging, with many features inaccessible through current non-invasive techniques.

High-density surface electromyography (HDEMG) offers a promising avenue by recording the electrical activity of motor units through grid(s) of electrodes placed on the skin. The resulting signals are a summation of surface action potentials (SAPs) from tens to hundreds of active MUs. Temporally, HDEMG signals reflect rich information about the neural drive to the muscle while the SAPs (the spatiotemporal footprint of individual units) encodes biophysical characteristics of MUs, including fibre distribution, conduction velocity and innervation zone geometry. However, conventional analytical approaches for MU property estimation rely on simplified biophysical models and make restrictive assumptions about motor unit architecture, limiting their accuracy in extracting these properties.

Here we applied simulation-based inference using neural density estimators to directly infer the posterior distribution of MU properties from decomposed HDEMG recordings. We configured a state-of-the-art EMG digital twin to closely match experimental conditions and generated a large synthetic dataset pairing SAPs with their underlying properties. Using neural posterior estimation, we trained models to perform inverse inference from SAPs to properties. We validated our approach experimentally by combining surface EMG measurements with fine-wire intramuscular EMG and ultrafast ultrasound imaging to obtain ground-truth measurements of motor unit territory and conduction velocity.

In both synthetic and experimental validation, our method consistently achieved higher accuracy for MU localisation, territory (size) estimation, and conduction velocity estimation, with respect to state-of-the-art algorithms. This framework enables longitudinal monitoring of motor unit remodelling and detailed characterization of biophysical and morphological properties across motor unit populations, expanding the possibilities for both research and clinical applications in motor neurophysiology.

P2-B-53 - Engaging working memory following skill memory reactivation has a time-dependent impact on skill generalization

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Details

Interlimb skill generalization, defined as the transfer of newly learned movements from the trained to the untrained limb, represents a fundamental aspect of human motor behavior with significant implications for rehabilitation and athletic training. Skill generalization is influenced by processes that drive learning and interact with the newly acquired memory. For instance, in our recent work, we reported that performing a secondary task that engages working memory (WM) immediately after a short skill-training session impaired skill generalization when the untrained arm was tested 24h later. This suggests that WM interacts with the early skill memory consolidation processes and thereby impacts skill generalization.

Motivated by this finding, in the current study, we investigate how WM interacts with reactivated skill memory and its subsequent impact on skill generalization, tested 24 h or 48 h post-skill training. We

recruited right-handed young participants (n=95) who performed a fast, accurate reaching task with their dominant right arm during a short training session (50 trials) on Day 1. After 24 h on Day 2, depending on the group type, participants had a brief skill reactivation session (10 trials) or no reactivation, followed by the WM task (or a control task). Interlimb generalization to the untrained left arm was assessed either immediately after the WM/control task on Day 2 or after a 24-hour time gap on Day 3. We found that engaging in the WM task (compared to the control task) after skill reactivation on Day 2 enhanced immediate generalization. Conversely, when generalization was tested 24 hours later on Day 3, the same WM engagement impaired transfer. These findings demonstrate that WM engagement during the post-reactivation phase has a time-dependent
influence on interlimb generalization. WM can facilitate immediate transfer, possibly due to sustained activation of neural processes that facilitate transfer of skill memory. However, when a 24h time gap is introduced, transfer is disrupted following WM engagement, possibly because of interference between underlying neural processes involved in WM and reactivation-induced (re)consolidation of the skill memory. This study highlights the delicate interplay between WM, motor memory reactivation dynamics, and skill transfer, and is suggestive of a time-dependent interplay of neural processes critical for optimizing outcomes in motor learning and clinical rehabilitation protocols.

P2-B-54 - Unveiling neural codes from motion tracking to action planning in posterior parietal cortex

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Details

How is a motor action planned in a dynamic world? While predictive signals have been observed in visual perception and motor generation, the spatial extrapolation shared by both perceptual and action processes remains obscure.

To investigate how the spatial extrapolation emerges and explicitly develops to infer the visual target or action goal, we designed an occluded manual interception task. During this task, the monkey was trained to manually intercept a circularly moving target with gaze fixation. The target, moving from a random location on an invisible circular path with one of five angular velocities, was first presented for a 400-800 ms Cue period, and then disappeared. After a fixed 500 ms Occlusion period, the monkey was allowed to perform a reaching movement. Therefore, the flexible relationship between target and movement enabled dissociation of neural tuning to the stimulus and intended goal. Furthermore, the fixed duration of the Occlusion period allowed the movement to be prepared without tracking the target.

We recorded neuronal activity from the lateral intraparietal cortex (LIP) and parietal reach region (PRR), areas where motion extrapolation and motor consequence estimation have been observed. A total of 331 (89 from monkey A, 242 from monkey N) and 359 (65 from monkey A, 294 from monkey N) well-isolated LIP and PRR units were included in this study. By comparing the stimulus- and movement-defined directional tunings in different target-velocity conditions, we tried to evaluate if single neurons convey the target of interest or the intended movement. We found sensorimotor transformation at the single-neuron level: in nearly half of the neurons showing either directional tuning, those modulated by the upcoming movement typically underwent stimulus modulation. Next, we further examined neuronal response latency to the stimulus. Notably, in both areas, neurons exhibited dynamic internal representations spanning from visual registration to visual extrapolation. Specifically, the goal for interception was found to be estimated as the visual consequence of the movement. This goal estimation was concurrent with motion extrapolation in the absence of visual input, supporting that visual extrapolation is integral to action planning. As continuous and varying spatial extrapolation in

single neurons facilitated the read-out over a broad range, the delayed, instantaneous, and inferred target location could be well decoded during both Cue and Occlusion period. Finally, through neural population dynamics analysis, we found that target tracking and motor planning shared a common spatial map, and the transition between their dominance could be achieved by exploiting different dimensions in the neural state space.

Our findings identified the spatial extrapolation achieved at both the perceptual and motor stages, suggesting that state estimation in guiding predictive sensorimotor control could be implemented in visual-based kinematic coordinates.

P2-B-55 - Motor memory is tuned to the level of uncertainty in decision making

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Details

In daily life, action is often preceded by a decision. However, it remains unclear how the decision-making process is associated with the memory of action (motor memory). In a previous study in our group (Ogasa et al., 2024), it was reported that differences in decision uncertainty levels can segregate the motor memory of the following action. In this study, we further investigated the detailed relationship between the decision uncertainty and motor memory, examining the tuning property of motor memory across different uncertainty levels.

Participants judged the direction (left or right) of a visual motion stimulus (random-dot motion) presented on a screen while holding a manipulandum with their right hand. They were asked to move the manipulandum towards the target in the perceived motion direction either immediately after making a decision (reaction time condition; Exp. 1) or after the 700 msec presentation of the motion stimuli (fixed duration condition; Exp. 2). In the learning-phase, each group of participants (n=17 for each group) learned a velocity-dependent force field (CW or CCW direction) followed by a motion decision with four different uncertainty levels (3.2%, 25.6%, 51.2%, or 100% motion coherence). The subsequent test-phase included probe trials in which participants performed the decision with six different levels of uncertainty (3.2%, 6.4%, 12.8%, 25.6%, 51.2%, or 100% motion coherence). In these probe trials, compensation force was measured using the error-clamp method to examine the generalization of learning across different uncertainty levels.

In the learning-phase, force-field learning was comparable across the four different uncertainty levels, showing that decision uncertainty itself does not affect the learning. In the test-phase, the retrieval performance of the motor memory (compensation force) in the test phase was highest near the uncertainty level which the participants experienced during the learning phase. This pattern was qualitatively similar regardless of the difference in pattern of decision-making task (Exp. 1 or Exp. 2).

Our results demonstrate that the motor memory is tuned to a particular decision uncertainty level of the action, possibly reflecting the different neural states in the motor cortex associated with different decision uncertainty levels (Gold & Shadlen, 2000; Selen et al., 2012).

P2-B-56 - Regional-dependent rate coding of deltoid motor units across one and two degrees-of-freedom tasks

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Details

BACKGROUND: The shoulder complex dynamically activates across a wide range of motion, with the deltoid playing a primary role in multidirectional movement. Previous research has indicated a non-uniform deltoid activation pattern during shoulder movements, with greater global EMG amplitude in

the anterior portion during flexion than during abduction [1]. However, whether this regional modulation occurs at the motor unit (MU) level during shoulder involvement in multiple-degree-of-freedom (DoF) tasks remains unclear. This study investigated MU rate coding during one and two-DoF shoulder isometric tasks while assessing potential deltoid region-specific modulation.

METHOD: Following a novel methodological framework [2], HD-sEMGs were recorded from the deltoid in 21 participants using two 64-electrode arrays. Participants performed two isometric tasks – isolated lateral abduction (1 DoF, Y); combined lateral abduction and flexion (2 DoF, YZ) – at 5%, 10%, and 20% of maximum voluntary contraction (MVC). The shoulder was positioned at 30° and 65° of abduction. Two trials were performed for each force. HD-sEMG signals were decomposed into individual MU spike trains and, separately for each force, MUs were matched across tasks using all possible trial combinations (e.g., Y_01 vs. YZ_T01, Y_01 vs. YZ_T02, …). Matched MUs were classified into anterior, lateral, and posterior regions based on the spatial distribution of their MU action potentials [3]. Mean discharge rates (MDR) and coefficient of variation of the inter-spike interval (CoV-ISI) were calculated for each matched MU and compared between one vs two DoF.

RESULTS: A significant DoF and muscle region interaction was observed on MDR across all forces ($p<0.01$) with no effect of trial ($p>0.93$). At both shoulder angles, the 2 DoF task resulted in a region-specific modulation in rate coding, with increased MDR observed for anterior deltoid MUs at 5% (15.5±0.6 vs 13.8±0.6 pps; $p<0.001$), 10% (15.1±0.6 vs 13.7±0.6 pps; $p=0.004$), and 20% MVC (16.4±0.7 vs 14.9±0.7 pps; $p=0.002$). Rate-coding modulation across tasks was not observed in MUs located in other regions. Additionally, for both shoulder angles, CoV-ISI of anterior deltoid MUs significantly decreased during the 2 DoF compared to 1 DoF task.

CONCLUSIONS: These results demonstrate that the central nervous system selectively manipulates rate-coding strategies within specific regions of the deltoid to cope with multidirectional demands. Combining flexion and abduction increased synaptic drive to the motoneurons innervating the anterior deltoid region. Our findings indicate that adaptations in neural control are region-dependent, supporting the functional compartmentalization of the deltoid and providing deeper insights into the coordination of complex shoulder movements.

[1] Brown et al., 2007
[2] Inglis et al., 2025
[3] Negro et al., 2016

P2-B-58 - Motor working memory for complex reach trajectories

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Details

Working memory (WM) allows us to maintain and manipulate a range of sensory and verbal information over short timescales. One sub-domain of WM that has received relatively little attention is WM for nonvisual motor information, or “motor working memory” (MWM). In recent studies we and others have provided evidence that MWM is a partly independent, domain-specific WM subsystem. However, prior studies have focused on WM for simple straight-path, point-to-point reaching movements, requiring participants to remember only movement endpoints (or postures). Moreover, movements were often delivered passively during memory encoding. Does MWM function differently when movements are actively planned and involve complex, naturalistic trajectories? In the present study, participants actively produced four novel, complex reach trajectories without visual feedback and were

later cued to recall one of them. On half of the trials, recall was performed with the opposite hand from the one used during encoding. Memory fidelity was measured as the Procrustes distance between the encoded and recalled reach trajectories. We predicted that recall would be more accurate when the same hand was used for both encoding and recall, but only for the most recently encoded movements, consistent with our prior findings in passive, point-to-point movements. Preliminary results supported this prediction, revealing smaller Procrustes distances in same-hand trials but only for the most recently encoded movement. These findings replicate and extend previous work, providing evidence that complex, naturalistic movement trajectories may be encoded and maintained in MWM. More broadly, this study advances our understanding of MWM as an independent WM subsystem and extends its relevance to more real-world motor behaviors.

P2-B-59 - Evidence of both compositional reuse and distinct subskills in speech motor cortex

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Details

To what extent can we view a compound movement's underlying neural activity as the modular combination of basic movements versus to what extent does a compound movement correspond to its own new neural computation? Such topics have been studied extensively for upper limb movements, but analogous questions can also be asked in the context of speech, which involves skilled coordination and sequencing of articulator movements. Does the brain utilize the same neural patterns to produce a basic articulator movement (e.g., pressing lips together) as it does to produce speech sounds that contain that same movement (e.g., the phoneme /m/ as in "me")?

To investigate this question, we collected action potential resolution neural recordings from four 64-microelectrode arrays implanted in the ventral precentral gyrus of one BrainGate2 clinical trial participant (T15) while he performed an instructed-delay task. Each prompt was either (A) a word to speak, such as "mall", or (B) a basic lip or tongue movement to perform, such as "[press lips together]". The prompts included 4 lip movements, 3 tongue movements, 6 words differing by specific lip movements, and 8 words differing by specific tongue movements. We observed a rich variety of individual electrode responses to both the basic movements and words. Both the basic movements and words were highly decodable from neural data, with classification accuracies between 0.85 and 0.95. The basic movement neural activity and speech neural activity overlapped moderately (subspace-alignment index=0.51 for lip movements vs. words, 0.33 for tongue movements vs. words), consistent with speech containing a mixture of reused basic movement neural patterns and speech-specific neural subskills.

We then sought to determine whether the speech neural activity was composed of basic movement neural patterns according to words' articulatory kinematic structure. Sparse component analysis (SCA) was applied to only the basic movements neural activity and revealed neural dimensions which were utilized during only one basic movement (e.g., a "press-lips-together dimension", a "tongue-between-teeth dimension", etc.). Projecting word trials' neural activity onto each of these basic movement dimensions displayed modulation consistent with articulatory phonetics. For example, neural activity during "mall" and "me" modulated along the "press-lips-together dimension" more than words without /m/ did, measured by PSTH area-under-the-curve.

These results reveal neural overlap between speech movements and their corresponding basic articulator movements, supporting the hypothesis that speech motor cortex modularly reuses neural patterns between basic movements and speech. However, we also highlight the large portion of speech

activity not explained by the basic movement neural dimensions studied. The extent to which this unexplored subspace pertains to speech-specific subskills or to additional basic movements is a future research direction.

P2-B-60 - PreSMA and M1 mechanisms underlying stopping and switching revealed by intraoperative human recordings

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Details

Humans exhibit a remarkable ability to dynamically regulate their actions, relying on stopping and switching behaviors to adapt to new situations. While both functions are critical, the precise behavioral and electrophysiological relationship between stopping and switching in humans remains incompletely understood. We aimed to delineate the neural mechanisms underlying these core action-regulation functions, examine how they interrelate within key brain networks.

We recruited eight patients with Parkinson's disease (PD) undergoing deep brain stimulation implantation surgery targeting the subthalamic nucleus (STN). Participants performed tasks requiring intermittent stopping or switching directions (up or down) while rapidly moving a joystick horizontally (left or right) in response to visual cues. We intraoperatively recorded single-neuron activity and local field potentials (LFPs) from the subthalamic nucleus (STN), along with cortical signals from the presupplementary motor area (preSMA) and the primary motor cortex (M1). We compared task-locked temporal evolution of signals in STN, preSMA, and M1 in response to stop and switch cues. For STN single neurons, we identified stop- or switch-responsive cells showing increased firing rates following the respective cues relative to baseline.

Behaviorally, we found that the initial horizontal displacement of joystick was significantly decreased during successful switching compared to failed switching, and the magnitude of this decrease was comparable to that observed during successful stopping. This suggests that sufficiently suppressing the originally planned action is a necessary prerequisite for initiating a switch to a new, goal-directed action. Moreover, we found that high-gamma (HG) activity (60–100 Hz) increased in the preSMA immediately after both stop and switch cues, regardless of whether the action regulation was successful or not. Notably, this preSMA HG response was preceded by movement-related HG activity in M1 specifically during failed stopping or switching attempts. Furthermore, successful stopping and switching were associated with increases in beta activity (13–35 Hz) in both STN and M1 following the stop and switch cues. These findings strongly suggest that preSMA has a functional role both in stopping and switching, which suggests that switching invokes stopping circuity. Action regulation may fail when the intended movement is triggered before the preSMA can effectively recruit the M1-STN inhibitory network. We also identified 21 STN neurons, of which 33.3% were stop-responsive and 28.6% were switch-responsive. Notably, most neurons responded exclusively to either stopping or switching (with only 2 showing responses to both), suggesting that distinct STN microcircuits are engaged in specialized action regulations.

Overall, we revealed a cascade of neural mechanisms underlying action stopping and switching, characterized by spatially and spectrally partially overlapping oscillatory activities. These findings indicate that stopping and switching share common network-level neural signatures – i.e., pre-SMA high-gamma activity and M1-STN beta oscillations – while potentially relying on distinct, specialized microcircuits within the STN to execute these functions.

P2-B-61 - Neural mechanisms underpinning the voluntary suppression of involuntary movements

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Details

Introduction: Humans can voluntarily suppress unnecessary or unwanted actions, such as successfully stopping oneself from reaching for an unhealthy snack. This ability is supported by a prefrontal–basal ganglia network that acts to suppress motor system excitability. A key neurophysiological marker of this network is a widespread, transient downregulation of corticospinal excitability referred to as a global motor system suppression. However, it remains unclear whether this mechanism is engaged when people attempt to suppress movements that arise involuntarily.

Aims: The present study aimed to determine whether global suppression is recruited when individuals attempt to tonically suppress a sustained involuntary movement and to further characterize the temporal dynamics of this process.

Methods: Healthy adults were recruited in two experiments: Experiment 1 (N=20) and Experiment 2 (N=20). The Kohnstamm phenomenon, an involuntary arm elevation following sustained deltoid contraction, was used as a model of involuntary movement. In a within-subject design, participants either: allowed the involuntary elevation to occur naturally (Allow condition); or attempted to prevent the arm from rising during a 5-s suppression period after a stop cue (Suppress condition) delivered when the arm crossed a threshold angle of 25° of elevation (ACT). To probe global suppression, motor-evoked potentials (MEPs) were recorded from task-unrelated muscle (first dorsal interosseous, FDI), contralateral to the rising arm, using single-pulse transcranial magnetic stimulation (TMS). Two stimulation timings were employed: early in the suppression period (500 ms in Experiment 1; 150 ms in Experiment 2, the latter consistent with the latency of global suppression in reactive-stopping paradigms, and later during the suppression period (4.5 s after ACT). Arm kinematics were continuously tracked and extracted at ACT, early and late TMS time points. Electromyography (EMG) was recorded from the deltoid (agonist) and latissimus dorsi (antagonist); root mean square (RMS) amplitudes were calculated and compared across the induction phase and three critical epochs (500 ms before ACT, ACT – early TMS, 500 ms before late TMS). ANOVA was conducted to analyse condition by time interactions for arm position, EMG and MEP amplitudes.

Results: Behavioural and EMG analyses confirmed that participants successfully suppressed involuntary arm elevation (Condition × Time interaction: Exp.1, $F(2,38) = 31.87$, $p < .001$; Exp.2, $F(2,38) = 49.59$, $p < .001$). This was achieved through control of the agonist deltoid – preventing the rise in agonist activity (Condition × Time interaction: Exp.1, $F(2,38) = 4.03$, $p = .028$; Exp.2, $F(2,38) = 28.25$, $p < .001$), and not through increased antagonist activity (Condition × Time interaction: Exp.1, $F(2,38) = 1.67$, $p = .202$; Exp.2, $F(2,38) = 5.46$, $p = .008$). However, MEP analyses in the task-unrelated FDI revealed no evidence of global suppression: at no timepoint were MEP amplitudes lower in Suppress than in Allow. A significant main effect of Condition was observed in both experiments (Exp.1: $F(1,19) = 13.73$, $p = .002$; Exp.2: $F(1,19) = 4.74$, $p = .042$), whereas the Condition × Time interaction reached significance only in Exp.1 ($F(1,19) = 7.30$, $p = .014$; Exp.2: $F(1,19) = 0.68$, $p = .419$). There were no differences in MEP amplitudes at the early time point (Exp.1: $t(19) = -1.47$, $p = .158$; Exp.2: $t(19) = -1.67$, $p = .111$). At the late timepoint, MEPs in Suppress were consistently greater, rather than smaller, than in Allow (Exp.1: $t(19) = -4.04$, $p < .001$; Exp.2: $t(19) = -2.12$, $p = .047$).

Conclusions: Across two independent experiments, we consistently found that voluntary behavioural suppression of sustained involuntary movement does not depend on the neural global suppression mechanism typically recruited during the suppression of voluntary movements. Instead, behavioural suppression may be achieved through selective neural suppression of the primary agonist muscle representation.

P2-B-62 - Neuromuscular control strategies preserve force output across the menstrual cycle despite muscle-specific changes in motor unit behavior

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Details

Background: Performance is generally preserved across the menstrual cycle despite endocrine fluctuations, but the neuromuscular strategies that support this stability remain poorly understood. Purpose: To determine whether motor unit-level control reorganizes across the menstrual cycle to maintain force output.
Methods: Fifteen healthy females (22.3 ± 1.3 years) performed isometric knee extensions at 10–70% maximal voluntary contraction (MVC) during the follicular, ovulatory, and luteal phases. High-density surface electromyography with longitudinal motor unit tracking quantified discharge rate, interspike interval variability, synchronization, root mean square (RMS) amplitude, and common synaptic drive. Linear mixed-effects models examined phase-related effects; hormone concentrations were included as exploratory covariates.
Results: Global performance remained stable across the cycle, with no significant change in MVC or torque steadiness. Similarly, common synaptic drive was preserved. However, local motor unit behavior exhibited muscle-specific reorganization: in the vastus lateralis, the discharge rate decreased and interspike interval variability increased during ovulation. Conversely, the vastus medialis showed increased RMS amplitude with only modest changes in discharge rate. Synchronization increased toward the luteal phase in both muscles. While hormone concentrations showed associative, phase-consistent relationships with specific neural variables, they did not account for overall stability of performance.
Conclusions: Force output is maintained across the menstrual cycle despite endocrine fluctuations. This stability is supported by muscle-specific reorganization of motor unit-level control rather than changes in global neural drive, indicating adaptive neuromuscular strategies that preserve performance under varying physiological conditions.

P2-B-63 - Unveiling the complexity of Octopus arm movements by developing a markerless underwater motion capture system

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Details

Octopus arms exhibit exceptionally high degrees of freedom through their unique distributed nervous system, enabling bending, elongation, rotation, and changes of stiffness at any location along the arm. Previous studies have attempted to quantitatively characterize octopus arm motion. However, the use of gross measurements without tracking the spatial coordinates of individual suckers limited their ability to capture complex arm movements, particularly elongation and rotation. Here, we developed a method that enables three-dimensional reconstruction of octopus arm and allows tracking of hundreds of individual suckers at sub-millimeter resolution. Using this approach, we quantitatively analyzed octopus arm movements during exploration in the absence of visual guidance. We found that the arm frequently generated characteristic wave-propagation movements. During these waves, the orientation and propagation speed of bending were continuously and actively controlled. Within this control process, we further resolved a limited spatial extent of motion correlations, spanning approximately ten suckers, consistent with a distributed movement control. Together, these findings reveal a distributed neural control system underlying complex octopus arm movements and suggest new paradigms for soft-robotic control.

P2-B-64 - Midbrain dopaminergic projections to the forelimb motor cortex: Anatomical, molecular, and sex-specific insights

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Details

Introduction:

Motor learning and recovery from injury rely on neuroplasticity, with dopamine acting as a key modulator. The motor cortex receives dopaminergic input from the ventral tegmental area (VTA), and disrupting cortical dopamine release impairs the acquisition of fine motor skills, especially the fine movements of hands in reaching and grasping. Because the VTA contains heterogeneous neuron types capable of combinatorial neurotransmission, understanding the molecular identity of VTA–motor cortex projections is essential for interpreting their functional roles. This study quantified the proportions, spatial distribution, and neurotransmitter profiles of VTA neurons projecting to the rostral (RFA) and caudal (CFA) forelimb motor areas, providing an anatomical and molecular framework for their contributions to forelimb motor learning. We also examined potential sex differences in projection patterns to explore anatomical factors that may underlie behavioral variability across sexes.

Methods:

Nineteen Long-Evans rats received unilateral injections of the retrograde tracer Fluorogold into either RFA or CFA (n = 5 points per area). One week later, brains were collected, sectioned coronally, and processed for Tyrosine Hydroxylase (TH) immunolabeling to quantify dopaminergic projection ratios. RNAscope fluorescent in situ hybridization was used to detect TH, VGAT, and VGLUT2 expression, corresponding to dopamine, GABA, and glutamate content, respectively. Confocal imaging was performed, and labeled cells were quantified using FIJI's cell-counter plugin.

Results & Discussion:

VTA inputs to the forelimb motor cortex were strongly ipsilateral: 97.3 ± 2% of all labeled VTA neurons projected to the cortex on the injected side, although sparse contralateral projections were observed. This laterality was consistent across dopaminergic (92.1 ± 5.2%) and non-dopaminergic (97.2 ± 0.6%) populations.

Overall, 23% of VTA neurons projecting to the forelimb motor cortex were dopaminergic. Roughly three-quarters of these originated from the mid-VTA (–5.2 to –5.64 mm), whereas >90% of non-dopaminergic neurons were concentrated in the anterior VTA (–4.68 to –5.0 mm), revealing a pronounced rostrocaudal segregation with functional implications.

Dopaminergic projections differed between motor areas: ~30% of VTA inputs to RFA were dopaminergic, approximately twice the proportion observed for CFA, suggesting a stronger dopaminergic influence on motor planning (RFA) relative to motor execution (CFA). A trend toward higher dopaminergic ratios in males was observed, but did not reach statistical significance and will require larger cohorts.

RNAscope analysis indicated that a subset of VTA dopaminergic neurons projecting to forelimb motor cortex co-express VGAT, suggesting potential GABA co-release and a more complex modulatory influence than dopamine alone.

C – Posture and Gait

P2-C-65 - Activation of plantarflexors in generating different speeds of walking in humans

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Details

BACKGROUND: Plantarflexors are critical for generating propulsive force during walking and running. As walking speed increases, propulsive demands rise, which comes with greater plantarflexor activity during mid-late stance. Proprioceptive afferents are suggested to contribute to activation and reinforcement of extensor muscle activity, but how their influence changes with speed remains unclear. Here, we sought to examine how muscle afferents may contribute to the generation of plantarflexor activity across a range of walking speeds. Ankle joint motion and ground reaction forces (GRF) were used as indirect indicators for changes in muscle length (spindle afferents) and loading (Golgi tendon organs). Triceps surae H-reflexes were measured to assess Ia pathway availability and excitability.
METHODS: Twelve women (27±5 yr, 166±6 cm, 66±11 kg) walked on an instrumented treadmill at six speeds (0.75-2.0 m/s, 0.25 m/s increments). During each walking bout, EMG (soleus, tibialis anterior [TA], medial [MG] and lateral gastrocnemius [LG]), sagittal-plane ankle motion, and GRF were recorded. Triceps surae H-reflexes were elicited during mid-late stance.
RESULTS: Mid-late stance triceps surae EMG amplitude increased with speed (+150-283% from 1.0 to 2.0 m/s). TA and MG EMG amplitude increased at higher speeds (≥1.25m/s) only. Mid-late stance H-reflex amplitude also increased with speed, but the predictability of the H-reflex amplitude by background (i.e., ongoing) EMG varied across participants and muscles. Notably, over submaximal speeds (0.75-1.75 m/s), the amount and rate of ankle dorsiflexion rotation over mid-late stance tended to decrease (although within a limited range) with increasing speed. In contrast, GRF and rate of force development (RFD) increased significantly with increasing speed. At near-maximal speed (2.0 m/s), both the amount and rate of ankle dorsiflexion were significantly reduced compared to that of lower speeds while GRF and RFD did not increase further, despite further increase in EMG amplitude.
DISCUSSION: The reduced magnitude and rate of ankle dorsiflexion with increasing speed (i.e., decreased muscle length change and stretch velocity) are consistent with spindle afferents (Ia and II) being unlikely origins of the observed plantarflexor activity increase in mid-late stance, assuming unchanged fusimotor drive. In contrast, H-reflex amplitude generally increased with speed, indicating that at least Ia afferent pathways remained accessible during this phase. GRF and RFD increased across submaximal speeds but did not increase further at 2.0 m/s. Assuming that proprioceptive afferents contribute to locomotor EMG these results suggest load-sensitive Ib afferents contribute to increasing plantarflexor activity across submaximal speeds (e.g., 0.75-1.75 m/s). At near-maximal speed (2.0 m/s), other mechanisms (descending or ascending input to the MN pool), are likely employed to further increase plantarflexor EMG activity.

P2-C-66 - Direction-dependent performance in functional center of pressure metrics during visually guided multidirectional control in sitting

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Details

Background: Sitting balance is essential for daily activities, which often require maintaining balance in multiple directions, and kinematic analysis of the center of pressure (COP) provides a reliable indicator of sitting balance. However, previous studies on sitting balance have predominantly relied on physical

performance measures, such as maximal COP distance, in a limited range of directions. Therefore, it fails to capture functional aspects of sitting balance control in multiple directions. From a kinematic perspective, functional balance performance can be characterized with accuracy, smoothness, and stability. Since leaning toward different directions involves different sets of muscle coordination, it is possible that some directions are more difficult than other directions, affecting those functional metrics. In addition, if such biomechanical properties indeed affect the difficulty, then relative difficulties between directions are shared across individuals. Thus, we hypothesize that the difficulty of sitting balance is direction-dependent and consistent across individuals. If this is true, then we predict a shared pattern in directional difficulty across individuals, manifested as different functional performance for different directions in those metrics.
Methods: Forty healthy adults performed a visually guided, eight-direction, center-out COP task. Specifically, they sat on a digitized pressure sensor sheet which visualized their COP position as a cursor on a computer display. They were asked to lean to move the COP and thereby the cursor from the center of the display to peripheral targets (located 8.8 cm radially from the center and equally spaced at 45-degree intervals), as quickly and accurately as possible. COP movement performance was quantified by directional accuracy, movement smoothness, and endpoint stability. Direction-dependent differences were analyzed by mixed-effects models. Between-participant consistency was evaluated by comparing observed participant-to-participant similarity with simulated data generated by random shuffling.
Results: There are direction-dependent differences in these metrics. Notably, backward diagonal directions exhibited relatively worse performance across all metrics (all: $p < 0.001$). Besides, directional performance profiles were highly consistent across participants, with significantly greater participant-to-participant similarity than the shuffled dataset (all: $p < 0.001$).
Significance: These findings indicate direction-dependent differences in COP-based functional metrics and demonstrate high consistency across healthy participants. The consistency may arise from general characteristics shared across people, such as biomechanical properties. This normative reference may support clinical evaluation in populations with impaired sitting balance.

P2-C-67 - Temporal structure and adaptation of therapist-applied gait assistance

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Details

In prior work using a simplified, non-adapting interactive virtual patient model, non-clinicians assisting the model's leg swing shifted from applying forces throughout swing to preferentially applying forces early in swing, consistent with exploiting pendular dynamics to shape step length. However, evidence from real gait suggests that therapist-applied assistance does not follow this pattern; instead, forces remain distributed throughout swing. This discrepancy suggests that real-world assistance, in which limb behavior is unpredictable, relies more heavily on continuous state-feedback control. Here, we examine this possibility and test the hypothesis that, when attempting to increase the step length of a real human, therapist assistance shifts toward mid to late-swing energy injection, reflecting ongoing state-feedback–based trajectory correction rather than primarily swing-onset energy injection.

Fifteen healthy participants walked on a treadmill under a substantial sensorimotor challenge: hamstring electrical stimulation triggered at swing onset, elastic leg resistance (~4% body weight), and a goal of increasing step length by 20%. A single physical therapist provided manual assistance to the artificially impaired limb during four 2.5-min walking trials using a handle attached to a shank-mounted cuff. During each trial, the therapist received stride-by-stride visual feedback of step length along with a desired step-length reference. Lower-limb kinematics were recorded using motion capture, and therapist-applied forces were measured with a six-axis force/torque sensor. To assess within-session adaptation, we

compared the first training trial with the fourth trial. Assistance forces were time-normalized to the gait cycle using anterior–posterior shank kinematics. Force timing was quantified using a bounded early–late index, as (E-L) / (|E| + |L|), where E and L denote the integrated therapist assistance (resultant force) during early and late swing, respectively. Subject-level median indexes (across steps) were compared using paired t-tests, and one-sample Wilcoxon signed-rank tests assessed deviation from zero.

The early–late assistance index did not differ significantly between the adaptation trials (paired signed-rank test: $p = 0.978$). However, the index was significantly negative in both the first trial (median = -0.18, $p = 0.001$) and fourth trial (median = -0.19, $p < 0.001$), indicating consistent late-swing–biased assistance. Mean absolute anterior–posterior and vertical forces decreased over training (paired t-tests: $p = 0.023$ and $p = 0.016$, respectively). Force vector and envelope analyses showed dense, high-magnitude assistance early in training, transitioning to sparser, lower-magnitude force application later.

In contrast to simplified, non-adapting contexts where early-swing energy injection can heavily influence step length, the observed assistance during real walking was concentrated in mid to late-swing, when limb state is more informative for corrective control of step length. The preserved timing across training indicates that a stable, phase-locked force policy was established early, with subsequent adaptation occurring through gain modulation as performance stabilized. Because assistance was provided by a single physical therapist, these results reflect a consistent assistance strategy within this experimental context rather than population-level therapist behavior.

P2-C-68 - Fear markers of the perceptual motor style during locomotion: The Richie's plank model

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Details

Humans exhibit distinct perceptual–motor styles that reflect their intra- and inter-individual variability when implementing sensorimotor transformations. A central challenge is to determine when these styles should be readjusted to preserve optimal motor control, and whether their modification signals basic emotions, the onset of pathology, or progress during rehabilitation.

Background and previous work

In previous work, perceptual–motor style was characterized in healthy individuals during quiet standing and locomotion. This work showed that each person's style can be decomposed into a static component (a stable configuration of body segments relative to the gravitational vertical) and dynamic components (head, trunk, and limb movements), from which static and dynamic markers can be derived that show high inter-individual variability and low intra-individual variability.

Aims of the present study

The present study examined how one basic emotion, fear, modulates perceptual–motor style during locomotion in 20 participants without a history of fear of heights or acrophobia. A low-cost virtual reality (VR) game was used to increase anxiety during locomotion, with the long-term goal of adapting this protocol to detect and potentially treat fear of falling and falls in older adults.

Experimental paradigm

Participants played the VR game "Richie's Plank", in which they walk along a narrow plank suspended between two buildings at approximately the 30th floor. During this task, the study quantified both static markers (segment configurations of the head, trunk, and limbs with respect to gravity) and dynamic

markers (jerk, root mean square, sample entropy, and the Two-Thirds Power Law at the head, trunk, and limb levels) previously identified as defining perceptual–motor style during locomotion.

Main findings
First, both the static marker (body-segment configuration relative to the gravitational vertical) and several dynamic markers captured the modulation induced by fear during the VR task, indicating that these style markers are sensitive to emotional state. Second, the study revealed a striking heterogeneity in how fear altered perceptual–motor style in young healthy individuals exposed to virtual height.

Implications
These results suggest that, beyond the weighting of multisensory information used to control posture and locomotion, individual differences in fear susceptibility and anxiety traits strongly shape perceptual–motor style, especially when locomotion control becomes challenging. This supports the use of perceptual–motor style markers as candidate tools for personalized assessment and intervention in conditions involving fear of falling and balance disorders.

P2-C-69 - A quality control-driven pipeline for GRINminiscope calcium imaging of cerebellar nuclei during naturalistic movement

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Details

One-photon (1p) calcium imaging with a miniature microscope enables recording neuronal population activity in freely moving mice during naturalistic movement, including motor-related deep brain targets such as the Cerebellar Nuclei (CN) via GRIN-lens optics, where optical constraints and background signals further amplify motion sensitivity. However, during unconstrained, naturalistic movement (e.g., high-speed locomotion and climbing/vertical exploration), head-mounted miniscope recordings are particularly susceptible to motion-related artifacts – abrupt translations and in-plane rotations, intermittent occlusions, focus/brightness fluctuations, and background contamination – that can dominate the signal and compromise downstream Region of Interest (ROI) segmentation and calcium trace extraction. While robust analysis pipelines are widely available for two-photon recordings, practical end-to-end workflows tailored to 1p miniscope data with strong movement-induced artifacts remain limited, and failures are often difficult to diagnose without extensive manual intervention.

We present a Quality Control (QC)-driven, end-to-end processing pipeline designed specifically for 1p miniscope time-lapse stacks acquired during freely moving behavior. The workflow targets movement-induced artifacts by combining (i) illumination/flat-field correction to reduce GRIN-related shading and slow intensity drift; (ii) robust rigid motion estimation (translation and in-plane rotation) using automatically selected informative ROIs, with outlier-aware aggregation to handle transient occlusions and low-quality regions; (iii) stack stabilization with explicit valid-pixel masking to prevent edge artifacts from padding and to enable safe, consistent cropping across frames; and (iv) automated ROI segmentation followed by signal extraction with neuropil/background correction to mitigate diffuse 1p background. The pipeline produces standardized outputs - stabilized stacks, ROI masks, raw and corrected fluorescence traces, dF/F signals - and a comprehensive QC report.

QC components provide interpretable diagnostics tailored to miniscope recordings acquired during natural movement, including inlier/outlier ROI overlays, residual motion curves that highlight motion jumps, valid-mask visualization, and ROI health metrics reflecting SNR (Signal-to-Noise Ratio) and neuropil contamination. We evaluate the approach on GRIN-lens miniscope recordings from mice

targeting deep regions including the CN, and show improved motion stability, more reliable ROI detection, and cleaner calcium traces compared to baseline processing without robust QC and masking. By combining automation with transparent quality assessment, our pipeline aims to reduce manual tuning and accelerate reproducible analysis of 1p calcium imaging datasets in studies linking neuronal dynamics to movement.

P2-C-70 - Dynamic evolution of brain structure-function coupling asymmetry and its relationship with motor function after spinal cord injury and treatment

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Details

This study examines changes in structure-function coupling within brain networks after unilateral spinal cord injury (SCI) and relates them to hindlimb motor parameters. Although motor tasks involving the affected limb post-SCI are known to induce hyperactivation in the contralateral sensorimotor network, the dynamic regional evolution of structure-function coupling and its relationship to motor function remain unclear. Structural covariance networks, which capture covariation in gray matter volume across regions, can reveal how macroscopic structural organization supports functional connectivity. In a rhesus monkey model of right-sided spinal cord hemisection, we compared an SCI-only group with a treatment group that received an NT3-chitosan implant. We acquired gray matter volume and resting-state functional magnetic resonance imaging data at multiple time points both before and within one year after the injury. Spearman rank correlation quantified individual-level coupling strength between structural covariance and functional connectivity, and we further evaluated its hemispheric asymmetry (left minus right hemisphere coupling value). Kinematic parameters of right hindlimb treadmill walking were also recorded. Generalized additive mixed model analysis showed that from injury onset to one year post-SCI, coupling asymmetry significantly increased in the accessory cuneate nucleus ($F = 4.002$, $p = 0.002$), magnocellular part of the red nucleus ($F = 0.910$, $p = 0.030$), and anteromedial nucleus of the thalamus ($F = 5.412$, $p = 6.242\times10^{-4}$) in SCI animals, a change not observed in the treated animals. Linear mixed-effects models further indicated that, between 2 and 12 months post-injury, coupling asymmetry in the inferior frontal gyrus ($\beta = -0.175$, $p = 0.009$) and magnocellular part of the red nucleus ($\beta = -1.239$, $p = 0.023$) in SCI macaques correlated negatively with right hindlimb kinematic parameters (path length, stride length). In contrast, coupling asymmetry in the inferior frontal gyrus of treated animals exhibited a positive correlation with locomotor parameters ($\beta = 0.391$, $p = 0.003$). These findings demonstrate that SCI induces a hemispheric imbalance in structure-function coupling within specific brain regions, which is closely associated with motor dysfunction. Moreover, treatment may foster motor recovery by remodeling brain network coupling patterns. This work introduces structure-function coupling asymmetry as a novel perspective for understanding post-SCI brain network reorganization and a potential biomarker for assessing the mechanisms of neurorehabilitation strategies.

P2-C-71 - Region-specific changes in neural states across locomotor regimes in mice

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Details

Animals often need to counteract unexpected perturbations by quickly adapting their locomotor patterns. These corrections are thought to involve cortical and subcortical regions that modulate the activity of the spinal circuits, but the details remain elusive.

To address this, we designed a task in which head-fixed mice running on a large spherical treadmill experienced rapid, unpredictable perturbations delivered by 12 actuators evenly distributed on two levels of the treadmill. This allows us to elicit a broad range of behavioural responses, determined by

the actuator's location, the perturbation strength, and the animals' ongoing gait cycle. Simultaneously, we recorded from subregions of the primary motor (M1) and somatosensory cortices (S1), downstream basal ganglia projections, relay centres in the motor thalamus, as well as the secondary motor cortex (M2). Each experimental session had three blocks: an initial block without perturbations (5-20 min), a second block with random perturbations (40-75 min), and a final block without perturbations. While our data show region-specific responses to perturbations, here we focus on a different question: whether unperturbed running during the random perturbation block is associated with different activity patterns than those observed during spontaneous running in the unperturbed running blocks.
We projected the firing rates of neural populations onto region-specific manifolds that we calculated using principal component analysis computed on the entire session. Intriguingly, neural activity during inter-perturbation running occupied a distinct region of this manifold compared to the initial unperturbed running block. In contrast, activity during the final unpertubed running block overlapped with the inter-perturbation state. This activity shift was most prominent in M1 and M2, followed by thalamus and dorsal striatum; it was weakest in S1.
In M1 alone, the transition into the inter-perturbation neural state became more sudden as the same mice performed the experiment over successive days, which would be consistent with a learnt change in cortical involvement during behaviours that require more direct motor cortical control (Miri et al, Neuron 2017). Importantly, these changes could not be simply explained by changes in locomotion between inter-perturbation periods and unperturbed blocks, since they held when we matched the distributions of limb velocities across them. Neither could they be attributed to electrode drift, since we recorded from multiple areas that differed in their changes using the same probes. We speculate that these changes may suggest a change in the "control policy," where adaptive locomotion in the presence of perturbations engages cortical and subcortical regions in a way that may not be needed for unperturbed locomotion on a treadmill. Ongoing M1 manipulations will help us in defining causal contributions —if any— of these changes to adaptive locomotion.

P2-C-72 - Task-dependent modulation in EMG-EMG coherence during gait in Parkinson's disease

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Details

Corticospinal drive directly contributes to leg muscle activation during walking. Beta-band (13-30 Hz) EEG-EMG and EMG-EMG coherence, an electrophysiological marker of corticospinal drive, increases during swing phase and is further modulated when walking requires greater visual control (e.g., visually guided precision stepping). Although individuals with Parkinson's disease (PD) show reduced beta EEG-EMG and EMG-EMG coherence during walking compared to healthy controls, it is unclear whether they retain the ability to modulate beta coherence with task demands. Understanding how task-dependent beta coherence relates to mobility deficits in PD may inform targeted rehabilitation strategies.
Six individuals with PD (73±5.3 years) in their medication ON state completed the Timed Up and Go (TUG), steady-state treadmill walking (slow, fast and preferred speeds) and a goal-directed walking task. During the goal-directed task, participants were scored on how accurately they placed their foot within visual stepping targets. EMG was recorded bilaterally from the soleus (SOL) and gastrocnemius medialis (GM) muscles for coherence analysis.
Task-dependent modulation of SOL-GM beta coherence was observed in 5 of 6 participants in the 250 ms period preceding toe-off. Beta coherence significantly increased during goal-directed walking compared to steady-state walking, indicating greater corticospinal engagement under increased task demands. Longer TUG times (poorer mobility) were associated with higher SOL-GM beta coherence (steady-state: rho = 0.94, p = 0.02; goal-directed walking rho = 0.71, p = 0.14).

