XV Progress in Motor Control

"Crossroads between Neurophysiology and Applications"

University of Rhode Island, Kingston, RI, USA

June 30 – July 2, 2025

PROGRAMME & BOOK OF ABSTRACTS

MESSAGE FROM THE ORGANIZING COMMITTEE

On behalf of the Organizing Committee, Physical Therapy Department, College of Health Sciences and the ISMC, it is our great pleasure to welcome you to the **XV Progress in Motor Control Conference (XV PMC)** in beautiful Rhode Island. We are honored to bring together leading researchers, clinicians, and students from around the world to share the latest advances in motor control, foster new collaborations, and inspire future directions in the field.

We are especially proud to host this year's conference at the University of Rhode Island (URI), which has recently achieved a prestigious designation as an R01 institution. This recognition reflects the university's growing commitment to research excellence, innovation, and impactful scientific contributions.

Our program is designed to reflect the theme **"Crossroads between neurophysiology and applications"**, offering a rich blend of theoretical perspectives and practical insights. We hope you will find the sessions stimulating, the discussions engaging, and the setting conducive to both professional growth and personal connections.

We would also like to extend our sincere gratitude to our **sponsors**, whose generous support has made this event possible.

Welcome!

We look forward to an exciting and memorable conference together!

XV PMC Organizing Committee
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Carrie Brown
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Susan D'Andrea
Devina Kumar
John McLinden
Brittany Casey
Samantha Fallon
David Ornstein
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SPEAKERS

Alaa A. Ahmed, PhD	University of Colorado Boulder, USA
Stuart N. Baker, PhD	Newcastle University, UK
Andrea L. Behrman, PhD, PT, FAPTA	University of Louisville, USA
Raoul M. Bongers, PhD	University of Groningen, Netherlands
Evangelos A. Christou, PhD	University of Florida, USA
Daniela Corbetta, PhD	University of Tennessee, USA
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Mariusz P. Furmanek, PhD, PT, DPT
Mark L. Latash, PhD
Monica A. Perez, PhD
Eugene Tunik, PhD, PT

IMPORTANT INFORMATION

CONFERENCE VENUE

The Center for Biotechnology and Life Sciences (CBLS)
The University of Rhode Island
120 Flagg Rd, Kingston, RI 02881

FREE WIFI, CONNECTING TO WIFI AS A GUEST

1. Connect to **URI_Open** from the list of WiFi networks available on your device
2. Go to **rhodywifi.uri.edu**
3. Click on Guest Network Access
4. Click on Restricted Guest Access (blue button)
   (wait a few seconds to allow the system to give you access)