Individuals with PD demonstrated task-dependent modulation of beta EMG-EMG coherence during walking. The association between increased beta coherence and poorer mobility in PD suggests that individuals with greater impairment may rely on increased corticospinal drive to meet locomotor demands. These findings highlight EMG-EMG coherence as a potential marker of gait adaptability and mobility impairment in PD.

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P2-C-73 - Activation of hypothalamic-pontine-spinal pathway promotes locomotor initiation and functional recovery after spinal cord injury in mice

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Details

The hypothalamus is critical for regulating behaviors essential for survival and locomotion, but how it integrates internal needs and transmits locomotion commands to the spinal cord (SC) remains unclear. We found that glutamatergic neurons in lateral hypothalamic area (LHA) are essential for regulating motivated locomotor activity. Using single-neuron projectome analysis, trans-synaptic tracing, and optogenetic manipulation, we showed that LHA facilitates motivated locomotion during food seeking via pontine reticular nucleus, oral part (PnO) projection neurons, rather than direct SC projections or indirect stress signaling via medial septum and diagonal band. Activating PnO-SC projection neurons also initiated locomotion. Importantly, LHA-PnO projection neurons were crucial for regulating locomotor recovery following mouse spinal cord injury (SCI). Motor cortex signals gated LHA deep brain stimulation treatment markedly promoted long-term restoration of hindlimb motor functions after severe SCI. Thus, we have identified a hypothalamic-pontine-spinal pathway and the stimulation paradigm for potential therapeutic intervention after SCI.

P2-C-74 - Quantifying mutual hesitation and identifying kinematic predictors in near-collision avoidance in walking

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Details

Introduction

Humans navigate crowded environments by anticipating others' movements and coordinating locomotion to avoid collisions. When mutual anticipation fails, both pedestrians may choose the same avoidance side, producing mutual hesitation. Typically, mutual hesitation has been quantified from pedestrians' trajectories in previous work (Honma et al., 2015). This approach, however, fails to capture the spatiotemporal, bidirectional coupling within the dyadic interaction. Moreover, previous studies have examined only specific body parts and used non-reactive VR avatars or pedestrians with pre-scripted movements (e.g., Watanabe et al., 2011; Yamauchi et al., 2025). Therefore, the relationship between whole-body kinematics and mutual anticipation in truly interactive situations remains to be determined. Here, first, we propose a parsimonious method to quantify the degree of mutual hesitation in near-collision avoidance referred to as cross-recurrence quantification analysis (CRQA), which quantifies the spatial and temporal synchrony between two walkers. Second, we examined whether kinematics, specifically the inter-participant rotation angles of the head, shoulders, and pelvis, predict the degree of mutual hesitation.

Methods

Forty-five dyads (mean age 22.3 years; 30 same-gender [half male, half female] and 15 mixed-gender dyads) walked straight toward each other along a centerline and avoided a collision within two differently sized collision avoidance zones (20cm or 80cm width) located at the center of the path. For CRQA, we used the recurrence rate (RR) as an index of the degree of mutual hesitation, and trials with RR > 0 were classified as mutual hesitation. As pre-avoidance kinematics, we computed inter-participant angular differences for the head, shoulders, and pelvis. We used Statistical Parametric Mapping (SPM) to examine when inter-participant angular differences emerged between mutual-hesitation and non-hesitation trials. To test whether—and when—kinematics predict the degree of mutual hesitation, we segmented the 1s just before avoidance onset into ten 100ms bins. We then computed each kinematic within each bin, and fitted a linear mixed-effects model (LMM) with each time-binned kinematic measure as a fixed effect.

Results and Discussion

Mutual hesitation occurred in 10.0% (20cm) and 9.0% (80cm) of trials. The mean of RR in mutual hesitation trials was 37.97 (20cm) and 41.95 (80cm). SPM showed that the head-orientation difference between participants diverged earlier than the shoulder or pelvis in non-mutual hesitation trials. Consistently, smaller head-orientation differences of 0.3s (20cm) and 0.2s (80cm) before the avoidance onset predicted the degree of mutual hesitation. Overall, early head-orientation signaling appears to support stable perception–action coupling in collision avoidance, and failures in inferring avoidance direction from head kinematics may cause mutual anticipation errors that result in mutual hesitation.

P2-C-75 - Differential synergistic strategies between quadriceps and plantar flexors during gait

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Details

Human gait is consistently reproduced across strides. Although joint kinematics during walking show low variability [1], lower-limb muscle activation varies substantially [2], indicating that stable gait does not require consistent muscle activity. This variability has been attributed to motor redundancy [3]. We propose that consistent walking despite stride-to-stride muscle variability is enabled by coordinated interactions within muscle groups with similar functions, where reduced activation of one muscle is compensated by increased activation of another.

Following IRB approval and informed consent, electromyography data were collected from 12 lower-limb muscles of 11 male participants during five minutes of treadmill walking at a speed of 4 km/h. Comparisons were conducted on the quadriceps (vastus medialis, vastus lateralis, and rectus femoris) and the plantar flexors (gastrocnemius and soleus) to investigate compensatory mechanisms. The gait cycle was segmented into seven phases, and the average muscle activation was calculated within each phase. To account for the influence of other functional muscle groups, activation levels were normalized using the muscle set defined in [4]. To evaluate the coordination strategy, Pearson correlation coefficients were calculated between muscle pairs within the quadriceps and the plantar flexors ($p < 0.05$).

All subjects exhibited consistent negative correlations between the gastrocnemius and soleus muscles during the terminal stance ($-0.91 < r < -0.18$) and pre-swing phases ($-0.86 < r < -0.14$). These results indicate that the plantar flexor group exhibits a compensatory trade-off during ankle push-off. In contrast, correlations within the quadriceps muscles were consistently positive across most gait phases. Specifically, the vastus medialis–rectus femoris pair showed significant positive correlations throughout the entire gait cycle.

The negative correlations observed among the plantar flexors during push-off may reflect a compensatory mechanism, potentially consistent with reports suggesting relatively independent neural

inputs within this muscle group [5]. In contrast, the quadriceps showed predominantly positive correlations across gait phases, indicating a more synergistic activation pattern. This observation is in line with recent findings of substantial common synaptic input within the quadriceps [6].
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P2-C-76 - Reduced reliance on ankle proprioception for postural control in Diabetes Mellitus
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Details
Over 38 million US adults have diabetes mellitus (DM), and 50% to 66% of DM patients will eventually develop peripheral neuropathy (PN) during their lifetime (Dyck et al., 1993). DM patients with PN have a 2.33 times higher fall risk than those without PN (Khan et al., 2021). Individuals with early type 2 diabetes (< 3 years) have significantly smaller fiber sensory nerve density compared with healthy controls (Divisova et al., 2012), which suggests that early sensory hypofunction starts before overt clinical peripheral neuropathy in DM patients. To identify balance impairments and provide therapeutic interventions for DM patients without diagnosed PN in early stages, we developed a three-dimensional (3D) perturbation balance assessment. Since platform perturbations alter ankle proprioception by changing a support surface (Peterka, 2002), this pilot study tested the hypothesis that DM patients without diagnosed PN exhibit reduced sensitivity to platform perturbations due to early sensory hypofunction.
Pseudorandom perturbation trajectories were first generated by summing sinusoidal signals at three sets of five selected frequencies (0.06-1.55 Hz) and simultaneously delivered in three directions – earth-vertical (EV) translations and tilts in semicircular canal coordinate (RALP and LARP) using a motion platform (Virtualis). This approach enabled us to quantify spectrally separable postural responses. Center of pressure (CoP) data were collected from five individuals with DM but without a diagnosis of PN (47.6 ± 12.6 years, 3M), two individuals with DM and PN (75.5 ± 1.5 years, 2M), and 24 healthy adults (40.6 ± 13.6 years, 12M). Data from DM patients with clinical PN were excluded from the statistical analysis. Each trial lasted three minutes, and each participant completed four different trials that vary the peak-to-peak amplitude of the platform perturbations with arms crossed and eyes closed. Frequency response functions (FRFs) were quantified by normalizing the CoP spectral response by the platform stimulus.
A two-way repeated-measures MANOVA indicated significantly reduced sensitivity in DM patients without diagnosed PN at RALP ($p = 0.014$) and LARP ($p = 0.008$) tilt stimulus frequencies. Reduced sensitivity can be associated with decreased weighting of ankle proprioception or increased stiffness factors (Campbell et al., 2022). While increased stiffness leads to reduced phase lag (Campbell et al., 2022), we observed increased phase lag in DM patients without diagnosed PN, suggesting that the reduced sensitivity in these patients may be due to down-weighting of ankle proprioception secondary to the development of subclinical peripheral neuropathy.

The present study suggests high potential for our 3D pseudorandom perturbation paradigm to detect subclinical impairment attributed to somatosensory deficits in DM patients without diagnosed PN. The preliminary finding also provided effect size information to guide future study designs.

P2-C-77 - Before movement: signatures of human emotion in the micromotor structure of stillness

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Details

Motor output is continuously shaped by the internal state of the nervous system, even in the absence of overt movement. Emotional modulation of human movement has traditionally been studied through instructed actions such as gait or gesture, where task demands and expressive intent are tightly coupled. As a result, it remains unclear whether emotional state leaves measurable motor signatures outside of purposeful movement itself.

We recently showed in mice that low-amplitude motor activity during behavioral stillness carries robust state information that is not confounded by task structure. This suggests that stillness is not merely the absence of movement, but a distinct motor regime characterized by continuous, low-amplitude fluctuations that reflect ongoing neural state and provide the substrate from which overt actions emerge. Here, we test whether analogous emotion-dependent micromotor signatures are detectable in humans during overt stillness.

We recorded full-body marker-based motion capture while human participants viewed immersive emotion-inducing 360-degree videos in virtual reality. Participants were free to orient and move naturally while viewing the stimuli. Videos were selected from the LuVRe 360-video bank to represent five emotion categories (fear, disgust, joy, sadness, neutral), and category assignments were validated using post-stimulus self-reports. All participants were consenting adults, data were processed anonymously, and the study followed institutional ethical guidelines and the Declaration of Helsinki.

To quantify emotion-dependent micromotor structure, we analyzed the distributions of marker speeds during periods of stillness, defined as frames in which marker speed did not exceed 25 mm/s. For each subject and body part (head, upper torso, lower torso, arms, wrists, legs), we constructed empirical speed distributions for each emotion condition and compared them within subjects using the Kolmogorov–Smirnov (KS) distance, a measure sensitive to distributional differences beyond mean or variance.

Consistent with prior findings in mice, fear elicited a pronounced suppression of micromotor activity during stillness that was detectable across nearly all body parts, producing large separations in speed distributions relative to other emotional states. Beyond this global freezing response, we observed systematic but smaller distributional differences among non-fear emotions. Disgust showed the most robust separation from both sadness and joy, with additional differentiation between joy and sadness. These effects were most prominent in the wrists, lower torso, and head, whereas upper limb and leg markers exhibited weak or negligible separation during stillness.

Together, these results demonstrate that emotional state leaves body-part-specific signatures in micromotor activity even in the absence of overt movement, extending observations from animal models to naturalistic human behavior. Conceptually, they support the view that stillness constitutes an actively regulated motor regime in which internal state continuously shapes low-amplitude motor output. Practically, because these signatures arise during periods of minimal movement, they point to micromotor activity as a complementary behavioral readout of internal state alongside autonomic and ocular measures, particularly in contexts where individuals are seated, attentive, or otherwise behaviorally still.

P2-C-78 - Reticulospinal and Vestibulospinal response to PPN microstimulation - cell population study

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Details

Aim: Cholinergic system, together with the dopaminergic system, is vulnerable to the degenerative diseases. **Pedunculopontine tegmentum nucleus** (PPN) is one of the target for Deep Brain Stimulation (DBS) in the treatment of Parkinson's disease (PD) and contain cholinergic neurons. PPNDBS improves the rigidity and the disorder of posture reflex. Therefore we studied the effect of PPN stimulation on the activity of **Reticulospinal neurons**(RSN) and **vestibulospinall neurons**(VSN) in cats. Method: Decerebrated cats (n = 3) were used. PPN was stimulated using microelectrodes (40-100mA, 1-3 impulses) and the discharge of both RSN and VSN were recorded extracellularly. Result: Out of 129 RSNs and 139 VSNs analyzed, PPN stimulation resulted in orthodromic response in 56% and 27% of these spinally projecting neurons, respectively. Faithful orthodromic responses were observed predominantly in the **dorsal ponto-medullary reticular formation**. These data suggest that PPN stimulation may recruit cascades of both RSNs and VSNs, primarily in dorsal ponto-medullary reticular formation.

P2-C-79 - Neurochemical and brain fluid exchange mechanisms underlying walking in cognitively-impaired older adults

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Details

Introduction: Declines in mobility precede dementia onset by 6-10 years. Glutathione (GSH) – the most abundant antioxidant in the brain – is associated with mobility performance in older adults. The glymphatic system facilitates clearance of neurotoxic byproducts via brain fluid exchange, reducing the burden on GSH-dependent detoxification pathways. Lower GSH may impair glymphatic function, while reduced clearance could further increase oxidative stress, creating a cycle that accelerates functional decline. Clarifying these relationships in older adults could enable earlier detection and targeted interventions for individuals at high risk of progression to dementia. The objectives of this study were to (1) identify differences in cortical GSH levels between older adults with mild cognitive impairment (MCI) and cognitively healthy controls, and (2) examine associations between GSH and diffusion along the perivascular space (ALPS-index, a marker linked to glymphatic function) with walking speed in MCI.
Methods: Older adults with MCI were recruited for this study. Structural T1, edited magnetic resonance spectroscopy (Hadamard Encoding and Reconstruction of MEGA-Edited Spectroscopy) in the sensorimotor voxel, and diffusion-weighted (64-direction) magnetic resonance imaging scans were acquired. The ALPS-index was quantified as the mean of the x-axis diffusivity in the projection fibers and in the association fibers, normalized by the mean of y-axis diffusivity in the projection fibers and z-axis diffusivity in the association fibers (ALPS-index = mean[Dx*proj*, Dx*assoc*] / mean[Dy*proj*, Dz*assoc*]) (Taoka et al., 2017, *Jpn J Radiol*). Walking speed was assessed with a 25-foot walk at preferred pace. Comparisons with healthy older adults were made with previously published data from our lab (Hupfeld et al., 2021, *Cerebral Cortex*). Associations between neuroimaging markers and function was examined in MCI participants only.
Results: Cortical GSH was lower in MCI compared to healthy older adults (Bootstrapped Cohen's d = -0.487), replicating prior findings. After adjusting for sex, walking speed was significantly associated with ALPS-index ($\beta = 13.95$, $p = 0.047$) and showed a trend-level association with cortical GSH ($\beta = -4.96$, $p = 0.086$). The model explained 81% of variance in gait speed (Adjusted $R^2 = 0.68$).
Discussion: Lower cortical GSH was linked to slower walking, while lower ALPS-index was associated with faster walking in older adults with MCI. The relationship between brain health and function in MCI that

we report here are opposite to what is observed in healthy older adults. Our results suggest an inverted-U relationship between GSH and function across the cognitive spectrum. In typical aging, GSH may increase to help maintain reduction-oxidation balance, but levels appear lower in MCI, reflecting disrupted oxidative homeostasis. Larger studies are needed to confirm these preliminary results and elucidate underlying mechanisms.

P2-C-80 - Mapping the development of motor-social behavior in young rats

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Details

Social interaction is a fundamental component of animal behavior, and the acquisition and expression of social behaviors across development depend on the development of movement. Physical interaction can require precise timing and coordination, and motor deficits are known to correlate to social deficits in autism and other developmental disorders. Having built a framework to track and describe the high-resolution 3D kinematics of freely moving interaction in adult rats, I and my collaborators have extended our multi-animal tracking platform to capture the 3D kinematics of rat pups across their physical and behavioral development. I have collected a dataset from 5 to 60 days post birth for a cohort of six pups, with daily 3D tracked kinematics for each pup in a variety of contexts (ranging from alone, to pairs, triads, and groups of five or six with and without the mother present). This frequently sampled and rich dataset offers the opportunity to probe individual motor development alongside acquisition of social behavior, and map the emergence of motor-social behaviors in young pups. I have extended the deep phenotyping approach I have developed for adult animals to take into account physical growth and expanding behavioral complexity across development, and will use this multi-scale dataset to describe how motor elements arise, contribute to, and are shaped by social experience. In the future, I will use this paradigm to map the trajectory of behavioral development in rat models of autism that I have shown have vastly different patterns of social interaction as adults.

D – Integrative Control of Movement

Poster Cluster (P2-D-81 & P2-D-82)

P2-D-81 - Flexible exploitation of muscular and kinematic redundancy for learning novel control dimensions

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Details

Humans possess more degrees of freedom than are strictly required to accomplish upper-limb tasks, providing muscular and kinematic redundancy that the nervous system can flexibly exploit. Such redundancy defines null spaces in which variations of muscle activation patterns or limb postures do not affect task-relevant outcomes, but can be recruited to encode novel control dimensions. Understanding how humans learn to exploit these null spaces is central to motor control theory and provides a foundation for the design of intuitive human augmentation strategies.

Previous work has shown that supernumerary degrees of freedom (SuDoFs) can be controlled using either muscular or kinematic null space signals independently; however, their relative effectiveness within the same individuals and task, as well as their combined exploitation, has not been systematically examined. Here, we compare muscular and kinematic null space control and investigate a hybrid strategy

that enables flexible redistribution of control between the two modalities to command either one or two SuDoFs.
Sixteen participants performed a simultaneous reaching and orientation task in a fully immersive virtual environment using an HTC Vive head-mounted display. Hand, arm, forearm, and trunk kinematics were recorded using wearable HTC Vive trackers to extract kinematic null space signals, while muscular null space control was derived from high-density surface electromyography (HDsEMG) recorded from a single upper-limb muscle. Participants controlled the position of a virtual cursor using natural arm movements while modulating its orientation through null space activation. Task demands were systematically varied by requiring no rotation, single-axis rotation, or dual-axis rotation, thereby probing the learning, stabilization, and flexible combination of novel control dimensions during ongoing movement.
Participants successfully learned to voluntarily modulate both muscle activation patterns and limb postures to control SuDoFs without degrading performance of natural degrees of freedom. Performance depended on control modality and task demands: kinematic redundancy was exploited more effectively for low-amplitude control, whereas muscular redundancy supported higher control values. Hybrid control yielded the most robust overall performance, allowing participants to flexibly combine muscular and kinematic strategies and to personalize their control solutions.
These findings demonstrate that the nervous system can learn to flexibly exploit multiple sources of redundancy to support novel control dimensions, and suggest that hybrid redundancy exploitation may provide a powerful and intuitive substrate for scalable human augmentation.

P2-D-82 - Somatosensory feedback of muscular null space signals enhances control of redundant motor dimensions

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Details

During movement planning and execution, the nervous system optimally integrates multiple feedback sources to reduce uncertainty about the state of the body and task outcomes. While visual feedback plays a key role in many tasks, somatosensory feedback is critical for complex motor skills, including object manipulation and multi-joint coordination. In virtual reality (VR) environments, somatosensory feedback has been shown to facilitate motor learning and improve task performance. However, its role has not been investigated in tasks where the redundancy of the human body is exploited to extend the natural movement repertoire through null space control.
In null space control paradigms, voluntary modulation of task-irrelevant kinematic or muscular activity is mapped onto a supernumerary degree of freedom (SuDoF) that must be controlled while simultaneously performing natural movements. Although humans can learn to control such SuDoFs, feedback about the SuDoF state has so far been almost exclusively visual. Here, we investigate whether augmented somatosensory feedback by vibrotactile stimulation can improve muscular null space control of a SuDoF during a motor task in VR.
Participants performed a reaching and orientation task in which the position of an ellipsoidal cursor was controlled either through isometric forces generated at the arm or through dynamic wrist movement in space, while cursor orientation, representing a SuDoF, was controlled by a control signal derived from muscular null space activity. This signal was extracted either from surface EMG recorded from multiple arm muscles (isometric condition) or from high-density surface EMG recorded from a single muscle (dynamic reaching condition). In alternating blocks, participants received vibrotactile somatosensory feedback encoding either the SuDoF error (i.e., vibration intensity proportional to the difference

between the cursor and the target orientation) or the SuDoF state (i.e., vibration intensity proportional to the cursor orientation).
Results showed that somatosensory feedback significantly improved SuDoF control performance when the cursor was visually occluded and only the target was visible. During dynamic reaching, somatosensory feedback encoding SuDoF error improved both performance and movement speed even when visual feedback of the cursor was available. These findings demonstrate that somatosensory feedback enhances the control of SuDoFs through muscular null space signals, supporting its use in sensorimotor interfaces for human augmentation.

P2-D-83 - Ventral premotor–primary motor cortex pathways shape temporal coordination in dexterous actions

Andrea Casarotto [1], **Elisa Dolfini** [2], **Luciano Fadiga** [3], **Giacomo Koch** [4], **Alessandro D'ausilio** [2]
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Details

The ventral premotor cortex (PMv) and the primary motor cortex (M1) play a central role in the control of grasping behaviors. We provide converging neurophysiological and behavioral evidence demonstrating how Hebbian-like plasticity within this circuit selectively shapes motor output and movement coordination.
We applied a PMv–M1 cortico-cortical paired associative stimulation (cc-PAS) protocol—a TMS paradigm that promotes Hebbian spike timing–dependent plasticity (STDP)—stimulating M1 in both postero-anterior (PA) and antero-posterior (AP) directions to induce long-term changes in the activity of distinct M1 neuronal populations.
From a neurophysiological perspective, cc-PAS induced bidirectional, LTP- or LTD-like aftereffects in M1 neuronal activity that were strongly associated with direction-specific changes in I2-wave activity. In addition, cc-PAS selectively modulated GABA_B-mediated M1 intracortical inhibition and the PMv–M1 functional connectivity state. Together, these findings indicate that PMv–M1 plasticity is mediated by a selective influence of PMv on M1, providing mechanistic insights relevant to the optimization of brain stimulation protocols.
The functional relevance of this PMv–M1 stimulation protocol was also examined in a behavioral context. When PMv–M1 plasticity was induced by preferentially targeting deeper M1 neuronal populations (i.e., PA coil orientation), cortical motor output during either isometric precision or power grip was not affected. In contrast, when plasticity preferentially targeted more superficial M1 neuronal populations (i.e., AP coil orientation), the effects were selective to isometric precision grip. These observations support the notion that PMv projections preferentially engage superficial M1 circuits that are critically involved in the fine control required for dexterous actions.
Beyond isolated measures of corticospinal output, modulation of PMv–M1 connectivity also reshaped the organization of complex reach-to-grasp actions. Plasticity induced within superficial PMv–M1 pathways selectively altered the temporal structure of joint angle synergies during naturalistic precision grip actions. Importantly, these changes emerged in the timing of joint recruitment rather than in the spatial composition of movement synergies, indicating a reorganization of temporal coordination across the limb.
Taken together, this body of work delineates a mechanistically grounded link between PMv–M1 plasticity, the selective engagement of superficial M1 interneuronal circuits, and the control of precision grasping. These findings provide a unified framework for understanding the neural basis of dexterous motor control and offer a strong rationale for developing brain stimulation protocols that exploit pathway- and function-specific plasticity mechanisms to promote recovery of skilled motor behaviors in neurological conditions such as stroke.

P2-D-84 - Dissociation between online control behavior and adaptation in visually-guided goal-directed movements in patients with Schizophrenia

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Details

The Research Domain Criteria (RDoC) framework serves as set of principles to guide research on the biological underpinnings of mental disorders. The domain of sensorimotor systems is currently the least developed category for research into psychiatric disorders. For schizophrenia, general deficits in sensorimotor control are postulated but systematic investigations grounded in sensorimotor control theories are sparse.

We investigated a group of schizophrenia patients (n=8), diagnosed based on DSM-5 criteria by a trained psychiatrist, and healthy controls (n=10) with two sensorimotor tasks: 1) online control of movements operationalized with the double-step paradigm, in which a shift in visual target or cursor mid-movement prompts a corrective response, 2) visuomotor adaptation with a virtual rotation of the visual cursor that leads to a gradual shift in movement direction.

One patient and one control subject were excluded because about half their movements were not executed within the maximum velocity constraints (between 25 and 90 cm/s^2); The rest of the participants managed to execute the majority of movements within these constraints. Neither initial (after 250ms) nor end correction differed between patients and controls for any of the online perturbations (all p>0.1). For the development of the adaptation learning, however, we find a sign. interaction between time and group (F(23,322)=2.646; p<0.001): patients adapt and de-adapt slower than healthy controls with a sign. difference at the end of the first adaptation block (t(14)=2.290; p=0.038). This adaptation also shows a trend for a moderate correlation (r=0.441; p=0.087) with negative symptoms of schizophrenia.

This study is the first to demonstrate a clear dissociation between online control and adaptation behavior in schizophrenia patients for visually-guided goal-directed movements. The adaptation results corroborate two previous studies with a similar design and sheds light on additional parameters of the adaptation learning process. The connection to specific symptoms of the disorder support the clinical relevance of the tested behavior. Further putative associations with positive, negative, and psychomotor symptoms will be examined in an extended sample to establish broader clinical relevance.

P2-D-85 - Mixed-selective organization of reach and grasp in the primate fronto-parietal network

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Details

Reaching and grasping in primates require coordinated control of several parameters, such as grip type, wrist orientation, spatial position, and hand laterality. The anterior intraparietal (AIP) and rostral ventral premotor (F5) areas as key hubs in this process. We used electrophysiological data to investigate how these parameters are co-represented in AIP and F5. The results indicate that neurons predominantly show mixed selectivity with stable temporal organization related to movement and pre-movement phases. This uncategorizable mixture of selectivity allows flexible decoding. Despite condition-dependent shifts, selectivity preferences were largely preserved across task conditions. Notably, object-related factors (orientation and position) remained more stable during grip type changes in AIP, whereas grip type was more stable in F5, suggesting a functional hierarchical organization of parameter coding in both areas. Together, despite the continuous range of mixed selectivity at the single neuron level, neural

ensembles exhibit a stable organization on the temporal and functional scales, enabling flexible readouts.

P2-D-86 - A platform for large-scale, single-neuron spinal recordings during skilled forelimb movements in mice

Alzahraa Amer [1], **Lee Miller** [1], **Andrew Miri** [1]
[1] Northwestern University

Details

While single-neuron recordings in the motor cortex have revealed the role of cortical activity in motor learning, planning, and execution, establishing a parallel understanding of how the spinal cord processes input from the motor cortex is critical. Addressing this question in mice is especially powerful, as the experimental scale and genetic accessibility of the model allow systematic interrogation of spinal circuits during movement. Progress toward this goal has been limited by longstanding technical challenges to achieving stable spinal cord electrophysiological recordings during behavior. At the core of these challenges are biomechanical constraints that couple body and limb movements to the spinal cord, compromising recording stability, and the scarcity of technologies that enable simultaneous sampling of large spinal neuronal populations at single-unit resolution.

Here, we developed an experimental platform that enables state-of-the-art Neuropixels recordings in the cervical spinal cord of awake, behaving mice. By providing access to the spinal cord and mechanical stability for electrophysiological recording, this approach yielded, the first large-scale, single-neuron resolution recordings of spinal neural activity during skilled movement. We inserted ultrahigh-density Neuropixels into the cervical enlargement (800 µm depth, 250 µm lateral to midline), targeting intermediate laminae that contain dense populations of spinal interneurons receiving descending motor cortical input. Mice performed over 100 reach-to-grasp trials during ~1.5-hour recording sessions. Micromotion at the electrode–tissue interface due to breathing and voluntary limb movements, as well as slower drift over time, was first estimated from the neural recordings and then corrected using an automated algorithm that tracks features of the extracellular signal across channels over time. Motion-corrected data were spike-sorted using Kilosort 4. This pipeline yielded single units with high presence ratios—defined as the fraction of time bins spanning the recording session in which a unit was detected— and enabled robust isolation of units that met conservative quality criteria based on interspike interval violation rates and amplitude cutoff metrics. These data will be used to relate single-neuron and population-level spinal spiking activity to movement timing and forelimb kinematics, and to examine the structure and organization of coordinated population dynamics across trials. Future experiments will combine controlled perturbations of descending motor input with simultaneous recordings of spinal activity during skilled movement, allowing causal links between descending commands and spinal circuit dynamics to be established.

P2-D-87 - Feature space identification and reward function estimation by inverse reinforcement learning for aikido techniques based on EMG and motion capture data

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Details

Expert techniques in Aikido are often described using the subjective concept known as "*Ki*," and their physical mechanisms remain unclear. This advanced body manipulation that unbalances an opponent with minimal mechanical force is difficult to acquire through mere imitation, requiring the elucidation of the implicit behavioral norms. This study aims to describe the behavioral norms (reward function) as an

objective mathematical model using Maximum entropy inverse reinforcement learning (MaxEnt IRL) based on measurement data, focusing on the representative Aikido technique "*Katatedori Kokyunage*." In the experiment, whole-body motion and 16-channel EMG data were collected from experts, intermediates, and beginners. From 171 extracted features that characterize kinematic and kinetics of each participant, forward stepwise selection identified the 30 most discriminative dimensions utilized as a state vector of the dynamics. MaxEnt IRL was employed to optimize a unique nonlinear reward function defined as the sum of linear terms and Gaussian bases. Parameters for the reward function were adjusted using both expert and beginner data to "imitate experts while avoiding beginner characteristics," with the aim of extracting the essential components of highly skilled techniques. The results of this study redefine Aikido techniques, which are traditionally discussed intuitively, as optimization problems within the bioinformatic feature space. This approach is applicable not only to Aikido but also to other fields involving physical interaction, providing a generic framework for describing and evaluating complex techniques.

P2-D-88 - The effect of action on auditory signal detection

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Details

Auditory consequences of actions are often perceptually and neurally suppressed. This phenomenon has been attributed to predictions that are generated based on the efference copy. These predictions are compared to the actual feedback, leading to subsequent suppression in case of a match. In this way, resources are freed up to process other relevant sensory stimuli that are externally generated. However, enhancement of auditory action outcomes has also been reported, particularly when stimuli are noisy. Here, we investigated whether action would lead to increased signal detection performance, and whether the effect of action depends on the type of stimulus. Participants were presented with white noise, in which a signal was embedded half of the time. The signal was either a sine-wave beep, a recording of a click sound from a button press, or a recording of a human voice. In active conditions, participants elicited the stimulus themselves through a button press, whereas the stimulus was presented automatically in passive conditions. Participants reported whether they detected a signal in the noise, as well as how confident they were. We found a significant effect of stimulus type on false alarm rates, with significantly more false alarms for beeps than for either click or voice stimuli. Furthermore, perceptual sensitivity was higher for voice stimuli than for the other stimulus types. However, there was no effect of action on either false alarm rates or perceptual sensitivity. Furthermore, action did not affect response times. Overall, these results suggest that humans have an increased sensitivity to detect voices, which are socially relevant stimuli, and are more likely to falsely report unnatural stimuli. However, we could not provide evidence for an effect of action on perception, as neither suppression nor enhancement was observed. As previous studies reporting effects of action mostly used intensity judgment tasks, this suggests that action may mainly affect the perceived intensity of a stimulus, but not the ability to detect a stimulus in noise.

P2-D-89 - Disentangling indirect versus direct effects of somatosensory cortex microstimulation on neurons in primary motor and ventral premotor cortex

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Details

Intracortical microstimulation in the primary somatosensory cortex (S1-ICMS) is being developed to provide on-line feedback for bidirectional brain–machine interfaces. Because S1-ICMS can alter the discharge of the motor cortex neurons used to decode motor intent, successful application of S1-ICMS

feedback requires understanding the modulation it produces in motor cortex neuron activity. We therefore investigated the effects of S1-ICMS on neurons in both the primary motor cortex (M1) and the ventral premotor cortex (PMv) during a task in which some trials were instructed with visual cues and other trials with S1-ICMS. We observed both indirect modulation that could occur during and/or after ICMS trains, as well direct modulation time-locked to the individual S1-ICMS pulses within trains, with all possible combinations of the two types of modulation found among the majority of M1 and PMv neurons. Indirect effects typically were more prevalent and larger in magnitude than direct effects. Interestingly, when S1-ICMS produced both indirect and direct modulation in the same neuron, the effects were not always congruent. While sometimes both effects were excitatory or both were inhibitory, in many cases one was excitatory and the other was inhibitory. By simulating direct effects, we disentangled the concurrent indirect and direct effects, revealing not only that isolated direct effects failed to account for isolated indirect effects, but also that their magnitudes and directions were largely uncorrelated. Furthermore, indirect effects could be present 1 s or more after ICMS trains had terminated, when no direct effects could have occurred. Although the performance of movement decoders trained on visually-instructed trials was poor when applied to ICMS-instructed trials, decoders trained on ICMS-instructed trials performed well on ICMS-instructed trials, indicating that S1-ICMS altered the discharge of M1 and PMv neurons but did not degrade the decodable information available. When decoding movement intent from neural activity in M1 and/or PMv, accounting for indirect and direct modulation may improve the ability of bidirectional brain–machine interfaces to incorporate artificial somatosensory feedback delivered with S1-ICMS and restore functional movement.

P2-D-90 - The contribution of observed kinematics and outcomes in observation-induced contagions in pointing movements

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Details

Watching the actions of others can cause unintentional performance biases. Seeing correct, yet different, actions can bias performance in the direction of the watched action. Imitative contagions occur because of shared representations for action and action observation. Compensatory contagions have also been identified in response to seeing errors. Differences between predicted and observed actions are thought to elicit a prediction error (PE), updating the observer's internal model and causing later compensatory errors in subsequent actions. However, evidence of this effect is so far limited. Moreover, it is unclear what components of the observed action (i.e., kinematics or outcomes) underpin this PE and associated compensation. Seeing different, yet correct action outcomes, can suffice in bringing about imitative biases. Yet there is evidence that seeing an actor's kinematics is necessary for PE-based compensation. Compensation contagions were shown in pointing and throwing tasks, only when the kinematics reliably predicted the outcomes. As such, task-specific effects may be related to the availability of kinematic information needed to elicit PE-based compensation.

To test the information needed for directional biases associated with repeated observation and the conditions underpinning any biases, we conducted two pre-registered experiments (N = 40 each). In a partial replication of an earlier study where biases were shown, we manipulated vision of the action in a pointing task. Participants pointed to a vertically positioned centre target on a mounted touchscreen computer and watched demonstrations of similar actions. The target array consisted of 3 vertical lines. Participants alternated blocks of pointing without visual feedback and watching videos of an actor aim with directional biases in 3 blocked conditions. Participants saw videos of a full action (kinematics), landing points only (outcomes), or no video (control). An 'error' group was told that the actor always aimed for centre. A 'correct' group was told that the actor's lateral aim was intentional.

In Experiment 1, where the condition orders were random and target lines were spaced 2.5 cm apart, there was no evidence of imitative or compensatory biases across the groups or conditions (*p*s > .12). In Experiment 2, we widened the target array (6 cm apart) to increase the salience of the actor's errors. The kinematic condition was now completed first to control for potential order effects. Imitative biases were present for the 'correct' group in both the kinematics and outcomes conditions, which did not differ, but not in the control condition (*p* = .03). There were no biases shown in any condition by the 'error' group. The absence of compensation effects questions both the reliability of such an effect from watching, as well as the PE mechanism thought to underpin this effect and the associated need for kinematic information to inform the PE.

P2-D-91 - Hybrid VR object lifting matches real-object manipulation

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Details

Clinical deafferentation underscores the fundamental role of proprioception in motor control, but chronic sensory loss also drives long-term compensatory strategies that complicate mechanistic inference. Because proprioceptive reliability is difficult to reliably manipulate experimentally, its contribution to skilled control remains unclear. Virtual reality (VR) with controlled visuo-proprioceptive offsets provides a promising experimental model of proprioceptive unreliability that induces sensory reweighting toward vision during conflict. This VR-offset framework has substantially advanced our understanding of vision-dominant control under proprioceptive unreliability when reaching to virtual targets. It remains unknown how the motor system responds to proprioceptive unreliability during skilled object manipulation. Unlike reaching, manipulation requires anticipatory force/torque control and online adjustments to trial-to-trial variability in digit position and load forces; these policies are learned rapidly within a few trials, yet changes in object dynamics produce anterograde interference (bias toward prior dynamics) that increases with greater repetition before the dynamics switch. Although much is known about how vision, tactile cues, and prior experience support these hallmark features, the role of proprioceptive reliability remains comparatively unresolved. VR paired with real-world object interactions and programmable offsets between vision and proprioception offers a promising route to address this gap. Critically, before introducing offsets, we must first establish that a hybrid VR-object lifting task without an offset reproduces the hallmark signatures above. Here, we compared real-world object manipulation with a hybrid VR-object lifting task in which participants (*N* = 15) lifted and prevented tilting a visually symmetric object with an asymmetric mass distribution (viewed directly or via VR). Across conditions, the rate of anticipatory force control, trial-trial-to-trial position-force adjustment, and switch-related interference when the mass side changed (including larger and more persistent effects with greater pre-switch repetition) were statistically indistinguishable. These results demonstrate that VR-object lift tasks can reproduce hallmark features of dexterous manipulation, providing a foundation for future studies that use a VR offset paradigm to understand the contribution of proprioceptive reliability to object manipulation.

P2-D-92 - Decoding tool-extended tactile representations in the human brain

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Details

The functional organization of tactile perception in the somatosensory system supports localization on the body and its extension beyond the body, as on tools. To explore tactile localization on tools, previous

studies often involved delivering impacts at different locations on a hand-held rod. Here, we investigated whether impact localization through a hand-held tool is reflected in somatosensory processing, with minimal hand movement. In a 3T MRI environment, participants continuously held an 85-cm long rod while tactile stimuli were delivered at one of six locations spaced 10 cm apart, ranging from proximal to distal along the rod's length. Preliminary neuroimaging data suggest that tactile input delivered via the tool is represented in both the primary (S1) and secondary (S2) somatosensory cortices, as well as in motor-related areas. Multivoxel pattern analysis reveals that distinct impact locations, along the entire tool rather than only at the tip, can be decoded from activity patterns S1 and S2. Further, preliminary representational similarity analysis suggests that unique vibration patterns at different tool positions may evoke distinct neural patterns in the somatosensory cortex. Taken together, location-specific responses in S1 and S2 show that the brain can decode tactile signals along the tool. More advanced analyses will be presented on an extended dataset and discussed within the framework of somatosensory processing of hand-held tools.

P2-D-93 - Cross-modal convergence of digit-specific representations in human somatosensory cortex during imagined movement, natural touch, and electrical stimulation after spinal cord injury

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Details

Sensorimotor integration is essential for accomplishing any of the complex dexterous motor control tasks required for activities of daily living (ADLs). Disruption of accurate sensory feedback within motor control circuits, as occurs in patients with peripheral de-afferentation, spinal cord injury (SCI) or stroke, can profoundly impair motor performance and quality of life. Brain-computer-interface (BCI) devices show promise for restoring this sensorimotor control loop via decoding motor control signals and restoring somatosensory feedback via precise temporal spatial patterns of electrical stimulation which evoke somatosensory percepts. These interfaces enable quantification of both efferent motor signals projected to somatosensory cortex and evoked motor neuron activity from afferent sensory input. By characterizing the convergence of movement-related activity, natural sensory input, and causally evoked percepts, this work aims to clarify distributed motor control circuits supporting dexterous behavior.

We found digit-specific sensorimotor representations co-activated across human motor and sensory cortex across both volitional motor and passive sensory tasks in two right-handed participants with chronic cervical SCI (3 and 50 years post-injury). Participants first performed attempted or imagined individual finger movements during ultra–high-field (7T) fMRI. Each participant was then chronically implanted with Utah microelectrode arrays in contralateral S1 and M1, enabling simultaneous single-unit and local field potential (LFP) recordings during the same attempted or imagined movement task. To simulate afferent input, we causally probed somatosensory representations across M1/S1 via delivered intra-cortical micro-stimulation (ICMS) in post-central gyrus. In one participant with intact sensation, we captured natural afferent activity evoked in M1/S1 from mechanical tactile stimulation.

Despite profound sensory and motor deficits, attempted and imagined finger movements elicited robust, digit-selective BOLD responses in post-central gyrus. Digit preference within array-scale cortical regions was conserved across hemodynamic, electrophysiological, and stimulation-based measures. High-frequency LFP activity (>80 Hz) and population spike firing rates encoded digit identity during motor imagery, indicating that efference-related signals selectively engage somatosensory neuronal populations. These same populations predicted the spatial organization of ICMS-evoked percepts, linking predictive motor-related activity to behaviorally reported projected fields. In the participant with

residual cutaneous sensation, mechanically evoked receptive fields aligned tightly with both movement-related neural activity and ICMS projected fields, even five decades after injury. In contrast, digit-specific organization was weak or absent in pre-central gyrus under identical task conditions.
These findings demonstrate that human S1 retains stable, digit-specific neural populations which represent both efference motor commands, afferent mechanical sensory input and artificial perturbation via ICMS, providing a mechanistic substrate for sensorimotor integration in the human brain, even after long-term deafferentation.

P2-D-94 - Neuronal computations in the primate spinal cord during the preparation of volitional forelimb movements

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Details

Emerging technologies have allowed to obtain large scale recording of individual neurons and gain a more detailed understanding of the brain functions. Now, by employing a high-density recording electrode (128 Channels) we analyzed the role of the cervical spinal neurons on a behaving nonhuman primate (Macaca mulatta) during the preparation and execution of arm movements. Neuronal recordings were obtained by inserting the electrode at different tracks spanning the C5-C7 cervical segments while the monkey performed a time-delayed reaching task. These recordings spanned up to 5mm covering the dorsal-, intermediate and deeper zones of the gray matter. Simultaneously, we recorded the activity of different agonist and antagonist muscles from the forelimb involved on the reaching movement.
During a holding period lasting approximately 1s, the monkey held his hand at a specific home position on a touchscreen. At the halfway point of this period (~500ms), a visual “Target Cue” appeared on the screen indicating the location of a reaching target. Following the remaining 500ms of the holding period, a visual go-cue indicated that the monkey was allowed to touch the target and receive a reward. From the total sample of spinal cervical interneurons (n=713), approximately 48% of them (n=346), showed different spiking patterns during to the task. Interestingly, a subgroup of these interneurons (17%, n=58) was modulated to one or more target positions after the appearance of the Target Cue but before the movement had started and with no signs of related muscle activity. During this preparatory period that lasted 250ms, these interneurons expressed 3 principal patterns of activity. The first type (n=35) showed a sustained increasing activity starting at 75ms and extending beyond of the preparatory period. The second type of interneurons (n=13) showed a transitory increasing of activity starting at 25ms, reaching a peak at 100ms and ceasing their activity approximately at 250ms (the ending of the preparatory period). The third type of neurons (n=10), showed a double peak of activity during the preparatory period, the first peak started at 90ms and reached its maximum at 140ms, probably an effect associated to an early visual response. The second peak reached its maximum at 185ms and ceased their activity at the end of the preparatory period. These results further strength the relevant role of the spinal cord on the shaping and preparation of arm movements.

P2-D-95 - Effects of ageing on hand choice in a bimanual task

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Details

Background

Ageing is thought to be associated with reduced hemispheric asymmetry that may influence hand selection strategies during bimanual tasks; however, few studies have examined whether such age-related differences in hand selection exist. In this study, we examined hand selection in a bimanual task involving natural grasping, while varying the related motor and cognitive demands.

Methods

Eighty-five right-handed adults in two age groups (N = 44 young; N = 41 older) completed dexterity screening tasks (Nine-Hole Peg Test, Box and Block) with both upper limbs and completed a questionnaire of hand dominance (Edinburgh Handedness Inventory, 10-item version). They also performed a LEGO® Construction Task with varying *Motor* (Small vs. Large bricks) and *Cognitive* (6 vs. 12 bricks) demands. We measured which hand participants chose to use (i.e., proportionate dominant hand, DH) and construction speed (time per brick).

Results

Older adults showed significantly more symmetrical use of their upper limbs during the LEGO® Construction Task (DH mean ± SD: younger = 0.68 ± 0.13, older = 0.60 ± 0.14). Interestingly, groups showed comparable performance asymmetries (i.e., DH vs. NDH) for unimanual tests of dexterity and in self-reporti hand dominance. Greater motor (i.e., small-bricks) and cognitive (i.e., 12 bricks) demands were associated with increased DH use that was comparable across groups. Older adults were also significantly slower to complete the task (time per brick: younger = 4.2 ± 0.93 s, older = 8.45 ± 2.88 s). Furthermore, this slowing was significantly more pronounced for older adults when conditions were more demanding.

Conclusion

As predicted, older adults demonstrated more symmetrical hand use in this naturalistic bimanual task, consistent with the Hemispheric Asymmetry Reduction in Older Adults (HAROLD) model. However, we were unable to detect changes in either unimanual skill or self-reported hand dominance to explain the more symmetrical bimanual activity observed. It is known that interhemispheric inhibition reduces as we age and this may account for the more symmetrical hand selection observed in older adults. Additionally, age-related decline in the musculoskeletal system with an accompanying reduction in limb mobility may also be a factor.

P2-D-96 - Disrupting cerebellar outflow reduces motor cortical activity and impairs manual dexterity

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Details

The cerebellum is critical for coordinating multi-joint upper-limb movements through its interactions with motor cortex. While cerebellar contributions are often emphasized for proximal joints (shoulder and arm), distal finger control is typically viewed as more directly mediated by motor cortex. Growing evidence, however, implicates the cerebellum in finger control, but how cerebellar signals support dexterous finger movements remains unclear. To address this question, we trained a monkey (*Macaca Fascicularis*) to alternate between two motor tasks that emphasized either distal or proximal joints. We recorded single-cell activity from the contralateral primary motor (M1) and dorsal premotor cortices (PMd) (M1: $n = 32$, PMd: $n = 82$). Recording sites were functionally identified using intracortical stimulation delivered through the recording electrodes (333 Hz, 50 ms). To test the online involvement of

the cerebellum output, we reversibly disrupted cerebellar outflow using high-frequency stimulation (HFS, 130Hz) via a chronic stimulating electrode implanted in the ipsilateral superior cerebellar peduncle. Movements of distal and proximal joints were quantified using markerless video tracking, and neural behavioral relationships were assessed using event-related modulation of firing rates. Disrupting cerebellar outflow reduced task-related activity around movement onset in both proximal and distal motor cortical sites, with stronger effects at proximal (shoulder-related) sites. During the manual dexterity task, HFS also altered joint kinematics and degraded fine motor performance, accompanied with a drop in task-related activity. These findings indicate that cerebellar output provides essential drive to finger-related motor cortical circuits, and that loss of this input reduces cortical engagement and impairs dexterous behavior.

P2-D-97 - Anticipating action intentions in dynamic interactions relies on context more than kinematics

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Details

In social interaction motor action is shaped by predictions about what another person might do next. Whether pedestrians try to avoid a collision on a sidewalk or athletes anticipate their opponents' next moves, interacting successfully requires predicting others' action intentions under uncertainty. Such uncertainty increases when observable movement cues conflict with contextual expectations—for example, when a teammate's kinematics signal one action but the game situation suggests another. In these dynamic contexts, with a growing number of possible actions, successful anticipation depends on continuously weighting kinematic and contextual information.

To investigate how people anticipate others' actions in dynamic, real-time interactions, we recorded wrist kinematics while pairs of participants (dyads) played multiple rounds of Rock–Paper–Scissors. We quantified the discriminative information embedded in movement (encoding) and how opponents used this information (readout). Kinematic encoding increased over the course of each sequence, indicating that players' movements became more informative as an action unfolded. However, readout analyses revealed a divergence between the players who won and those who lost more often than chance: losing players showed stable and accurate reliance on kinematic cues, whereas winning players consistently misread these cues. Instead, as confirmed by a participant-level Bayesian modeling approach, winners' behavior was better captured by contextual inference than by sensitivity to kinematic information. Notably, the divergence between kinematic and contextual sources peaked shortly before actions were executed, distinguishing winners from losers at the moment when prediction mattered most.

These findings suggest that for dynamic interactive anticipation to be successful in social interaction, extracting information from movements may be helpful, but knowing when to let contextual expectations guide the action is indispensible. The work highlights the dynamic interplay between motor encoding, perceptual readout, and contextual inference that supports successful action prediction in interactive settings.

P2-D-98 - Task difficulty modulates the effects of transcutaneous vagus nerve stimulation on perceptual decision-making

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Details

Task difficulty modulates the effects of transcutaneous vagus nerve stimulation on perceptual decision-making

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Introduction: Arousal is a global state of neural activation that shapes attention, sensory processing, and decision-making by broadly modulating neural gain across the brain with a major contributor to arousal regulation being the locus coeruleus–norepinephrine (LC–NE) system [1]. Transcutaneous vagus nerve stimulation (tVNS) provides a non-invasive means to engage the ascending arousal system, with converging evidence indicating a central contribution of the LC–NE system to tVNS-evoked responses [2]. In prior work, we found that tVNS improves accuracy in perceptual decision-making without altering response speed [3]. Importantly, these accuracy benefits were most evident in task conditions associated with lower baseline performance, rather than uniformly across conditions [4]. However, the mechanisms underlying this selective enhancement remain unclear. Here, we tested directly whether the behavioral impact of tVNS depends on task difficulty by parametrically manipulating motion coherence within participants during a random dot motion (RDM) task.

Methods: 23 healthy participants (5 males; mean age = 24.1 $\pm$3.7 years) performed the RDM task under either tVNS or SHAM stimulation. Stimulation consisted of 4-second trains of electrical pulses (25 Hz, 200 µs), delivered on the left ear, either to the cymba conchae (tVNS) or the earlobe (SHAM), preceding the onset of coherent motion. Perceptual difficulty was individually calibrated to yield three target performance levels (low, medium, high), corresponding to approximately 60%, 70%, and 80% accuracy. Each participant completed 18 blocks of 40 trials (2 low-, 3 medium-, 4 high-difficulty blocks), distributed across two sessions, with tVNS and SHAM blocks alternating. Behavioral performance was quantified by accuracy and reaction time (RT); complementary drift diffusion modelling (DDM) analyses allow to characterise latent decision parameters.

Results: Data collection is complete, but the present results reflect analyses from the first 13 participants (the full sample will be analyzed by the time of the conference). These preliminary analyses confirm significant differences in accuracy across perceptual difficulty levels, as intended (χ^2 = 97.8, p < 0.001). We also observed a significant interaction between stimulation condition (tVNS, SHAM) and perceptual difficulty (low, medium, high; χ^2 = 8.6, p = 0.014). Although post hoc contrasts did not reach significance with this partial analysis set, accuracy tended to be higher under tVNS than SHAM in high (65.8% vs. 63.2% accuracy) and medium (74.0% vs. 71.3%) difficulty blocks, whereas the opposite pattern was observed in low-difficulty blocks (79.8% vs. 83.4%). RT was strongly affected by perceptual difficulty (χ^2 = 99.6, p < 0.001), with longer RTs under higher difficulty, but showed no evidence of modulation by tVNS (χ^2 < 5.1, p > 0.079). In addition, a robust post-error slowing effect was observed (RT longer after errors, χ^2 = 100.2, p < 0.001), with no difference between tVNS and SHAM (χ^2 = 1.2, p = 0.302).

Conclusion: These preliminary results suggest that tVNS preferentially supports perceptual decision accuracy under demanding conditions, without globally affecting response speed or post-error behavioral adjustments. This pattern is consistent with the idea that engaging arousal-related neuromodulatory systems can protect against performance declines when perceptual decisions are challenging. Full-sample analyses, including DDM, will be completed and presented at the conference to provide a more definitive test of the robustness and computational basis of these effects.

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P2-D-99 - Gyroscopic dynamic perturbations reveal feedback corrective responses during overhand throwing

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Details

Throwing objects, such as pitching in baseball, is a challenging motor task because it requires both high speed and precision, yet skilled athletes consistently achieve remarkable accuracy. Although throwing is often regarded as a ballistic movement, recent studies have reported the presence of online adjustments during throwing (e.g., Urbin, *Exp Brain Res*, 2013), raising the question of whether online movement corrections mediated by feedback control play a critical role in achieving high accuracy.

Here, we investigated the contribution of feedback-based movement correction by imposing mechanical perturbations on the arm during the throwing motion. To this end, we developed a novel gyroscopic device that applies pronation or supination torques to the forearm as a function of elbow extension angular velocity. Skilled (N = 9) and unskilled participants (N = 7) performed seated overhand throws with their dominant arm (right arm for all participants except one skilled participant) toward a target located at a fixed distance (4 m). After 10 throws without perturbation, participants completed five cycles, each consisting of 10 perturbation trials in one direction (pro- or supination), 2 trials without perturbation, and 10 perturbation trials in the opposite direction. Forearm and upper arm kinematics were recorded using two IMU sensors, and ball landing locations were reconstructed from video recordings using a direct linear transformation algorithm.

The applied perturbations systematically shifted ball landing locations in the direction predicted by the imposed torques (estimated torque magnitude: 200–300 mNm). Specifically, pronation torques shifted ball landings leftward (rightward for the left-handed participant), whereas supination torques shifted them rightward. However, the difference in landing positions between the two perturbations was relatively small (within 5 cm), suggesting that movement corrections may have occurred during the throwing motion. Consistent with this interpretation, analysis of forearm kinematics revealed compensatory responses opposing the applied torques with latencies of less than 100 ms, and these responses were observed in both skilled and unskilled participants. In contrast, compensatory responses in the upper arm were observed only in the skilled group.

According to feedback error learning theory (Kawato et al., Biol Cybern 1987), feedback motor commands are expected to drive trial-by-trial adaptation of motor commands (Albert & Shadhemr, J Neurosci 2016). However, no clear evidence of such adaptation was found in forearm kinematics; nevertheless, skilled participants exhibited small aftereffects in ball landing locations during subsequent unperturbed trials.

These results demonstrate the presence of rapid compensatory feedback responses to mechanical perturbations even in throwing movements traditionally regarded as ballistic. Moreover, the involvement of proximal upper-arm segments in skilled participants suggests that motor skill acquisition may be associated with more widespread feedback-related adjustments extending beyond the directly perturbed segment. Together, these findings highlight the functional importance of feedback control in multi-joint ballistic actions that require both high speed and accuracy.

P2-D-100 - Decoding others' action goals in the human brain with EEG

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Details

Humans can rapidly infer others' action goals from subtle body movements that precede overt action execution. Here, we investigated the neural time course of action-goal prediction during naturalistic action observation using electroencephalography (EEG).
Participants viewed short videos of an actor reaching toward one of two possible targets. A Plexiglas screen was positioned in front of the display, with two physical targets affixed to the screen at locations matching the targets shown in the videos. Participants were instructed to predict the actor's movement goal and touch the corresponding target as quickly as possible. The experiment included two conditions. In the Full-video condition, videos were presented unedited. In the Cut-video condition, all preparatory cues were removed by editing out the frames preceding the onset of the actor's finger movement. Participants' finger movements in 3D space were recorded using motion-tracking sensors.
Finger reaction times (fRTs) were significantly slower in the Cut-video condition than in the Full-video condition, indicating that observers rely on preparatory cues to predict action goals. We then applied multivariate pattern analysis to time-resolved EEG signals to decode the actor's intended goal. Action goals could be reliably decoded from scalp EEG activity, with decoding becoming significant earlier in the Full-video than in the Cut-video condition, demonstrating neural readout of goal information during the preparatory phase of the observed action.
A searchlight analysis revealed that goal-related information was distributed over frontoparietal electrode sites. Furthermore, dividing trials into slow, medium, and fast reaction-time groups showed that the rise in decoding accuracy was time-locked to video onset rather than to the onset of the participant's movement. Finally, a temporal generalization analysis—training the classifier on neural data from the preparatory phase and testing it on later trial periods—revealed a stable neural representation across time, consistent with a predictive goal signal.
Together, these findings demonstrate that the human brain rapidly extracts goal-relevant information from early kinematic cues and represents action goals at very early stages of a movement, supporting fast prediction of others' actions during naturalistic viewing.

P2-D-101 - Rapid online corrections for proprioceptive and visual perturbations recruit similar circuits across pmd and m1, with a proprioceptive bias in the sulcal bank

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Details

A key feature of the motor system is the ability to rapidly generate goal-directed motor corrections to counteract disturbances of the limb. An important question is what type of information generated from sensory feedback is communicated to motor cortical areas? Normative models, such as optimal feedback control, indicate it would be advantageous to integrate sensory feedback into single state estimation before updating the control policy, yet the cortical evidence is more complex. While responses in gyral (flat portion) M1 generated from rapid corrections to visual and proprioceptive perturbations recruit significantly overlapping neural populations, there remains evidence of unimodal circuits at both individual cell and subspace level of analyses [1]. It is unclear whether these unimodal responses are a product of specific sensory projections, or an artifact of computation.
Parietal regions have diverse projections to frontal motor areas. Specifically, PMd receives anatomical projections from visually dominant parietal areas such as V6a, whereas the caudal sulcal bank of M1 preferentially receives anatomical projections from proprioceptively dominant parietal areas, such as PE. If these projections only convey modality-specific information, then we predict a gradient in early neural responses to sensory feedback with greater visual responses in PMd, and greater proprioceptive responses in sulcal M1. Alternatively, if each parietal area regardless of bias is informed of other sensory modalities through intraparietal connections, we would predict similar overlapping recruitment across PMd and sulcal M1.

A male macaque was trained to perform reaching movements using the Kinarm Exoskeleton Lab. A cursor represented finger position on a horizontal screen. On random trials, the cursor was shifted (visual perturbation), or a mechanical load was applied to the limb (proprioceptive perturbation) requiring a motor correction to reach a goal target with the cursor. Individual micro-electrode recordings were conducted in sulcal bank of M1 (n = 50), gyral M1 (n = 85), and PMd (n = 59). Collection is ongoing.

Strikingly, there were no significant differences in the neural responses to cursor jumps across all three motor areas. Aligning with classic findings, the sulcal bank of M1 showed larger responses to mechanical loads, possibly due to the unique presence of corticomotoneuronal cells. The lack of clear deviations in corrective responses suggests that sensory integration occurs either quickly within the motor cortices or upstream in the parietal cortex.

Efforts to collect upstream signals have begun in PE, where recordings demonstrate responses only to mechanical loads, aligning with past observations of a proprioceptive dominance. We are continuing large-scale recordings across these frontoparietal circuits to tease apart subtle differences in timing and response patterns.

P2-D-102 - Cross-modal matching is not bidirectionally invertible: Implications for multisensory representation

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Details

Humans rely on multiple sensory modalities to guide motor control, integrating visual, tactile, and proprioceptive feedback. After stroke, impairments in sensory feedback often disrupt this process, contributing to degraded motor function and difficulty performing daily activities. Accordingly, a central research goal is to understand how altered sensory feedback shapes motor behavior and how sensory information can be leveraged to support rehabilitation.

One widely explored strategy is multimodal sensory integration, in which multiple sensory channels are combined to augment or substitute an impaired sensation. However, if feedback modalities are not perceptually balanced, individuals may rely disproportionately on the more salient modality, supporting compensation but potentially limiting engagement and retraining of impaired sensory pathways when recovery is the goal. As such, cross-modal matching (CMM) can be used to establish perceptual equity across feedback modalities.

In a typical CMM task, participants match stimulus intensity across modalities, yielding a perceptual mapping used to calibrate multimodal feedback and personalize feedback to account for individual differences in sensory perception.

CMM, however, relies on a critical yet largely untested assumption. Because matching can be performed in either direction (Stimulus 1→Stimulus 2 or Stimulus 2→Stimulus 1), CMM yields two distinct mappings that are typically treated as equivalent, implicitly assuming bidirectional, invertible relationships between sensory modalities.

We tested this assumption in two independent paradigms: an across-domain visuo–vibrotactile task (N = 12) and a within-domain, co-located pressure–vibration task (N = 12). Participants performed matching in both directions, and bidirectionality was assessed using individual-subject model comparisons and cycle-consistency analyses.

Across both paradigms, perceptual mappings were systematically non-bidirectional. Models learned in one direction generally failed to predict behavior in the reverse direction, with bidirectionality satisfied by only 1 of 12 participants in the visuo–vibrotactile task and 2 of 12 participants in the pressure–vibration task. Cycle-consistency analyses further revealed structured asymmetries: cycle error slopes

were significantly different from zero (mean slopes ≈ −0.6 to −0.8), whereas offsets were small and inconsistently significant.
Taken together, these results challenge the assumption that sensory intensities are mapped onto a single, modality-independent internal scale. Instead, they suggest that perceptual magnitude representations are direction-dependent and context-sensitive, reflecting intensity-dependent gain distortions rather than global additive shifts. More broadly, these findings reframe cross-modal matching not as a neutral methodological step, but as a window into sensory representations and the transformations that shape perceptual judgments and sensorimotor behavior.

P2-D-103 - Quantifying the impact of monocular visual blur on control of upper-limb movements in virtual reality

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Details

Accurate reach-to-grasp movements are necessary for everyday tasks and rely on binocular visual information to support visuomotor planning and online control. This process is mediated by close interplay between the dorsal and ventral visual streams. The dorsal stream integrates binocular information for visually-guided action, supporting grip coordination and trajectory correction. The ventral stream provides complementary information regarding monocular visual cues such as texture, shape, and size. Together, these pathways enable the integration of visual and motor representations underpinning motor planning and execution. Blur or unilateral visual degradation disrupts this integration by reducing the quality of binocular and monocular cues. This may explain why the presence of visual impairments (e.g. amblyopia and cataracts) can significantly impact the ability to perform everyday tasks, such as reaching for an object on a table or aligning a key with a lock. Previous research has demonstrated that monocular visual blur alters reach-to-grasp kinematics, evidenced by reduced movement speed and impaired grasp accuracy when vision is blurred monocularly. However, research identifying thresholds at which this occurs, as well as the extent of individual differences in visuomotor function, remain limited.

We sought to identify a threshold at which visual blur meaningfully impaired prehension and examined individual differences in visuomotor control. We conducted experiments in virtual reality (VR), which offers a platform for the precise manipulation of visual input, including the ability to tailor visual blur to each individual or experimental condition and allows for efficient switching between conditions. We investigated the threshold of motor impairment by degrading vision monocularly at 5 levels of increasing blur. Participants were required to reach, grasp, and lift a virtual object, which was calibrated with a real-world object to ensure accurate haptic feedback when grasping. Upper-limb kinematics were quantified using motion capture to assess markers of movement planning and execution, such as reach velocity, grip aperture and deceleration time. We hypothesised that movement kinematics will be increasingly impacted with greater severity of monocular visual blur. Specifically, we predicted slower movement velocities and altered grip aperture scaling, reflecting changes in visuomotor planning and control. Preliminary results showed increased movement time, lower peak velocities and altered grip aperture scaling under stronger blur.

This study improves our understanding of the threshold at which visual impairments have a significant impact on motor planning and execution and may inform clinical thresholds for intervention for individuals with visual impairments. Future research may provide insight into how VR may be beneficial for the development of at-home and lab-based rehabilitation and non-clinical research on visually-guided action.

P2-D-104 - Cortical state during preparation predicts movement performance differently in adolescent and adult pianists

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Details

Stable movement preparation is essential for accurate execution of skilled actions. Cortical state fluctuations can influence variability in motor output, yet how this neural–behavioral coupling changes across development remains unclear. Here, we examined how the 1/f slope of the EEG signal during movement preparation relates to performance quality in adolescent and adult expert pianists performing a highly familiar motor sequence.

Twenty pianists (10 adolescents, 10 adults) completed 5–8 multi-day sessions of a task performing a fast and complex movement sequence on the piano with their left hand (i.e. a chromatic scale). Because this task is a fundamental component of daily piano practice and frequently appear in musical repertoire, all pianists were highly familiar with the task and required no additional learning. Each session included 24 trials and a self-reported attention rating. Behavioral performance was quantified using a speed–accuracy metric derived from keystroke timing accuracy and velocity. Neural state was assessed by extracting the aperiodic 1/f slope—a proxy for cortical excitation–inhibition balance—from preparation-phase EEG recorded at C4.

Although the mean performance and mean slope values were comparable between the two groups, adolescents exhibited substantially greater between-session performance variability. Crucially, linear mixed-effects models revealed that the preparation-phase 1/f slope predicted trial-level performance in adolescents, such that steeper slopes were associated with better execution. This prediction is stronger on low-attention days, suggesting that preparatory neural state plays a larger role when attentional control is low. In adults, a sharper slope predicted better performance only on low-attention days, and with a reversed pattern observed on high-attention days, indicating that high attention in adults could already enables optimal performance with less need for stronger neural modulation.

These findings demonstrate differences in the neural control of movement preparation depending on the developmental stage and identify the 1/f slope as a state-dependent marker of performance quality during skilled sequential actions.

P2-D-105 - Beyond reach-to-grasp: Neural encoding of object placement

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Details

Most studies of human reaching treat grasping as an endpoint, yet in natural behavior, grasping is typically followed by a purposeful action on the object. For example, object placement is a crucial, but understudied, part of natural action sequences that gives rise to additional demands on visuomotor planning, spatial updating, and sensorimotor integration. While grasping requires advanced specification of object properties such as location, orientation, shape, and grip forces prior to contact, placement may rely more heavily on online adjustments during movement execution. We therefore hypothesized that reach-to-place actions engage distinct neural processes both on the level of motor-planning as well as the online control of the action. To test this, we combined high-density EEG with motion capture while twenty-two right-handed participants (age: 23 ± 3 years, 9 male) performed alternating reach-to-grasp and reach-to-place movements. Behavioral analysis revealed faster reaction-times and longer movement durations for placing compared to grasping; potentially signifying the differential reliance on feed-forward versus feed-back mechanisms of movement implementation between the 2 tasks. Sensor-level

brain activity was source-reconstructed using sLORETA and analyzed in source space. Response-locked brain activity differed well before movement onset within the canonical sensorimotor networks spanning premotor, parietal, and occipital regions. Relative to placement, reach-to-grasp movements showed stronger preparatory activity up to almost 1 second before action initiation in pre-motor, dorsal parietal, and lateral occipital regions, consistent with differential anticipatory demands across tasks. During movement execution, these task differences shifted to a broader set of regions, including ventral premotor, primary somatosensory, parietal, and early visual cortices, consistent with increased requirements for accurate object transfer, spatial updating, and tactile and visual feedback during placement. Time–frequency analyses showed that time-domain differences, both prior to and after movement onset, were driven primarily by low-frequency activity. Low-frequency activity was consistently different between the two tasks over premotor and parietal-occipital regions. This finding was consistent with prior work underlying the relevance of slow motor-related cortical potentials below 8 Hz (delta and theta bands) in movement preparation and goal-related processing (Shibasaki & Hallett, 2006). Higher-frequency activity showed no reliable task specificity. The importance of low-frequency components was further supported by multivariate decoding. More specifically, linear support vector machines reliably classified task intention well before movement onset and throughout execution. Taken together, our results show that the preparatory brain activity elicited by grasping and placement is distinct both in terms of response-locked waveform amplitudes and low-frequency oscillations. These findings show that object placement is not simply an extension of grasping but engages distinct, distributed neural processes.
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P2-D-107 - Kinematic adaptation to expected sensory feedback during uni- and bimanual motor sequences

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Details

Actions are typically seen as a means to manipulate the environment and achieve intended outcomes. However, emerging evidence highlights a dynamic interplay, where anticipated sensory outcomes actively shape the kinetics of motor execution – even when these kinetics do not directly affect outcome properties. For example, examining the force profile of a simple act of pressing a button shows that participants apply less force when the button is (vs. is not) associated with an auditory outcome. Nevertheless, what attributes of expected action outcome are embedded in action kinetics and how, is not well understood. In the current set of studies, we characterize how expected attributes of action outcome shape the kinetics of uni- and bimanual action sequences in healthy adult participants.
We used a force-sensitive plate to measure the force profiles of presses performed with the index finger while the contingency between presses and auditory outcome was manipulated. We find an inverse relationship such that participants applied more force when the expected amplitude of the outcome was low (vs. high). Importantly, when the amplitude of sound outcome was not known in advance, no amplitude-dependent modulation of press force was found. Furthermore, such modulation of press force was related to agentic control and flipping the temporal order between action and sound abolishes sound amplitude-dependent force differences. In other words, when participants tap in response to sounds (instead of generating them), participants applied similar force levels across preceding sound amplitudes. The results of these studies show that action kinetics are sensitive to agentic control and expectancy of sensory outcome.
We further examined whether such expectations affect only the kinetics of the last movement component that is coupled with the outcome or earlier movement components. To this end, participants

performed single or double taps which generated (or not) a sound immediately following the last tap in the sequence. Surprisingly, we find sound-dependent modulations in the force profile of the first tap in the double-tap sequence. In other words, the applied force in the first (silent) tap was lower when the second tap in the sequence was associated with a sound compared to when it was not. Moreover, this was true even when the initial tap of a double-tap sequence was performed with the opposite hand. For example, in a left-to-right hand tap sequence, we find that left hand force profiles are modulated by the association of sound to the right-hand tap (and similar right hand modulations were found for right to left hand tap sequences). Thus, even though the first tap is temporally and causally separate from the actual sound event, and controlled by the opposite hemisphere, it is still modulated by expectation of future sensory outcome.
Taken together, our results demonstrate that prediction of future action-outcome attributes shapes action kinetics in early stages of movement and such prediction signals are shared across hemispheres.

P2-D-108 - Development of a VR reaching task to detect age-related declines in sensorimotor integration and validation of associated brain activity

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Details

Decline in sensory integration function is a critical issue affecting quality of life in older adults. If such decline could be easily assessed at home, it would contribute to early detection and prevention of functional deterioration. The aim of this study was to develop a system for evaluating sensory integration function in daily-life settings by proposing a motor paradigm using a virtual reality head-mounted display (VR-HMD), and to investigate whether resting-state functional connectivity associated with sensory integration could be identified based on its correlation with motor indices measured by this paradigm.
Older and younger adult groups performed a VR-based reaching task under multiple levels of cognitive load. Sensory integration function was assessed using movement accuracy, defined as the angular error between the target position and the hand endpoint. In addition, resting-state functional magnetic resonance imaging (rsfMRI) was acquired from the older adult group to examine resting-state functional connectivity between brain regions showing significant correlations with movement accuracy in the VR reaching task.
Comparison of movement accuracy revealed that the older adult group exhibited significantly lower accuracy than the younger adult group. Furthermore, among older adults, higher movement accuracy was significantly associated with stronger resting-state functional connectivity between the primary motor cortex and the left inferior temporal gyrus. As functional connectivity between these regions is known to be involved in visuomotor integration, these findings suggest that visuomotor integration contributes to age-related decline in sensory integration function. Moreover, the results indicate that the movement accuracy metric derived from the VR reaching task is a valid indicator of sensory integration functional decline.

P2-D-109 - Using a cognitively challenging reaching task to assess the effects of augmented visual and auditory feedback on motor performance

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Details

Accurate movement requires coordination between intact cognitive, sensory, and motor execution processes. Therefore, impairments in any of these processes can deteriorate overall movement;

conversely, augmenting an impaired process may improve movement outcomes. We designed a reaching task on the Kinereach virtual reality motion capture system (6 blocks, 15 trials each) in which we introduced a sequential cognitive challenge, thus requiring the individual to utilize their working memory to successfully complete it. Our central hypothesis was that augmented sensory feedback simultaneously reduces overall cognitive load and improves motor performance of an individual. We also explored whether the type of augmented feedback (visual vs. auditory) had a differential effect on these outcomes. Blocks 1 and 6 consisted of simple reaching trials with no added cognitive challenge. In Blocks 2-5, participants were required to store in and recall from memory a sequence of shapes in order to locate and reach for the correct target. In Blocks 3 and 5, we introduced augmented sensory feedback of the hand position, in the form of visual (the cursor turns from red to green as it moves closer to the target) or auditory (a bidirectional beeping sound that gets faster as the cursor moves closer to the target) feedback. We assessed perceived cognitive load after each block using the Paas' mental effort rating scale. We recruited 12 neurotypical adults (age: 27.8 +/- 4.6 years; 8 females, 4 males). Our mixed model ANOVA showed that the type of feedback (none, visual, auditory) had a main effect on movement accuracy ($F(2,45) = 6.75$, $p = .0027$), such that augmented auditory feedback results in significantly improved accuracy compared to no feedback ($p = .0028$). We also found that although the Paas' score was higher in conditions with augmented feedback, this was not statistically significant ($X^2(2) = 1.12$, $p = .57$). Examination of Paas' score differences between auditory and visual feedback conditions showed that the Paas' score was significantly higher with auditory feedback ($p = .025$). These results suggest that, during challenging conditions, augmented sensory feedback may be used to improve motor performance. However, the type of augmented feedback (i.e., visual or auditory, in this case) may moderate any performance improvements and level of cognitive load imposed on the individual. Therefore, the choice of feedback modality needs to be carefully considered to maximize motor performance while minimizing mental effort.

P2-D-110 - Syllable representations in cerebellar speech areas

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Details

Speech production is a fundamental human ability supported by a large network of brain regions. The cerebellum is a critical node in this network, yet how it represents speech remains unknown. Patients with cerebellar damage often show impaired articulation and disrupted prosody, reflecting deficits in articulatory and temporal speech features. Given the dense reciprocal connections between the cerebellum and the neocortex, cerebellar speech representations may be shaped by representations in one or multiple cortical regions. To better understand their roles and interaction in speech, we analyzed the representational geometry of overt syllable production in the cerebellum and neocortex.

Participants (N=12) were prompted to produce syllables differing along two features: place of articulation - where the sound is produced in the vocal tract, and voice onset time - how soon the voice started. Functional magnetic resonance imaging (fMRI) data were used to analyze activity patterns during the task. Univariate analysis was used to determine speech-related regions of interest. Multivariate pattern analysis was applied to evaluate syllable specific activation patterns within each region.

We found that overt syllable repetition engaged six neocortical regions: The ventral and dorsal sensorimotor cortex, supplementary motor area, frontal and parietal operculum, sylvian parietal–temporal area, and auditory cortex; and two cerebellar regions: a superior cluster in lobules V/VI and an inferior cluster in lobule VIII. Importantly, all regions showed significant positive pattern reliability

($p<0.05$), indicating that syllable identity could be reliably decoded from these regions. Using non-negative linear regression, we estimated the contributions of place of articulation and voice onset time to cortical representations. Ventral sensorimotor cortex showed a clear preference for place of articulation ($p<0.001$), whereas other cortical regions showed mixed preference, suggesting more complex encoding of speech production features. Evaluating the cosine similarities between cerebellar and cortical syllable representations revealed that the representational geometry of syllables in the cerebellar regions was most similar to that found in the operculum , followed by the sensorimotor cortex (0.74 vs. 0.70). When predicting cerebellar representations from cortical ones, we found that adding the operculum to a model that already included ventral sensorimotor cortex significantly improved the prediction ($p =0.01$), whereas adding ventral sensorimotor cortex to a model containing the operculum did not.

Taken together, the results show that the cerebellar speech areas encode syllables differently from primary motor cortex, and more closely resemble secondary regions such as the operculum. More broadly, these findings support the view that the cerebellum contributes to speech beyond place-of-articulation control, which drives activity in primary sensorimotor cortex.

P2-D-111 - Same arm, different plan? Comparing motor planning for static reaches and moving-target interception

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Details

From swatting a fly on a table to hitting a fastball, humans routinely execute rapid upper limb movements under vastly different task demands. Swatting a fly requires spatial precision, while hitting a baseball demands spatiotemporal accuracy within remarkably tight margins (~10 ms, ~2–3 cm). Despite extensive research on the execution phases of reaching and interceptive actions, surprisingly little is known about how motor planning itself differs between these two classes of movement. Intercepting a moving target likely requires predictive estimation of its future location and continuous online corrections through dynamic comparison of target and hand position — processes that may fundamentally reshape the motor plan relative to a simple reach. To investigate this, we compared motor planning for reaching to static targets versus intercepting moving targets. Young healthy adults either reached to static targets presented at one of two locations (0°/s), or intercepted targets originating from those same locations and moving counterclockwise at 75°/s or 150°/s along a circular trajectory. Using a Kinarm Endpoint robot, we simultaneously recorded limb kinetics, eye movements, and EMG from upper extremity muscles, enabling a comprehensive analysis of the planning processes underlying these distinct movement types. Reaction time data for both limb kinematics and the initial saccade were modeled using a drift diffusion framework to dissociate contributions of evidence accumulation rate, decision bound, and non-decision time across conditions. Preliminary results (n=8) revealed a main effect of target speed on non-decision time — with post-hoc differences between moving and static targets — but no effects on evidence accumulation rate or decision bound, suggesting that interceptive planning primarily shortens pre-decisional sensorimotor processing rather than altering the decision process itself. Additionally, the absolute angular difference between the hand movement vector and target location at movement onset, a measure of predictive control, where larger values indicate aiming toward a future target position, showed a main effect of target speed, confirming that interceptive movements are initiated under predictive control. These findings suggest that the motor system accommodates the demands of interception through enhanced sensorimotor preprocessing and predictive aiming strategies rather than changes in decision policy, offering a framework for

understanding how planning deficits may contribute to impaired interceptive performance in clinical populations and aging.

P2-D-112 - Intrinsic spinal circuits can control dexterous manipulation

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Details

The ability to control dexterous movements of the hand relies heavily on somatosensory information from the fingers. Past studies suggest that mechanical stimulation of the fingertips. which alters cutaneous sensory input to the spinal cord, can modulate motor output at very short latencies. We tested the hypothesis that changes in somatosensory information derived from the force applied by a manipulated object would produce changes in the motion of the hand at latencies indicative of control by intrinsic spinal cord pathways. Subjects (25 male, 20 female) performed three haptic tasks involving responses to surface features of virtual objects rendered by a robotic pantograph. The pantograph applied a viscoelastic force to the index finger simulating the contour of a two-dimensional object, which subjects traced while vision was occluded. The contour of the virtual object was altered in a random manner, modifying the direction of force applied by the pantograph to the finger, and thereby requiring a modification to the ongoing movement. The latency between the time at which the contour of the virtual object was altered and modification in the ongoing movement was determined. Response latency distributions for each of the three haptic tasks was found to include a proportion of responses indicative of contorl by intrinsic spinal cord pathways. The results demonstrate that the human hand can respond to unpredictable changes in haptic features at latencies indicative of sensorimotor processing intrinsic to the spinal cord. We propose that somatosensory information conveyed by cutaneous mechanoreceptors in the finger pad is sufficiently sophisticated to be integrated by motoneuronal circuits in the spinal cord in a manner that appropriately modulates the pattern of wrist and finger muscle activation to track relatively simple changes in the tactile environment. Although intrinsic spinal pathways are likely important for dexterous manipulation, the results of the present study suggest that subjects vary in their ability to utilize these circuits and that the more demanding the task, the less they account for the entire response. Further research is necessary to establish the interaction between spinal and supraspinal neural pathways in dexterous manipulation.

P2-D-113 - Patched and parallel networks encode visual and tactile spatial information in effector-based and transformed reference frames in Macaques

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Details

In everyday behavior, we rely on both vision and touch to localize stimuli on and near the body, yet these signals are initially represented in different coordinate systems. Visual targets are encoded in retinotopic coordinates, whereas tactile targets are encoded in somatotopic (skin-based) coordinates. To integrate these modalities, the brain must align them within a common reference frame—meaning that at least one representation must be transformed into another coordinate system.

To determine which brain regions encode visual and tactile targets in body-centered and hand-centered reference frames, we delivered LEDs (visual) and air puffs (tactile) to the ulnar and radial sides of the left and right hands while macaques held their arms either crossed or uncrossed. Crossing the arms dissociates body- and hand-centered coordinates by introducing a systematic misalignment between the two frames. We formalized candidate representations: arm posture, body-centered location, and hand-

centered location as theoretical models for representational similarity analysis (RSA). Using a searchlight RSA, we computed voxelwise correlation maps (rMaps) between neural representational dissimilarity matrices (RDMs) and each model; voxels with positive correlations were interpreted as encoding task-relevant structure consistent with that model. Because posture effects dominated the rMaps, we removed posture-related variance via residualization and repeated the RSA on the residual neural patterns to isolate reference-frame-specific representations.
For visual stimuli, we found an effector-based, body-centered network spanning V4, higher STS, MT/MST, and distributed parietal and prefrontal regions, with additional involvement of insula and SII. In parallel, we observed a transformed, hand-centered network including PMZ in premotor area F4, AIP, and VIP, as well as SI/SII and a focal STS region. For tactile stimuli, the effector-based, hand-centered network included SI, SII, STP, vlPFC, and principal sulcus regions, with additional engagement of anterior insula. The transformed, body-centered network encompassed SI/SII, dlPFC, VIP, insula, MT/MST, and V4. Together, these results suggest that effector-based and transformed reference frames coexist in a patched, parallel organization within and across tactile, higher visual, and multisensory cortices. This distributed architecture provides a mechanistic substrate for how visual and tactile spatial signals are represented, transformed, and ultimately integrated to support coherent perception and action.

P2-D-114 - Causal manipulation of neural activity using a brain-computer interface during a working memory task

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Details

Understanding how neural population activity relates to computation and behavior is a key goal in systems neuroscience. Traditionally, we observe neural activity while an animal performs a behavioral task, which only reveals a correlational relationship between neural activity and behavior. To establish a causal relationship requires direct control of neural activity by the experimenter, and an observation of the ensuing behavior. Here, we embed a brain-computer interface (BCI) task into a standard behavioral task to deliver precise, transient manipulations of neural population activity, akin to electrical or optogenetic stimulation but driven by the animal's own volition.

For a neural manipulation to be maximally informative about the role of neural activity in a task of interest, the manipulation should be (1) task-relevant (i.e., move population activity along dimensions where task-relevant activity unfolds); (2) consistent (i.e., repeatedly steer population activity to the same location in population activity space on individual trials); and (3) flexible (i.e., steer population activity to different locations in population activity space). Achieving these properties can be challenging with traditional perturbation approaches such as electrical or optogenetic stimulation. Thus, we leverage BCI control to harness volition to manipulate population activity in a manner that is task-relevant, consistent, and flexible. By embedding a BCI task into a standard behavioral task, we can use BCI as a causal probe of the link between neural activity and behavior.

We apply this approach to investigate the role of motor cortex in motor working memory. Specifically, we asked whether motor cortex is essential for maintaining remembered reach locations. We recorded spiking activity of ~80 neural units from two Rhesus monkeys, each implanted with Utah arrays in motor cortex (primary motor and dorsal premotor cortex), while they performed a memory-guided reach task. In such tasks, neural activity during the memory period is thought to persistently encode the upcoming reach plan. Therefore, the animals performed BCI control during the memory period to causally probe

this memory-period activity. We demonstrate that BCI manipulations can flexibly and consistently modulate activity along dimensions that encode the remembered reach direction, overwriting the prior reach plan encoding. After the BCI manipulation, neural population activity evolved to encode the ensuing arm reach direction. These results suggest that motor cortex is not essential for maintaining the reach plan. In summary, this study demonstrates BCI as a tool for causal manipulations of neural population activity and positions BCIs as a causal probe useful for studying neural population dynamics and their impact on behavior.

P2-D-115 - Context-dependent sensorimotor encoding in the secondary motor cortex

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Details

In operant conditioning, the neural mechanisms underlying the transformation from conditioned stimuli to conditioned responses remain unclear. The secondary motor cortex (M2) is a candidate site for this transformation, as many M2 neurons respond to task-relevant cues such as auditory tones in trained animals. Here, we ask whether sensory-evoked responses in M2 reflect fixed stimulus-driven encoding or are flexibly shaped by behavioral context.

To address this question, we trained rats to perform a lever-release simple reaction time (SRT) task and made chronic Neuropixels recordings in the secondary motor cortex (M2). By combining chronic recordings with a clustering-based tracking method, we were able to track the same neurons over sessions. In this task, rats were trained to hold a lever and release it promptly upon presentation of a brief tone. Neurons in M2 exhibited diverse, task-related modulations across multiple phases of the task, including lever press, cue onset, lever release, and reward-port nose poke. In particular, we observed short-latency (~25 ms), cue-evoked responses in a subset of M2 neurons. These neurons exhibited either phasic (transiently after cue onset) or sustained (from cue onset to movement execution) responses. These sensory-evoked responses were highly context dependent: when a pair of identical tones was presented sequentially and rats were trained to respond only to the second tone, neural responses to the first tone were abolished while the responses to the second tone were preserved. To study stimulus selectivity, we randomly presented either a tone or a flash cue on each trial as the conditioned stimulus within a single session. In these experiments, some M2 neurons responded to both stimuli with similar amplitude, whereas others responded selectively to either tone or flash, suggesting coexistence of stimulus-generalized and stimulus-selective encoding. Together, these results suggest that M2 neurons flexibly encode sensory information to drive motor responses.

E – Disorders of Motor Control

Poster Cluster (P2-E-116 & P2-E-117)

P2-E-116 - Trauma exposure patterns shape movement strategies under rule reversal

Céann Marks [1], **Anthony Machula** [1], **Lauren Sergio** [1]
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Details

Emotional trauma has been associated with alterations in cognitive and affective processing, but its influence on motor adaptation remains poorly understood. We investigated whether lifetime emotional trauma exposure patterns (single-incident trauma, complex trauma, and cumulative trauma) were associated with differences in reaction time, movement time, peak velocity, path length, and error measures across standard and reversed task conditions of a cognitive-motor integration task.

Participants (n = 602) completed a questionnaire battery including trauma history information, followed by a computerized cognitive-motor integration task with standard and reversed stimulus-response mappings. The standard task condition required individuals to move from a central to peripheral target as quickly and accurately as possible, with the reverse condition's movement feedback rotated by 180°. Participant-level mean kinematic measures were used to calculate temporal, spatial, velocity, and error-based aspects of movement execution. Trauma exposure patterns were classified as single-incident, complex, or cumulative. To examine the impact of trauma exposure patterns on movement execution, repeated measures ANOVA was conducted among trauma-exposed participants, with task condition as a within-subject factor and trauma exposure as a between-subject factor. Group differences were further assessed using paired comparisons between task conditions.