OFFICIAL CONFERENCE WEBSITE

https://web.uri.edu/chs/events/xv-progress-in-motor-control/

PROGRAMME - PDF

BOOK OF ABSTRACT - PDF

POSTER SESSIONS - The Center for Biotechnology and Life Sciences (CBLS) Foyer

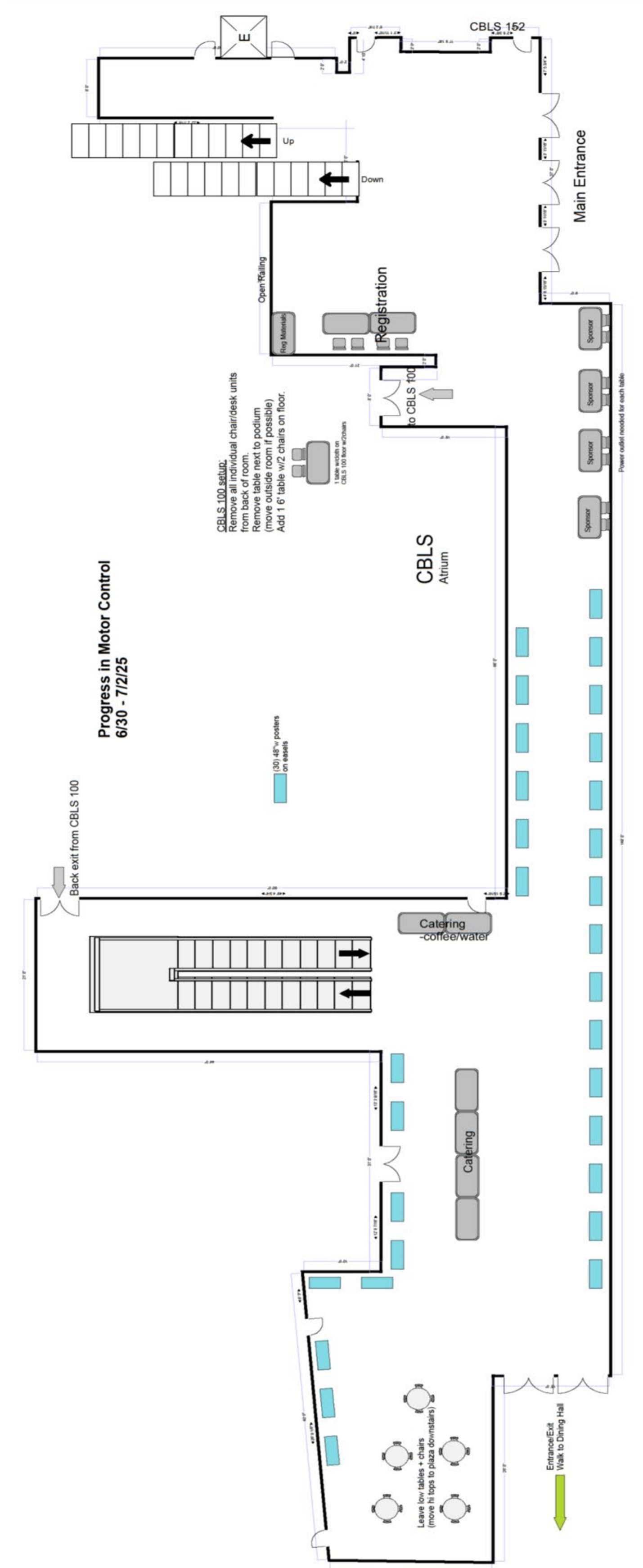
P1 - POSTER SESSION I, Monday (06/30), 1:00 – 3:00 PM
"Neural and Biomechanical Mechanisms of Motor Control and Adaptation"

P2 - POSTER SESSION II, Wednesday (07/02), 1:00 – 3:00 PM
"Clinical and Functional Applications in Motor Impairments and Rehabilitation"

CLOSING GALA DINNER

Mosby Center
The University of Rhode Island (Narragansett Campus)
230 S Ferry Rd, Saunderstown, RI 02874

THE CENTER FOR BIOTECHNOLOGY AND LIFE SCIENCES (CBLS) – FLOOR PLAN



PROGRAMME

DAY 1, JUNE 30 (MONDAY) – Auditorium at the Center for Biotechnology and Life Sciences (CBLS #100)

07:30 – 12:00 Registration, CBLS Lobby (Poster setup)
07:30 – 08:45 Continental Breakfast, CBLS Foyer
08:00 – 17:00 Exhibitors, CBLS Lobby

09:00 – 09:15 **Opening remarks**
Chair of the Organizing Committee: Mariusz Furmanek, PhD, PT
Dean of the College of Health Sciences: Patrick Vivier, MD, PhD
President of the University of Rhode Island: Marc B. Parlange, PhD
President of the ISMC: Gene Tunik, PhD, PT

PART I: THEORETICAL ADVANCES IN MOTOR CONTROL

Chairs: Mindy F. Levin, PhD, PT & Gene Tunik, PhD, PT

09:15 – 09:40 **Mark L. Latash, PhD**: *Origins of processes within the uncontrolled manifold*
09:40 – 10:05 **Jonathan R. Wolpaw, MD:** *Heksor: The CNS substrate of a skilled behavior*