Across trauma-exposed participants, reverse stimulus-response mappings reliably altered motor performance. A repeated measures ANOVA revealed a significant trauma exposure by task condition interaction, for path length ($F(2, 733) = 3.54$, $p = 0.029$), indicating condition-dependent modulation of movement trajectories across trauma exposure patterns. Further trend-level main effects of trauma exposure emerged ($F(2, 733) = 2.98$, $p = 0.051$), with post-hoc comparisons for the reversed task condition finding significantly shorter path lengths for the complex trauma exposure group ($M = 3.15$, $SD = 1.03$) compared to the single-incident group ($M = 3.54$, $SD = 1.49$). A significant main effect of trauma on peak velocity ($F(2, 738) = 6.54$, $p = 0.002$) emerged, such that higher velocities were associated with single trauma exposure compared to complex trauma exposure. Follow-up Tukey comparisons revealed a significant decrease in peak velocity when moving from single-incident ($M = 14.6$, $SD = 9.58$) to complex trauma exposure ($M = 12.0$, $SD = 6.54$).

These findings suggest that lifetime trauma exposure patterns differentially modulate movement execution under altered task demands. Trauma-related differences in task strategies may reflect distinct modes of motor control rather than generalized performance impairments. These modes of motor control may introduce particular implications for populations exposed to high frequencies of traumatic events, such as first responders and military personnel.

P2-E-117 - Frontal and parietal regions maintain resilient relationships to visuomotor control across age, sex, and brain health conditions

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Details

There is a considerable literature documenting the brain regions that are important for the neural control of both basic visuomotor performance and cognitive-motor integration (CMI), where the integration of rules is required to attain the goal of the task. Further, there are a variety of factors known to change the relationship between brain region size/activity/connectivity, and behavioural performance, such as age, sex, and neuropathology. Prior work from our group has demonstrated altered associations between CMI performance and white matter integrity, cortical thickness, and resting-state network function in working-aged adults having either persistent post-concussion symptoms (PPCS) or dementia/dementia risk. These altered associations were all impacted by age, sex, and condition severity.[1-4] **Objective:** Rather than examine how CMI control-related brain regions are affected by demographic and brain health factors, in this exploratory study, we flipped the question by asking which brain regions do *not* change their structural relationship to basic and rule-based visuomotor control across factors. **Methods:** 41 working-aged adults (24 females; 47.2± 9.8 years old, range 30-64) completed two visuomotor tasks, one requiring direct hand-to-target movement on a touchscreen, and one comprising an indirect interaction involving an element of spatial dissociation and feedback reversal between the visual stimulus and reach target, requiring CMI. MRI scans (3T Siemens

MAGNETOM PrismaFit) were used to obtain thickness and headsize-adjusted volume of regions previously shown to be involved in CMI control. **Results:** Hierarchical regression analyses examined whether cortical thickness and adjusted volume in 16 visuomotor control-related regions predicted visuomotor performance after controlling for age, sex, and brain health status group (concussion history only, or both concussion and familial dementia history). Greater cortical thickness in the left caudal middle frontal and left precentral regions significantly predicted higher/worse trajectory performance in the CMI condition, while greater right precentral thickness predicted higher/worse trajectory performance in the direct condition ($p < .05$). Similarly, greater adjusted volume in the left caudal middle frontal, left precentral, left superior frontal, and right precuneus regions significantly predicted higher/worse trajectory performance in the direct condition, independent of age, sex, and group ($p < .005$). **Conclusion:** Structural variation within a small subset of frontal and parietal CMI-related regions significantly predicted rule-based visuomotor performance, independent of age, sex, concussion impact, and dementia risk status. These data provide insight into which key visuomotor control regions resiliently support basic and complex visuomotor function – and which regions may show more vulnerability – in both sexes having different brain health levels across a range of ages.

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P2-E-118 - Dysfunction of cortical inhibitory interneurons in amyotrophic lateral sclerosis

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Details

Background

Amyotrophic lateral sclerosis (ALS) is a neurodegenerative disorder affecting human motor system. ALS disease is characterised by a progressive loss of lower motor neurons (LMN, bulbar and spinal motoneurons) and upper motor neurons (UMN, pyramidal cells in the motor cortex). It was shown that imbalance of excitation / inhibition, leading to hyperexcitability of UMN is a key mechanism in ALS. Previous studies using transcranial magnetic stimulation (TMS), have reported a depressed short-Intracortical Inhibition (sICI) and an enhanced Intracortical Facilitation (ICF) in ALS patients. (Vucic & Kiernan Handb Clin Neurol 2013; Singari et *al.* Clin Neurophy 2016). To shed light on mechanisms causing neuron excitability disorders, it is crucial to consider afferent interneurons that project onto UMN.

Objective:

The present study aims to investigate inhibitory interneurons afferent to UMN in ALS. Paired pulse TMS (ppTMS)was used to evaluate sICI in 20 ALS patients and in 16 age-and -gender matched healthy subjects (HS) (Kujiral et *al*. J Physiol 1993).

Methods

Electromyogram recordings and ppTMS of the motor cortex were used to evoke sICI in abductor digit minimi (ADM). To stress changes in inhibitory interneuron excitability, sICI was evaluated in different conditions: 1) Test TMS intensity was set at 1.2 of the resting motor threshold (RMT). Two intensities of conditioning TMS were tested (0.7 X RMT and 0.7 of the active MT, AMT) 2) sICI was compared at rest and during 10% of the maximal voluntary contraction.

Results

Consistent with previous studies, The RMT was higher in ALS patients compared to HS. Given that test TMS intensity was stronger in ALS patients, the amplitude of the test motor evoked potential (MEP) was

about 10% of the maximal motor action potential (Mmax) while it was about 5% Mmax in HS. Thus, the test MEP in ALS patients was optimal to follow the modulations of sICI across conditions (Lackmy & Marchand-Pauvert Clin Neurophysiol 2010; Lackmy-Vallée et *al*. Eur J Neuros 2012). At rest sICI was weaker in ALS patients than in HS. Interestingly, we found that sICI was not modulated by the tonic contraction in ALS patients while in HS the contraction depressed the sICI.

Conclusion

These finding suggest a dysfunction of inhibitory interneurons afferent to UMN, at early stage of ALS. This opens avenues to new approaches to counteract the imbalance of E/I observed in the motor cortex in attempt to slow down UMN loss in ALS.

Acknowledgements:

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P2-E-119 - Early behavioral manifold dynamics predict rehabilitation response in persistent post-concussion syndrome

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Details

Predicting rehabilitation response early in treatment remains a critical challenge in persistent post-concussion syndrome (PPCS), particularly in chronic cases well beyond typical recovery windows. We investigated whether trajectory dynamics on a behavioral manifold derived from augmented reality (AR) gameplay could serve as early candidate markers of clinical outcomes.

Seven adults with PPCS (mean 38.1 months post-injury) completed 10–16 sessions of AR-based cognitive-motor integration training — an immersive task requiring simultaneous visuospatial memorization, object manipulation under direct and mirror-reversed control, and progressive vestibular challenge. We extracted 36 behavioral features spanning cognitive, spatial, motor, and kinematic domains per session. Principal component analysis revealed a 7-dimensional behavioral manifold (95.5% variance explained), embedded via UMAP for trajectory visualization. For each participant, we computed early trajectory properties from sessions 2–4: velocity, acceleration, sinuosity (exploration breadth), heading preservation (directional consistency), and curvature.

Early manifold acceleration — the rate of change in behavioral reorganization speed — showed a strong preliminary association with post-concussion symptom reduction (RPQ-3: Spearman $\rho = -0.946$, exact permutation $p = 0.003$; RPQ-13: $\rho = -0.893$, $p = 0.007$), stable under leave-one-out analysis (minimum $\rho = -0.912$). Early velocity correlated with social functioning improvement ($\rho = 0.898$, $p = 0.006$). Trajectory profiles further distinguished adaptive exploration from rigid non-response across participants.

Behavioral manifold trajectory dynamics offer early, gameplay-derived candidate markers of neurotherapeutic response. These preliminary findings (n=7) suggest that by the fourth training session, trajectory properties may identify likely responders, supporting timely clinical decision-making in chronic PPCS rehabilitation.

P2-E-120 - Locomotor phenotyping reveals double dissociation in animal models of autism

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Details

In humans, autism spectrum disorder (ASD) is commonly assessed using cognitive and social phenotypes, which are less evident in other species, hindering comparative assessments across animal models of ASD. While motor behavior is known to be affected in ASD in humans, it remains sparsely investigated in mouse and marmoset models, despite the potential for comparative assessment. Locomotion serves as an ideal motor phenotype because it is readily exhibited by diverse species and captures various aspects of movement control, offering the potential to identify subtle yet systematic differences between ASD genotypes. Here, we investigated whether different mouse models of ASD have distinct locomotor phenotypes and whether a specific mutation is associated with a unique phenotype across mice and marmosets. To address this, we studied naturalistic locomotor behavior in three mouse models (Shank3, Cntnap2, L7-Tsc1) and one marmoset model (Shank3) moving freely in an open arena (a 35cm square for mice and a 1m x 15cm tunnel for marmosets) using a camera placed beneath a transparent floor. We used markerless motion capture (SLEAP) to obtain position time series for the paws, nose, and tail base to extract the location and timing of individual foot contacts. We characterized locomotor behavior along four phenotypes: gross behavior (velocity and distance covered), velocity-dependent behavior (modulation of step lengths, widths, and cadences with velocity), coordination (interlimb contact timing and stereotypical gait patterns), and foot placement control (amplitude and laterality of error-dependent foot placements). We observed that each mouse mutant group exhibited a specific alteration of these locomotor phenotypes, revealing a double dissociation between any pair of mutant groups: the phenotypes were not merely different from controls, but each mutation produced a unique signature that was statistically distinct from the other mutations. Furthermore, the comparison of Shank3 mice and marmosets suggests that similar locomotor phenotypes can emerge across species for the same genetic model. Overall, this work highlights that while different mouse models of ASD have divergent locomotor phenotypes, a single genetic model yields similar phenotypes across mice and marmosets, providing evidence for cross-species motor phenotyping in animal models of ASD.

P2-E-121 - Automated kinematic scoring of tool-use pantomime gestures in limb apraxia

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Details

Tool usage requires integration of cognitive and motor processes, from knowledge of a tool's function and physical properties to prediction of its dynamics when external forces act upon it. Following stroke, disruption in these processes can result in limb apraxia, a disorder characterized by skill loss often marked by difficulty using tools. A widely used approach for assessing praxis ability is tool pantomime, in which participants view images of common tools and demonstrate their use. Pantomime performance is manually scored by trained coders who evaluate movement quality based on posture and timing. The psychometric properties of this coding method are well established. However, extensive time is required both to train the coders and to score videos. In addition, because the coding relies on binary judgements, it may fail to capture subtle variations in movement quality that are informative about mechanisms underlying tool-use deficits in limb apraxia. In this work we developed a machine learning model to predict the quality of tool pantomime gestures based on motion capture data. The dataset consisted of 49 stroke patients with chronic left-hemisphere brain damage and 11 controls. Participants were equipped with eight 6-dof electromagnetic trackers and pantomimed the use of 39 tools. Two trained coders rated performance across four dimensions: content, hand posture, arm posture and trajectory, and movement amplitude and timing. Each dimension was scored as a 0 (error) or 1

(otherwise). The sum of the non-content scores represents gesture quality, with no score given if content scores are 0 (an incorrect tool pantomimed). Item scores were averaged to obtain participant-level scores. Based on the patient assessment rubric used by raters, we automatically extracted postural and timing features from the kinematics and used these to train ridge regression models to predict scores. Item-specific models were trained to map kinematic features to scores for each tool and aggregated to estimate participant-level performance. In parallel, a participant-level model was trained on summary data of the kinematic features to capture overall movement characteristics. Estimates from both models were combined to predict participant-level scores. Using leave-one-participant-out cross validation, we found predicted scores closely matched observed scores ($r = 0.90$; MAE = 0.11). Despite substantial score imbalance, we could classify stroke and control participants with high accuracy (AUC = 0.93). Our results suggest that tool pantomime gesture quality can be estimated from kinematic data, reducing reliance on time-intensive manual scoring. A look at the selected kinematic features may provide insight into the specific motor disruptions during tool use planning and execution. Our modelling framework naturally integrates with markerless pose estimation methods, which can enable richer and more scalable characterization of tool use deficits after stroke.

P2-E-122 - Motor variability and reduced specialization reveal altered neural control of movement in autism

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Details

Altered neural variability has been proposed as a hallmark of autism spectrum disorder (ASD), yet its impact on real-world motor control remains poorly understood. Here, we examined intra- and inter-individual variability across three distinct visuomotor paradigms. First, in a naturalistic LEGO-building task, autistic participants exhibited highly idiosyncratic hand-use patterns and significantly reduced lateralization, indicating a failure of motor specialization. Second, using dynamic time warping on aperture trajectories obtained from a precision grasping task, we found that autistic individuals displayed heightened trial-to-trial inconsistency and diminished trajectory modulation in response to object size changes. Third, a dyadic action-prediction paradigm revealed that the observed motor variability extends to social interaction, characterized by delayed and inconsistent anticipatory movements. Across paradigms, these results converge on a distinctive movement profile driven by neural noise rather than uniform motor impairment. We propose that this pervasive variability reflects instability in predictive control mechanisms. Finally, we demonstrate the clinical utility of these metrics: machine-learning models achieved above 85% classification accuracy based solely on kinematic features. Together, our findings establish variability as a defining feature of visuomotor control in autism and a potential objective biomarker for altered neural organization.

P2-E-123 - Freezing of upper limbs in Parkinson's disease: A reaching study

Jennifer Stevenson [1], **Leah J. Steinke** [1], **Liana E. Brown** [1]
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Details

Abstract

Freezing of Upper Limbs in Parkinson's Disease: A Reaching Study

Jennifer Stevenson, Leah J. Steinke, and Liana E. Brown

Freezing of gait (FOG) is a debilitating motor symptom affecting almost 50% of people with Parkinson's disease (PwPD). Emerging evidence suggests freezing may represent a global motor control deficit beyond gait. We investigated whether freezing-like episodes could be elicited in the upper limbs during reaching and writing, and in the lower limbs during walking, using tasks that mimic established triggers

of FOG. Because PwPD exhibit changes in their ability to process visual patterns, for example, spatial-frequency information in the intermediate and high frequency range, we also examined whether manipulating visual spatial frequency backgrounds would influence motor performance.
Fourteen PwPD and 13 similarly-aged controls participated in this study. For all participants, motor impairment was assessed using the Movement Disorder Society-Unified Parkinson Disease Rating Scale Part III (MDS-UPDRS). The Freezing of Gait Questionnaire (FOG-Q) was used to determine freezing status and severity. Participants completed three reaching tasks designed to parallel known FOG triggers: reversals, corners and navigating through a virtual tunnel, analogous to walking through a doorway. Targets were presented against low-frequency (.14 cpd), high-frequency (.89 cpd) and a stippled control backgrounds. Participants then completed analogous walking tasks on flooring with corresponding spatial frequency patterns. A writing task (The Funnel Task) designed to elicit freezing during amplitude transitions was also employed. The results of the reaching tasks are reported here.
PwPD exhibited significantly longer movement times and lower mean movement speeds than controls, and the tunnel condition was disproportionately challenging for PwPD, resulting in movement times significantly longer than those of controls. PwPD showed altered patterns of movement coordination compared with controls, as revealed by measures of movement curvature in the reversal and tunnel conditions. These differences were not accompanied by differences in movement accuracy, ruling out explanations based on different priorities in terms of speed and accuracy. To bring focus to our search for signatures of freezing at movement initiation and at transitions, we parsed reaching time and distance into phases defined by movement initiation, peak acceleration, peak velocity, peak deceleration and movement termination. This movement-phase analysis revealed that PwPD allocated movement distance differently than controls in both the reversal and tunnel conditions. In the reversal task, the percentage of total distance covered was significantly greater in the final phase for PwPD. In the tunnel task, the percentage of total distance covered was significantly greater for PwPD in the initial motor output and final trajectory adjustment phases. This analysis is continuing. Manipulating spatial frequency backgrounds did not produce consistent effects on reaching performance.
These findings demonstrate that reaching tasks that include transitions, especially the reversal and tunnel tasks, elicit kinematic disruptions in the reaching performance of PwPD. Ongoing analyses focused on transition phases will reveal whether instances of freezing-like behaviour during reaching are related to participants' subjective reports of freezing, and potentially, to observed instances of freezing during the walking and funnel tasks.

P2-E-124 - Binocular horizontal saccade velocity patterns in mTBI

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Details

Mild traumatic brain injury (mTBI) can result in significant deficits affecting vision and eye movements, including vergence, saccades, pursuit, and the vestibulo-ocular reflex. These issues can result in problems with balance, eye-head coordination, and visual-motor transformations underlying goal-directed movements. The deficits can occur after multiple head trauma events, and in some cases after a single mild TBI event. The symptoms can persist for years after the original trauma and become progressively worse over time.

This research focuses on the effects of mTBI and cerebellar disease on gaze and eye-head coordination. The broad objectives are to characterize the coordinated movement of the eyes during changes in gaze, head movement, and visual tracking; to compare and contrast oculomotor deficits in mTBI with those in patients with cerebellar dysfunction; and to gain further insight into the underlying

motor control problems with simulations. The specific aim for the present experiments is to identify binocular patterns in the saccadic eye velocity trajectories.

Methods

There were 32 participants with a history of one or more events causing the mTBI (greater than 6 months prior to testing), 16 control participants (without any neurological or neuro-ophthalmological disease), and 4 with essential tremor. Those with mTBI were symptomatic for gaze instability during movement, difficulty with tasks involving eye-head coordination, or problems with visuo-spatial orientation and postural stability. Binocular eye movements were recorded during horizontal saccades to a visual target displaced between 5 and 25 degrees from center. The 1st, primary saccade to the target was analyzed. All data were scaled with the peak right eye velocity for each saccade set to 350 deg/sec. All data for both eyes for a given saccade were multiplied by the scale factor for the peak right eye velocity for that saccade. Four, 2nd order regressions were fit to the data in plots of left eye velocity vs. right eye velocity: acceleration right and left; deceleration right and left.

The regression analyses identified several patterns with different time courses for the right and left eye movements during horizontal saccades. One pattern shows a difference in right vs. left eye velocity (e.g., left greater than right) during the acceleration phase of a saccade and the opposite difference (e.g., left less than right) during the deceleration phase of a saccade. Other patterns include different velocity trajectories for adduction vs. abduction (associated with convergence excess or a deficit) and a right vs. left eye velocity relation that is the same during acceleration and deceleration. Initial data from essential tremor suggest some similarities and differences.

The definite patterns of left vs right eye velocity can be correlated with vergence deficits and saccadic dysmetria. These patterns and associated variability across subjects might be associated with different subtypes of mTBI, including those with cerebellar dysfunction. Simulations with a bilateral model for saccades, including oculomotor control signals and a parametrization of saccadic movement trajectories, might suggest different pathologies involving the brainstem burst neurons, cerebellum, and oculomotor pathways and give insight for treatment strategies.

P2-E-125 - Anxiety disorders alter cognitive-motor integration during visuomotor adaptation and retention

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Details

Anxiety disorders are associated with prefrontal dysfunction, yet their impact on neural mechanisms underlying skilled motor learning remains poorly understood. Recent clinical studies demonstrate cerebellar and primary motor cortex dysfunction also contribute to anxiety manifestation, implicating a wider network of anxiety-related dysfunction that encompasses the motor system. Cognitive-motor integration, the bidirectional interaction of cognitive functions and motor control systems that produce purposeful movement behaviors, can be indexed using movement-readiness potentials (MRPs) recorded with EEG. MRPs represent cortical activity associated with the preparation of voluntary movement occurring prior to movement onset. Despite evidence that anxiety affects motor cortical regions, no studies have examined how anxiety disorders specifically alter the temporal dynamics of movement preparation during adaptive skill learning. Thirty-one young healthy right-handed adults participated in this study [age range: 19–27 years, mean (M) ± standard deviation (SD): 21.59 ± 2.02 years [13 clinically diagnosed with an anxiety disorder, 18 without]. Participants performed center out reaching movements to a 45° counterclockwise rotation to hit a target across 200 adaptation trials, followed by 200 retention

trials without visual feedback. Relative hand angle indexed behavioral performance during these conditions. Mean MRP amplitude was analyzed across three temporal components before movement onset: readiness potential (-1500 to -500 ms), negative slope: (-500 to -100 ms), and (-100 to +100 ms). Linear mixed-effects models were conducted on relative hand angle and each component of the movement readiness potential. Both groups demonstrated equivalent visuomotor learning and retention. Relative hand angle increased from Early Adaptation to Late Adaptation [MD: 34.139, $p < .001$]. However, hand angle was similar during Late Adaptation to Late Retention [MD: 0.172, $p = .941$]. Early Retention had a greater hand angle compared to Early Adaptation [MD: 34.3411, $p < .001$]. Anxiety disorders reduced MRP amplitudes negative slope [MD: 0.883, $p = .033$] and motor potential [MD: 1.289, $p = .047$] amplitude compared to controls, while readiness potential remained intact [MD: 0.165, $p = .598$]. Despite these neural differences, anxiety disorders selectively disrupt late-stage cognitive-motor integration processes during movement preparation and execution. The dissociation between impaired neural activity and preserved behavioral performance suggests compensatory mechanisms that maintain motor learning despite underlying neural inefficiencies. These findings reveal that anxiety affects integrated systems of cognition and action, providing new insights into their functional neurophysiological impact on motor control networks and skilled learning.

P2-E-126 - Network responses related to subthalamic nucleus deep brain stimulation in the cortico-basal-ganglia circuit

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Details

Parkinson's disease is a neurodegenerative movement disorder characterized by dopaminergic neuronal degeneration, leading to impaired motor control. High-frequency deep-brain stimulation (DBS; ~130 Hz) of the subthalamic nucleus (STN) is an effective surgical therapy for alleviating akinetic symptoms. Despite its clinical efficacy, the circuit-level mechanisms underlying STN-DBS remain unresolved, limiting rational optimization of stimulation parameters and contributing to undesirable side effects, including psychiatric and motor disturbances. Previous studies have proposed increased primary motor cortex (M1) activity via antidromic activation as a key therapeutic mechanism, while other work has implicated activation of the globus pallidus externus (GPe) as a potential mediator of DBS efficacy. However, the demonstration of direct relative contributions of these pathways and their interaction within the motor control network remains unclear in both healthy and Parkinsonian circuits.

Here, we probe the neural basis of STN DBS by combining controlled electrical stimulation with fiber photometry calcium imaging in both healthy and dopamine-depleted (DD) mice. Calcium activity was recorded from the M1 and the GPe in separate experimental cohorts, allowing region-specific characterization of cortical and basal ganglia network responses to STN stimulation. To validate the reliability and sensitivity of calcium signals in each region, STN DBS was delivered at systematically increasing stimulation amplitudes (100, 150, and 200 μA). This approach demonstrated robust, stimulation current–dependent modulation of calcium activity in both M1 and GPe, with proportional scaling of responses across stimulation intensities and consistent fluorescence recovery after each stimulation, supporting stable chronic recordings.

Building on this validation, we employed chronic STN DBS in freely moving animals to assess how region-specific calcium dynamics relate to behavioral output. In the GPe, STN DBS produced a sustained increase in calcium activity throughout the stimulation period, whereas in M1, stimulation resulted in an overall suppression of calcium transients. These complementary network responses were accompanied

by increased locomotor activity in healthy animals and were preserved in DD mice, where STN DBS rescued pathological akinesia.
Together, these observations support a network mechanism in which STN DBS restores motor function by upregulating GPe activity, which is otherwise pathologically reduced in Parkinson's disease, while suppressing cortical calcium activity consistent with attenuation of hyper-synchronous cortico–STN drive. The preservation of this network pattern in dopamine-depleted mice, along with rescue of akinetic behavior, suggests that STN DBS rebalances basal ganglia–cortical dynamics rather than acting through a single downstream pathway. This coordinated modulation of pallidal and cortical activity provides insight into the inhibitory network mechanisms underlying the therapeutic effects of STN DBS in the Parkinsonian circuit.

P2-E-127 - EEG-based deep learning reveals cortical sensitivity to small changes in deep brain stimulation parameters

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Details

Deep Brain Stimulation (DBS) is an invasive procedure used to alleviate motor symptoms in Parkinson's Disease (PD) patients. Despite its effectiveness, the impact of DBS on brain activity and the way to optimise stimulation parameters remains unclear. In this study, we aimed to identify the cortical neural response most sensitive to changes in DBS parameters in a clinically relevant setting. We recorded in-clinic EEG data from 12 PD patients during DBS programming sessions, both at rest and during arm movement. A siamese variant of the EEGNet deep learning architecture was trained to determine whether two 1-sec-long EEG segments were recorded under the same or different DBS parameters. Explainability methods were then applied to extract the neural oscillations learned by the models. Our models achieved an average accuracy of 78% in classifying whether two 1-second EEG segments corresponded to the same or different DBS parameters. Ablation studies identified mid-gamma oscillations (60-90Hz) as the key band for classifying these changes. Importantly, that was not driven by 1:2 gamma entrainment. In a subgroup of patients, the theta-alpha oscillations (4-12Hz) also contributed to detecting changes in DBS parameters. We demonstrate that small DBS parameter changes can be detected at the cortical level using shallow convolutional networks on EEG recordings from PD patients. Our findings suggest that cortical mid-gamma features (60-90Hz) are highly sensitive to small changes in DBS settings. This could be leveraged to guide DBS programming and adaptive DBS systems, potentially improving future treatment outcomes for PD patients.

P2-E-128 - Sex moderates the effect of concussion history on cognitive-motor integration in working-age adults

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Details

Background: Concussion affects millions of working-age adults annually, yet sex-specific effects on motor recovery remain poorly understood. Cognitive-motor integration (CMI) tasks requiring online spatial transformations to guide movement may be particularly sensitive to concussion-related impairments due to their reliance on distributed parietal-frontal neural networks. Understanding sex differences in motor control following brain injury is critical for developing personalized assessment and rehabilitation approaches.
Purpose: To examine whether sex moderates the effect of concussion history and symptom burden on cognitive-motor integration performance in working-age adults.

Methods: Eighty-eight participants (43 females, 45 males; aged 25-65 years) were stratified by concussion history and current symptom burden using validated clinical measures: Controls (n=29), Lower Symptoms (n=29), and Higher Symptoms (n=30). Participants completed a validated CMI paradigm requiring goal-directed upper-limb reaching movements under four spatial transformation conditions of increasing complexity. Six kinematic measures quantified motor performance: reaction time, movement time, peak velocity, absolute error, variable error, and path length. Multivariate analysis of variance examined Group × Sex effects across all outcomes, with follow-up univariate analyses and simple effects tests for significant interactions.
Results: A significant Group × Sex interaction emerged multivariately (Pillai's Trace=0.246, p=0.048, partial η^2=0.123), driven primarily by peak velocity (p=0.003, partial η^2=0.134) and movement time (p=0.040, partial η^2=0.080). Simple effects analyses revealed striking sex-specific patterns. Males with higher symptom burden demonstrated marked motor slowing: peak velocity decreased 6.37 cm/s from controls (Cohen's d=1.61) and movement time increased 453 ms (d=1.48). In contrast, females maintained remarkably stable performance across all concussion groups: peak velocity varied only 0.32 cm/s (d=0.07) and movement time by 34 ms (d=0.13). Males demonstrated superior baseline performance across all measures, but this advantage progressively diminished with increasing symptom burden, ultimately converging with female performance levels. Critically, spatial accuracy measures (absolute error, variable error, path length) remained unaffected across groups and sexes.
Conclusions: These findings reveal fundamental sex differences in neural vulnerability following concussion, with males demonstrating dose-response motor impairments completely absent in females. The selective deficit in motor timing and output, with preserved spatial accuracy, suggests concussion specifically disrupts motor execution pathways while sparing parietal-mediated spatial transformation processes. This dissociation provides novel insights into the neural substrates underlying cognitive-motor integration and indicates potential differential vulnerability of motor output circuits (corticospinal, cerebellar, or basal ganglia pathways) versus spatial processing networks. The convergence pattern—where males' baseline motor advantage disappears following injury—has critical implications for understanding sex differences in neural plasticity and recovery mechanisms.
Clinical Significance: Current concussion protocols rarely account for sex-specific motor vulnerabilities. These results demonstrate that males may experience substantial functional impairments in motor control despite appearing recovered on standard assessments, supporting the development of sex-stratified evaluation approaches and personalized return-to-work protocols.

P2-E-129 - Stretching the ankle: Differential impacts on postural control in Parkinson's disease, older adults, and young adults

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Details

Postural instability represents a cardinal symptom of Parkinson's disease (PD) typically unresponsive to medical treatments. Distal rigidity and impaired ankle proprioception, known to hinder postural control, occur often in people with PD. Accordingly, ankle-focused stretching may produce meaningful and immediate improvements in stability in this population. In this study, we offer the first direct comparison of postural sway before and immediately following bilateral ankle stretching in people with PD. We examined the acute effects of opposing ankle muscle stretches on postural sway, range of motion (ROM), and proprioception in people with PD, age-matched older adults (OA), and young adults (YA) to provide insight into disease- and age-related changes. We hypothesized that stretching would yield an increased ROM and increased or unchanged proprioception with a negative association between proprioceptive errors and postural sway. We assessed static postural sway with eyes closed, passive and active ankle

ROM, and active ankle proprioception in 20 PD (Age: 69 +/- 9.62, 4 F/16 M), 20 OA (Age: 68.9 +/- 10.9, 16 F/4 M), and 20 YA (Age: 24.7 +/- 3.42, 10 F/10 M) before and after completing passive bilateral opposing muscle ankle stretches (dorsiflexion, plantarflexion). Mixed-Model repeated measures ANOVAs revealed effects of Group and Condition on variables of interest (p<0.05). YA produced greater ROM, OA revealed greater path length in center of pressure (COP), and PD displayed greater sway displacement and variability in multiple directions compared to other groups. Regardless of group, stretching increased proprioception and ROM, while reducing sway adaptability in the medio-lateral direction as indicated from fractal analyses of COP. Results from Pearson's correlations showed that with ROM gains from greater dorsiflexion, people with PD improved postural stability as evidenced by reduced sway amplitude and increased sample entropy of sway, an indicator of greater automaticity to improve balance control. Greater dorsiflexion abilities also positively correlated with increased sway and reduced sample entropy, thus poor postural stability, for YA, and did not positively or negatively associate with postural sway variables for OA. Stretch-induced ankle mobility improvements influenced postural sway differently across groups. In PD, greater ROM apparently restores more effective postural adjustments by alleviating their elevated rigidity. In YA, greater dorsiflexion after stretching likely pushed some participants beyond their typical optimal balance range. OA revealed intermediate responses, reflecting moderate baseline stiffness and subtle sway alterations. We found evidence that the functional impact of stretching depends on baseline rigidity associated with PD and age. Clinicians should tailor ankle stretching and balance interventions to individual rigidity levels and age to maximize mobility gains while minimizing destabilizing effects.

P2-E-130 - Afferent-driven modulation of spinal interneuron circuits across disease stages in amyotrophic lateral sclerosis

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Details

Amyotrophic lateral sclerosis (ALS) is a neurodegenerative disease that progressively disrupts voluntary motor control through combined upper and lower motor neuron degeneration. However, how spinal circuits reorganize during the disease remains poorly understood, particularly in humans. This study examined the function of excitatory and inhibitory spinal interneuron circuits that control upper and lower limb movements, using non-invasive electrophysiological techniques targeting specific afferent–motoneuron pathways at cervical and lumbar levels. These segments are clinically relevant, as spinal-onset forms constitute the predominant clinical presentation of ALS. We compared patients with ALS at different stages of functional impairment to healthy individuals. Inhibitory circuits, especially those activated by muscle spindle afferents (group Ia and II), exhibited an early reduction in inhibitory drive even when motor disability was mild, whereas excitatory propriospinal pathways were more active in patients with greater functional impairment. In contrast, circuits driven by cutaneous or muscle tendon afferents (group Ib) appeared preserved in unstratified group comparisons, but stage-adjusted analyses revealed significant modulation related to disease severity. These findings reveal an afferent- and stage-dependent hierarchy of spinal dysfunction, following a reproducible sequence from early disinhibition to maladaptive excitation. This hierarchical organization mirrors patterns observed at the cortical level, where loss of inhibition is widespread, while increased intracortical excitation emerges selectively in certain clinical phenotypes. Together, these results refine the mechanistic understanding of motor network disorganization in ALS and identify inhibitory interneurons as potential therapeutic targets to stabilize spinal network function.

P2-E-131 - Normal motor execution in Parkinson's disease implies bradykinesia is due to impaired motor planning

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Details

Bradykinesia in Parkinson's disease has been proposed to reflect reduced motor vigour, in which heightened sensitivity to energetic cost of movement biases the motor system toward slower, smaller movements. This account attributes bradykinesia to abnormal motor planning, predicting that movements are inappropriately scaled despite an otherwise intact capacity to execute them. In other words, the vigour hypothesis implicitly assumes that the neural mechanisms of motor execution are normal, and that slowness arises from the selection of an undersized motor command. An alternative hypothesis is that bradykinesia instead reflects impaired motor execution, consistent with reports of irregular spinal motoneuron discharge in Parkinson's disease.

We directly tested motor execution in eleven people with Parkinson's disease and seven age-matched controls using high-density surface EMG during ballistic isometric contractions to 15, 30, and 50% of maximum voluntary force. Participants with Parkinson's disease reached target forces as accurately as controls but were ~150 ms slower. Controls typically achieved the target in a single force burst, whereas Parkinson's disease participants reached the same targets using multiple smaller bursts (mean 2.64 ± 0.27). When deep brain stimulation (DBS) was turned off, movements slowed further and the number of bursts increased (3.03 ± 0.31). Parkinson's disease participants generated only 25% and 31% of maximal force in the first burst when the targets were 30% and 50%, respectively; participants could have used the 31% force (from the 50% condition) to reach the 30% target but did not – consistent with impaired scaling.

Despite these behavioural differences, indices of motor execution were normal in Parkinson's disease. Spinal totoneuron firing rate and discharge variability did not differ between Parkinson's disease on DBS (12.2 ± 1.99 Hz; 37.5 ± 2.33 ms), Parkinson's disease off DBS (12.9 ± 2.50 Hz; 39.6 ± 4.05 ms), and controls (13.0 ± 2.16 Hz; 38.0 ± 3.70 ms). The rate of force generation was also indistinguishable across groups.

These findings demonstrate that the final common pathway for movement, the behaviour of spinal motoneurons and resultant force production, is preserved in Parkinson's disease. Bradykinesia therefore reflects abnormal motor planning rather than impaired motor execution.

F – Adaptation & Plasticity in Motor Control

Poster Cluster (P2-F-132 & P2-F-133)

P2-F-132 - Is auditory-motor adaptation of speech influenced by the search for intelligibility?

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Details

Introduction

Speech auditory-motor adaptation is classically studied using paradigms that perturb auditory feedback, notably via real-time modification of vowel formants (Caudrelier & Rochet-Capellan, 2019; Houde & Jordan, 1998). Although these paradigms have helped describe fundamental mechanisms of speech motor control, particularly within the DIVA model (Tourville & Guenther, 2011), sensorimotor adaptation is often perceived as an automatic process of detecting and correcting sensory errors. However, several

studies suggest that it can be modulated by linguistic constraints, such as when the perturbation causes auditory feedback to cross a phonological boundary (Niziolek & Guenther, 2013), or when the word has a lexical competitor (Bourguignon et al., 2014; Frank, 2011). In this context, the present study aims to examine the influence of task intelligibility demands on auditory-motor adaptation of speech.

Material and methods

A pilot study of the planned experiment was conducted with four native French speakers. They performed a picture-naming task while receiving perturbed real-time auditory feedback of their own voice. Two factors were manipulated: (i) the degree of possible lexical confusion, with 50% of word pairs corresponding either to minimal pairs (confusable) or to acoustically very different words (non-confusable), randomly distributed, and (ii) the level of interaction, with words spoken either alone to a computer or addressed to an interlocutor. Each condition of the interaction variable (i.e., computer vs. interlocutor) included a reference phase without perturbation (baseline), an adaptation phase with a gradual F2 shift, a phase with maximal and constant F2 shift (+30%), and a phase in which auditory feedback returned to normal (wash-out).

Results

Supporting our hypotheses, the first and fourth speakers tended to compensate more for the perturbed auditory feedback when words were confusable, although this trend was not significant (p = .33 for S1, p = .11 for S4), and was not observed in the second and third speakers. As predicted, greater compensation was also observed in the interactive condition, but for the second and fourth speakers only (p < .001 for S2 and S4).

Discussion and Conclusion

The results of this pilot study do not show a systematic effect of the tested communicational factors on the degree of auditory-motor speech adaptation. Nonetheless, the observation of the expected effects in at least half of the participants does not disprove our hypotheses and encourages further investigation with more participants, expected to be recorded by the time of the conference.

P2-F-133 - Balancing effort and intelligibility in speech auditory-motor adaptation

Maeva Garnier [1], **Sarah Rochas Ben Lalou** [2], **Elodie Ronayette** [3], **Fabien Cignetti** [4], **Pascal Perrier** [2]
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Details

This poster cluster presents a series of complementary studies conducted within a broader research project that investigates **speech sensorimotor adaptation as a decision-making process.** Rather than viewing adaptation as a purely automatic response to sensory perturbations, this project adopts a functional perspective in which speakers continuously arbitrate a trade-off between communicative goals and production costs. More specifically, adaptation is assumed to result from balancing, on the one hand, the level of speech clarity that is considered necessary or acceptable in a given context, and, on the other hand, the physical effort – as produced, but also perceiced – required to compensate for altered sensory feedback.

Within this framework, three studies address distinct but interrelated dimensions of this effort–intelligibility trade-off.

First, we examine how speech auditory-motor adaptation is shaped by the physical effort required to generate compensatory articulatory movements, showing that increased mechanical constraints may both limit the magnitude of adaptation and bias the selection of compensatory strategies.

Poster title : « **Articulatory Effort Modulates Speech Adaptation to Auditory Perturbations** »

Authors : Elodie Ronayette, Fabien Cignetti, Pascal Perrier, Maëva Garnier

Second, we investigate inter-individual differences in the perception and self-evaluation of articulatory effort, and assess to what extent these subjective measures account for variability in the degree of speech adaptation across speakers.
Poster title : « **Self-Perceived Effort as a Possible Source of Inter-Individual Variability in Speech Adaptation to Altered Auditory Feedback** »
Authors : Elodie Ronayette, Fabien Cignetti, Pascal Perrier, Maëva Garnier

Finally, we explore how auditory-motor adaptation is modulated by task-related intelligibility demands, by comparing the production of words with low versus high confusability, as well as situations involving communicative interaction with a partner versus simple reading aloud.
Poster title : « **Is speech auditory–motor adaptation driven by intelligibility demands?** »
Authors : Sarah Rochas Ben Lalou, Maëva Garnier

Together, these studies aim to provide converging evidence that speech adaptation reflects flexible, goal-dependent control processes integrating effort costs and communicative benefits.

P2-F-134 - Self-perceived effort as a possible source of inter-individual variability in speech adaptation to altered auditory feedback

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Details

Speech sensorimotor adaptation to altered auditory feedback is typically partial and highly variable across individuals, yet the sources of this variability remain poorly understood. Reduced and slower compensatory responses have been reported in older adults, children, and individuals with neuro-motor speech disorders, and have mainly been attributed to differences in auditory acuity, error sensitivity, or sensory weighting. Building on this literature, the present study tests the complementary hypothesis that speech adaptation is also constrained by the articulatory effort perceived by individuals when producing compensatory gestures, and that inter-individual differences in this perceptual evaluation partly account for variability in adaptation magnitude.

36 French speakers participated in a two-session experiment.
In the first session, participants produced the rounded vowel /ø/ in a picture-naming task while receiving gradually increasing real-time upward shifts of the second formant (F2; 0–50%). Adaptation was assessed acoustically (F2 and F1 changes) and physiologically using surface electromyography (EMG) of the orbicularis oris muscle. F2 compensation was quantified by its maximum magnitude across the perturbation range, its value at a moderate perturbation level (35%), and the perturbation level at which compensation began to saturate, estimated using piecewise regression.
In the second session, the same participants performed sustained, non-vocalized lip-rounding gestures while EMG was recorded. Using a magnitude-estimation paradigm, participants adjusted muscle activation to visually displayed targets defined as percentages of their maximal voluntary contraction (MVC) and rated perceived articulatory effort after each trial. Individual descriptors captured bias and slope of the relationship between objective muscle activation and perceived effort, as well as task performance measures reflecting fatigability over time, and success in maintaining high contraction levels.

Among the 33 participants who showed significant F2 adaptation, only 16 exhibited a concomitant increase in lip muscle activity, indicating a lip-rounding–based compensatory strategy. In this subgroup, maximal F2 compensation correlated with the slope of the effort psychometric function ($r(14)=0.63$,

p=0.009), while the perturbation level at which compensation saturated was predicted by bias in perceived articulatory effort (r(14)=0.69, p=0.010). Reduced compensation at a moderate perturbation level (35%) was further associated with greater fatigability over time and lower success in reaching high contraction levels.

These results support that speech auditory–motor adaptation is shaped not only by sensory error correction, but also by individual differences in the perception of articulatory effort. This perspective may help explain maladaptive speech behaviors in clinical populations (hyperfunctional dysphonia, Parkinson's hypo-articulation).

P2-F-135 - Examining the underlying neural changes during the asymmetric recalibration of bimanual coordination

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Details

Bimanual coordination is common to many daily life activities (e.g. opening a jar); however, a majority of research has examined tasks where both hands perform similar functions (e.g. finger tapping). Far less is known about how we coordinate distinct but complementary movements. Here, we developed a novel experimental paradigm where the two hands jointly control different aspects of a single, virtual cursor moving to a target. Specifically, the paradigm required distributed, but unequal, bimanual coordination, where one hand reaches using a robotic manipulandum (trajectory control) and the other hand rotates using a knob (orientation control). We utilized this paradigm in two experiments:

In Experiment 1 (N = 116; 92 percent right-handed), we characterized the kinematic features of bimanual coordination through an adaptation paradigm. Initial familiarization trials required trajectory control without rotation. Subsequent blocks required both rotation and reaching to move and orient the cursor to a target. During training trials, we introduced visual feedback perturbations to either the cursor trajectory or orientation. Perturbations to trajectory produced adaptive changes in both the perturbed and unperturbed limb, while perturbation to rotation feedback induced minimal changes in the unperturbed limb. Importantly, these findings were independent of reaching amplitude, duration, and limb dominance. This asymmetry suggests cross-limb interactions that may depend on the required motor function and may reflect differences in the underlying neural mechanisms.

Experiment 2 (N=40) extended this paradigm by incorporating electroencephalography (EEG) to examine the neural activity during isolated and combined movements. Participants completed separate rotation only and trajectory only conditions before completing bimanual coordination trials. We observed interhemispheric desynchronization in the beta frequency band (12-30 Hz) during movement execution, coupled with alpha band (8-12 Hz) desynchronization, potentially indicative of attentional, visuospatial and/or sensorimotor engagement. These results provide preliminary insights into the behavioral and neural signatures associated with each motor function and coordinated motor planning. Additionally, the experimental design may allow a dissociation between motor planning and execution, further delineating the neural correlates underlying the asymmetric adaptation in response to the respective feedback perturbations.

P2-F-136 - Consolidation drives flexible, task-specific expression of implicit and explicit motor memory

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Details

Motor learning engages multiple distinct adaptive mechanisms that contribute to the learned behavior. In real-world scenarios, both implicit recalibration and explicit strategic processes are recruited during adaptation, resulting in a behavioral expression that reflects their combined influence. However, how these compound motor memories are stored and expressed over time remains poorly understood. In this study, we investigated how motor memories, formed through simultaneous engagement of implicit and explicit mechanisms, are expressed immediately and after consolidation. We hypothesized that when both mechanisms are engaged simultaneously, the immediate expression would reflect the compound memory. On the other hand, this memory would reorganize into its underlying components following consolidation. Across three visuomotor adaptation experiments (n=120), participants learned to compensate for both target jumps (explicit re-aiming) and gradual cursor rotations (implicit recalibration) presented simultaneously, resulting in a compound memory formation. We systematically manipulated the sequence in which the compound memories were formed by varying when the implicit component was isolated, either prior to or after compound learning. Later, these memories were assessed using the probe trials with clamped zero-error feedback to the target, thereby preventing the online error corrections during expression. Memory expression was tested immediately after learning or after a 24-hour delay to examine the nature of the memory post-consolidation. Immediately after learning, the expression during retention trials reflected the integrated compound motor memory, where both implicit and explicit components were expressed together, regardless of the task demand. However, after 24 hours, the expression was biased towards the individual component depending on the task demand. When the retention context was task-neutral, implicit adaptation remained robust and stable across both immediate and after-consolidation conditions, showing aftereffects. Additionally, when implicit adaptation was stabilized prior to compound learning, the memory was biased towards the implicit component, shaping subsequent expression. But after consolidation, participants showed expression depending on task demand. These findings demonstrate that the compound motor memory formed through simultaneous engagement of implicit and explicit learning processes does not stabilize through consolidation. Instead, this memory undergoes active reorganization, creating flexible, context-sensitive representations of the individual learning states.

P2-F-137 - Involvement of excitatory and inhibitory primary somatosensory cortex activity in motor skill performance and adaptation in underwater environments

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Details

Somatosensory information processing is known to depend on temporal context and long-term experience. However, few studies have examined how environmental changes modulate somatosensory information processing.

The underwater environment is significantly different from the terrestrial environment in human daily life. Immersion in water requires the processing and integration of multiple somatosensory information, including touch, hydrostatic pressure, and temperature. Furthermore, the high viscosity of water significantly changes the drag acting during movement. Therefore, it is thought that the underwater environment affects the sensorimotor system differently from a terrestrial environment.

Therefore, the purpose of this study was to examine the effects of temporal context manipulation and long-term adaptation to an underwater environment on motor control and adaptation.

The subjects were nine male competitive swimmers (20.4 ± 0.96 years old) with over 10 years of competitive swimming experience. The axillae were immersed in underwater conditions at a neutral temperature of 34 ± 0.5°C. First, maximum wrist flexion velocity was measured. Instructions were given to a monitor placed in front of the subjects, and velocity was measured using a photoelectric sensor. Next, subjects performed an adaptation task with a target speed of 50% of their maximum speed. Deviation from the target speed was fed back as ± deg/sec. Somatosensory evoked potentials (SEPs) and paired-pulse inhibition (PPI) were measured before and after the adaptation task. Finally, subjects performed a random speed adjustment task at speeds of 10%, 30%, 50%, 70%, and 90% of their maximum speed. A behavioral index of adaptation skill was calculated as the area under the convergence curve (AUC) of adaptation efficiency to the target speed, and adjustment skill was calculated as the standard absolute error (MAE) from the target speed during the random speed task.

Results showed no significant differences between the land and underwater environments for adaptation to the target speed and the adjustment task, with subjects demonstrating similar skills in both environments ($p > 0.1$). Neural activity in the underwater environment showed a significant decrease in spSEPs both before and after adaptation ($p < 0.05$), and PPI30 was higher than on land ($p < 0.05$), suggesting a decrease in S1 inhibitory function (disinhibition) in the underwater environment. These results suggest that the brain switches the balance between excitation and inhibition in S1 in the unique underwater environment. This adaptive strategy may be involved in motor control and consolidation in the underwater environment.

P2-F-138 - The embodied clock: How Visuomotor control, spatial interaction, and tool embodiment dynamically shape subjective time

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Details

Introduction: Time perception is fundamental to motor control and behavioral planning and is increasingly recognized as an embodied process intertwined with sensorimotor systems. Our research investigates how visuomotor behavior, spatial interaction and tool-use modulate temporal judgments across peripersonal and extrapersonal space.

Methods and Results: Evidence is drawn from three complementary studies demonstrating the plasticity of temporal processing under distinct sensorimotor conditions.

In **Study 1** (N=77), a time reproduction task (1600–2400 ms) quantified extensive oculomotor behavior and autonomic arousal (pupillometry). While blink duration percentage significantly predicted reproduction error (Adj. Marginal-R^2 = 0.362, beta = 2.651, p = 0.0008), the collective set of pupil size and arousal metrics explained the most substantial variance (39.1%) in temporal error. Specifically, greater pupil dilation (higher arousal) at stimulus onset was negatively correlated with error (underestimation), while dilation at stimulus offset was positively correlated with error (overestimation). This suggests the timing of arousal relative to critical events dictates its effect. Furthermore, the maximum rate of pupil change and pupil asymmetry were highly significant predictors of between-subject variability (up to 13% variance), indicating that temporal integration is partially modulated by dynamic, moment-to-moment changes in cognitive-autonomic state. In **Study 2** (N = 100), time reproduction and bisection tasks (2100–2900 ms) probed the effects of spatial distance (60, 120, 240 cm) and tool-use training. Intervals presented in near space were consistently underestimated relative to far space, revealing distance-dependent compression of subjective time. Tool training with a mechanical grabber expanded peripersonal boundaries and shifted baseline timing biases, demonstrating that temporal perception can be recalibrated through spatial interaction and sensorimotor experience. **Study 3** (N=60) used a virtual reality tool-use paradigm under simulated gravitational conditions (microgravity,

Earth, hyper-gravity) to investigate how tool embodiment and perceived agency relate to task load. Rapid tool incorporation into the body schema was observed, evidenced by higher ownership ratings in microgravity correlating with reduced reaching distance (RDE) and forearm tactile distance (TD) estimation errors. Load-dependent effects revealed that mental load increased ownership in young adults, while physical load negatively affected their agency. Fine-grained analysis using an embedded analogue scale demonstrated that the subjective sense of control was a significant predictor of faster movement performance, suggesting a direct link between perceived control and motor timing efficiency, independent of explicit ownership ratings. This relationship pointing to distinct mechanisms underlying agency and motor control.
Conclusion: Synthesizing these results, time perception emerges as a flexible and embodied process, intricately shaped by the integrity of visuomotor signalling, the dynamic influence of autonomic arousal, the brain's spatial map, and tool-mediated motor action. Tool embodiment is context-dependent (gravity) and dynamically modulated by cognitive and physical demands. These findings reveal the profound malleability of internal timing mechanisms, demonstrating their deep and active integration with autonomic state, action planning, and the neural control of movement.
Keywords: Visuomotor control, temporal perception, oculomotor behavior, tool embodiment, sensorimotor plasticity, peripersonal space, gravitational physics, agency

P2-F-139 - Temporal representation shapes motor memory separation
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Details
Effective motor control requires acquiring and selecting among similar motor memories, with contextual cues helping to prevent interference between them. Prior work suggests that dynamic contextual cues, such as follow-through movements, reliably separate motor memories, whereas sensory cues are typically ineffective (Sheahan et al., 2016; Howard et al., 2013, 2015). We recently showed that time, which fits neither category cleanly, can also serve as an effective context. In that work, internally monitored temporal delays supported simultaneous adaptation to opposing perturbations. This motivated us to ask whether the effectiveness of temporal context depends on how temporal information is represented. Specifically, does changing this representation from internally monitored to externally observable alter its impact on motor memory separation?
Participants performed a visuomotor dual adaptation task where reaches were associated with fixed cursor rotations of +15° or -15°. They were informed about the clamped feedback and instructed to ignore it, ensuring that the resulting adaptation was implicit (Morehead et al., 2017). Importantly, each rotation was deterministically linked to either a short (500 ms) or long (1500 ms) preparation delay, with conditions randomly interleaved. Passage of time was externalized by having the target gradually grow to full size over the delay interval, with participants instructed to initiate movement only once the target reached full size. Thus, shorter delays corresponded to faster target growth and longer delays to slower growth. After 400 learning trials, participants completed a 150-trial test phase that probed temporal generalization by introducing intermediate delays at increments of 250 ms (i.e., 750, 1000, 1250 ms) and removing all cursor feedback.
Our results suggest that externalizing temporal context separates motor memories associated with the two opposing perturbations. A preliminary comparison with our previous internally-timed task suggests stronger separation during learning. In the test phase, participants showed a near-linear, stepwise change in hand angle proportional to changes in the temporal delay duration, with a steeper slope than observed with internally monitored delays.

Together, these findings provide early evidence that the representation of temporal information can modulate motor memory separation and generalization. In contrast to purely sensory cues that have proven ineffective, externalizing time through a growing target enabled effective memory separation. Whether this reflects strengthened temporal indexing through externalization, or whether temporal structure renders visual information contextually relevant, remains to be explored.

P2-F-140 - Indirect touch conveys distinct tactile information that can be used to program movements to tactile targets on an artificial body part

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Details

Artificial limbs typically lack tactile and proprioceptive receptors, meaning that users do not receive feedback indicating the outcome of movements of the artificial limb. However, previous work suggests that indirect tactile signals generated by object interactions are transmitted to the interface between the body and wearable artificial limbs or handheld tools, potentially providing a source of usable tactile feedback. In this study, we investigated whether such indirect tactile signals convey distinct information that can be used to localise touch on an artificial body part. Using an additional robotic thumb (The Third Thumb, Dani Clode Design), we measured tactile signals reaching the interface between the Third Thumb and the hand, and assessed whether participants could discriminate these signals and combine them with the Third Thumb posture to spatially localise touch.

We recorded indirect touch signals using a piece of soft, conformable artificial skin, equipped with 12 photonic Fiber Bragg Grating sensors, placed between the Third Thumb handpiece and a mannequin hand. Tactile signals were elicited by four vibration motors located at different positions on the Third Thumb. We recorded these touch signals in six Third Thumb postures ranging from extended to flexed. In our behavioural experiment, participants wore the Third Thumb and localised touch stimuli delivered from the same four locations, across the same six postures. In each trial, participants received a touch stimulus from one of the four locations and pointed with their left index finger towards the judged origin of the stimulus, with their vision and audition occluded. We recorded participants' pointing movements using a custom marker-based motion tracking setup.

Indirect touch measurements revealed that stimulation at each of the four locations produced distinct and reliable tactile signals on the artificial skin. Our behavioural results showed that participants' localised touch at above-chance accuracy levels. Touch locations associated with more discriminable tactile signals (more distinct signals compared to other locations) corresponded to a lower pointing variance. This suggests that distinct touch signals improve localisation precision. Computational modelling showed that participants' behaviour was best explained by the spatial positions of the touch stimuli, rather than limb-based positions or indirect signal patterns alone, demonstrating flexible mapping of indirect touch signals to the Third Thumb posture.

Together, these findings show that indirect tactile signals transmitted through an artificial limb can provide distinct tactile information that the somatosensory system can discriminate and flexibly map to the spatial touch location on the artificial limb. Designing artificial limbs with materials that enhance the transmission of reliable and distinct tactile signals may therefore support more effective tactile feedback for motor control of artificial limbs.

P2-F-141 - Longitudinal changes in hand dominance in normal aging and mild cognitive impairment (MCI): A kinematic study

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Details

Background. Decrements on hand dominance are observed in neurodegenerative conditions affecting older populations. However, currently the issue of how normal aging and the stage of preclinical dementia (i.e., mild cognitive impairment, MCI) affect hand dominance has not yet been explored.
Aim. To investigate longitudinal changes of hand dominance in normal aging and MCI patients through a detailed kinematic analysis of unimanual actions.
Methods. Sixteen MCI patients (*M* age = 67.4 yrs) and 20 healthy controls (HC) (*M* age = 70 yrs), all right-handed, were assessed at two points in time, with approximately 4.5 yrs between test and retest sessions. Two Purdue Pegboard tasks were used to assess performance: inserting pins with the right hand and inserting pins with the left hand. Performance was recorded with a 2D motion capture system (Vicon Motus) and segmented into four movement types: reaching, grasping, transport, and inserting of pins. Linear and angular velocities, as well as path length together with their coefficients of variability were calculated separately for each movement type. Laterality indices (LI) were computed based on the kinematic measures and provided information about the direction and degree of lateralization (-1 to +1). A series of factorial repeated-measures MANOVA were used to examine LI by Test session and Group, while kinematic changes were analyzed across Hands and Test sessions (within-subjects variables) as a function of Group (between-subjects variable).
Results. At time 1, significant group differences in LIs showed values approaching zero for MCI patients, which indicated symmetric movement ability in this group. In contrast, HCs displayed a clear lateralized ability, with larger LIs. At time 2, no group differences in LIs were observed as the HC group also developed symmetric hand dominance like patients. MCIs did not show any change from test to retest, preserving symmetric hand dominance.
Kinematic results showed improved gross motor function (reaching, transport) in the HC group over time, mainly in the left hand. Fine motor function (grasping, inserting) showed declines in this group, for both hands. In contrast, MCI patients demonstrated declines in both gross and fine movements, for both hands.
Conclusions. Our findings suggest that in normal aging gross motor function is preserved, while fine movements show decline. In MCI patients, however, both gross and fine motor function decline longitudinally. LIs clearly differentiated normal controls from patients at early stages, which indicates accelerated loss of hand dominance in the patient group. Hence, loss of hand dominance may serve as an indicator of the early phases of MCI. However, longitudinal findings from both groups suggest that the development of symmetric hand dominance late in life is a hallmark of the aging process and not a distinct trait of pre-clinical dementia.

P2-F-142 - Cortico-cerebellar dynamics underlie flexible control of sensorimotor timing in humans

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Details

Humans can accurately and flexibly learn the timing of movements. Motor timing processes have long been attributed to cerebellar functioning and often tested using well-established models of eyeblink conditioning. Recent animal electrophysiology studies suggest that it is the interconnected cortico-cerebellar loops that adapt to learn distinguishable and precise sensorimotor timing. Uncovering such mechanisms in humans has remained challenging, because of a lack of neuroimaging techniques that

can accurately capture cerebellar activity. Using novel wearable magnetoencephalography called optically pumped magnetometers (OPM-MEG), we obtained simultaneous cortical and cerebellar recordings in humans. This allowed us to elucidate human cortico-cerebellar dynamics during a flexible motor timing task, and how these dynamics change over the course of learning.

Using a novel context-dependent timing task which provides both explicit cortically-generated and implicit cerebellar-generated motor responses following a cue we recorded OPM-MEG activity from cortical motor and cerebellar regions as participants performed the task (*n*=14). We recorded 68-channels of OPM-MEG positioned over both cortex and cerebellum. If manual responses were not made within a Weber-fraction controlled window following the cue, a low-latency air puff was administered. Surprisingly, we detected a well-timed conditioned eyeblink response (CR), which is known to have cerebellar origins, during correct manual response trials. We focused on the emergence of this unexpected, conditioned response.

Manual response and CR timings followed the expected timings for both contexts. During the contextual interval, cortical motor and cerebellar dynamics exhibited beta-band (13-30 Hz) desynchronisation, matching the timescales of the context-guided time intervals. Such motor-related desynchronisation plays a key role in providing accurate predictive timing during sensorimotor events. Cerebellar activity also comprised a unique biphasic gamma-band (30-60 Hz) synchronisation up to 300ms after the context started, which is reminiscent of learning-dependent complex spikes in animal models. The gamma bursts are consistent across participants and cannot be explained by artefacts. Support for cortico-cerebellar interactions were indicated by bidirectional Granger causality in the beta band. Whilst showing resemblances in beta-band desynchronisation, cerebellar beta-band desynchronisation occurred earlier and stronger during the contextual interval relative to the cortical motor areas. Moreover, during initial learning (first 150 out of 450 trials), beta-band desynchronisation of the cerebellum decreased more strongly than the desynchronisation over the cortical motor areas.

In summary, using simultaneous non-invasive recordings of cortex and cerebellum in humans, we reveal macroscopic cortico-cerebellar signatures which support precise and flexible sensorimotor timing, and how these change during learning.

P2-F-143 - Speech motor learning with visual-acoustic feedback: Evidence of a guidance effect

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Details

Speech motor learning under typical conditions is primarily guided by acoustic and somatosensory feedback. Clinical research has also demonstrated that individuals with speech disorders may benefit from the real-time *visual* presentation of oral motor or acoustic parameters (i.e., visual-articulatory or -acoustic biofeedback) during speech practice (e.g., McAllister et al., 2025). The benefits are presumed to arise from increased perceptual salience of properties related to both the individual's speech motor performance and the speech target. It remains unclear, however, whether beyond short-term improvements in speech accuracy, such tools may interfere with retention of speech motor learning following removal of the visual feedback. In motor domains outside of speech such as visually-guided reaching, it is well known that the benefit of providing augmented feedback of performance can depend critically on the frequency of availability -- with high-frequency presentation (e.g., on every practice trial) resulting in reduced retention of motor learning when the feedback is removed (a phenomenon known as the guidance effect; Salmoni et al., 1984). This potential downside of high-frequency augmented feedback is often cited in clinician training guides for treatment of speech motor disorders, however

there is surprisingly little direct evidence that such a guidance effect occurs in the domain of speech-sound (phonetic) learning. The goal of the current study was to specifically explore how the frequency of visual-acoustic biofeedback (VAB) interacts with speech motor learning in a highly controlled phonetic learning task.
Methods: 45 adult English speakers underwent a period of focused speech training to produce a novel vowel target that was situated precisely between the existing English high-front vowel [ɪ] (as in “hid”) and mid-front vowel [ɛ] (as in “head”). On each practice trial, an auditory model of the new vowel was presented for the speakers to imitate, and -- depending on the experimental condition -- visual feedback of vowel spectral properties (first and second formant frequency) from the current attempt was provided. A series of training blocks (64 trials with the auditory model and VAB) were interleaved with test blocks (without the auditory model or VAB), allowing for the assessment of changes in performance and retention. Three groups of participants (n=15 each) differed in the proportion of practice trials during which they were provided the visual feedback: 100%, 50%, and 0% of trials.
Results: Speakers in all three feedback frequency groups showed improvement in vowel production accuracy over the course of training, with the largest magnitude of improvement observed in the 100% visual feedback group. Production of the vowel during the test blocks, however, revealed a difference in performance between the groups, with the 0% and 50% feedback groups showing stronger retention than the 100% group.
Conclusion: The present results suggest there is indeed a risk of a guidance effect when visual-acoustic biofeedback is provided during a focused vowel learning task. While potentially enhancing short-term production accuracy, providing visual augmented feedback of speech performance on 100% of practice trials may interfere with the retention and/or transfer of phonetic learning.

P2-F-144 - Children born without a hand show signs of typical motor development in the missing limb

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Details

Children with a unilateral, congenital, below-elbow deficiency (UCBED) are born with one typical upper limb and one lacking a hand. The level of motor control they have over their missing limb has often been assumed to be limited due to the fact that they have never actuated an intact hand on the affected side. Yet despite this, we have shown that children with UCBED can purposefully control their muscle activity when asked to imagine moving their missing hand. Across 52 participants (ages 5–21yrs), we have observed distinct and consistent muscle activation patterns during up to ten attempted missing-hand movements, resulting in highly accurate prediction of intended gestures using electromyography, ultrasound, and machine learning. We also observed that grasp classification, separability, and variability improve with participant age in both the affected and typically developed limb, and these changes were not different between limbs. This suggests that motor control abilities may still develop in the affected limb on a similar time-course as the typical limb. To examine finer aspects of muscle control, a subset of 12 participants (ages 10–20yrs) modulated their missing-hand force and position during five grasp types. Using mirroring of the typical hand as ground truth, we found that proportional control (modulation of intended force or position in intermediate levels) was reliably achieved and closely correlated with the typically developed limb. These findings represent the largest cohort to our knowledge of this population, revealing that children with UCBED retain rich, controllable motor signals in their residual limbs. This implies that there is a level of motor organization retained in the cortex driving the control of the missing hand. We demonstrate for the first time the factors that influence children’s level of motor control, such as age, limb length, and limb circumference . Importantly, these results raise interesting

questions about the role of sensory feedback in developing robust motor control, and have clinical implications for the future of pediatric prosthetics.

P2-F-145 - Ageing influences motoneuron excitability during acquisition and retention of a force-matching skill

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Details

Ageing is associated with neuromuscular changes that impair physical function and reduce quality of life. Reduced control of muscle force in older adults has been linked to declines in motor neuron (MN) firing frequency, limiting the ability to meet task demands. Persistent inward currents (PICs) play a critical role in enhancing motoneuron excitability by amplifying and sustaining firing; however, PIC estimates have been shown to be lower in older compared with young adults.

This study investigated whether performing an isometric force-matching skill task could enhance PIC estimates in older adults, thereby increasing MN excitability and improving the capacity to modulate firing rates to meet task demands. Motor unit spike trains were decomposed from high-density surface electromyography signals recorded from the first dorsal interosseous muscle of young (18–30 years) and older (65–80 years) adults during ramp-up and ramp-down contractions at 20% of the maximum voluntary contraction force (MVC), before and after a skill-learning paradigm involving randomly varying force targets. PIC contribution to MN firing was estimated using the paired motor unit technique to calculate Δfrequency (ΔF).

Both young and older adults significantly improved target force-matching performance during the learning task ($p = 0.029$). However, older adults demonstrated significantly lower accuracy than young adults, exhibiting greater root mean square error across acquisition and retention sessions (2.69 ± 0.25 vs. 1.66 ± 0.24 %MVC, respectively; $p = 0.007$). At baseline, ΔF was lower in older adults (3.56 ± 0.33 pps) compared with young adults (4.82 ± 0.33 pps; $p = 0.012$). Both groups demonstrated increased ΔF following skill acquisition. However, only older adults showed further increases in ΔF during retention (3.31 ± 0.34 pps vs. 3.86 ± 0.35, pps; $p=0.04$).

Together with poorer force-tracking performance, these findings suggest that older adults may rely on increased motoneuron excitability while continuing to improve force control, potentially as a compensatory response to reduced sensory input. Future research should examine whether incorporating force-matching skill training into exercise programmes for older adults can enhance MN excitability and improve functional performance in daily activities.

P2-F-146 - The many faces of motor learning research

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Details

Motor learning is studied across a wide range of disciplines, including neuroscience, psychology, rehabilitation, sports science, robotics, and computational modeling. While these communities often address related questions, they frequently do so using different concepts, methods, and experimental traditions. As a result, it is increasingly difficult to see how the field fits together as a whole, or whether it is converging at all. Which research communities currently study motor learning? What questions are they working on? And how closely are these communities connected to one another?

Here, we use a large-scale citation network analysis to map the community structure of motor learning research and to characterize the intellectual relationships between these communities. We compiled nearly 27,000 publications spanning the field from its inception through 2025 and constructed a citation network that captures how papers reference one another. Using community detection methods, we

identified clusters of studies that form distinct research communities. To understand what defines each community, we analyzed the keywords and concepts that most strongly distinguish their work and used topic modeling to further characterize research within each cluster.
This analysis reveals that motor learning is not organized into a single, unified field but rather into a collection of partially connected communities. These include neuroscience-focused research centered on specific brain regions and mechanisms, behavioral approaches using diverse task paradigms, and applied traditions such as rehabilitation and skill learning. While some communities are densely interconnected, others show surprisingly limited interaction despite overlapping research goals.
By providing a structural map of motor learning as a network of research communities, this work highlights both the diversity and the fragmentation of the field. We aim to help researchers situate their own work within this broader landscape, promote awareness of neighboring traditions, and encourage reflection on the benefits and costs of conceptual separation within motor learning research.

P2-F-147 - Expansion of working memory capacity explains online gains during naturalistic skill learning

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Details

Real-world motor skills depend on the precise spatiotemporal coordination of action sequences, refined through practice. Performance of naturalistic skills requires working memory (WM) and preplanning of upcoming actions, both contributing to temporarily sustain and manipulate task-relevant information. The relative contribution of WM capacity and preplanning to online rapid skill gains during early procedural skill learning is not known.
To address this gap, we conducted three experiments in which participants learned different naturalistic sequential keypress skills. Within each practice trial and skill, we reproducibly identified segments of high-initial-skill (HIS)—brief periods of elevated performance followed by skill drops, which were absent practicing non-repeating (control) sequences. HIS segment keypress content scaled with speed of practice and continued to expand with training even after skill plateaued, inconsistent with HIS dynamics reflecting reactive inhibition (i.e., motor fatigue). Importantly expansion of HIS segment keypress content predicted performance across the three skills tested.
Alternatively, training-dependent expansion of HIS segment content may reflect the progressive expansion of effective WM capacity supporting the learned skill. We found that, depending on skill speed, HIS segments comprised between 10 and 18 keypress actions, exceeding the typical capacity limits of WM (3–7 items), suggesting that individual keypresses are unlikely to constitute the fundamental units of naturalistic skill memory as training progressed. Importantly 10-18 actions vastly exceed the 2-4 keypresses that can be preplanned. Next, we investigated the organization of HIS segment content into chunks. Chunks simplify sequential execution and memory storage in situations where the number of individual sequence actions exceeds the constraints of WM capacity (e.g., phone numbers or passwords). The key finding was that HIS segments encompassed strikingly similar number of chunks across skills—ranging between 7 and 8—aligning closely with the canonical WM capacity described by Miller's rule (of 7). Crucially, the number of keypresses per chunk kept increasing with practice, even after the overall skill level had reached a plateau, inconsistent with a prominent contribution of reactive inhibitory to HIS segment dynamics.
Finally, MEG analyses revealed elevated theta–gamma phase–amplitude coupling (θ/γ PAC) and beta (β)-band bursts, neural markers of WM capacity, during HIS segments. Of note, hippocampal θ/γ PAC strongly correlated with HIS segment content, identifying a possible mechanism contributing to binding individual actions into dynamic enlargement of WM representations during early learning.

In summary, our findings challenge the notion that reactive inhibition significantly impacts early naturalistic skill learning and instead highlight the crucial contribution of expanding working memory capacity (10-18 items) well beyond the more limited window where preplanning effects are observed (2-4 items).

P2-F-148 - Modeling neural adaptation to permanent musculoskeletal reconfiguration

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Details

Motor adaptation is typically studied in the context of counteracting transient environmental perturbations. In contrast, adaptation to persistent changes in the neuromusculoskeletal system remains poorly understood. Tendon transfer surgeries provide a unique experimental platform as they impose permanent biomechanical changes. Previous studies utilizing this paradigm highlight the complexity of the recovery. A human study investigated within-session adaptation to a virtual tendon transfer under two conditions: compatible surgeries that preserved existing muscle synergies, and incompatible surgeries that disrupted them, thus requiring new patterns of muscle coordination. Incompatible surgeries led to dramatically slower adaptation. A study in monkeys showed that multiple processes may underpin the multi-week process of regaining hand function after an incompatible tendon transfer swapping flexors and extensors. While recent modeling work suggests that adaptation to such transfers requires the reorganization of muscle synergies, the primate study indicates that synergies remain stable. Thus, it remains unclear whether recovery relies on reshaping synergies or plasticity elsewhere in the control hierarchy.

We used a musculoskeletal model (MyoSuite) and reinforcement learning to investigate adaptation to tendon transfer surgeries by physically rerouting muscle tendons in a realistic hand model. For compatible transfers, we swapped the agonist muscles FDS and FDP. For incompatible transfers, we swapped antagonist muscles, FDS and EDC. We trained agents on pose control, object manipulation, and isometric force tasks. To simulate the constraints imposed by relatively fixed spinal circuits, we introduced a synergy bottleneck by explicitly restricting the dimensionality of the layer immediately preceding the action output in the controller network. We simulated transfers affecting one to four fingers and analyzed adaptation dynamics and the controller network changes following each surgery. To probe the locus of adaptation, we selectively froze weights in different parts of the controller network during the adaptation to tendon transfers and compared recovery across conditions.

Our first results confirm that incompatible transfers require longer adaptation periods with larger initial performance drops compared to compatible transfers, with adaptation difficulty scaling to the number of affected fingers. Through weight freezing ablations and analysis of the synergy bottleneck, we aim to gain insights into the underlying adaptation mechanisms and where in the neural control hierarchy plasticity is most critical following persistent neuromusculoskeletal changes.

P2-F-149 - Whole-body motor adaptation during learning for prosthetic limb usage

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Details

Abstract

Motor adaptation to prosthetic control

Motor adaptation to prosthetic control requires whole-body reorganisation beyond the artificial limb itself. This study examines how performance, coordination, movement efficiency, and postural stability

change between adaptation stages (S2: fitting stage → S3: after training stage) during learning to use a multi-DoF myoelectric prosthesis.

Data acquisition
Whole-body kinematics during SHAP, BBT, and CPRT were recorded in one participant using motion capture with a multi-DoF myoelectric prosthesis across adaptation stages, while force plates quantified postural changes. Joint contributions were derived from aggregated DoF range of motion, and movement smoothness was quantified using spectral arc length (SPARC).

Results and discussion
From S2 to S3, adaptation resulted in improved functional performance, smoother joint coordination, and enhanced postural stability across tasks. Joint contribution patterns revealed redistribution of movement from compensatory trunk use toward more balanced upper-limb involvement, indicating progressive whole-body motor reorganisation during prosthesis learning.

P2-F-150 - Effects of multimodal passive training on predictive control of musical meter
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Details
To reduce potential risks triggering overuse syndrome by musical training, passive training of a target sensorimotor skill without voluntary movement production can be a promising approach. However, it is unclear whether passive training is effective for enhancing predictive control of temporal features of intricate movement sequences such as musical meter. Here, we propose a novel multimodal passive training method combining auditory and somatosensory stimulation.
Fifteen musically untrained individuals (i.e. non-musicians) (1 female, 22.1 ± 1.2 years old) and 23 professional pianists (18 females, 22.4 ± 2.5 years old) participated in the study. During the intervention, the participants were exposed to auditory stimuli via headphones and somatosensory stimuli via electrical stimulation of the median nerve. They were randomly assigned to two training groups: the “Lock” group (synchronized stimuli) and the “Unlock” group (asynchronized stimuli). The pretest and posttest were performed before and after the intervention, respectively, which consisted of a piano tapping task incorporating both 2/4 and 3/4 meter. Participants also completed the Micro-PROMS questionnaire to assess latent musical perception abilities.
We applied the Wing-Kristofferson model to the tapping data in order to estimate the central timer variance. We evaluated the effectiveness of the intervention according to a difference in this metric between the pretest and posttest. A mixed-design ANOVA was performed to test the condition effect. The central timer variance was reduced through the intervention specifically in the 3/4 meter under the “Lock” condition ($p < 0.01$). In this condition, a large effect size ($d = 1.17$) was confirmed between the non-musician and pianist groups, displaying a pronounced decrease of the variance for the former group.
To determine whether the group difference was driven by long-term musical training or by latent musical abilities, we performed a correlation analysis using Micro-PROMS scores as an explanatory variable. Overall, there was a significant negative correlation under the “Lock” condition in the 3/4 meter, with having the significant training effect ($R^2 = 0.423$, 95%CI [-0.826, -0.380]). The correlation indicated that the individuals who had a larger decrease in the variance through the intervention in this condition showed a lower latent musical perception ability. With respect to the slope and intercepts of regression lines for the two groups, there were no discernible group-wise differences (all $p > 0.32$), indicating that the two regression lines aligned on a single line.

Our findings suggest that the passive training significantly improved predictive control of musical meter, specifically for the 3/4 meter under the synchronization between auditory and somatosensory stimuli. This improvement was explained by the latent musical perception ability of the individuals rather than their experience of playing musical instruments.

P2-F-151 - The costs of algorithmic force-field "mental rotation": Preparation-time costs scale with strategic compensation strategies in force adaptation

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Details

In visuomotor rotation tasks, the use of strategies has been shown to facilitate rapid learning but at the cost of additional cognitive effort: preparation time increases with the rotation angle of the cursor, echoing classic Shepard mental rotation (Shepard and Metzler, 1971; McDougle and Taylor, 2019). Recent work has reported the use of strategies in other forms of sensorimotor adaptation, such as in force fields (McDougle et al., 2015; Schween et al., 2020; Forano et al., 2022), but it remains unclear whether they incur a comparable cognitive cost as in visuomotor adaptation. Here, we sought to determine whether preparation time increases parametrically with perturbation magnitude in a center-out force-field adaptation task. Participants performed an observe–then–counteract trial-pair task. On the first trial of each pair, participants were instructed to observe a lateral force perturbation while reaching directly to a target. On the second trial, they were instructed to counteract the force they had just experienced in order to reach the target accurately. To prevent cumulative learning, force perturbations were counterbalanced in both magnitude and direction across trials. On a fraction of counteract trials, a force channel was imposed on the movement, allowing precise measurement of predictive force output. To limit preplanning, the target location on the counteract trial either remained the same or switched to a different location. We found that participants reliably scaled their compensatory force in proportion to the magnitude of the previously experienced perturbation—a scaling effect not observed in studies using single-trial designs that primarily elicit implicit adaptation (Fine and Thoroughman, 2006). Critically, preparation time increased parametrically with the magnitude of the produced compensatory force. Moreover, this force-dependent reaction time cost was significantly steeper when the target location changed between observation and counteract trials, indicating an additional planning cost associated with remapping the countering force across movement contexts. In contrast, participants in a control condition, in which they were not instructed to counteract the force perturbation, showed only modest reductions in movement error and exhibited no preparation-time scaling with perturbation magnitude. Together, these findings demonstrate that explicit strategies in force-field adaptation impose a measurable, magnitude-dependent preparation cost that cannot be explained by implicit adaptation alone. This suggests that strategic force compensation relies on an algorithmic and time-consuming planning process, analogous to the mental rotation–like strategies observed in visuomotor adaptation; however, it remains to be determined if strategies for force field adaptation are homologous to visual rotations.

P2-F-152 - Motor adaptation and intermanual transfer do not support the dynamic dominance theory

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Details

Sensorimotor adaptation is driven by sensory prediction error - the mismatch between predicted and actual movement outcomes. Dynamic dominance theory posits that the dominant hand has a more accurate feedforward predictive model of the limb, generating stronger prediction error signals that enhance adaptation. This account further predicts greater intermanual transfer from the trained non-

dominant to the untrained dominant hand, reflecting the dominant hemisphere's ability to engage error-based learning even during non-dominant hand use.
However, support for the dynamic dominance theory has been mixed: our first meta-analysis (N = 23 studies) revealed no significant effect of hand dominance on motor adaptation. In our second meta-analysis (N = 25 studies), we found that motor adaptation transfers robustly across hands (mean transfer = 73.13%). Importantly, this transfer is not modulated by which hand adapts first. Both results argue against the dynamic dominance theory.
We reasoned that these mixed findings likely reflect two factors: pervasive underpowering in prior studies (mean N = 11.41) and a failure to dissociate the explicit and implicit components of adaptation. In particular, opposing effects of handedness on these components may cancel, thereby masking its true influence on adaptation within each process. Moreover, because previous studies have overwhelmingly recruited right-handed participants, it remains unknown whether dynamic dominance, if true, would generalize to left-handers.
To address these gaps, we conducted a series of pre-registered experiments to examine if the dominant hand confers an advantage, using behavioral tasks that isolate implicit (Experiment 1) and explicit adaptation (Experiment 2). Across both studies, we recruited large cohorts of left- and right-handers who adapted using either the dominant or non-dominant hand (mean N = 52; total N = 419).
In Experiment 1, both left- and right-handers implicitly adapted to the same extent with the dominant and non-dominant hands. Implicit transfer across hands was partial (~43.25%). Critically, we found no evidence that intermanual transfer was greater from the non-dominant to the dominant hand.
These results were mirrored in Experiment 2. For both left- and right-handers, the dominant and non-dominant hand explicitly adapted to the same extent. There was near-full explicit transfer across hands (93.13%). We again found no evidence that intermanual transfer was greater from the non-dominant to the dominant hand.
In summary, despite pronounced skill differences between the hands, comparable motor adaptation and symmetric intermanual transfer argue against the dynamic dominance theory. Instead, these data support an effector-independent account in which both hemispheres contribute similarly to motor adaptation.

P2-F-153 - Reduced cortical flexibility during balance perturbations may underlie balance dysfunction in Parkinson's disease

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Details

Uncovering the neural mechanisms of cognitive and motor inflexibility is foundational for precision rehabilitation. Balance perturbations reliably evoke a cortical response (N1) that is associated with cognitive and balance function in young adults, older adults (OA), and Parkinson's disease (PD). People with PD exhibit cognitive inflexibility, such as slower set-shifting, which is correlated with mobility deficits. However, the neural correlates of behavioral inflexibility in PD remain unclear. The N1 decreases with predictability in YA and provides a mechanism to examine cortical flexibility. Here, we used the degree of cortical response habituation to repeated balance perturbations to measure cortical flexibility, and we predicted that it would be diminished in PD and associated with impaired cognitive set-shifting performance and balance dysfunction.
25 OA and 17 participants with PD off dopamine medication received pairs of standing balance perturbations. In each pair, the 1st perturbation occurred with unpredictable timing while the 2nd perturbation followed the 1st with predictable timing. We recorded electroencephalography and extracted the N1 from the central midline electrode as the most negative potential 100-300ms post-perturbation. We calculated N1 habituation as the change in N1 amplitude across perturbations

separately for predictable and unpredictable perturbations (ΔN1). We then determined if N1 habituation differed between groups and tested its associations with cognitive set-shifting (Trail Making Test B-A) and clinical balance function (miniBEST).
In predictable perturbations, N1 amplitude decreased across perturbations in OA (ΔN1=-6±8μV) but not in PD (ΔN1=0.3±8μV, p=0.03). ΔN1 for predictable perturbations was not associated with set-shifting time or miniBEST scores in either group. In unpredictable perturbations, N1 amplitude did not decrease in either group. However, there was a trend for an association between ΔN1 and clinical balance function in PD, with more negative ΔN1 (greater habituation) associated with higher clinical balance function (b=-1.7, p=0.06).
Our findings suggest that cortical response habituation is impaired and may be associated with balance dysfunction in PD. Impaired N1 habituation in PD suggests that neural structures implicated in the pathophysiology of PD are necessary for cortical flexibility. Absence of N1 habituation with unpredictable perturbations in both groups suggests that temporal predictability may be a prerequisite for cortical habituation. These results suggest that neurorehabilitation approaches aimed at enhancing cortical flexibility may improve balance function in PD.

P2-F-154 - Cerebellar contributions to savings in visuomotor adaptation

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Details

Visuomotor adaptation relies on multiple learning processes with distinct neural substrates. The contribution of these processes also changes with age. Yet the resting-state (rs) neural signatures that predict their long-term retention remain poorly understood. The cerebellum supports implicit recalibration, while regions related to visuospatial working memory are associated with early stages of explicit learning. It is unknown whether cerebellar rs-fMRI predicts age-related changes in retaining and re-engaging these components over extended timescales.
Younger (YA, N=25, age=21+3.5y.o.) and older adults (OA, N=23, age=72+6.6 y.o.) completed two visuomotor rotation sessions separated by an average of one week (session 1, S1; session 2, S2). Perturbed trials consisted of a 45° rotation clockwise or counterclockwise, counterbalanced across participants and across sessions. Hand movements were obscured for the duration of the experiment. A target was positioned at 90° (directly away from the participant) on the screen. Explicit learning was measured by selecting the direction of an arrow on the screen to indicate intended movement, while overall movement was measured by the heading angle determined 3cm into the movement. Implicit learning was the angle difference between these two measurements. A subset of participants (OA: N=7, YA: N=7) underwent a rs-fMRI scan at most 4 weeks after the last VMR session. Rs-data was analyzed to calculate fractional amplitude of low-frequency fluctuations (fALFF) within cerebellar functional networks defined from the Yeo 17-network atlas. Correlation analyses tested whether intrinsic cerebellar signal averaged within a network predicted individual differences in implicit and explicit savings, measured by the change in error across sessions for each component.
YA demonstrated faster relearning during the counterbalanced perturbed block of S2, with a large relative contribution of explicit learning, indicating savings after one week. OA relearning during S2 was similar to initial S1 and dependent on implicit processes, indicating a lack of savings. Measures of same-day savings from both groups had similar contributions of explicit and implicit processes. Preliminary imaging findings revealed a positive trend between fALFF in visual-related cerebellar regions and implicit savings (p=0.045). Cerebellar fALFF in the frontoparietal network showed a negative association with explicit savings (p=0.031), potentially indicating cerebellar compensation for explicit processes.
These results provide initial evidence that spontaneous cerebellar oscillations are indicative of long-term retention of distinct motor learning processes. Explicit savings was negatively correlated with cerebellar

fALFF within frontoparietal rs-networks across all learners. Implicit savings was positively correlated with visual rs-networks. Together, these results indicate how cerebellar function may contribute to maintaining motor performance with age.

P2-F-155 - Implicit and explicit motor adaptation processes vary between morning and afternoon

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Details

Motor adaptation depends on two separate processes: explicit (conscious, intentional) and implicit (unconscious, automatic). These processes work together to gradually reduce errors and achieve accurate movements. Recent research has highlighted competitive interactions between them (Albert et al., 2022), which might explain differences in motor adaptation under various conditions, such as age (Cisneros et al., 2024) or mental fatigue (Apreutesei & Cressman, 2024). The influence of other factors, such as time of day—which affects motor learning (Truong et al., 2022)—on the explicit and implicit parts of motor adaptation remains uncertain. In this study, we investigated possible diurnal fluctuations in visuomotor adaptation when both components are active (Exp. 1), or when either the implicit (Exp. 2) or explicit (Exp. 3) component is isolated. All experiments involved participants (Exp. 1, n=34; Exp. 2, n=30; Exp. 3, n=34) completing a 45° clockwise (CCW) visuomotor adaptation task. Participants were split into two groups, with sessions scheduled at 10 am (morning) or 3 pm (afternoon). Before the adaptation phase, all participants completed familiarisation (40 trials) and baseline (40 trials) sessions, with only the adaptation phase varying across groups. In Exp. 1, participants performed 320 trials and reported their adaptation strategies (explicit adaptation) every 3 trials using the 'verbal report' method (Maresch et al., 2021). Implicit adaptation was determined by subtracting explicit adaptation from the total adaptation. In Exp. 2, participants completed 480 'clamped visual feedback' trials (Cisneros et al., 2024) to isolate the implicit component. In Exp. 3, the explicit component was isolated using 'delayed visual feedback' (Cisneros et al., 2024) over 128 trials. In all three experiments, the adaptation phase was split into early and late stages, representing the start and end of adaptation (40 trials each). When both components were active (Exp. 1), a repeated measures ANOVA with factors group (morning/afternoon) and phase (early/late) showed significantly faster adaptation in the afternoon during the early phase ($p<0.01$). This was mainly due to greater engagement of explicit strategies in the afternoon ($p<0.01$), although implicit adaptation did not differ between groups. Conversely, when the components were isolated, neither explicit (Exp. 2) nor implicit (Exp. 3) adaptation exhibited time-of-day differences during early learning ($p>0.5$). Importantly, no differences between groups were observed during the late phase of adaptation in any of the three experiments ($p>0.5$). These results suggest that diurnal effects only appear when both components are expressed together. Specifically, during early adaptation, these processes seem to compete in the morning, with a weaker expression of explicit strategies resulting in slower adaptation, while in the afternoon, implicit and explicit components appear to work together, leading to more efficient and quicker adaptation.