10:05 – 10:45 Coffee break, CBLS Foyer

Chairs: Shirley Handelzalts, PT, PhD & Reza Shadmehr, PhD

10:45 – 11:10 **Alaa A. Ahmed, PhD**: *Movement slowing and rational decision making in healthy aging*
11:10 – 11:35 **Edward Large, PhD:** *Musical neurodynamics*
11:35 – 12:00 **David A. Rosenbaum, PhD**: *Preparedness in thought and action*

12:00 – 13:00 Lunch – Mainfare Dining Hall (Hope Commons, 19 Butterfield Rd)

13:00 – 15:00 POSTER SESSION I: “Motor control theory and mechanisms” – CBLS Foyer

PART II: MOTOR LEARNING AND NEURAL PLASTICITY

Chairs: Giselle M. Petzinger, MD & Stuart N. Baker, PhD

15:00 – 15:25 **Gene Tunik, PhD, PT**: *Posterior parietal contributions to motor learning*
15:25 – 15:50 **Michael Vesia, PhD:** *Effects of multi-day state-dependent parietal intermittent theta burst stimulation on the motor control network*
15:50 – 16:15 **Daniela Corbetta, PhD**: *Body mapping and the development of goal-directed reaching in infancy*
16:15 – 16:40 **Raoul M. Bongers, PhD***: Searching for new coordinative structures in degrees of freedom space*
16:40 – 16:50 **Q&A**

17:30 – 20:00 Welcome Reception, CBLS lower lobby

DAY 2, JULY 1 (TUESDAY) – Auditorium at the Center for Biotechnology and Life Sciences (CBLS #100)

07:30 – 12:00 Registration, CBLS Lobby
07:30 – 08:30 Continental Breakfast, CBLS Foyer
08:30 – 08:45 Yoga Session I: "Breathwork for mindfulness", CBLS #010
08:00 – 16:00 Exhibitors, CBLS Lobby

PART III: ADVANCES IN UNDERSTANDING NEUROPHYSIOLOGICAL MECHANISMS

Chairs: Alaa A. Ahmed, PhD & Mark L. Latash, PhD

09:00 – 09:25 **Stuart N. Baker, PhD**: *Relative contributions of corticospinal and reticulospinal tracts to control of the primate upper limb*
09:25 – 09:50 **Reza Shadmehr, PhD**: *The potent vectors of the cerebellum*
09:50 – 10:15 **Mathew Yarossi, PhD**: *Measuring corticospinal recruitment gain with TMS*

10:15 – 10:45 Coffee break, CBLS Foyer

Chairs: Daniela Corbetta, PhD & Jonathan R. Wolpaw, MD

10:45 – 11:10 **Cristian Cuadra, PhD, PT**: *The dual roles of vestibulospinal reflexes: excitatory and inhibitory influences on limb muscle activity*
11:10 – 11:35 **Richard E.A. van Emmerik, PhD**: *Locomotor coordination, shock attenuation and dynamic visual acuity*
11:35 – 12:00 **2025 Early Career Award Presentation**
Greg Pearcey, PhD, CSEP-CE: *Decoding human motoneuron firing behaviour illuminates diversity in movement control*

12:00 – 13:00 Lunch – Mainfare Dining Hall (Hope Commons, 19 Butterfield Rd)
12:10 – 13:00 ISMC Board Meeting, CBLS #152

PART IV: MOTOR DISORDERS MECHANISMS AND REHABILITATION

Chairs: Ela Plow, PhD & Raoul M. Bongers, PhD

13:00 – 13:25 **Michael W. Jakowec, PhD**: *Astrocytes bridging motor behavior and synaptic plasticity in Parkinson's Disease*
13:25 – 13:50 **Brooke Dexheimer, PhD, OTD, OTR/L:** *Multimodal approaches for identifying lateralized motor learning mechanisms and their implications in early Parkinson's Disease*
13:50 – 14:15 **Giselle M. Petzinger, MD**: *The association of cognitive and motor performance in Parkinson's Disease: understanding the role of cerebellum and related circuitry*