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P2-F-156 - A counterintuitive effect of rewards on implicit adaptation

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Details

Sensorimotor adaptation enables us to recalibrate movements to changes in body and environment, a process studied in visuomotor rotation tasks (VMR) involving reaching movements with rotated cursor feedback. Adaptation is thought to arise primarily through sensory prediction errors (SPE), but is also impacted by target errors (TE) and reinforcement mechanisms. A challenge for researchers has been to isolate how these processes impact adaptation. SPE learning has been linked to cerebrocerebellar loops, encoding the discrepancy between predicted and actual sensory feedback. Cortical circuits have been associated with TEs, which represent the direction and magnitude of errors to a reaching target. Supplementing sensory feedback with rewards appears to aid motor performance via mesolimbic reward circuitry, aiding future action selection. A concern with attempts to distinguish across these 3 processes relates to the conflation of TEs and rewards in VMR tasks. Some researchers have provided extrinsic rewards (e.g., money), whereas others relied on intrinsic rewards (ie, target success). The latter conflates the vectorial TE and a non-vectorial reward. In this study, we dissociated the contributions of TE and reward, while controlling for SPE learning, to test whether these signals independently impact implicit adaptation.

In a pre-registered (N=64) VMR experiment, we provided explicit instructions to ignore a 3° clamped feedback cursor. We manipulated TE via target size, such that the clamped cursor either hit (no TE) or missed (TE) the target. Some participants received performance-based monetary reward when they successfully reached to the intended target. Thus, reward was given for not adapting to the cursor. We predicted that adaptation, reflected by changes in reach direction opposing the clamp, should be attenuated without TE. We expected mitigated adaptation in reward groups, because rewards were given exclusively for accurately reaching to the target.

Adaptation was attenuated in no-TE groups ($p<.01$). However, errors (compensating for the clamp) increased when rewards were present rather than absent ($p=.02$). In support, rewards at trial t-1 led to a larger compensation at trial t ($M=7.4°$) compared to non-rewarded trials ($M=-1.5°$). When we calculated each participant's reward history (preceeding three trials), the magnitude of compensation scaled with reward prediction error at t-1.

In summary, reward uniquely impacted adaptation. Rather than reinforcing actions to maximize monetary gain, reward augmented error compensation. The process is potentially one of enhanced error salience on rewarded trials, resulting in subsequent amplification of involuntary corrections. In a second study, we will test this by introducing extrinsic reward at adaptation asymptote. This allows us to test, with competing computational models, whether error amplification persists when adaptation saturates and individual differences in obtained rewards are minimized.

P2-F-157 - Who's in control? Agency for an augmentation finger with autonomous perception

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Details
Recent advances in sensing and autonomous control have transformed fields such as robotics and transportation, yet most human motor assistance and augmentation technologies still rely on continuous user-driven interfaces such as motion and force sensors or bioelectrical signals (EMG, EEG). While these approaches allow fine-grained control, they often impose substantial cognitive and physical demands on the user and remain sensitive to noise and calibration drift. An open question is whether perception-driven autonomy—widely used in autonomous systems—can support effective, intuitive, and trustworthy control in human assistance and augmentation without diminishing the user's sense of agency.
We investigate this question using a supernumerary robotic finger (SRF), the Third Thumb (Dani Clode design), controlled either by conventional toe-controlled force-based input or by a compact LiDAR-driven autonomous control strategy. A miniaturized time-of-flight LiDAR sensor embedded at the fingertip enabled real-time depth perception and closed-loop control of object detection, approach, and grasp execution, with user input reduced to a simple binary intent signal. In a within-subject, counterbalanced study, participants completed a series of increasingly difficult fragile-object transport tasks under both control modalities. Performance metrics were complemented by a dual-task cognitive load paradigm and both explicit and implicit measures of causality, agency and embodiment, including an intentional binding task.
LiDAR-based autonomous control yielded significantly higher baseline success rate, reduced error rates, and greater movement efficiency compared to force-based control and kept equivalent or superior performance for higher task demands. Crucially, autonomy did not impair subjective agency or embodiment, which were comparable across control modalities, nor did it increase sensitivity to cognitive load. Similarly, binding effects for both control modalities were statistically equivalent. These findings suggest that perception-driven autonomy can enhance motor performance and efficiency in augmentation devices without undermining the user's sense of control.
Overall, this work demonstrates the feasibility and benefits of integrating compact LiDAR sensing into wearable motor augmentation, highlighting a promising path toward more adaptive, robust, and user-friendly human–machine collaboration.

P2-F-158 - Effect of exogenous dopamine on implicit and explicit sensorimotor adaptation
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Details
Sensorimotor adaptation involves both implicit and explicit learning processes driven by sensory prediction errors and task errors. Recent theories propose that implicit and explicit learning systems compete for shared error signals, yet the neurochemical mechanisms modulating this competition remain unclear. Dopamine has been implicated in processing performance prediction errors during motor behaviour. Dopamine may thus also influence how implicit and explicit systems respond to task errors during adaptation.
In a double-blind, placebo-controlled study using a between-subjects design, 57 healthy adults received either levodopa (100mg/25mg benserazide) or placebo, before performing a visuomotor rotation task where implicit and explicit processes were set in conflict, as per Mazzoni and Krakauer (2007). Participants were explicitly instructed to counter a 45° rotation of hand-movement feedback by re-aiming away from an original target, by aiming toward a neighbouring target positioned 45° away from the original target. No extrinsic rewards were provided during the task. During exposure to the cursor rotation, participants who received Levodopa showed reach directions with more than one mode, with a

primary mode at 45.3° containing 67.2% of trials (indicating successful re-aiming); a secondary mode at 91.7° containing 27.7% of trials (suggestive of implicit drift), and a small outlier component (5.1%)). Participants who received placebo showed a predominantly unimodal distribution, with 97.2% of trials centred at 42-46° indicating successful re-aiming, and 2.8% of trials representing outliers. Participants who received Levodopa also showed a larger increase in reaction times relative to baseline than participants who received during early and middle adaptation phases (148.7ms vs 102.6ms early; 68.0ms vs 16.2ms middle). However, Levodopa did not alter post-training implicit aftereffects or explicit strategy measures.
These effects might have resulted from exogenous dopamine ncreasing the expression of implicit processes, increasing implicit drift but incurring a cost to explicit processes, as shown in lengthened reaction times. Alternatively, exogenous dopamine might have suppressed the expression of explicit processes, which might have resulted in a compensatory increase in reaction time and an increase in implicit drift, consistent with an inverted-u shaped relationship between brain dopamine and cognitive control. Future studies will be required to disambiguate between these possibilities. Our findings are broadly consistent with dopamine's role in evaluating natural performance fluctuations in the absence of extrinsic rewards. These results provide the first direct evidence for dopamine's role in human sensorimotor adaptation using a paradigm where implicit and explicit systems compete for error signals.

P2-F-159 - Movement paired with nerve stimulation generates plasticity in the human motor system

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Details

Over 50% of spinal cord injuries (SCI) result in tetraplegia, leaving more than half of the SCI population with upper limb impairments. Patients consistently prioritise regaining arm and hand function over other outcomes, including walking, bowel/bladder control, and pain relief. However, conventional rehabilitation lacks strong evidence for sustained functional gains, highlighting the need for novel neuroplasticity-based therapies.

This study investigated whether plasticity can be induced within the motor system by pairing voluntary movement with peripheral nerve stimulation (PNS). Healthy participants performed precisely timed index finger abduction movements in response to an on-screen cue, paired with ulnar nerve stimulation at motor threshold. Motor evoked potentials (MEPs) elicited by transcranial magnetic stimulation (TMS) over the primary motor cortex were recorded before and after the intervention. A high-dose protocol (216 pairings; <20 minutes) produced significant facilitation of MEP amplitude 20 minutes post-intervention (+88%; p=0.0056), demonstrating a progressive increase in corticospinal excitability. A lower-dose protocol (108 pairings) produced non-significant increases, highlighting the importance of stimulation dosage for plasticity induction.

To investigate the site of plasticity, MEPs were also elicited using transcutaneous cranial electrical stimulation (tCES), which activates corticospinal axons directly and therefore is less dependent on cortical excitability than TMS. tCES-MEPs increased by 24% (p=0.0449) 20 minutes following the intervention, indicating that plastic changes occurred at corticomotoneuronal synapses. The larger facilitation observed with TMS compared to tCES suggests that plastic changes within the cortex also contribute to the overall effect.

Reticulospinal contributions were assessed using the StartReact paradigm, which measures reaction time shortening following a startling acoustic stimulus. Responses remained unchanged, suggesting no

reticulospinal involvement. TMS paired with acoustic startle also showed no significant changes, suggesting that changes in cortico-reticular connections did not contribute to the observed effect.

Pairing precisely timed voluntary movement with PNS enhances motor output through an effect on cortical excitability and enhanced corticomotoneuronal connections. By integrating stimulation with natural voluntary movement, this protocol shows promise as an accessible and engaging home-based rehabilitation strategy for improving motor deficits following neurological injury.

P2-F-160 - Exploring the neurocognitive basis of phantom limb sensations and pain

Malgorzata Szymanska [1], **Hristo Dimitrov** [1], **Vicky Root** [2], **Guan Yu Seng** [1], **Rani Moran** [2], **Nicholas Holmes** [3], **Flavia Mancini** [1], **Tamar Makin** [1]
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Details

Following limb amputation most individuals experience phantom limb sensations (PLS), ranging from non-painful to painful phantom limb pain (PLP), with an often blurry boundary. Research has been constrained by the subjectivity and heterogeneity of phantom experiences, amputation-related covariates, the physical absence of the limb, alongside historically debated accounts spanning peripheral explanations and maladaptive cortical remapping. We treat PLS/PLP as a unified neurocognitive account of inference under uncertainty: residual peripheral activity persists after limb loss but evidence is weak while internal beliefs and predictions about the missing limb remain. Our aim is to test how this internal model is maintained under altered input and whether phantom experiences reflect individual differences in weighting prior expectations versus ambiguous evidence. We hypothesise that phantom experiences reflect increased reliance on prior predictions over degraded evidence. We test this framework with two complementary studies.

Study 1 explores learning and belief updating about aversive outcomes. Amputees across PLP severity and controls learn cue-outcome associations for painful vs non-painful thermal stimuli. Surprise trials deliver an unexpected outcome, allowing us to quantify expectancy bias when predictions are violated. We manipulate context (passive vs phantom-movement trials) and environmental statistics (stable vs volatile contingencies via reversals) and we will fit reinforcement-learning models to quantify updating. Ongoing data (n=10 amputees, n=13 controls) qualitatively shows amputees having higher learning accuracy and a stronger expectancy bias on surprise warm trials (pain expected, non-pain delivered), in the passive condition, consistent with priors shaping beliefs.

Study 2 investigates sensorimotor inference under degraded peripheral evidence: how perceptual decisions are made under manipulated evidence strength. Single-pulse TMS over M1 (80-120% rMT) is used to evoke movement-related sensations while high-density EMG measures motor-evoked potentials (MEPs). We compare missing versus intact hands within participants and test report–MEP coupling between groups. Preliminary data (n=2 amputees, n=5 controls) show reliable evoked sensations and MEPs in amputees, but reduced alignment: amputees report sensations despite fewer MEPs than controls, consistent with weaker coupling between peripheral evidence and perception. Planned drift diffusion modelling will capture evidence accumulation and decision thresholds.

Together, these studies operationalise how priors and evidence are integrated when evidence is weak, ambiguous, or mismatched with predictions in the phantom experience. Larger samples and modelling (reinforcement learning; drift diffusion) will provide further information of whether PLS/PLP track a shift toward prior-weighted inference and will be presented at the meeting.

P2-F-161 - Perceptual sensitivity supports online control, while perceptual errors drive predictive control in walking

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Details

Humans rely on perception and action to adjust walking when the environment changes. These adjustments draw on fast feedback corrections and predictive mechanisms that support sustained changes in gait. Although motor adaptation is well studied, less is known about how perception relates to these processes and how it adapts during sustained movement perturbations.

We hypothesized that perception of leg speed differences would change after a locomotor adaptation protocol, and that this perceptual adaptation relates positively to motor adaptation and learning. We measured perception and movements in young healthy adults (n=14, 9 females, 20.86 ± 1.92 y.o.) before and during split-belt walking, where the legs moved at a constant speed difference of 0.5 m/s. Perception of leg speed differences was measured using two-alternative forced choice tasks throughout the protocol. At each perceptual trial, participants had up to 9 seconds to indicate which leg was perceived as slower while experiencing smaller speed differences ranging from 0.05 to 0.45 m/s. Each of the speed differences was repeated at least 10 times. We used participants' choices to estimate: 1) perceptual sensitivity, which captured speed differences that were consistently detected, and 2) perceptual errors, which captured the mismatch between perceived and actual speed differences.

We found that higher perceptual sensitivity predicted step-by-step corrections during early split-belt walking ($p=0.003$), but did not relate to aftereffects during regular walking post-adaptation ($p=0.084$). These results indicated that perceptual sensitivity supports online control rather than predictive adjustments. Conversely, perceptual errors predicted aftereffects ($p=0.003$), but did not correlate with step-by-step corrections ($p=0.44$), suggesting that perceptual errors drive sensorimotor adaptation. Lastly, perceptual errors were reduced during split-belt walking ($p<0.001$), but perceptual sensitivity remained constant ($p=0.236$). Thus, sustained external perturbations adapt people's walking without altering their sensitivity to such disturbances.

Taken together, our findings demonstrate that perceptual sensitivity predicts real-time stabilization, whereas perceptual errors may be the teaching signal driving motor adaptation in walking. These results clarify how perceptual and motor processes support flexible walking and motivate future work in clinical populations with sensory impairments.

P2-F-162 - The physiological aging of the proprioceptive system: Insights from behavioral performance and cortical functional connectivity

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Details

Proprioception, the sensory capacity that enables the perception of body position and movement, depends on a range of peripheral and central structures that may undergo age-related changes, leading to declines in proprioceptive function. The present contribution investigates the effects of physiological aging on proprioception by reporting findings from two studies.

In the first study we characterized how the sense of position and movement changes during aging. Twenty-nine young and 26 healthy older adults completed three experiments designed 1) to evaluate how accurately participants could reproduce a target wrist angle in a position-matching task; 2) to explore the perception and subsequent reproduction of an illusory movement induced through proprioceptive stimulation delivered at multiple frequencies; 3) to examine participants' ability to discriminate between illusory movements generated by distinct vibration frequencies using a two-

alternative forced-choice paradigm. In the position-matching task, no significant group differences in reproducing the target angle were found. In contrast, older adults experienced markedly stronger movement illusions, reporting sensations of faster and larger displacements than young adults, particularly at the lower stimulation frequencies. Psychometric analyses further revealed that older adults showed diminished sensitivity in distinguishing between different illusory movement magnitudes relative to their younger counterparts.
The second study described how the functional connectivity between the posterior parietal cortex (PPC) and the primary motor cortex (M1), two key cortical hubs for processing proprioceptive afferences, changes during aging. Connectivity was measured in 25 young and 27 older adults using a dual-site TMS protocol, administered both at rest and during proprioceptive stimulation, across four inter-stimulus intervals (4, 6, 8, 10 ms). A subgroup of older participants (n=12) also completed a movement-reproduction task to evaluate proprioceptive accuracy. Bayesian analyses assessed group and condition differences. Young adults showed clear facilitation at shorter intervals (4–6 ms) at rest, whereas older adults did not. Under proprioceptive stimulation, the young group maintained similar facilitation patterns, while older adults displayed delayed facilitation, emerging only at longer intervals (8–10 ms). Moreover, stronger PPC–M1 coupling was linked to better proprioceptive performance in the elderly subgroup.
These findings suggest that aging amplifies illusory movement experiences by older adults, likely reflecting alterations in the mechanisms regulating Ia muscle spindle responses and in the central processing of proprioceptive afference. Moreover, the cortical network responsible for integrating these signals exhibits a shifted temporal profile, characterized by slower and less efficient functioning, which may further contribute to age-related declines in proprioceptive performance.

P2-F-163 - Predictive sensorimotor signaling during recovery of fine hand movements after spinal cord injury

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Details

The lateral corticospinal tract (l-CST) is essential for precise hand movements in primates, and its lesion impairs fine motor control. Our previous studies showed that the ipsilesional motor cortex contributes to recovery via interhemispheric pathways. However, the role of the sensory system remains unclear. Because sensory feedback is critical for motor control, we hypothesized that the primary somatosensory cortex (S1) also supports recovery. In intact monkeys, S1 receives an efference copy from the primary motor cortex (M1) before movement onset which would predict the action outcomes. As the evaluation of the prediction error becomes crucial after injury, we further hypothesized that this efference copy system dynamically changes during recovery. To test this, we recorded electrocorticography from bilateral M1 and S1 while macaque monkeys with right C4/C5 l-CST lesions performed precision grip and gross grasp tasks. In intact animals, Granger causality analysis showed that pre-movement connectivity in the high-gamma band increases from contralateral M1 to S1 during the task, whereas activity and signal flow from ipsilateral M1 remain minimal. In early recovery, high-gamma activity during precision grip increased in bilateral M1 and S1. Granger causality analysis revealed enhanced interhemispheric connectivity from ipsilesional M1 (Ip-M1) to contralesional S1 (Co-S1) before movement onset in precision grip, which declined in late recovery as performance plateaued. By contrast, during gross grasp, the interhemispheric connectivity did not increase, although the activity in high gamma band was increased in the Ip-M1 in the early recovery stage. These results suggest that, although the Ip-M1 was involved in both gross and precise hand movements during the early recovery stage, it sends the motor command signals not only to the spinal cord but also to the sensory cortex, specifically for the precise

hand movements. This signal flow from Ip-M1 to Co-S1 before movement onset is potentially involved in the prediction of movement outcomes and the estimation of prediction errors, thereby contributing to the recovery of precise hand movements.

P2-F-164 - Thalamic deep brain stimulation restores motor adaptation in essential tremor

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Details

Essential Tremor (ET) impairs sensorimotor adaptation. Prior work suggests that deep brain stimulation (DBS) of the ventral intermediate nucleus (VIM) of the thalamus may further exacerbate this deficit (Chen et al., 2006). However, because motor adaptation arises from multiple learning processes, it remains unclear which components are specifically affected by ET or by VIM-DBS. In this preregistered study, we used two complementary tasks—one isolating implicit adaptation and one isolating explicit strategy use—to determine how ET and VIM-DBS influence these distinct motor learning processes. We tested 31 ET patients in both DBS ON and DBS OFF conditions, and 32 age- and sex-matched healthy controls. Participants performed reaching movements using a robotic manipulandum and received visual feedback on a monitor that occluded vision of their hand. To induce learning, the feedback cursor position was experimentally manipulated: delayed feedback isolated explicit strategy use, while clamped feedback isolated implicit adaptation (Brudner et al., 2016; Morehead et al., 2017).

Performance when delayed feedback was similar in the ET and Control groups, with no change between DBS ON and DBS OFF. As such, explicit strategy use is unaffected by either ET or DBS. In contrast, adaptation in response to clamped feedback was significantly attenuated in ET patients relative to controls when DBS was OFF, suggesting disrupted implicit adaptation. Contrary to previous findings, turning DBS ON restored rather than disrupted implicit adaptation. Importantly, this recovery could not be explained by DBS-related tremor suppression. These findings show that VIM-DBS restores implicit adaptation in ET without altering explicit learning strategies. I will discuss potential circuit-level mechanisms through which thalamic DBS modulates sensorimotor adaptation and clinical implications of our findings.

P2-F-165 - Context dependent protection of reactivated motor memory

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Details

Newly acquired memories are initially fragile and are transformed into stabilized long-term memory through a process of consolidation. Although consolidated memories were once thought to be resistant to any interference, accumulating evidence has shown that memory reactivation returns them to a transiently labile state during which they are susceptible to modification or interference before reconsolidation. Crucially, however, there is a lot of variation in whether reactivated memories are sometimes disrupted by new information, yet at other times are protected or even strengthened, and what guides this modification is largely unknown. To systematically investigate this, we examined motor memory interference using a classic A-B-A visuomotor rotation paradigm. Participants adapted to a 30° clockwise rotation (A) on Day 1. On Day 2, an interfering 30° counter-clockwise rotation (B) was introduced under varied conditions: directly without reactivation, after brief reactivation of A, after expression of A without feedback, or following a gradual transition from A to B. A final experiment used explicit contextual cues (secondary follow-through target) to distinguish A and B trials. Contrary to the

reconsolidation theory, reactivating the original memory before introducing interference led to its protection, evidenced by significant savings upon relearning on Day 3. In contrast, introducing interference directly without reactivation caused disruption of the original memory. This protection was mediated by contextual inference: the large sensory prediction error experienced during the abrupt transition from A to B served as a latent contextual cue, signaling a new context and thereby shielding the original memory from overwriting. Eliminating this prediction error—through an immediate washout session with a similar error profile or through a gradual A-to-B transition—abolished the protective effect and led to the disruption of original memory. Furthermore, when explicit contextual cues distinguished the two perturbations, memories were protected even in the absence of a salient prediction error. Our findings demonstrate that the fate of a reactivated memory - whether it is modified or protected - is guided by contextual inference, supported by both explicit cues and latent signals such as sensory prediction error. These results align with the COIN (Contextual Inference) model, where the brain infers whether new experiences originate from the same or a different latent cause, updating an existing memory only when the context is judged to be the same. Thus, contextual inference, driven by explicit or latent cues, critically determines whether consolidated motor memories are disrupted or preserved upon encountering interfering information.

P2-F-166 - Walking on the Moon reveals a conserved motor control strategy for adaptive locomotion in hypogravity

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Details

Astronauts on the Moon spontaneously adopted a skipping gait, yet the neural basis of this behavior has remained unexplained. Here we show that skipping in hypogravity reveals a conserved motor control strategy based on flexible timing rather than structural reorganization. In humans walking, running, and skipping under simulated lunar and Martian gravity selectively reshape the temporal activation of muscle synergies while preserving their spatial composition, enabling the expression of a more stable non-canonical gait. We also identify a homologous adaptation in mice exposed to hypogravity, where an asymmetric skipping-like gait spontaneously emerges. Using genetic ablation, we demonstrate that muscle proprioceptive feedback is required for this flexible retuning. Together, these results reveal a conserved, proprioception-dependent neural strategy that flexibly adapt locomotion to different gravitational environments.

P2-F-167 - The effect of continuous theta-burst stimulation (cTBS) to posterior parietal cortex in a visuomotor adaptation task

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Details

Motor adaptation is the process by which sensorimotor representations are updated during goal-directed movements. Prior work has shown that left, but not right, posterior parietal cortex (PPC) lesions disrupt visuomotor adaptation in both contralesional and ipsilesional arms (Mutha et al., 2011). Supporting this, cathodal high-definition transcranial direct current stimulation (HD-tDCS) to the left-PPC in neurotypical adults has been shown to disrupt both adaptation and interlimb transfer (Kumar et al., 2020). However, recent work from our laboratory found that left-PPC stimulation (anodal HD-tDCS) had no effect on initial adaptation, but facilitated intermanual transfer (Dexheimer et al., 2026) from right to left arm. In contrast, right-PPC anodal tDCS stimulation had no effect on any phase of transfer. This apparent discrepancy may reflect differences in the polarity, strength, timing, and/or spatial specificity of

stimulation effects: lesions produce permanent loss of neural function, whereas non-invasive brain stimulation (NIBS) modulates excitability.
To further investigate the role of PPC in visuomotor adaptation with a more spatially localized technique, we used continuous theta burst stimulation (cTBS), a form of repetitive transcranial magnetic stimulation (rTMS) that induces strong but temporary inhibition of cortical activity, to test whether transient suppression of PPC mimics lesion effects on visuomotor adaptation. Healthy, right-handed young adults received 40 seconds of cTBS to the left or right PPC (three pulses at 50 Hz repeated at 5 Hz; Huang et al., 2005) at 70% of resting motor threshold (RMT), defined as the minimum intensity at the motor hotspot that elicited ≥50 μV muscle response in ≥50% of trials. Following a baseline phase without stimulation or visual perturbation, participants received cTBS or sham stimulation, followed by exposure to a 30° visuomotor rotation with their dominant (right) hand. This was followed by reaching with the non-dominant (left) hand under rotated feedback, and a final non-dominant hand phase with veridical feedback to assess aftereffects. Preliminary results demonstrate left-PPC stimulation interfered with right arm adaptation, most notably in the later phase, consistent with prior lesion studies. In contrast, right-PPC stimulation improved intermanual transfer to the left arm, plausibly through reducing interhemispheric inhibition during initial learning. These findings are compatible with the idea that strong inhibition of left-PPC (or lesion) interferes with adaptation. The effects of right-PPC stimulation might be related to reducing interhemispheric inhibition during adaptation. Further research is necessary to probe these preliminary conclusions.

P2-F-168 - Practice makes precision: Motor execution improvements in a 2-D racing task are retained and generalized but depend on movement direction

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Details

Humans are remarkable in acquiring motor skills and refining movement execution through practice. Previous motor learning research have focused on how we establish or adapt control policies, to select and perform appropriate actions. Beyond correct action selection, however, most daily tasks require that we refine motor acuity by executing actions with greater accuracy and precision. The underlying mechanisms of such motor execution improvements are not well understood. Hence, we examined whether the principles that underlie learning during skill acquisition also drive continued improvements in motor performance during skill-based practice.
We developed a 2-D racing task where participants controlled a race car with a stylus on a digitizing tablet while viewing the car and track on a monitor. Their goal was to navigate the track as quickly and accurately as possible, with off-track movements penalized to enforce accuracy. We assessed performance using measurements of lap time (speed), percentage of on-track movements (accuracy), and path length (efficiency). On day 1, participants (N = 45) completed 300 training laps. On day 2, participants (N = 43) performed 30 laps on the trained track to assess retention. We then tested for generalization by manipulating the track: participants completed 30 laps with the track orientation flipped 180°, 30 laps of moving the hand along the track in the reverse direction, and finally 30 laps on the trained track.
Accuracy was immediately high (>90%), but lap times and path lengths showed continued improvements across the first day. On the second day, we observed robust retention, with offline gains in accuracy ($p = .02$) and sustained path length ($p = .5$). Notably, greater within-session accuracy improvements on day 1 were associated with smaller offline gains ($r = –.55$, $p < .001$). For the flipped track, speed and accuracy initially declined before quickly rebounding, indicating partial generalization. For the reverse movement direction, accuracy also dropped at first but improved within the block. However, final lap times and path lengths remained longer than the final trained-track block ($p < .001$), suggesting no generalization to the

reverse movement direction. The absence of generalization could either be due to learning interference or inherent movement biases in right-handed participants. Thus, in a second study, participants (N = 38) experienced the same experiment but trained with the reverse direction. Although accuracy improved across both training days, overall lap times and path lengths remained longer than in study 1, suggesting that the direction effect stems from inherent movement biases.
Taken together, motor execution improves quickly with practice, is substantially retained, and generalizes to different contexts, suggesting shared learning principles with skill acquisition. However, these improvements seem specific to the trained movement direction, likely dependent on one's previous experience.

P2-F-169 - Large-scale plasticity associated with motor recovery from severe spinal cord injury in macaques

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Details

Recent studies have shown that brain areas not typically involved in motor control contribute to motor recovery following neuronal injury. However, the underlying mechanisms remain unclear.
In this study, we further investigated the motor networks involved in recovery following subhemisection spinal cord injury (SCI) at C4/C5 in macaques. We chronically implanted multi-channel ECoG electrodes over bilateral premotor (PM), primary motor (M1), and somatosensory (S1) cortices and monitored brain activity longitudinally. After the lesion, the monkeys were unable to perform a reach-and-grasp task. However, those that received cortical electrical stimulation (3 mA, 3 pulses at 20 Hz, 100 trains per site per week; 18 cortical sites per hemisphere, total 36 sites bilaterally) began to recover grasping ability between post-injury Weeks 3 and 4. Muscle twitches were first evoked from contralesional PM/M1 around Week 2 in proximal muscles, then gradually spread to distal muscles and were later evoked from ipsilesional PM/M1. These observations suggest large-scaled plasticity in the motor networks during recovery.
Next, we analyzed cortical activity and connectivity during movements. During reaching, activity in the ipsilesional PM/M1 increased in the β (13–30 Hz) band, and connectivity within the ipsilesional motor cortex, as assessed by Granger causality, was enhanced in the β band. During grasping, activity in the contralesional PM and M1 increased in the α (8–13 Hz) and high-γ (71–120 Hz) bands. Furthermore, connectivity from the ipsilesional PM to the contralesional PM/M1/S1 was enhanced in the α band during recovery.
Finally, we investigated morphological changes in the corticospinal tract. In monkeys that exhibited global disinhibition, a greater number of labeled axons originating from the contralesional M1 were observed in bilateral spinal gray matter both rostral and caudal to the lesion site. In addition, more labeled axons were distributed in laminae VIII and IX at the ipsilesional C6 level, where the hand motor nuclei exist.
These findings suggest that bilateral motor cortices were involved in the recovery process from severe SCI and that different cortical networks contribute to recovery at distinct frequency bands.

P2-F-170 - A human motor learning circuit outside primary motor cortex

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Details

Previous work has documented the involvement in motor learning and retention of a region in the posterior postcentral gyrus, overlying brain areas 2 and 5, which we refer to here as the rostral parietal

cortex. This area is neuroanatomically connected to dorsal premotor cortex and accordingly learning related changes to this region of parietal cortex may be associated with corresponding changes to the dorsal premotor zone. To test this hypothesis, adaptation to altered visual feedback was used as an experimental model. Following learning, continuous theta burst magnetic stimulation (cTBS) was applied to either primary motor cortex, to the rostral parietal cortex, or to dorsal premotor, to test for their contribution to learning. In retention tests, 24h later, disruption of rostral parietal cortex or dorsal premotor cortex each led to an impairment, whereas disruption of primary motor cortex did not. When rostral parietal cortex and dorsal premotor cortex were both disrupted together, to test for independent effects on retention, the impairment was no greater than if either area alone was disrupted. This indicates that these areas are interconnected in a motor learning circuit such that disruption of either one results in a similar impairment when the circuit is broken. In addition, this work shows there is adaptation and learning in humans which does not depend on primary motor cortex.

P2-F-171 - A forward approach to understand how implicit and explicit perturbations shape/contribute to motor adaption

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Details

Humans' remarkable ability to adapt their movements to environmental changes mainly involves two processes: an explicit, strategic system driven by performance errors like failure to achieve goal, and an implicit, automatic system driven by sensory prediction errors. These processes co-occur but are often inferred inversely, assuming linear interaction, and their respective contributions are linked to adaptive properties like reaction time, retention, savings and generalization. Despite their widespread use, it remains unclear whether they operate independently or interact to reduce motor errors.

In this study, we used a direct, forward approach to probe implicit- and explicit-like learning by generating perturbations that primarily induce distinct errors known to drive each process. For this, we employed target-jump and gradual-rotation tasks, which in isolation produce goal-based and sensory-based errors, respectively, and compared their adaptive signatures. Target Jump adaptation expressed explicit-like learning: rapid correction, increased reaction time, limited retention, stronger savings and generalization. In contrast, gradual-rotation adaptation exhibited implicit-like learning: slow, incremental learning with strong retention and relatively small changes in reaction time, savings, and generalization.

We then combined these two perturbations in a single task in which subjects experienced both target-jump and gradual-rotation errors. Depending on the direction of each perturbation, we tested two variants. In the Combined-Aligned task, the reaching solution required for both perturbations was aligned with the target-jump direction; in the Combined-Non-aligned task, the reaching solution opposed the target-jump direction. In both cases, adaptive behaviour fell between the patterns observed in the isolated tasks, suggesting combined contributions from implicit- and explicit-like processes.

Finally, we evaluated whether these processes add linearly and whether they are driven by independent or shared error signals. In the model-free analysis, we superimposed implicit- and explicit-like behaviours from the isolated tasks and compared them with behavioural data from the combined tasks. For the model-based approach, we applied single state-space models to the isolated tasks to estimate learning and retention parameters serving as proxies for implicit and explicit processes in a dual state-space model, enabling forward simulation of the behaviour of the combined task. We further modified the model to test common and independent-error formulations. Both analyses indicated independent error processing for the combined task adaptation, with evidence of a possible shared error influence at the asymptote. Overall, the relationship between implicit and explicit learning in the combined task appears quasi-linear, with indications of more complex or competitive interactions near asymptotic learning.

P2-F-172 - Reward-driven emergence of auditory pattern encoding in the primate motor system

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Details

The ability to anticipate rhythmic patterns is fundamental to human experience, enabling music appreciation, speech comprehension, and dancing in sync to music. How the brain learns to use acoustic information to guide motor behavior remains a key question whose neural underpinnings and evolutionary origins are debated, especially in non-human primates. To understand how brain areas involved in motor control naively respond to predictable tone patterns, we recorded large single neuron populations across primary somatosensory (S1), primary motor (M1), dorsal premotor (PMd), supplementary motor (SMA), pre-supplementary motor (preSMA) cortices, globus pallidus interna (GPi), and medial geniculate body (MGB) of a rhesus monkey. During passive listening (Experiment 1) with a reward only at the end of each trial, primarily the MGB, not motor areas, responded to the auditory tone patterns, ruling out the spontaneous entrainment of motor activity to auditory patterns. Almost all areas robustly represented the elapsed time within the trial, suggesting a general tracking of trial progression and reward structure. Next, we tested if motor areas learn to respond to auditory patterns if associated with rewards. When each tone was simultaneously accompanied by a liquid reward (Experiment 2), all areas except S1 showed clear responses to the tone patterns. To test if the tone responses persisted, the reward contingency was subsequently removed (Experiment 3). Strikingly, although the reward was delivered only at the trial's end as in Experiment 1, GPi neurons continued to track the occurrence of the tones. These findings suggest that while basic sensory processing of tone patterns occurs in the MGB, higher-order processing in motor areas is profoundly shaped by reward association. This reorganisation of neural responsiveness shows that the capacity for auditory association can be elicited in the motor system through appropriate motivational contexts.

P2-F-173 - An arbitrary olfactory stimulus can become a sensory cue to form context-dependent memories in visuomotor adaptation

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Details

A wealth of evidence suggests that contextual sensory stimuli can bind to motor adaptation, enabling learners to acquire context-dependent motor memory and behavior. Past studies employ sensory cues with substantial task-relevance, such as cues that directly affect motor planning and execution (e.g., initial posture), share sensory modality with tasks (e.g., target color for eye saccade), and/or signal presence of perturbation (i.e., concurrent presentation of a cue and perturbation). Is such task-relevance necessary for context-dependent motor adaptation, or it has more freedom to select sensory stimuli, even ones with little task-relevance? Given general, associative nature of context-dependent learning shown in cognitive psychology (e.g., Pavlovian learning), we hypothesize that context-dependent motor adaptation can still occur with arbitrary sensory stimuli. To test the hypothesis, we combine a visuomotor adaptation paradigm with an olfactory stimulus with minimal task-relevance.

Eighteen healthy volunteers [9 males, ages 23-29] performed a visuomotor rotation task in which they made center-out shooting movements to a visual target at 60° (front-right direction). First, they were exposed to lemon odor while repeating movements with veridical cursor feedback so that presentation of odor and rotation did not start simultaneously. Then, 15° rotation was applied to the cursor while they kept exposed to the odor. The rotation was gradually applied to minimize awareness of rotation. After

they adapted to the rotation, the odor was removed, and the rotation was gradually removed to wash out the memory of adaptation. Then, a previously established error-clamp test was used to probe latent motor memory manifested as aftereffect (i.e., altered hand direction due to a previously acquired motor memory). A context-dependent motor memory was quantified by comparing aftereffect sizes for the trained direction and an untrained direction. 9 participants were randomly selected and assigned to re-exposure group, in which the same order was presented in the second phase of the test. No odor was presented in the first phase. The other 9 were assigned to control group, in which no odor was presented throughout the test. In the first phase, the two groups did not show significantly different context-dependent motor memory ($t(16)=1.02$, $p=0.32$), which was expected as the task was identical. In contrast, in the second phase, the re-exposure group showed significantly larger context-dependent motor memory than the control group ($t(16)=2.14$, $p=0.048$), confirming context-dependent motor behavior associated with the odor.

This study shows that people can associate visuomotor adaptation with an olfactory stimulus with little task-relevance. Thus, it suggests associative nature of context-dependent motor adaptation like other context-dependent learning, enabling humans to form context-dependent motor memories with minimal requirements on selection of sensory stimuli.

P2-F-174 - Origin of interindividual variability in movement: early motor exploration constrains sensorimotor maps during redundant de novo learning

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Details

Humans exhibit substantial individual differences in movement forms, even in simple actions such as throwing a ball. Because the human body possesses many joints and muscles, there exist infinitely movement solutions that can achieve the same task goal (Bernstein, 1967). How the motor system selects a particular solution, and why these solutions differ across individuals, remains poorly understood. One promising framework to address this question is *de novo* learning, in which a novel sensorimotor map is acquired without relying on previously learned ones (Krakauer et al., 2019). By minimizing the influence of prior motor experience, this framework provides an opportunity to examine how individual-specific movement solutions emerge during learning. Here, we leverage *de novo* learning to investigate how individual differences in sensorimotor maps are shaped.

Twenty-five participants controlled an on-screen cursor using two three-axis joysticks. To induce *de novo* motor learning, the 6-dimensional joystick signals ($\boldsymbol{h}$) were linearly mapped to 2-dimensional cursor position ($\boldsymbol{p}$) through a redundant and unintuitive transformation ($\boldsymbol{p = Ah}$), which was common across participants (Haith et al., 2022). The experiment consisted of a total of 1080 trials, divided into four phases. The four phases comprised two training phases (Training 1 and Training 2) and two interleaved test phases (Test 1 and Test 2). In Training 1, participants practiced movements toward three targets. In Training 2, three additional targets were added. In both test phases, participants performed movements toward 24 evenly spaced target directions, allowing estimation of the sensorimotor map after each training phase. We estimated the sensorimotor map by modeling the relationship between the target position ($\boldsymbol{x}$) and joystick position ($\boldsymbol{u}$) as a linear transformation ($\boldsymbol{u = Mx}$), where $\boldsymbol{M}$ represents the sensorimotor map.

With training, initially erratic cursor trajectories became straighter toward the targets. Notably, sensorimotor maps estimated from Test 2 revealed clear individual differences. To determine when these differences emerged, we analyzed the exploration space during the early phase of learning. Exploration space was estimated from joystick position data in the initial 96 trials using principal component analysis. The analysis showed that clear individual differences in exploration space were

already present at this early stage. To assess the relationship between the exploration space and the sensorimotor map, we performed a Mantel test between the distance matrix of exploration spaces and that of the learned sensorimotor maps. This analysis revealed a significant correlation between the two matrices ($r = 0.426$, $p < 0.05$), indicating that participants with similar exploration spaces tended to acquire similar sensorimotor maps. These results suggest that individual differences in the sensorimotor maps are constrained by the exploration space during the early phase of learning.

P2-F-175 - Are sensorimotor memories generated by task errors independent from those driven by sensory prediction errors?

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Details

Current theories suggest that sensorimotor adaption is supported by at least two distinct learning processes, one relying on unconscious, implicit memory, and another relying on conscious, explicit memories. Moreover, because sensorimotor adaptation is an error-based learning process, it has been suggested that these two learning processes may rely on different types of prediction errors. In particular, sensory prediction errors (SPE), defined as discrepancies between expected and observed sensory feedback of movement, have been linked to implicit learning, whereas task errors (TE), or failure to achieve the task goal, have been associated with explicit learning. The notion that manipulating error types can dictate the underlying learning process implies that adapting to different error types might generate separate motor memories. To test this hypothesis, we designed an experiment where participants performed reaching tasks which induced only SPE followed by tasks that induced only TE, using error-clamp and target-jump perturbations respectively. Our aim was to test whether adaptation to a second perturbation involving only TE generates a distinct motor memory that does not affect an existing SPE adaptation. Three groups of participants performed the task such that the TE was A) in the same direction as the SPE, B) in the opposite direction to the SPE, or C) absent as a control. To measure the magnitude of the sensorimotor adaptation, we used no-feedback blocks before and after each adaptation phase. During the second adaptation phase, we sought to maintain the implicit adaptive state established in the previous SPE phase. To do this, a visuomotor rotation (VMR) was applied with a magnitude equal to the reaching angle measured for each individual in the last cycle of the post error-clamp no-feedback block. The same no-feedback reach angle was also used to define the subsequent target jump magnitude. During the first no-feedback block, participants in all three conditions had no prior experience of a perturbation and the adaptation magnitude was close to 0°. However, in the second no-feedback block, after experiencing SPE, the magnitude of adaptation rose to ~12°. The final reaching angles in the second adaptation phase were either ~24° or ~0° for target jump groups depending on the direction of TE. Remarkably, in the last no-feedback block, the adaptation magnitude was similar ($p = 0.2$) for all three groups at a level consistent with subtle decay from second no-feedback block (~ 8.3°). This suggests that adapting to TE does not affect a previously induced sensorimotor recalibration to SPE. Therefore, it appears that learning from different error types produces fundamentally distinct sensorimotor memories that do not interact with each other. Future work will expand the scope of the task contexts tested to verify whether error type per se, or some other task feature, is the key driver of distinct learning processes.

P2-F-176 - Contextual cues signaling upcoming perturbations attenuate implicit feedback movement correction

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Details

When a visual perturbation is imposed on the target and/or cursor, the motor system rapidly corrects the movement through implicit feedback processes (Day & Lyon, Exp Brain Res, 2000; Franklin & Wolpert., J Neurosci, 2010). However, it remains unclear how implicit feedback correction is influenced when the perturbation can be predicted in advance. In other behavioral domains, advanced information about an upcoming stimulus facilitates behavioral performance. For example, in the Posner cueing paradigm (Posner, Quart J Exp Psychol, 1980), valid directional cues presented before a choice reaction task reliably reduce reaction time. Building on these findings, advanced information about an upcoming perturbation may also enhance feedback correction.

Here, we investigated the influence of visual cues signaling the direction of a cursor perturbation on feedback correction. Participants (n = 11; 7 males and 4 females; age range: 21–30 years) performed reaching movements toward a frontal target (20 cm from the start position) while holding the handle of a robotic manipulandum (KINARM End-Point Lab, Kinarm). In perturbation trials, nine types of clamped visual perturbations were imposed on the cursor (±45°, ±30°, ±15°, ±5°, and 0°). Two types of visual cues were presented approximately 600 ms before movement onset and were displayed for 1000ms at a location 10 cm from the start position. A circle cue provided no information about the upcoming perturbation, whereas a triangle cue informed participants of the upcoming perturbation via its orientation. After the perturbation trials, two null trials were performed to wash out possible adaptation effects. Participants were instructed to always aim at the target and not to use any explicit strategy or explicit movement corrections. The feedback correction under different cue conditions across perturbation magnitudes was assessed by one-way repeated measure ANOVA with 8 levels (2 types of cue (predictive triangle, nonpredictive circle) × 4 perturbation sizes (±45°, ±30°, ±15°, ±5°).

Contrary to our initial expectation, feedback corrections—quantified as changes in movement direction during the movement—were significantly attenuated across perturbation magnitudes when triangle cues were presented (main effect of cue: $F(1,10)=8.27$, $p=0.0165$). Furthermore, counterintuitively, when the perturbation was predictable, initial movement directions tended to shift toward the perturbation (cue × perturbation size interaction: $F(3,30)=3.55$, $p=0.0251$), rather than toward the opposing direction. Although feedback correction is typically thought to reduce sensory prediction error by adjusting movement in the direction opposing the perturbation, our results suggest an alternative mechanism: when a perturbation is predictable, the implicit motor system may instead reduce sensory prediction error by shifting sensory predictions toward the perturbation, thereby improving the correspondence between predicted and observed sensory feedback.

P2-F-177 - Effects of three-month tool-use practice on grasping kinematics and bodily perception

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Details

[Introduction and Methods]

This study investigated the effects of three months of tool-use practice on reach-to-grasp kinematics and bodily perception. Participants were enrolled in a 12-week tool-use program (25 min per day, 4 days per week) using a scissors-like tool at home. Half of the participants practiced with a standard plier (standard plier group: SP), whereas the other half practiced with a reverse plier, in which the tips of the

pliers move in the opposite direction to finger movement (reverse plier group: RP). Grasping performance was assessed five times at three-week intervals in the laboratory. Participants also completed questionnaires on bodily self-perception and performed a visuomotor task (S–R conflict task) to measure the efficiency of automatic responses to visual stimuli of the tool practiced. Based on performance in the S–R conflict task, the congruency effect was calculated as a measure of automatic responses to the newly acquired visuomotor mapping through practice. The congruency effect in the RP group was expected to reverse as practice progressed. This study protocol was approved by Keio University's ethics committee (#24005).

[Results]

In both tool groups, grasping kinematics improved. Although movement duration shortened in both groups, other kinematic measures showed different developmental patterns. Whereas maximum grip aperture (MGA) increased in the SP group, it decreased in the RP group. Plateau duration, representing the relative plateau time in the aperture profile, decreased in the SP group but remained almost unchanged in the RP group. Interestingly, kinematic measures of hand grasping and tool-use grasping became correlated as practice progressed in the pooled data across groups (*rs* = .87, .63, and .63 for movement duration, MGA, and plateau duration, respectively), whereas no such correlations were observed before practice. Questionnaire results showed that sense of ownership, sense of agency, and affection toward the tool (how much participants liked the object) improved in both groups. Although the degree of sense of agency did not differ between groups, the sense of ownership in the RP group was lower than in the SP group. Contrary to our prediction, the congruency effect in the RP group was not reversed, although it was reduced as practice progressed.

[Discussion]

Three months of tool-use grasping practice induced kinematic profiles that reflected individual differences originally present in hand-use grasping, suggesting the emergence of motor aspects of embodiment. Differences in the acquisition of the sense of ownership between groups suggest the importance of the mechanical configuration of external objects or the number of coordinate transformations involved in developing ownership of an incorporated object. The unchanged congruency effect in the RP group may indicate difficulty in updating the visuomotor map at an unconscious and automatic level.

P2-F-178 - Learning reconfigures temporal dynamics of preparatory activity in the secondary motor cortex

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Details

Before movement execution, neurons in the secondary motor cortex (M2) exhibit sustained firing patterns that correlates with upcoming movements. However, how such “preparatory” activity evolves with learning has not been investigated. In this study, we developed a versatile shuttling maze with ports in the ground and trained freely moving rats to perform a directional delayed response task (i.e., simple reaction time task), in which they sustained a nose-poke during a random delay period and responded with a poke-out action after an auditory cue. We conducted chronic Neuropixels recordings throughout all training sessions. Early in training, the reaction time shortened with longer delay period, also known as speeding effect; as performance improved with training, such effect attenuated. We observed a corresponding change in neural activity during the delay period. In early sessions, neural activity in a proportion of M2 neurons showed a monotonic ramping pattern; after several sessions of learning, this ramping activity rapidly saturated at a time corresponding to the shortest delay duration, and remained constant for the rest of the delay period. When the task was switched to a self-timing paradigm, the activity of these ramping neurons reverted to the monotonic ramping pattern, suggesting its role in

temporal anticipation. To test the role of M2 for behavioral performance, we reversibly inactivated M2 using chemogenetics. M2 inactivation re-introduced the speeding effect observed in early training in the reaction-time task. In the self-timing task, M2 inactivation impaired timing precision. Overall, our findings reveal a cellular mechanism of temporal anticipation that exhibit task-dependent reconfiguration.

G – Theoretical & Computational Motor Control

P2-G-179 - Averaging versus selection of motor memories under contextual uncertainty

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Details

Human dexterity relies on learning and managing multiple motor memories. Numerous studies have shown that humans, for example, learn opposing force fields if each is linked to a sensory cue that indicates the context (field direction). In these tasks, the sensory cues deterministically predict the field direction. However, cues can be noisy in natural environments, creating uncertainty about the context. Models of contextual inference (Heald et al., 2021) propose that under contextual uncertainty, behavior should reflect a belief-weighted average of memories (so-called Model Averaging, MA), which is optimal for force-field learning under quadratic costs. However, work on conditioned perception (Stocker & Simoncelli, 2007) suggests that once an explicit categorical (contextual) choice is made, subsequent behavior becomes self-consistent with that choice, implying a single memory may be expressed (Model Selection, MS). We therefore tested two hypotheses that contextual uncertainty leads (i) to MA in the absence of an explicit choice before movement, but (ii) to MS after an explicit choice before movement.

We conducted experiments in which participants made reaching movements through opposing force fields. The field direction was indicated by the motion direction (left vs. right) of a noisy 0.6 s random-dot motion (RDM) stimulus presented before movement onset. Contextual evidence was controlled by motion coherence (C, proportion of coherently moving dots), which varied across trials. In all experiments, participants first trained with high-coherence cues to learn both fields, then completed field and channel trials at all coherence levels.

In Experiment 1 (n = 8), participants viewed the RDM, moved through the force field, and then indicated their perceived motion direction with a follow-through movement. In Experiment 2 (n = 8), participants reported their choice explicitly before moving by pressing one of two buttons with their left hand after the RDM. In both groups, the proportion of rightward choices followed a logistic function of signed coherence, confirming contextual uncertainty. Model-free analysis (regression of adaptation by coherence) showed significant modulation for Experiment 1 (p = 0.001) consistent with MA but no significant modulation in Experiment 2 (p = 0.4) consistent with MS.

For model-based analysis, we used an ideal-observer model in which inferred motion-direction beliefs were generated under Gaussian observation noise and mapped to the two learned memories in two ways: (i) MA, where adaptation is the belief-weighted average of two memories, or (ii) MS, where adaptation corresponds to the memory with the highest posterior probability. The model had five parameters (observation noise, choice bias, two learned memories and motor noise) and was fit jointly to adaptation and choice behavior. Model comparison showed that Experiment 1 was best explained by MA (ΔBIC = 53.2), whereas Experiment 2 was best explained by MS (ΔBIC = 75.5).

Together, these results demonstrate that under contextual uncertainty, participants show Model Averaging but reporting an explicit choice before movement alters expression to Model Selection. By linking perceptual decision-making with motor execution, this work advances understanding of how the brain reconciles uncertain sensory cues with the expression of stored motor memories.

P2-G-180 - Preserved neural dynamics across arm and brain-controlled movements

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Details

In nature, proficient motor execution relies on adequate movement preparation. According to the dynamical systems perspective, neural dynamics of the motor cortex are initialized during motor preparation and autonomously evolve to issue descending motor commands during motor execution. This leads to the speculation that this computational dissociation between neural preparatory and execution may still be preserved in the absence of muscle control or biomechanical constraints. However, most current intracortical brain-machine interfaces (iBMI) work in a manner of pure feedback control, i.e. they do not distinguish these two states. To test this hypothesis, we designed a feedforward iBMI that features distinct preparatory and execution epochs.

Our feedforward iBMI framework had the following key features: (1) Clear delineation of an adjustable 'premovement' epoch and a ballistic 'execution' epoch. During the premovement epoch, a decoder enabled subjects to initialize neural states with visual feedback. During the execution epoch, the initial state determined the launch time and direction of a ballistic movement in a pure feedforward manner. (2) A detector or 'gate' separated the two epochs and acted as a movement-onset trigger. The gate's activation was determined by the subjects' own intent, rendering the BMI asynchronous.

In the present study, two Utah arrays were implanted into the primary motor cortex (M1) and dorsal premotor cortex (PMd) of monkeys B and L. Both were trained to intercept a moving target using a brain-controlled cursor, where the target moved at a constant circular velocity of ±120 deg/s. The mean success rates were 66.8 ± 2.6% across 19 sessions for monkey B and 66.9 ± 2.6% across 25 sessions for monkey L. The mean path efficiencies were 0.94 ± 0.007 for monkey B and 0.96 ± 0.006 for monkey L, with mean times to target of 0.59 ± 0.015 s and 0.66 ± 0.03 s, respectively.

We compared neural activities between the brain-controlled and arm-controlled conditions in the two monkeys and identified three conserved features. (1) At the single-neuron level, the preferred directions of a subset of neurons remained stable within either the premovement or execution epoch but shifted between these two epochs. (2) A 'pre-movement subspace' and an 'execution subspace' that were nearlly orthogonal were identified in the neural population activity. (3) A rotational structure emerged in the iBMI task after the application of jPCA to the neural population activity, and three neural modes were conserved across the two conditions. These results demonstrate that a reaching-like dynamic emerged in the motor cortex under the implementation of pre-movement and execution epochs in BMI, which suggests that there exists a shared low-dimensional manifold between arm movement and brain control.

P2-G-181 - Learning embodied neuromechanical control for realistic walking and flying from 3D kinematics

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Details

The real-time integration of motor control, sensory feedback, and environmental adaptation in closed-loop to generate coordinated movement patterns are essential for survival. A critical limitation in studying locomotor control is that essential biomechanical quantities—forces and joint torques exerted by muscles—are not directly observable through conventional keypoint tracking. Here we use deep reinforcement learning (DRL) to train agents that mimic realistic fruit fly walking and flying movements using a biomechanically realistic body model in the MuJoCo physics simulator. We implemented a variational encoder-decoder architecture to build an interpretable latent space for low-level motor control and while generalizing to flexible transitions between behaviors. To ensure biological realism we constrain our DRL model with high-fidelity 3D kinematics. In walking, our agent reproduces accurate joint kinematics of real flies and ground reaction forces. In flying, we implemented a biologically realistic quasi-steady aerodynamic model of winged animals at the scale of small insects, accounting for rotational forces due to leading-edge vortices during wing rotation. We then combined walking and flying policies to demonstrate smooth transitions between locomotion modes. To show generalization, we trained a joystick-control policy while maintaining realistic movements by freezing the decoder (which translates latent space into realistic movement) and training a new encoder with joystick commands. Finally, we demonstrate the approach's power through a real-time interactive demo. Taken together, this computational framework provides a novel platform for investigating the neural basis of adaptive motor control by enabling systematic manipulation of neuromechanical variables that are experimentally inaccessible.

P2-G-182 - A computational account of tactile suppression during reaching movements

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Details

Humans suppress externally-generated tactile inputs to a limb during movements, such as in goal-directed reaching. Such sensory suppression is not an all-or-nothing effect but follows a distinct time course of increase and decrease of sensitivity. A possible explanation for this is that the central nervous system predicts future body states through an efference copy of the motor command and a forward model, suppressing sensory feedback. However, it is an open question whether this process is actually predictive, or only caused by non-predictive mechanisms, such as masking from peripheral afferent signals. Furthermore, a computational explanation of the temporal profile of suppression during movements is still elusive.

Here, we consider state estimation with internal forward models within the framework of optimal feedback control as a possible mechanism for tactile suppression during movements. Specifically, optimal feedback control with signal-dependent noise integrates sensory feedback from cutaneous mechanoreceptors about limb movement direction with the predictions of a forward model of limb movement. Importantly, this integration of signals changes dynamically throughout the movement.

We measured how well participants (N = 31) could detect near threshold level vibrotactile stimuli on the forearm during reaches to targets on a computer screen. Our experiment replicates earlier psychophysical findings, showing that suppression starts well before movement onset and recovers continuously during the reach. The model accounts for the recovered time course of suppression. In a further experimental condition, we manipulated participants' uncertainty of their initial belief over movement direction. As predicted by our model, participants were more sensitive to tactile stimuli during the initial phase of the reaching movement, due to an increased demand of sensory feedback to compensate for the increased uncertainty. Furthermore, the model can also account for the changed

time course of sensitivity when vision was blocked to increase the uncertainty of proprioceptive feedback.

Previous experimental work has suggested the involvement of forward models in tactile suppression, and this study provides a computational account of this phenomenon. The advantage of optimal control models is that they provide testable hypotheses for experimental manipulations and interpretable parameters. This provides a computational explanation of the source of various human suppression phenomena during movement. That the model explains the dynamically changing time course of suppression in multiple experimental manipulations, indicates that tactile suppression during movement relates to proprioception and not only cutaneous touch and that the system keeps track of perceptual uncertainties in a continuous integration process of sensory feedback with forward model predictions.

P2-G-183 - Submovement modelling of conflict tasks: effect of the previous trial

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Details

Arm movements can provide a window into the decision-making process. By examining arm movements produced while a decision is being made, we can observe details of the decision process's time course. This is particularly relevant in decisions involving conflict, as we can quantify when different processes are in play and their relative strengths over time. For example, in the Simon task, a shape can appear on either the left or the right side, and the side to reach depends solely on the shape's identity (e.g., square = left, triangle = right). Here, there is a conflict between an automatic movement likely planned toward the shape's location, and a more deliberate movement planned to the correct side indicated by the shape. To model this process, we decompose the movements into submovements, assuming that the overall movement is composed of the overlapping concatenation of one or more submovements. We assume that the direction of each submovement is dependent on the current state of evidence accumulation at that time. Using this modelling approach, we quantified the time courses of the automatic and deliberate processes for a Simon task and a flanker task. Using this approach, we can quantify the strength of the two processes at different time points, and demonstrated that much of the trajectory in a given trial is dependent on whether the previous trial was congruent (e.g., the target appeared on the same side that should be reached to) or incongruent (e.g., the target appeared on the opposite side that should be reached to). This study demonstrates that measuring kinematics during decision-making allows us to quantitatively describe detailed time courses of activation for automatic and deliberate processes during tasks with conflict, thereby enabling us to develop accurate models of these processes.

P2-G-184 - Identification of orthogonal subspaces that concurrently encode current and future movement directions

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Details

Previous studies have proposed that preparation and execution of hand movements (HMs) are represented in orthogonal subspaces of motor cortical neural dynamics [1], avoiding interference between the two processes. It remains an open question how to best identify these subspaces when the phases for preparation and execution are not clearly separated in the behavior.

Here we propose a method to identify the orthogonal preparation subspace (PS) and execution subspace (ES) for datasets without clearly defined preparatory periods. The method is tested on spike recordings from M1/PMd of two macaques (monkey Y and J) trained for a sequential reaching task with no explicit preparation phase.

For the identification of the PS and ES, spike counts of parallel spike trains were reduced to 8 latent variables using Gaussian process factor analysis[2]. Then, principal component analysis was performed on the latent variables at ~100 ms prior to HM onsets, and at the peaks of HM velocity, to obtain candidates of PS (cPS) and ES (cES), respectively. For each subspace, a decoder was trained to predict HM directions from the neural trajectories [3]. The cPS decoder performed best at predicting future HMs lagging 297 +/- 187 ms (monkey Y; mean +/- std. over 60 sessions) and 63 +/- 246 ms (monkey J; 103 sessions) behind the neuronal activity, while the cES decoder performed best for the immediate HM (75 +/- 103 ms for monkey Y; -23 +/- 43 ms for monkey J). Notably, cPS maintained predictive power even during HM execution, indicating concurrent encoding of current and future HMs in different subspaces [3].

We further orthogonalize cPS against cES by removing cES from the latent space and identifying another cPS in this reduced latent space [4]. The obtained subspace is called orthogonal PS (oPS). The best prediction lag is largely prolonged by this orthogonalization: 375 +/- 103 ms (monkey Y) and 195 +/- 196 ms (monkey J). Furthermore, the decoding performance (measured by cosine similarity between predicted and actual HM direction) is enhanced: 0.344 +/- 0.183 (cPS) to 0.384 +/- 0.143 (oPS) in monkey Y; 0.215 +/- 0.166 (cPS) to 0.293 +/- 0.146 (oPS) in monkey J. Therefore, the orthogonalization emphasises the predictive nature of the neural dynamics in the PS.

Thus, our method provides a promising tool to investigate the subspace organization in the motor cortex for movement coordination in naturalistic behavioral conditions, without requiring a clearly defined preparatory period.

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P2-G-185 - An open-source musculoskeletal hand model in ArtiSynth for simulating diverse hand dexterity tasks

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Details

Musculoskeletal modeling provides a powerful framework for studying the biomechanics and neuromuscular control of the human hand. However, due to the hand's intricate structure, many degrees of freedom, and the complex coordination of intrinsic and extrinsic muscles, simulating hand function remains a challenge. Here, we report our work in progress to convert a musculoskeletal hand model (McFarland et al., 2023) to the ArtiSynth (Lloyd et al., 2012) simulation platform and evaluate its performance. We chose this platform for its fast simulation speed and finite element modeling capabilities,

which enable realistic soft-tissue deformation. Originally developed on the OpenSim platform, the model features 43 Hill-type muscle–tendon actuators representing the intrinsic and extrinsic muscles of the hand and includes 23 degrees of freedom.

We evaluated the model's ability to reproduce both kinematic and kinetic hand tasks using inverse simulation techniques. For kinematic evaluation, motion capture data were collected using a VICON system (14 cameras, 25 hand markers). A static calibration was used to scale the model to each participant's hand dimensions. Participants performed a finger-tapping task between the thumb and each of the other fingers and a hand-opening-closing task, in which the hand started from full extension, slowly closed the fingers, and returned to full extension. Simulations were generated using ArtiSynth's IKSolver and inverse simulation workflow, and trajectories of fingertip distance from the simulated motion were close to the experimental data. Muscle activation patterns during these tasks were consistent with established muscle functions (e.g., Physiopedia: https://www.physio-pedia.com).

For kinetic evaluation, we simulated a finger individuation and a precision grip task using all 5 fingertip force data collected with a 3D force-recording device. During a finger individuation task, participants generated isometric finger forces toward a target in a 3D virtual space while minimizing activity in the non-instructed fingers. During a precision grip task, participants produced isometric forces between the thumb and index finger to grasp a virtual object in 3D space. The inverse simulation framework mapped these forces to the corresponding muscle activation patterns. We also simulated a thumb-index pinch on a deformable soft ball in ArtiSynth.

Overall, this study demonstrates that an open-source musculoskeletal hand model can be integrated into ArtiSynth and driven by inverse simulation to reproduce realistic hand movements and force-generation tasks. By supporting finite element modeling of soft tissues alongside muscle dynamics, this framework enables simulations of tissue compliance and contact interactions that rigid-body models alone cannot capture. In the long term, it may inform rehabilitation strategies by bringing model-based insights to clinical and engineering applications.

P2-G-186 - Asymmetric bilateral effects in rapid bimanual coordination: Nondominant hand facilitation and extended coupled oscillator model integrating hand dominance

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Details

Background: Bilateral deficit—reduced performance during simultaneous bilateral movements compared to unilateral execution—has been consistently reported in movement speed and force production. However, recent findings in clinical populations showing bilateral facilitation in paretic limbs suggest that bilateral effects may be more complex than previously assumed, raising questions about whether bilateral deficit in movement speed is uniform across the dominant and nondominant hands, and across coordination patterns.

Purpose and Hypothesis: We investigated whether hand dominance produces differential bilateral effects on movement speed during maximal-speed bimanual coordination. We hypothesized that analyzing each hand independently would reveal asymmetric bilateral effects modulated by coordination mode (in-phase vs. anti-phase), with inter-hand asymmetries and amplitude modulation contributing to these effects.

Methods: Seventy-three right-handed participants performed maximal-speed cyclic index finger movements under three conditions: unimanual (UNI), in-phase bimanual (IN), and anti-phase bimanual (ANTI) coordination. Movement frequency and amplitude were analyzed separately for each hand. Multivariate regression examined predictors of bilateral effects, including inter-hand asymmetry in unimanual performance and coordination-induced amplitude changes.

Results: Hand-specific analysis revealed asymmetric bilateral effects: the dominant hand showed classical bilateral deficit (IN < UNI: $p = 0.002$), whereas the nondominant hand demonstrated facilitation

(IN > UNI: $p = 0.009$). Anti-phase coordination produced significantly slower frequencies for both hands ($p < 0.001$). Multivariate regression ($R^2 = 0.71$ for dominant hand; $R^2 = 0.35$ for nondominant hand) identified frequency asymmetry during unimanual trials as the strongest predictor of dominant hand deficit ($\beta = -0.80$, $p < 0.001$), while amplitude modulation predicted nondominant hand facilitation ($\beta = -0.04$, $p < 0.001$).
Theoretical Framework: We extended the coupled oscillator model by incorporating hand-specific parameters, deriving an extended HKB model. The analysis reveals that in-phase coordination remains stable, while anti-phase coordination becomes unstable beyond a critical frequency dependent on amplitude. The model predicts synchronized frequency as a weighted average of natural frequencies, explaining asymmetric bilateral effects.
Conclusions: These findings demonstrate that bilateral facilitation and deficit can coexist during in-phase coordination mode depending on hand dominance. The extended coupled oscillator model provides a theoretical account of how inherent asymmetries and amplitude modulation influence bilateral coordination dynamics. This framework also carries implications for interhemispheric interactions and for broader applications in motor control and learning, including clinical and sports contexts.

P2-G-187 - Learning stable endpoint control in a musculoskeletal arm via internal models and discrete reinforcement learning

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Details

In musculoskeletal motor control, the system's high dimensionality, nonlinearity, and redundancy, together with neurophysiological constraints on muscle activation, such as the size principle, make it essential to develop learning frameworks that can simultaneously specify target positions and establish dynamical stability in their vicinity. Especially for upper-limb movements under substantial gravitational influence, effective control requires not only defining a reaching endpoint but also shaping a stable mechanical equilibrium around it, enabling restorative behavior against disturbances and errors. In this context, our approach can be interpreted as an endpoint position control hypothesis augmented with an internal model, in which a steady equilibrium is achieved through an internal representation of the musculoskeletal system, while feedback mechanisms provide corrective modulation around the target.This study aims to develop an appropriate method for delivering muscle stimulation to a musculoskeletal arm model with two joints and six muscles operating within the sagittal plane, such that both rapid end-effector movement from a predefined start position to a target end position and stable posture maintenance at the target can be achieved. Rather than allowing muscle stimulation to take continuous values between 0 and 1, we restrict it to selecting from discrete, nonlinear activation candidates, thereby increasing fidelity to the size principle. This discrete action selection problem is well suited to reinforcement learning and is implemented using Q-learning, which is known for its algorithmic simplicity.However, in sagittal-plane movements where gravitational effects are substantial, it is difficult to robustly achieve both reaching and posture stabilization using a single controller. To address this limitation, we introduce a dual-network control architecture that separates the formation of a steady equilibrium from the generation of corrective control signals. The first component is an Inverse Statics Model (ISM), which takes the target end-effector position as input and learns to generate a steady control signal that balances the musculoskeletal system near the target, effectively establishing an equilibrium-like state. The second component is a Feedback Controller (FBC), which employs Deep Q-learning to generate discrete corrective muscle-stimulation signals that are added to the ISM output, enabling compensation for transient errors and disturbances during movement.By structuring the control system so that the FBC explicitly learns corrective signals relative to the ISM output, the ISM can be trained by treating the FBC output as an error signal, following the principle of Feedback Error

Learning (FEL). This learning framework allows the internal model to gradually acquire the steady-state control required for endpoint stabilization, while the feedback controller focuses on exploration and correction. Our results suggest that establishing a stable learning framework for FEL not only improves endpoint stability under gravity but also substantially supports action exploration in Deep Q-learning, leading to more robust acquisition of goal-directed motor behavior.

P2-G-188 - Network mechanisms for selective engagement in motor control

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Details

Neural activity often reflects kinematics even in brain regions that can be dispensable for generating the actions they encode. However, these regions can shift to control movements under certain circumstances, such as for learned tasks (Hardcastle et al., 2025). But how does a circuit switch between being in control and being an observer?

The hierarchical organization of the motor system may offer a clue. While highly differentiated low-level control circuits in the brainstem and spinal cord generate stable and species-typical motor programs, larger and more general-purpose upstream networks (e.g., cortex, basal ganglia) modulate and receive feedback from these circuits, and can engage them selectively (Dragoi et al., 2026). To probe possible circuit-level mechanisms for such flexible engagement in control, we consider two possibilities. One possibility is that a thresholding nonlinearity gates whether upstream signals influence the downstream controller. In this case, observer-mode activity can be present and even overlap control-related patterns, yet remain behaviorally silent because the effective input is subthreshold, and control is engaged by increasing effective drive, for example through larger population amplitude, stronger temporal coordination, or broader recruitment of neurons. Another possibility is that there is no thresholding gate at the relevant stage, so observer-mode activity is constrained to lie in a readout-null direction and thus be orthogonal to controller-mode activity (Churchland and Shenoy, 2024). In this case, there is no constraint on the amplitude, spread, or synchrony of the activity.

Motivated by these alternatives, we analyze dorsolateral striatum population activity during kinematically similar movements in two contexts: natural behavior, where DLS is dispensable, and a learned task, where DLS is essential. We found that the variance spectrum decays at similar rates in both contexts. Additionally, the norm of DLS activity was not different across conditions. These observations suggest that switching between observer and controller in DLS is not implemented by changes in activity amplitude or spread, and is more compatible with utilizing orthogonal subspaces.

To gain more insight into these possibilities, we established a multi-region recurrent neural network in which a downstream controller is bidirectionally coupled to a larger upstream network. This framework allowed us to explore the class of solutions that upstream networks can find to flexibly switch between observed and controller modes. For example, we found that increasing the dimensionality of the upstream network almost always leads to the solution in which observer-mode activity is orthogonal to control-mode activity. This is also true when we increased the sparsity of descending connections. We will furthermore use this framework to explore the possible functions and benefits of having 'observer' representations for processes like transfer learning.

P2-G-189 - A reasonable misjudge: Bayesian sensory integration explains the ball-count-specific bias in major league baseball home plate umpires' decision making

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Details

Human perception is inherently limited by sensory noise. The Bayesian sensory integration model is a well-established theoretical framework for computational processes that minimize the effects of sensorimotor uncertainty. While this model has been extensively studied in controlled laboratory settings, its application to expert behavior in the real world remains limited. This study provides empirical evidence of Bayesian sensory integration in Major League Baseball (MLB) home plate umpires' decision-making, a task characterized by significant visual uncertainty.

A well-known phenomenon in this context is "count bias," where the subjective strike zone expands in ball-ahead counts and shrinks in strike-ahead counts. We confirmed this count bias through a psychometric function analysis of a dataset containing approximately 450,000 four-seam fastballs from MLB games between 2015 and 2024. We then tested the hypothesis that count bias results from a Bayesian integration process in which umpires combine noisy visual information with prior expectations of pitch locations learned through experience. The Bayesian model, utilizing the distribution of pitches under each ball-strike count as a prior, successfully explained between 51% and 94% of the observed count bias in the high, inside, and outside regions. Furthermore, we conducted a correlation analysis across 88 individual umpires to test a core prediction of the Bayesian framework: that individuals with greater sensory uncertainty should rely more heavily on prior information. The results revealed a significant positive correlation between decision-making inconsistency and the magnitude of count bias ($r = 0.235$, $p < 0.05$).

These findings suggest that systematic shifts in the strike zone are not mere errors, but rather represent a statistically optimal strategy for the brain to reduce perceptual uncertainty in complex sensorimotor tasks. This study provides a compelling example of how Bayesian principles govern expert decision-making in professional environments, extending the reach of computational neuroscience beyond the laboratory.

P2-G-191 - Postural representations associated with motor commands may contribute to limiting real-time compensation for altered auditory feedback in speech production

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Details

Unexpected alterations of auditory feedback during speech typically elicit compensatory responses that are only partial and often asymmetric with respect to the direction of the perturbation, yet the mechanisms underlying these patterns remain debated. In this study, we investigate these phenomena using a computational model of speech motor control that integrates a biomechanical model of the vocal tract with an optimal feedback control (OFC) framework for movement planning and online correction (Rakotomalala et al. 2025). The biomechanical model included an account of muscle force generation mechanisms in response to motor commands. Auditory perturbations were implemented as shifts in frequency peaks of the vocal tract resonances (formants), a widely used experimental paradigm in speech motor control studies.

Using this framework, we simulated transitions from a rest position to vowel [e] with upward and downward shifts of 100 Hz in auditory feedback. We could replicate key empirical findings: immediate compensation in the direction opposite to the perturbation are observed, the magnitude of

compensation is incomplete, and asymmetries emerge between upward and downward formant shifts (Hantzsch et al. 2022).
Next, we tested the hypothesis that the nature of control commands themselves shapes compensatory responses to altered auditory feedback. To this end, we compared two models that differ in the nature of the motor commands. In the first model, motor commands are strongly linked to articulatory postures, relying on the lambda-model (Equilibrium Point Hypothesis), embedding postural information directly within the commands. In the second model, control commands act on plant acceleration without explicit postural encoding; obviously, viscous damping and repulsive constraints are included to maintain biological plausibility. Under identical conditions, the second architecture produces significantly less constrained and larger compensatory responses than the first, suggesting that posture-related commands inherently limit deviations from target configurations. This makes sense since in that case, efference copy provides larger evidence of the current plant position.
Overall, our simulations reproduce the asymmetries observed experimentally. Besides, our comparison of models suggests that partial and asymmetric compensation in speech may not arise solely from sensory or perceptual factors, but also from the nature of the control commands and their interaction with the plant biomechanics. This provides a novel contribution to speech motor control modelling and emphasizes the influence of the hypotheses made on the biomechanical transformation of the motor signals into movement.

P2-G-192 - Development of internal models for a biomechanically realistic virtual arm using artificial neural networks

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Details

Understanding how the central nervous system learns and controls movement remains a major unresolved problem in neuroscience. The theory of internal models offers one promising explanation. However, in-silico investigations of internal models using artificial neural networks (ANNs) and the understanding of their neural representations and functional properties remain limited. Moreover, prior ANN-based models have explored neural representations associated with different control strategies but have relied on simplified arm models that ignore the challenges of training ANNs to control realistic biomechanical arm models that incorporate muscle and joint redundancy. This work addresses these gaps by explicitly modeling internal models for a biomechanically realistic 3D virtual human arm model with 5 degrees of freedom and 50 muscles simulated under the influence of gravity, enabling a more comprehensive investigation of sensorimotor transformations relevant to biological motor control.

Our approach systematically develops four classes of internal models corresponding to core sensorimotor computations: forward kinematics, forward dynamics, inverse kinematics, and inverse dynamics. A staged learning approach inspired by developmental psychology was adopted to train these models, beginning with motor babbling, wherein random muscle excitations were used to explore the sensorimotor space and train the forward model via prediction error minimization. The next stage involved goal-directed babbling, where randomly generated desired trajectories were used to train the inverse model via distal supervised learning, guided by predicted performance errors generated using the forward model. In the final stage, both the forward and inverse models were jointly fine-tuned on reaching tasks using distinct strategies based on learning rates. This stage utilized prediction errors and actual performance errors to improve the accuracy of the forward and inverse models, respectively. A key result from this stage is that the inverse model's performance can improve through learning from actual performance errors, even when the forward model remains imperfect and unrefined. Beyond

neuroscience, these findings also contribute to AI and may have practical applications in developing controllers for robotic systems and neural co-processors for prosthetic devices.

We also conducted an in-silico characterization of the inverse dynamics model and systematically compared its internal representations with those observed in the primary motor cortex (M1). Our analyses revealed several key parallels: directional tuning of units, postural dependence of preferred direction (PD), non-uniform PD distributions, etc. While inverse dynamics computations likely involve multiple brain regions, these findings suggest that M1 could be a strong candidate for contributing to this process, given also its direct role in transmitting motor commands to the spinal cord.

P2-G-193 - Long term exposure to weightlessness reveals that gravity and limb biomechanics shape the kinematics of arm movement

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Details

On Earth, gravity shapes the kinematics of arm movements: vertical movements typically exhibit directional asymmetries in velocity profiles or curvature, whereas the horizontal movements addressed in most studies to date do not. Current theories attribute asymmetries in vertical hand movements to an optimization process in the motor system that accounts for gravitational forces to minimize energy expenditure. However, previous work focused mainly on monoarticular movements with the arm fully extended such that arm inertia was kept constant, leaving the influence of limb biomechanics on this optimization process unclear. Here, we investigate the combined effects of gravity and limb biomechanics on the kinematics of bi-articular arm movements. Eleven astronauts performed sequences of multi-joint, visually guided reaching movements towards targets aligned along vertical and horizontal axes before, during and after long-duration spaceflight missions onboard the international space station. In weightlessness, velocity profiles of vertical movements became more symmetrical across upward and downward directions, consistent with previous findings. Unexpectedly, horizontal movements of the hand exhibited directional asymmetries between forward and backward motions that varied with the distance from the body and became more apparent in 0g. The interaction effect between movement direction and gravity level demonstrates that limb biomechanics plays a clear role in shaping movement kinematics. These effects can be predicted through the lens of movement optimization. We designed an optimal control model that explicitly addresses the interplay between nonlinear arm dynamics and gravity and a cost function that combines measures of muscular effort and smoothness of motion. With this model we were able to produce patterns of directional asymmetries in both motion axes, in both gravity conditions, and as a function of the joint configuration - which varied through different initial and final target configurations, requiring different contributions of shoulder and elbow joints across movements. These simulations were comparable to what we observed empirically in the movements performed by the astronauts. These results support the hypothesis that the formation of arm movement trajectories in the motor system is shaped by internal representations of gravitational and biomechanical effects.

P2-G-194 - Disentangling gravity compensation and intersegmental dynamics in neural control of reaching

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Details

Background: Reaching movements require the nervous system to compensate simultaneously for gravity load and for the interaction torques generated by multi-joint dynamics. Gravity produces joint torques that depend only on limb orientation, not on movement velocity. In contrast, the passive torques that arise during reaching with a multisegmented limb include complex, velocity-dependent intersegmental interactions. This mathematical separation provides a natural way to probe whether the compensation for gravity and interaction moments rely on distinct neural mechanisms.
Methods: We analyzed data from parabolic-flight experiments and from ground-based reaching performed at different orientations relative to gravity. Subject-specific inverse dynamic simulations using a multi-segment upper-limb model were used to estimate muscle torques. These torques were decomposed into (1) velocity-independent components associated with gravity compensation and (2) velocity-dependent components arising from residual intersegmental dynamics. The resulting torque profiles were compared with electromyographic (EMG) patterns to interpret how each component is expressed in muscle activity.
Predictions: If gravity compensation relies on an internal estimate that is independent of the reaching plan, the gravitational component of EMG should remain velocity-independent and appear only as a static baseline shift. If, instead, gravity load interacts with the reaching plan, increased gravity load should produce larger velocity-dependent EMG bursts. Preliminary results support the latter pattern.
Conclusions: This modeling framework sheds light on the neural mechanisms underlying gravity and intersegmental dynamics compensation. These insights help identify neural mechanisms for posture and movement control and inform neuromuscular models relevant to both health and spaceflight applications.

P2-G-195 - Decomposing juggling skill into sequencing, prediction, and accuracy using low-gravity virtual reality training

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Details

Complex real-world motor skills emerge from multiple interacting processes, yet learning is often evaluated using a single performance score, making it difficult to interpret what actually improves over practice. Here, we introduce an interpretable computational framework that decomposes three-ball cascade juggling into three component processes: Sequencing (S), Prediction (P), and Accuracy (A). S represents spatiotemporal coordination among balls, P represents prediction of the landing position of a briefly occluded ball, and A represents the spatial consistency of catch locations.
We evaluated this framework in a 10-day longitudinal study with 20 juggling novices. Participants completed daily practice and assessments combining real-world juggling, visuo-haptic virtual reality (VR) juggling training, and a shutter-glasses visual-occlusion task. To reduce temporal demands during early learning, VR training manipulated effective gravity (slow-tempo training). The Low-g group trained with progressively increased gravity, while the Normal-g group trained at constant high gravity. On standardized test days (Days 1, 5, and 10), we computed day-level indices of S, P, and A from multimodal behavioral recordings and modeled their relationship to overall juggling performance.

A generalized linear modeling approach (Gamma distribution with a log link) captured the strictly positive, right-skewed nature of performance and enabled direct interpretation of component contributions. Across test days, higher Sequencing and Prediction were most strongly associated with better performance, with Sequencing showing the largest contribution in early-stage learning, while Accuracy showed a smaller independent contribution under the current definition. Longitudinal patterns further suggested that S, P, and A can evolve at different rates, supporting the view that early juggling acquisition is not a single uniform process. These results demonstrate a practical template for decomposing complex skill learning into interpretable sub-processes and for relating component-wise improvements to observed performance, with potential extensions to neural and physiological correlates of motor learning.

P2-G-196 - Whole-brain connectomic graph model enables whole-body locomotion control in fruit fly

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Details

Whole-brain biological neural networks naturally support the learning and control of whole-body movements. However, the use of connectomes as neural network controllers in embodied reinforcement learning remains unexplored. We investigated using the exact neural architecture of an adult fruit fly's brain for the control of its body movement. We developed Fly-connectomic Graph Model (FlyGM), whose static structure is identical to the complete connectome of an adult Drosophila for whole-body locomotion control.

To perform dynamical control, FlyGM represents the static connectome as a directed message-passing graph to impose a biologically grounded information flow from sensory inputs to motor outputs. The model partitions the connectome's neurons into three functional sets: afferent neurons that receive external sensory inputs, intrinsic neurons that mediate internal processing, and efferent neurons that produce motor outputs. At each control step, sensory observations are encoded and injected into afferent pathways, propagated through the brain-wide graph via synapse-weighted message passing, and decoded from efferent states into motor actions. To ground the model in biological reality, we incorporated signed synaptic weights based on neurotransmitter types, distinguishing excitatory (acetylcholine, glutamate) from inhibitory (GABA, glycine) connections. Each neuron carries trainable intrinsic descriptors that capture cell-specific computational properties not encoded in structural connectivity alone. The training pipeline consists of imitation learning from expert trajectories followed by reinforcement learning with Proximal Policy Optimization for task-specific adaptation.

We integrated FlyGM with a physics-based biomechanical fly model in MuJoCo, and evaluated performance across four locomotion tasks: gait initiation, straight-line walking, turning, and flight. Our method achieved stable control across all tasks without task-specific architectural tuning. To verify the structural advantages of the connectome-based model, we compared FlyGM against three baselines: a degree-preserving rewired graph, an Erdős–Rényi random graph, and multilayer perceptrons. Results demonstrated that FlyGM yields significantly higher sample efficiency and lower tracking error, suggesting that the biological connectome's organization is non-randomly optimized for embodied control constraints. Beyond behavioral performance, we analyzed internal neural representations and found that functional segregation across sensory, central, and motor populations emerges naturally from the trained dynamics.

This work demonstrates that static brain connectomes can be transformed to instantiate effective neural policies for embodied learning of movement control, establishing a framework for investigating how connectome-derived architectures give rise to adaptive motor behavior.

An anonymous webpage with demonstration videos and source code is available at:
https://sites.google.com/view/FlyGM

H - Neurorehabilitation

P2-H-197 - Premotor cortical activity is critical for recovery on a skilled reaching task following ischemic injury to primary motor cortex in the rat

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Details

Stroke impacts over 800,000 people in the United States annually and often leave survivors with severe impairments and very limited treatment options. An injury in primary motor cortex (M1) results in significant fine motor deficits that are the result of global disruption in motor network activity including corticocortical pathways and descending pathways to the spinal cord. Despite the loss of M1, some spontaneous recovery of function is possible, although the precise underlying mechanisms and pathways are largely unknown. Neuroplastic responses within premotor cortex (PM) following injury have been proposed to facilitate this recovery but its role and timing in these processes is unclear. To gain a greater understanding of how PM contributes to recovery, we performed a study to determine if and when PM is involved in spontaneous motor recovery following M1 injury. In one study, Long-Evans rats (13 male, 17 female) were trained on a skilled reaching task before random assignment to one of five groups. Rats were given an ischemic injury (or sham) over forelimb M1, while PM was inactivated using a continuous infusion of muscimol (1mg/ml @ 1µl/hr), for 0, 1, 2, or 3 weeks through an implanted cannula (Controls: C-injury – injury/no muscimol, C-muscimol – sham/3wk muscimol; Experimentals: E1 – injury/1wk muscimol, E2 – injury/2wk muscimol, E3 – injury/3wk muscimol). Skilled reaching data were collected bi-weekly for 8 weeks post-injury to assess the effect of PM inactivation on spontaneous motor recovery. Our results indicate that PM inactivation significantly impairs task initiation and motor performance. Four days post-injury, all groups demonstrated a behavioral deficit compared to baseline performance with only C-injury rats able to perform the task. Within one week following the cessation of muscimol infusion, all rats began reaching (except one rat in group E3). The C-injury group steadily improved from Day 4, reaching >80% baseline success by Week 5. All groups receiving muscimol reached >80% baseline success by 5 weeks post-muscimol cessation. These results not only suggest that PM is necessary to perform the skilled reaching task, but that there is not a critical period (at least to 3 weeks post-injury) in which PM must be active after the injury for spontaneous recovery to occur. To further refine how activity in the sensorimotor cortex contributes to motor function, we performed a second study to look at behaviorally related neural activity before and after M1 injury and subsequent PM inactivation. A 32-channel microelectrode array was implanted in the hand area of S1 and a similar 32-channel cannulated array was implanted in PM. As expected, muscimol reduced the activity within PM, which corresponded to a reduction in behavioral performance. Behaviorally-related neural activity started to recover once muscimol infusion was stopped. This may indicate that there is a longer post-injury window in which interventions could be effective.