14:15 – 14:45 Coffee break, CBLS Foyer

Chairs: Monica A. Perez, PhD & Danielle Piscitelli, PhD, PT

14:45 – 15:10 **Aiko K. Thompson, PhD**: *Non-invasive neurobehavioral training to improve motor behaviors and functions of the targeted pathway in CNS disorders*
15:10 – 15:35 **Evangelos A. Christou, PhD**: *Ataxic symptoms in essential tremor: can DBS help?*
15:35 – 16:00 **Andrea L. Behrman, PhD, PT, FAPTA**: *The lens matters: walking recovery after pediatric spinal cord injury*
16:00 – 16:10 **Q&A**

Free time (Newport, Narragansett, Providence)
Dinner on your own (make sure to make a reservation)

DAY 3, JULY 2 (WEDNESDAY) – Auditorium at the Center for Biotechnology and Life Sciences (CBLS #100)

07:30 – 12:00 Registration, CBLS Lobby (Poster setup)
07:30 – 08:00 Yoga Session II: "Body awareness" (outdoor in front of the CBLS)
07:30 – 08:45 Continental Breakfast, CBLS Foyer
08:00 – 15:00 Exhibitors, CBLS Lobby

PART V: RECOVERY OF MOTOR FUNCTION

Chairs: Brooke Dexheimer, PhD, OTD, OTR/L & Michael Vesia, PhD

09:00 – 09:25 **Mindy F. Levin, PhD, PT**: *Translation of motor control principles to functional movement improvement after stroke*
09:25 – 09:50 **Monica A. Perez, PhD**: *Strategies to maximize functional restoration following spinal cord injury*
09:50 – 10:15 **Danielle Piscitelli, PhD, PT**: *Motor control as a pathway to recovery in neurorehabilitation*

10:15 – 10:45 Coffee break, CBLS Foyer

Chairs: Andrea L. Behrman, PhD, PT, FAPTA & Michael W. Jakowec, PhD

10:45 – 11:10 **Shirley Handelzalts, PT, PhD**: *Understanding lower-limb coordination deficits to facilitate gait recovery after stroke*
11:10 – 11:35 **Ela B. Plow, PT, PhD, FASNR:** *The undamaged motor cortex in stroke: friend or foe?*
11:35 – 12:00 **Manuel F. DaSilva, MD:** *Hand control: intersection of biomechanics, motor control, and implications for clinical practice*

12:00 – 13:00 Lunch, CBLS Foyer
12:15 – 13:15 Journal of Motor Control Board Meeting, CBLS #152

13:00 – 15:00 POSTER SESSION II "Motor impairments and rehabilitation" – CBLS Foyer

15:00 – 15:30 **2025 Bernstein Prize Presentation**
Introduction: Mark L. Latash, PhD
T. Richard Nichols, PhD: *Determinants of the force-length characteristic*

15:30 – 15:35 **Annual General Meeting Presentation** – President of the ISMC: Gene Tunik, PhD, PT
15:35 – 15:40 **Best Poster Presentation Awards**

PART VI: HISTORY AND FUTURE OF THE EQUILIBRIUM-POINT HYPOTHESIS (Tribute to Anatol G. Feldman, PhD)

15:40 – 15:50 David A. Rosenbaum, PhD
15:50 – 16:00 Mindy F. Levin, PhD, PT
16:00 – 16:10 Gene Tunik, PhD, PT
16:10 – 16:20 Danielle Piscitelli, PhD, PT
16:20 – 16:30 Raoul M. Bongers, PhD
16:30 – 16:40 Mark L. Latash, PhD
16:40 – 16:50 **Concluding statement by Anatol G. Feldman, PhD**

18:30 – 19:00 Aperitif (Mosby Center, 230 S Ferry Rd)
19:00 – 21:00 Closing dinner, (Mosby Center, 230 S Ferry Rd), dress code: smart casual