P2-H-198 - Spinal cord stimulation to treat Parkinson's disease freezing of gait

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Details

Spinal cord stimulation (SCS) is emerging as a promising therapy to treat Parkinson’s Disease (PD) freezing of gait (FOG). But optimal parameters that maximize its therapeutic effect are not known. We developed beta-triggered dorsal column stimulation (BT-DCS) where spinal stimulation was regulated by the onset and offset of corticostriatal beta oscillations and implemented it in a bilateral intrastriatal 6-

OHDA rat model of PD. BT-DCS created a pro-locomotion brain state that improved locomotion (distance traveled increased 204%, $p<0.01$), reduced akinesia (time immobile decreased 17%, $p<0.01$), and disrupted ongoing beta oscillations (max reduction of 61% in right striatum, $p<0.001$) in six rats. BT-DCS was superior to continuous DCS in improving locomotion ($p<0.001$) and enabling beta desynchronization (53% more in left striatum). To translate our work in humans, we implanted a PD patient with FOG symptoms with percutaneous spinal electrodes. We recorded gait kinematics and local field potentials (LFPs) from bilateral subthalamic nucleus (STN) electrodes before and three days after implantation of SCS leads while testing several SCS parameters during locomotion. To study the impact of SCS on supraspinal activity, we quantified the spectral power of STN beta (13-35 Hz) oscillations, and measured STN phase amplitude coupling (PAC). Our results showed that SCS increased gait velocity (27%, $p<0.001$) and stride length (39%, $p<0.001$ when compared to pre-operation conditions. SCS drastically reduced freezing episodes, shown by complete cessation of long (>5s) freezes and substantial decrease in short (2–5s) freezes. FOG episodes decreased from 8 short – 22 % and 1 long – 7 % of locomotion time during pre-op-OFF to 1 short – 5 % and 0 long – 0 % of locomotion time during SCS. Blinded clinical scoring of gait, FOG, and posture (MDS-UPDRS sum of 3.10, 3.11, and 3.13) reduced from 6 (pre-op-OFF) to 3 (post-op-OFF) and 2 (SCS) corroborating objective assessment. In both left and right STN 13-35 Hz beta power was significantly reduced with all SCS parameters compared to pre-op-OFF. Normalized PAC averaged across walks showed a significant reduction in Lβ-γ and Hβ-γ PAC during SCS conditions as compared to both the post-op-OFF and pre-op-OFF conditions in the right STN, and there was a significant reduction in α-Lβ and α-Hβ PAC in the left STN. Additionally, gait velocity during the combined application of SCS and DBS was significantly superior to that when DBS or SCS were applied individually; SCS alone ($p<0.05$); DBS alone ($p<0.01$); and DBS alone in the pre-op session ($p<0.001$). Thus, our preclinical and clinical results establish SCS as a viable treatment option for PD FOG. We envision that SCS could be implemented concurrently with DBS to address the axial symptoms associated with PD which are untreatable with current methods.

P2-H-199 - A continuous control paradigm for motor brain-computer interfaces

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Details

Introduction: A large part of research on Motor Imagery Brain-Computer Interfaces (BCI) relies on variations of a cue-based paradigm. The user fixates on a target for a period, then is cued to perform or imagine the movement for a fixed duration, and then stops. This is a simple setup, but also results in very limited commands, making it impractical for Spinal Cord Injury or Stroke Patients.

We propose a new paradigm for the development of Motor BCIs. By simultaneously recording EMG and EEG of executed movements, we can continuously measure the ground truth movement of the user during a control task. This gives us a mapping of EEG to movement actions to be learned by Machine Learning methods. Previous research on BCI control treats control as a task without a ground truth, where performance is measured indirectly. In our setup, the exact control commands can be measured.

Methods: We record 32 channel EEG, 4 channel EOG, and 4 channel EMG data of 19 healthy participants. Each participant first performs a standard, cued calibration session moving their left and right hands. After this, participants perform a control task in which they steer a simulated car by moving their left and right hands. With this paradigm, we develop EEG decoding models based on the calibration session, and evaluate their quality with EMG as ground truth during the control task. This allows us to establish the exact movement onset and offset, forces models to distinguish between movement

preparation and movement execution, forces models to be robust against EEG patterns arising from a more complex task environment, and forces models to be robust for both short and long movements.

We train a within-subject Common Spatial Patterns (CSP) classifier and a Convolutional Neural Network (CNN) using the cues from the calibration session, and evaluate whether they are able to generalise to the control task, classifying segments into left, right or rest. Additionally, we establish a regression task based on the EMG envelopes between the two hands, indicating overall steering strength for either direction at any time, which is tackled with a ridge regression model.

Results: Both classifiers perform well on the calibration session with an average F1 score (i.e., mean of precision and recall) of 0.7 for CSP and 0.63 for the CNN. The CNN failed to generalize to the control task, with an F1 score of 0.37, while the CSP performed reasonably well with an average F1 score of 0.53. With the CSP there were four subjects with an F1 score>0.7, suggesting this model is effective. The ridge regression model failed to meaningfully reconstruct the EMG envelope.

Conclusion: We introduce a new paradigm and dataset to support the development of robust control methods from Motor BCIs. This new dataset still has many avenues for exploration, such as decoding for short "bursts" of movement, as well as optimally estimating the strength, onset, duration and progression of the movement.

P2-H-200 - Stimulation of the ventral spinal cord: A viable target for motor recovery?

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Details

Epidural spinal cord stimulation (SCS) is used clinically to treat pain, with recent clinical trials showing improved motor function with rehabilitation. Typically, SCS leads are implanted on the dorsal aspect of the spinal cord, where they stimulate the large diameter afferent fibres in the dorsal roots that indirectly activate motoneurons through reflex pathways. This indirect activation causes broad muscle activation, which limits finer control of movement. We propose implanting leads along the ventral epidural space to achieve more specific activation of individual muscles, which may improve motor recovery following neural injury or disease.

We implanted 9 SCS leads into three cadaver specimens: one 22-year-old female and two males, aged 68 and 69. Under fluoroscopic guidance, SCS leads were implanted by procedural clinical experts using 4 different approaches:

Sacral hiatus: leads were inserted through the sacral hiatus, then guided ventral to the roots and advanced cranially along the ventral surface of the spinal cord.

Transforaminal: leads were inserted through the intervertebral foramen, where the spinal roots enter and exit, and directed ipsilaterally and cranially within the ventral epidural space.

Interlaminar-contralateral: leads were inserted through the interlaminar space, steered dorsally across the spinal cord to the contralateral side, then advanced cranially along the ventral surface beneath the roots.

Interlaminar-ipsilateral: leads were inserted through the interlaminar space and immediately directed ipsilaterally toward the ventral epidural space and advanced cranially.

Once the SCS leads were in place and secured in the specimen, electrode placements were verified using computed tomography reconstruction and anatomical dissection.

Of the 88 SCS electrodes, 5 were dorsal, 65 were ventrolateral, and 18 were ventromedial. The 5 electrodes that were dorsal to the roots occurred in the first cadaver and with the interlaminar-contralateral approach). The interlaminar-ipsilateral approach resulted in 14 electrodes placed

ventrolateral and 18 electrodes placed ventromedial. The sacral hiatus approach led to all 8 electrodes placed ventrolateral. The transforaminal approach had a 100% success rate in ventrolateral lead placement; however, it may be risky with the leads implanted through the space where the roots are exiting/entering, especially if the foramen is narrowed due to arthritis, for example. Therefore, for ease of translation, the standard sacral hiatus and interlaminar entry points are recommended, with an ipsilateral steering of the leads to best achieve ventrolateral placement of the electrodes.
The successful ventrolateral placement of nearly all electrodes demonstrates the feasibility of several implant approaches to target the ventral spinal cord. Ventral SCS may provide more precise activation of individual muscles, which could restore motor function in people with neural injury or disease.

P2-H-201 - From suppression to enhancement: Why deep brain stimulation at 130Hz suppresses but at 50Hz potentiates cortical activity

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Details

Historically, deep brain stimulation (DBS) at frequencies above 100Hz has been used as a tool to suppress hyperactive cortical rhythms generated by neural pathologies, such as essential tremor or Parkinson's. While the suppressive nature of deep brain stimulation is well-documented in literature, a natural question arises: Can DBS also enhance cortical activity? Enhancing cortical excitability through DBS holds significant therapeutic promise for treating conditions that cause cortical hypo-excitability (e.g., stroke or traumatic brain injury). Indeed, in such a scenario, DBS becomes a unique neuromodulatory tool that can both enhance or suppress cortical activity reliably. Recently, Ho & Grisby et al. (Nat. Comm.'24) provided the first experimental evidence of enhancing motor cortical activity in monkeys and humans through motor thalamic DBS (mThDBS), by stimulating at lower frequencies (50Hz-80Hz). These results present a striking dichotomy in the cortical response to the frequency of DBS, where higher frequencies (>100Hz) suppress and lower frequencies (50Hz-80Hz) enhance cortical activity, an observation not well-explained by existing DBS mechanisms. Hence, it becomes imperative to better understand the neural mechanisms underlying DBS to fully assess its potential as a tool to enhance cortical excitability. In this work, we use computational tools to analyze cortical dynamics induced under DBS. We construct a bio-physical model of mThDBS consisting of a finite element model (to model current spread), existing biophysical models of thalamocortical relay neurons (to model thalamic responses), and a simple cortical network model (to model cortical responses). Our model replicates the experimental results and reveals a novel mechanism that combines rate-dependent depression of thalamic fibers and network dynamics of inhibitory neurons to explain the frequency-dependent effects of mThDBS. Briefly, the efficacy of thalamo-cortical synapses slowly decreases (on the order of seconds) during stimulation (rate-dependent suppression), but the rate of decrease is effectively larger in the excitatory cortical neurons than their inhibitory counterparts. At high frequencies, these different synaptic dynamics increase the relative firing rate difference between inhibitory and excitatory neurons during the stimulation, shifting the excitation-to-inhibition (E/I) ratio of the cortical network towards inhibition, suppressing cortical activity. The E/I shift tends towards excitation at lower frequencies, as the resultant inhibitory firing rates are not high enough to overcome the excitation coming from mThDBS, leading to potentiation. Our proposed mechanism and the accompanying model provide a general framework for understanding the frequency-dependent cortical effects of DBS. Furthermore, our mechanistic insights suggest DBS parameters that can further enhance cortical activity.

P2-H-202 - Potential of residual hand EMG activity in individuals with tetraplegia for ipsilateral control of a soft hand exoskeleton

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Details

Regaining voluntary hand function is a top priority for individuals with cervical spinal cord injury (SCI). While current assistive technologies often rely on compensatory inputs—such as contralateral limb or head movements—true neurorehabilitation aims to re-engage the impaired sensorimotor loop directly. In this work, we investigate the feasibility of using residual ipsilateral electromyography (EMG) to drive a soft hand exoskeleton, exploiting a "homologous" control strategy where attempted hand movements map naturally to the device's actuation.

We developed a wearable interface combining a 32-channel EMG sleeve with a pneumatically actuated soft hand exoskeleton designed to assist individual finger movements. First, we validated the decoding framework in eight participants with cervical SCI (C3–C7, AIS A–D) using a virtual hand interface. Online decoding using Long Short-Term Memory (LSTM) based decoder yielded high accuracy for hand opening/closing (mean 92.6 ± 8.0%) and remained well above chance for single-finger flexions (mean 73.9 ± 19.0%), even in participants with severe motor deficits. Notably, even in participants with severe motor deficits the EMG activity remained well for decoder to identify, indicating that localized spared activity preserves dinstict, usable motor command structures.

We then translated this framework to the control of physical soft exoskeleton. Pilot functional tests in 3 patients with SCI (GRASSP and box-and-block test) suggest the device successfully restores grasping functions and that homologous EMG control may lowers perceived effort during object manipulation compared to compensatory control strategies (e.g. button presses). However, transferring from virtual to physical actuation for EMG decoding introduced stability challenges, particularly in subjects with minimal EMG trace activity. These results confirm that residual ipsilateral EMG offers a rich, intuitive control source for neuroprosthetics, though robust physical deployment requires adaptive processing to handle the instability inherent to real-world interaction.

P2-H-203 - Training deep muscles in action: Wearable device for pelvic floor motor control

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Details

Neurorehabilitation is not just strengthening muscles – it is restoring motor control by rebuilding the brain's ability to sense and adjust action. This is hardest for deep muscles with weak proprioception, where limited sensory access restricts precise control. Pelvic floor muscles (PFMs) are a clear example. Damage to these muscles can result in PFM dysfunction, defined as the inability to correctly engage, coordinate, or sustain activation. PFM dysfunction affects roughly 20–40% of adults (predominantly women) and remains undertreated despite the effectiveness of exercise-based rehabilitation.

General access to specialist physiotherapy is limited, which shifts treatment toward use of invasive, strength-focused devices (vaginal/anal probes, Kegels/weights) or non-invasive digital tools (reminder/visual-cue apps) without informing users about actual muscle activation. Critically, no scalable, non-invasive technology exists that supports guided PFM training during movement, limiting transfer to daily activities.

To address this gap, we developed a non-invasive platform that infers deep muscle engagement from surface EMG electrodes and delivers discrete haptic cues during functional exercise. Our first application is a wearable device for PFM monitoring and feedback, consisting of eight surface EMG patches placed on the upper legs and torso, and two vibrotactors positioned on the hip bones. AI algorithms interpret the EMG signals to estimate PFM engagement and provide feedback when needed.
To date, the device was validated in 88 adults (76 females, 18–65 years), demonstrating a median accuracy of 94.8% for distinguishing engaged versus resting PFM states. We further compared model outputs against simultaneous intravaginal probe recordings (gold standard) in 19 women during a proportional-control task. Decoded engagement showed strong correlations across exercises and participants ($0.0001 < p < 0.01$, median $r = 0.75$). Clinical relevance was further assessed in five postpartum women (32–42 years), achieving a median accuracy of 93.7%, with additional validation ongoing.
Real-time vibrotactile feedback was further introduced in 34 novice participants, delivered to the hip bones when PFM engagement was classified as insufficient. Participants demonstrated a significant increase in PFM activation when receiving feedback ($p < 0.001$), with improvements of up to 48% from baseline (classifier output), confirming an appropriate behavioural response to feedback. Crucially, much of all validation data was collected in fitness studios and participants' homes, supporting real-world feasibility.
Together, these data establish a non-invasive, movement-compatible wearable to monitor deep muscle engagement and support feedback-guided adjustment. With deployment outside the lab already verified, the platform is now poised for large-scale, ecologically valid evaluation under varied physical demands, capturing learning where motor control actually matters: outside the lab.

P2-H-204 - TMS-based neurofeedback as an intervention for the early phase after stroke in a multi-modal neurorehabilitation approach

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Details

Neuro- and biofeedback approaches are emerging in motor neurorehabilitation to complement traditional methods such as physiotherapy. Neurofeedback (NF) may be especially beneficial early after a stroke in a critical time window for enhanced neuroplasticity while movement is completely absent. Current NF approaches are typically based on scalp-recorded electroencephalography (EEG), where reported outcomes are mixed and clinical implementation is challenging. Here we investigated NF based on transcranial magnetic stimulation (TMS)-evoked muscle responses. In TMS-NF participants receive direct visual feedback of corticospinal excitability (CSE) by motor-evoked potential (MEP) amplitudes. We tested the feasibility of applying TMS-NF at the bedside 4 weeks post-stroke in a case study with 6-month follow-up. As the end goal is to use TMS-NF as the first phase (at the bedside) of a multi-phase multimodal rehab approach, we additionally tested whether healthy participants could use TMS-NF to up- and down-regulate their CSE, and whether this training would transfer to typical EEG-based NF. An EEG-only group (n=17) underwent five EEG-NF sessions, while a TMS-NF group (n=17) underwent two TMS-NF training sessions followed by three EEG-NF sessions. All sessions took place on separate days and participants were provided with recommended mental strategies for up- and downregulation. In TMS-NF sessions, participants received visual feedback based on MEPs measured in their right First Dorsal Interosseus (FDI) muscle. For EEG-NF we used a Graz-style BCI providing real-time feedback of oscillatory activity associated with up- and downregulation of CSE.
The sub-acute stroke patient demonstrated an increase in volitional upregulation of CSE from 4 weeks post-stroke (122.59%) to 6 months post-stroke (218.70%), concurrent with recovery of upper limb motor function (Fugl-Meyer upper extremity at 4 weeks: 12; at 6 months: 55). This demonstrates feasibility of

TMS-NF in clinical environments. Results from healthy participants show that TMS-NF enables successful up- vs downregulation of CSE ($p < 0.001$). Additionally, the TMS-NF group showed a faster learning rate in the EEG-NF task compared to the EEG-only group ($p < 0.05$) and performed better in their last EEG-NF session ($p < 0.05$), indicating faster adoption of the EEG-NF task after priming with TMS-NF training. The data suggests that training to modulate CSE with TMS-NF transfers well to an EEG-NF approach by producing more distinguishable EEG activity patterns. Given the lengthy time periods typically required for participants to achieve control of EEG-NF, we propose TMS-NF as an approach for neurorehabilitation at the bedside prior to (more portable and scalable) EEG-NF approaches. Ultimately, when patients have acquired functional muscle control, NF approaches are no longer mandated and progression to EMG-biofeedback or traditional physiotherapy approaches are recommended.

P2-H-205 - The feasibility of rehabilitation program in patients with multiple system atrophy

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Details

Background: Therapeutic options for multiple system atrophy (MSA) are limited, and rehabilitation may serve as an alternative approach to improve functional outcomes. This study aimed to evaluate the effects of rehabilitation on functional and clinical outcomes in patients with MSA.
Methods: Patients diagnosed with MSA and referred for rehabilitation were retrospectively analyzed. Functional outcomes, including the Berg Balance Scale (BBS), Timed Up and Go (TUG) test, and Modified Barthel Index (MBI), as well as clinical outcomes, including the Unified Parkinson's Disease Rating Scale (UPDRS), Unified Multiple System Atrophy Rating Scale (UMSARS), and Scale for the Assessment and Rating of Ataxia (SARA), were assessed before and after rehabilitation. Changes were analyzed in the total cohort and according to MSA subtype: parkinsonian-predominant MSA (MSA-P) and cerebellar-predominant MSA (MSA-C).
Results: In the total cohort of 31 patients, significant improvements were observed in BBS and TUG following rehabilitation, whereas no significant change was noted in MBI. Subgroup analyses demonstrated a significant improvement in BBS in the MSA-C group, with marginal improvements observed in BBS in the MSA-P group and TUG in the MSA-C group. Clinical outcome analysis conducted in a subset of patients showed significant worsening in UPDRS, with marginal worsening trends in UMSARS and SARA. Worsening of UPDRS was observed in both MSA-P and MSA-C subgroups.
Conclusions: Rehabilitation was associated with improvements in balance and functional mobility, as reflected by improvements in BBS and TUG. However, rehabilitation alone was insufficient to prevent clinical disease progression in patients with MSA.

P2-H-206 - Utility-modulated granger causality among PMd, M1, and S1 in NHPs

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Details

Primate sensorimotor cortices (S1, M1, and PMd) are modulated by expected future rewards. Increasing the effort to obtain rewards decreases subjective value and modulates neural activity in sub-cortical regions associated with reward predictions. However, it is largely unknown how expected reward/effort levels modulate local field potentials (LFPs) in sensorimotor cortices before motor planning. To address this gap in our knowledge, we trained a macaque to perform a center-out reaching task while recording LFPs in the sensorimotor cortices from 96 electrodes. We utilized visual cues indicating possible levels of future reward (R1-3 reward only task), effort (E1-4, effort only task), or both reward and effort in three tasks, which dissociated utility context (reward and effort levels) from motor planning, as the reaching target was only shown after the reward and effort information.

We found robust modulation of post-contextual-cue Granger Causality in the alpha (8-13 Hz), beta (14-30 Hz), low gamma (30-80) and high gamma (80-200Hz) band amplitudes. The alpha and beta bands showed similar GC to each other with the main GC directionality going from PMd → M1 for the reward only task and from M1 → S1 for the effort only and reward/effort tasks. While low and high gamma differed from each other and from alpha and beta. Low gamma had its strongest GC directionality from S1 →M1 for all three tasks and high gamma from M1→PMd for reward only, PMd→M1 for effort only and reward effort tasks. This information along with linear encoding of reward and effort levels from the LFPs within these regions and Phase amplitude coupling allow us to track task type and reward/effort levels, which help define an affective state space towards autonomously updating reinforcement learning BMIs.

P2-H-207 - Impacts of transcutaneous spinal cord stimulation on muscle activity and heart rate responses during robotic gait trainer use in children with Cerebral Palsy

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Details

Children with cerebral palsy (CP) often exhibit muscle weakness and impaired motor control, limiting mobility (Graham 2016). The Trexo is a battery-powered exoskeleton mounted to the frame of a commonly used Rifton gait trainer that provides hip and knee actuation to generate walking patterns, which may improve walking function and support rehabilitation (Diot 2021). Transcutaneous spinal cord stimulation (tSCS) may further enhance motor output during rehabilitation (Solopova 2017), though its impact during Trexo-assisted walking remains unknown. This case series examined muscle activity and cardiovascular responses during Trexo use with and without tSCS in children with CP.

Four young children with non-ambulatory CP (1M/3F, 32 ± 8.0 months) completed Trexo-assisted walking trials with and without tSCS. tSCS was delivered with electrodes placed at C6 and L1 vertebral levels. Stimulation amplitude, trial duration and device settings were individualized for comfort and engagement. Surface electromyography (EMG) data were recorded bilaterally from the biceps femoris (BF), vastus lateralis (VL), and rectus femoris (RF) and filtered, rectified, and normalized to the 95th percentile maximum of each visit. Heart rate (HR) was collected continuously with an optical HR sensor. All participants displayed cyclic muscle activity during Trexo use, similar to gait. Heart rate increased with Trexo use by 32.4% (range:19 to 65%) compared to resting values. To isolate tSCS effects, we compared trials matched for cadence and mode for each participant. During matched tSCS trials, peak heart rate decreased by an average of -3.9% (-16.4 to 11.1%) compared to trials without tSCS. Muscle activity also decreased with tSCS for by 6.8% (-20.2 to 3.7%), 5.8% (-15.2 to 6.2%), and 13% (-39.1 to 2.3%) for the BF, RF, VL, respectively.

Muscles were active and heart rate elevated during Trexo use in young, non-ambulatory children with CP. Adding tSCS may modulate muscle activity and cardiovascular response, although immediate acute effects were small. Reductions in muscle activation and HR with tSCS may suggest decreased effort or altered control. This modulation could be therapeutically beneficial, as avoiding excessive physiological demand and fatigue is important to support neuroplasticity. Prior studies with tSCS and children with CP (Solopova 2017, Gad 2021) demonstrated decreased co-contraction with tSCS, though we observed minimal changes in our cohort. The Trexo may have provided more constraints on limb movement that altered muscle response. Understanding these physiological responses can guide clinicians in optimizing treatment protocols for children with CP.

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P2-H-208 - Cortical dynamics of motor and tactile imagery

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Details

Mental imagery is widely applied in cognitive neuroscience, yet its underlying neural mechanisms remain incompletely understood. Here, we examined the neural correlates of motor and tactile imagery using simultaneous electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS). Sixteen healthy participants performed guided motor and tactile imagery tasks while brain activity was recorded. We analyzed event-related desynchronization (ERD) of the mu rhythm and hemodynamic responses (HRs) in sensorimotor regions.

Similar spatio-temporal EEG patterns were observed for both motor and tactile imagery conditions (*e.g.,*prominent contralateral ERD at C3), whereas hemodynamic responses differed: motor imagery induced activation in both precentral and postcentral regions ($p = 0.433$), while tactile imagery predominantly engaged postcentral regions ($p = 0.003$). Correlation analysis revealed a strong across-subject correlation ($r = 0.84$; $p < 0.001$) between ERD values in motor and tactile imagery, but no correlation between ERD and hemodynamic responses. Linear mixed model analysis revealed significant ($p < 0.001$) associations between precentral and postcentral HRs for both MI and TI.

Taken together, these results demonstrate that motor and tactile imagery share common oscillatory patterns in the sensorimotor cortex, but differ in their hemodynamic responses. The dissociation between EEG and fNIRS markers underscores the complexity of neural dynamics during mental imagery and highlights the value of multimodal approaches. These findings provide new insights into imagery-related brain processes and may inform the development of brain–computer interfaces and rehabilitation strategies based on mental imagery.

P2-H-209 - Corpus Callosum morphometry as determinant of bimanual motor control in children with unilateral cerebral palsy

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Details

Introduction:

Children with unilateral cerebral palsy (uCP) often have impaired bimanual motor control (BMC), both dexterity and coordination, which impacts their independence and daily life. Quantifying BMC and linking it to neurological factors may guide early prognosis and personalized therapy. Because the corpus callosum (CC) supports interhemispheric communication, essential for BMC, we explored whether CC morphometry can explain variability in BMC outcomes.

Participants/methods:

Forty-nine children with uCP (7-16 years; mean age = 11.90 ± 2.87) completed various bimanual tasks using the Tyneside-Pegboard test, the Box-Opening Task, and the Kinarm exoskeleton (Ball-on-bar, Object-hit). Morphometrical measures of the CC (thickness and total length) were obtained with MRI using the Garel Scale. Spearman's coefficients examined correlations between BMC and CC's morphometry whereas backward multiple linear regression (AIC; α=0.05) investigated the variability in BMC outcomes.

Results:

Lower CC morphometric measures were correlated with worse scores in several BMC outcomes (ρ =-0.304 to - 0.461). Backward multiple linear regression revealed that the combination of genu and splenium thickness explained 30% variability in Object-hit task. Combining rostrum and genu's length

explained 16% variability in Ball-on-bar task. The rostrum and isthmus explained only 5% variability of the Box-Opening task and 2.5% variability of the Tyneside-Pegboard test.
Conclusion:
These findings show that CC morphometry can partially explain BMC. Nevertheless, the task-dependent heterogeneity suggests that specific CC subregions explain some bimanual tasks better than others (particularly tasks requiring more coordination). This task-specific pattern underscores the relevance of quantitatively analysing CC morphometry as a meaningful marker of interhemispheric communication and BMC in children with uCP.

P2-H-210 - Neural-behavioural coupling during walking to music and metronomes in cerebellar ataxia and healthy controls

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Details

Introduction: Cerebellar ataxia is characterised by impaired temporal prediction. Auditory-motor coupling paradigms entailing entrainment of auditory and motor systems, offers a method for probing these deficits. Paced finger-tapping studies have shown that cerebellar patients exhibit reduced behavioural synchronisation and diminished neural entrainment. Here, we extend investigations to walking as it requires higher complexity of motor control involving (sub)cortical and cerebellar regions. We aimed to investigate whether deficits in step-to-beat synchronisation are mirrored by disturbed coupling between EEG signals and auditory rhythms of different complexity in persons with cerebellar ataxia (PwCA) as compared to healthy controls (HC).

Methods: Fourteen PwCA and HC completed two blocks: one music and one metronomes. Per block, participants walked to seven randomised tempi (±12%, ±8%, ±4%, and 0% relative to preferred walking cadence) for three minutes each. They were fitted with two inertial measurement units, a music player, and a 64-channel EEG, and were instructed to synchronise their steps to the beats. EEG signals were pre-processed for artifact removal (bad-channels, ICA, and surface Laplacian transform), band-pass filtered to the theta, alpha and beta ranges, and segmented into six gait-cycle epochs. Instantaneous EEG phase and amplitude and step and beat phases were extracted from the analytic signal. Neural-behavioural coupling was quantified using the phase synchronisation index (PSI) between EEG phase and step/beat phase, while cross-frequency coupling was quantified using the modulation index (MI) between EEG amplitude and step/beat phase. Condition effects (music vs. metronome) were assessed using cluster-based permutation statistics, using two contrasts a) average across tempi and b) U-shape tempo contrast, weighting extreme tempi against the mid tempi. Thereafter, non-parametric Monte Carlo was applied (n=5000; cluster-forming $p<0.05$; two-tailed) to test within-group one-sample effects and between-group differences at the channel level per outcome.

Results. At theta and alpha frequencies, music (vs. metronomes), averaged across tempi, elicited stronger coupling in HCs than patients over a right frontal cluster (theta: MI EEG-beat p=0.0436 and step p=0.0368 | alpha: PSI EEG-beat, p=0.0096 and step p=0.0060). While at beta frequencies, within-group effects were found for the U-shape contrast. In HCs, music (vs. metronomes) significantly enhanced beta amplitude coupling to gait phase over a left centro-parietal/temporo-parietal cluster (p=0.0002), and this enhancement was more pronounced at tempi -12% and +12%. In patients, music (vs. metronomes) significantly enhanced beta phase-phase coupling: a) of the EEG phase to beat phase over left posterior-parietal cluster (p=0.0002) and b) EEG phase to step phase over a left fronto-centro-parietal cluster (p=0.0002), both aligning with the planned U-shaped tempo contrast (i.e. extreme tempi > mid-tempi).

Conclusion: Overall, music produced frequency-specific, group-dependent modulation of neural-behavioural coupling during walking. Music elicited stronger coupling in controls than cerebellar patients over right frontal clusters in both theta and alpha bands when averaged across tempi, whereas beta-band modulation was evident only within groups and was maximal at extreme tempi.

P2-H-211 - Neurophysiological correlates of exoskeleton-assisted gait training

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Details

Gait training with robotic devices represents a promising approach to promote functional recovery and neuroplasticity in individuals with motor impairments. However, despite evidence of abnormal muscle activation [1] and altered resting-state EEG patterns [2], objective neurophysiological markers able of capturing short-term and training-related changes remain limited [3]. Here we investigated muscle synergy structure and resting-state EEG connectivity before and after a 4-week locomotor training intervention assisted by the TWIN lower-limb exoskeleton [4] in a cohort of 10 post-stroke individuals, with the aim of identifying neurophysiological signatures underlying response to assisted gait rehabilitation.

Analysis of muscle synergies from 24 EMG-recorded from trunk and leg muscles, revealed a trend toward more physiological activation patterns following rehabilitation, particularly in the timing of synergy activation [5].

Resting-state EEG was recorded from 64 channels, signals were source-localized to 21 cortical regions of interest grouped into 6 canonical networks using eLORETA and functional connectivity was computed across canonical frequency bands [6]. Changes in connectivity were correlated with clinical measures of motor function and participation, including the 5 Times Sit-to-Stand test (5TSTS, lower values indicate better performance) and the Stroke Impact Scale (SIS, higher values indicate more favorable self-reported outcomes). Results revealed consistent and physiologically meaningful patterns. Better clinical outcomes were associated with a reduction in theta and alpha connectivity and an increase in beta-band connectivity, suggesting a shift toward more physiological cortical dynamics. Specifically, a decrease in connectivity in the theta band within and across the dorsal attention network correlated with improvement in SIS score while a decrease in the alpha band default mode network, dorsal attention network, and somatomotor network showed negative correlations with 5TSTS and positive correlations with SIS scores. In the beta band, similar networks exhibited correlations between connectivity changes and 5TSTS performance. Notably, intra-network connectivity changes in the visual network correlated with both 5STS and SIS in both alpha and beta bands, suggesting a potential role of visuomotor integration in locomotor recovery.

Overall, these results support the neurophysiological validity of overground robotic-assisted gait training and its association with functional outcomes. Building on these findings, we are currently investigating robotic-based gait training combined with functional electrical stimulation to further enhance neuroplasticity. Preliminary pilot data from this combined intervention highlight its potential to amplify neurorehabilitation outcomes.

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This work received funding from the Italian Ministry of Health under the European Union-Next Generation EU-PNRR-M6C2 (grant n. PNRR-POC-2022-12375689, project “PoCH-Rehab-Proof of Concept of Hybrid robotics for gait Rehabilitation of persons post-stroke”).

P2-H-212 - Dancing in the metaverse: Motor control alterations in virtual reality versus real-world dance environments

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Details

Introduction: Dance offers both therapeutic and recreational benefits for children with motor disabilities such as cerebral palsy, yet accessibility barriers limit participation. Metaverse and social virtual reality (VR) present promising opportunities for remote and immersive dance experiences, but their appropriateness for this population remains unexplored, particularly in rehabilitation contexts. Understanding how motor control differs between VR and real-world dance environments is critical: immersive VR introduces unique sensorimotor constraints such as headset-mediated vision and incomplete body tracking (with standard commercial systems) that may fundamentally change movement patterns in ways that could either enhance or impede therapeutic outcomes. Identifying these motor adaptations is essential for designing safe, effective VR dance interventions for children with motor disabilities.
Methods: This two-experiment study investigated VR dance for children with motor disabilities. Experiment 1 employed a convergent mixed-methods design with 23 participants (children with motor disabilities, therapists, and dance instructors) to evaluate the feasibility of VR dance using Meta Quest 3 headsets on VRChat. Experiment 2 used a randomized crossover design where 10 healthy adults performed a standardized 10-minute dance routine in both real-world and VR environments, one week apart. The choreography incorporated progressive complexity with increasing tempos (89–128 BPM). Participants’ movements were recorded using a Kinect 2.
Results: In Experiment 1, dancing in the metaverse was found to be highly entertaining and interactive, with dance instructors reporting similarities to in-person classes. Both instructors and therapists identified strong potential for enhancing motivation, fostering creativity, and supporting social connection. However, they expressed concerns that incomplete body tracking could pose safety risks and restrict teaching of technical movements, with adolescents emphasizing the need for accurate avatar leg tracking. In Experiment 2, participants showed significantly greater arm extension in VR than non-VR, but significantly lower hand displacement and velocity in VR. Area covered by the left hand, right hand, left foot, and right foot did not differ significantly between VR and real-world conditions, suggesting that spatial coverage was not strongly affected by the medium.
Conclusion: Results reveal distinct motor control strategies in VR versus real-world dance environments. Participants adopted extended arm postures with constrained, slower hand movements in VR, suggesting compensatory strategies that may reflect reduced reliance on feedforward control and increased dependence on feedback-based corrections. These findings highlight critical motor control adaptations and tracking limitations that should inform the design and refinement of metaverse-based dance interventions to safely and effectively support children with motor disabilities.

P2-H-213 - Impairments in central conduction do not inhibit motor adaptation to perturbation-based gait training in people with multiple sclerosis

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Details
Background and Purpose: The purpose of this study was to quantify reactive postural responses (RPRs) and central conduction in people with multiple sclerosis (PwMS) during high-intensity gait training (HIT) with postural perturbations. Although perturbation-based gait training is often used to decrease fall risk in PwMS, and our lab has shown that healthy adults can improve their perturbation response within a single training session, the ability of PwMS to adapt their RPRs during HIT is unknown. Notably, while cardiovascular exercise may improve adaptation of motor skills in other neurologic populations, PwMS demonstrate increased sensitivity to increases in core temperature, which can cause transient conduction blocks secondary to disease-specific demyelination. These blocks may manifest clinically as delayed evoked potentials and could be indicative of afferent and efferent central conduction impairment, ultimately inhibiting the execution and adaptation of RPRs.
Methods: PwMS (n = 14) ambulated on a treadmill for 30min, with a target heart rate reserve of 70-80%. Every ~40 seconds, during single limb stance, the treadmill belt suddenly sped up at one of 3 random intensities of increasing belt acceleration and displacement, totaling 15 perturbations of each intensity over the 30min. Post-perturbation stability was defined as the peak-to-peak difference in whole body angular momentum (H_R) in the sagittal plane during the stride in which the perturbation occurred, with lower H_R values indicating greater stability. Peak-to-peak trunk flexion amplitude was quantified over the same window, to describe possible strategies underlying changes in stability. Corrective step length was defined as the anteroposterior length between heels at the first heel strike after perturbation initiation. As a surrogate measure of central conduction, somatosensory evoked potentials (SSEPs) were recorded via sural nerve stimulations timed to mid-stance, with EEG epochs from -100 to 200ms around each stimulation. Non-stimulated motion artifact EEG data from mid-stance were subtracted from stimulated epochs and averaged over 10min periods. Perturbation adaptation was quantified with a linear regression of the time series of 15 perturbations averaged across intensities during HIT. SSEPs were compared from the first to the last 10min of HIT using a paired t-test.
Results: SSEP latencies increased (46.16 to 71.00ms, $p = 0.012$), while sagittal plane H_R decreased ($R^2 = 0.480$, $p = 0.004$) and corrective step lengths ($R^2 = 0.169$, $p = 0.128$) and trunk flexion did not change ($R^2 = 0.028$, $p = 0.554$). Baseline or changes in SSEP latencies were not significantly correlated with baseline or changes in any kinematic elements of RPRs.
Discussion and Conclusion: PwMS develop central conduction impairments during HIT with perturbations yet retain their ability to adapt RPRs to improve stability. Interestingly, despite this improvement, PwMS did not adapt RPR amplitude, as measured by corrective step length and trunk flexion. Furthermore, there were no significant correlations between SSEP latencies and kinematic measures of RPRs. These data suggest that central conduction impairments during training may not have a significant effect on the execution and adaptation of RPRs. Secondarily, improvements in stability despite the lack of amplitude adaptation may indicate that modulation of efferent signals which control segmental velocity take precedent over amplitude modification following perturbations.

P2-H-214 - Proprioception during transcutaneous spinal cord stimulation in individuals with spinal cord injury

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Details
Introduction: Proprioception is the sense of limb position and movement. This sense can be impaired in neurological conditions such as spinal cord injury (SCI). Transcutaneous spinal cord stimulation (tSCS) can improve upper-limb motor outcomes after SCI, but the underlying mechanisms remain unclear. Because tSCS is thought to engage dorsal column afferent pathways, one possible mechanism is modulation of

proprioceptive processing. The goal of this pilot study was to test whether tSCS alters proprioceptive performance during upper-limb movements after cervical SCI.
Methods: Nine participants with incomplete cervical SCI (AIS C/D) and nine age-matched neurologically-intact (NI) participants completed two KINARM tasks with and without tSCS: (1) Position Matching, where the non-dominant arm was passively moved to 1 of 9 targets and the dominant arm mirrored the position (6 repetitions per target), and (2) Arm Movement Matching, where participants mirrored ongoing passive movements of the non-dominant arm across 3 targets (36 trials). Stimulation electrodes were placed over C3–C4 and C6–C7 with return electrodes over the iliac crests. Single pulses were used to identify the spinal evoked potential threshold in the biceps brachii muscle at the beginning of the experiments, and tSCS was delivered as 40 Hz trains of 1 ms pulses with a 10 kHz carrier at the threshold amplitude during stimulation blocks.
Several kinematic metrics to capture both accuracy and temporal aspects of proprioceptive control were evaluated. These included endpoint error in position matching and trajectory error in movement matching, along with reaction time and offset delay, which reflect how accurately participants sensed movement initiation and termination. Movement duration and movement smoothness (using the number of peaks in the speed profile) were also assessed during the movement matching task.
Results: In the position matching task, endpoint error showed a difference, NI participants performed significantly worse than participants with SCI ($p = 0.029$) and there was no effect of tSCS on endpoint error. In the movement matching task, NI participants exhibited faster offset delay than participants with SCI ($p = 0.08$). While tSCS increased movement duration ($p = 0.042$) within the SCI group, it nearly improved the smoothness of the movements for the NI participants ($p = 0.052$).
Conclusions: In this preliminary dataset, tSCS did not measurably affect static position sense, but it was associated with altered movement timing during movement matching in SCI, and smoothness for the NI participants. This pattern suggests that if tSCS influences sensorimotor behavior, it may act through changes in movement execution or online sensorimotor integration rather than improving position-matching accuracy. Larger studies are needed to determine whether stimulation parameters, impairment level, or task demands modulate these effects.

P2-H-215 - Walking with an asymmetric hip exosuit produces aftereffects on several muscles and gait phases

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Details

Introduction: Rehabilitation is shifting from assistive devices toward greater participation and effort[1,2], using error-driven neural adaptation to promote motor recovery. Error augmentation devices (e.g., split-belt treadmills[3], resistive hip exoskeletons[4,5], shoe-style devices[6]) have been developed for improving spatiotemporal symmetry, but phase focused analyses may miss gait-cycle-level aftereffects in muscle activity. We measured EMG in healthy adults wearing an asymmetric passive hip exosuit. We hypothesized that aftereffects relative to baseline would be largest in hip muscles on the resisted side, with minimal changes in distal muscles.
Methods: Eight healthy adults completed three 15-min overground walking: *Baseline* (retractors disconnected), *Exo-Adapt* (retractors applying 15% bodyweight on the anterior right thigh to resist hip extension and 10% on the posterior left thigh to resist hip flexion), and *After* (retractors disconnected). Bilateral leg EMG data were filtered, rectified, stride-normalized, and normalized. We analyzed the last 10 *Baseline* strides, the initial 10 *After* strides. We fit linear mixed-effects spline models with and without condition effects and interactions[7], refit the best-fitting models for final estimates. Holm-adjusted *Baseline–After* contrasts were performed with $\alpha=.05$.

Results: Exosuit removal produces phase dependent EMG aftereffects. Right gluteus maximus and biceps femoris increased across much of the gait cycle and left rectus femoris and vastus lateralis also increased. Distal aftereffects were also evident, including tibialis anterior and soleus, showing responses were not confined to the hip. Effects were strongest during stance and transition to swing, with significant windows across toe off and additional effects in late swing.
Discussion: Asymmetric passive hip forces elicited bilateral aftereffects across proximal and distal muscles, consistent with locomotor sensorimotor adaptation rather than changes limited to the perturbed joint[3,8]. These results align with prior reports of stored sensorimotor recalibration and bilateral, time varying EMG changes[9–11]. A passive resistive hip device can therefore drive multi joint neuromuscular aftereffects, highlighting the need to monitor distal response in clinical populations.
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P2-H-216 - Integration of ICMS-elicited artificial sensation and natural vision: Implications for sensory feedback in brain–machine interfaces

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Details

Effective neural control of movement depends on continuous and reliable sensory feedback. Spinal cord injury interrupts both descending motor commands and ascending somatosensory signals, impairing coordinated, dexterous actions. Although brain–machine interfaces (BMIs) can restore purposeful movement by decoding neural activity to control prosthetic devices, performance remains limited without somatosensory input. Visual feedback alone cannot support fine grasp control because it is prone to occlusion, lacks force and contact timing information, and becomes unreliable during complex hand-object interactions.

Somatosensory brain-machine interfaces aim to deliver sensor-driven direct-to-brain tactile feedback to improve BMI performance. Intracortical microstimulation (ICMS) of primary somatosensory cortex (S1) has proven to be a reliable means of generating tactile sensations in humans, but the challenge of making these sensations feel natural and congruent as feedback remains. Consistent with S1's somatotopic organization, reported locations (projected fields, PFs) associated with these sensations depend on the stimulating electrode's cortical location. Little is known about how these artificially generated sensations are integrated with natural stimuli, particularly vision. To study this interaction, we paired ICMS delivered to S1 with congruent or incongruent visual cues projected onto corresponding PFs in two tetraplegic humans implanted with microelectrode arrays in somatosensory, motor, and posterior parietal cortices. We characterized behavioral and neural responses to ICMS and visual stimuli delivered alone or in combination.

We found that ICMS delivered alone reliably elicited artificial sensation while vision alone did not, and that congruent visual input increased the probability of sensation relative to ICMS alone, suggesting that the integrated aligned signals boosted perceptual salience. Additionally, pairing ICMS with natural visual input could change the elicited sensations, altering their perceived location, spatial extent, and variability. These effects were strongest when visual input occurred concurrently with ICMS compared to when the two were presented separately in time. Neurons recorded across sensory, motor, and posterior

parietal cortices showed robust ICMS-evoked modulation, with additional visual-context modulation evident in the posterior parietal cortex. In primary sensory and motor areas, congruent visual cues were found to increase the number of ICMS-responsive units. Taken together, our findings demonstrate that visual context shapes both perceptual and neural responses to ICMS, revealing a need for somatosensory BMIs that explicitly consider multisensory interactions in their design to provide increasingly natural and effective sensory feedback for the restoration of movement.

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