2025 BERNSTEIN PRIZE RECIPIENT

Determinants of the force-length characteristic

T. Richard Nichols, PhD
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Abstract: At the level of a single muscle, the Equilibrium Point Hypothesis of Feldman has two key elements, namely a force-length characteristic and the parameter lambda. Lambda, the threshold for activation, represents motor commands from a variety of sources. The force-length characteristic is a nonlinear relationship by which the muscle interacts mechanically with other muscles and with external forces. The increasing dependence of slope, and therefore stiffness, of this characteristic enables the smooth increase in joint stiffness with co-contraction. Long-term studies of this relationship have led to the following conclusions. First, the stretch reflex and intrinsic properties of the muscle work together to determine the shape of the autogenic force-length relationship to ensure that the muscle presents the property of a nonlinear, damped spring, and depending on the motor task, one or the other may predominate. Second, the stretch reflex is robust across motor tasks, whereas the hyperreflexia of pathological conditions is most likely due to accentuated firing of interneurons in the deep dorsal horn, leading to excessive muscle activation through the corresponding decrease in lambda. Third, post-synaptic inputs from other muscles that are mechanically coupled to the given muscle can influence the shape, and therefore stiffness, of its apparent force-length characteristic. For example, reciprocal inhibition increases muscle, and therefore joint, stiffness in conjunction with the feedforward command of coactivation with little or no change in equilibrium point. Fourth, intermuscular length feedback tends to compensate for the effects of inertial coupling between limb segments through changes in stiffness of the target muscles. Fifth, in an expansion of the Stiffness Regulation Hypothesis of Houk, intermuscular inhibition from Golgi tendon organs combines with the above reflexes from muscle spindles and excitatory force feedback to determine limb stiffness. Finally, the force feedback system plays a key role in modulating limb stiffness for different motor tasks by altering the apparent force-length characteristics of the participating muscles.

Keywords: muscle spindle, golgi tendon organ, equilibrium point hypothesis, stiffness regulation hypothesis, inertial coupling

Short Bio: Richard Nichols received his undergraduate degree in biology and mathematics from Brown University, and his Ph.D. in Physiology from Harvard Medical School. Following postdoctoral training at the University of Alberta and Johns Hopkins University, and a first faculty position at the University of Washington, he was appointed to the faculty of Physiology at Emory University, where he remained for 24 years, attaining the rank of Professor and Interim Chair. In 2007, he took the position of Chair of the School of Applied Physiology at Georgia Tech and was appointed Professor in the newly formed School of Biological Sciences in 2016. He received an honorary membership in the American Physical Therapy Association in 2017. He served as President of the Association of Chairs of Departments of Physiology in 2016 he was appointed Fellow of the American Physiological Society in 2022. He is currently Professor emeritus in the School of Biological Sciences. His research has been focused on the role of proprioceptive pathways and muscle mechanics in motor coordination, with applications to spinal cord and peripheral nerve injuries. Nichols also serves as the science advisor to the Association for Body Mapping Education (Teaching the Art of Movement in Music).

Movement slowing and rational decision making in healthy aging

Alaa A. Ahmed, PhD
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Abstract: Movement slowing is symptomatic of a range of movement disorders, mental health conditions, as well as healthy aging. Despite its prevalence, our understanding of why movement slows remains incomplete. In this talk I will focus on our recent work investigating the control of movement speed in older adults. Theory predicts that movement speeds are invigorated by reward yet enervated by effort. The reward circuits of the brain decline with aging, raising the possibility that movement slowing is due to the diminished value our brain assigns to movements. However, as we grow older it also becomes more effortful to make movements. Is age-related slowing principally a consequence of increased effort costs from the muscle or reduced reward valuation by the brain? I will present a mathematical framework to disassociate between the effects of reduced reward valuation and elevated effort on movement slowing. Next, I will review a series of studies in which we measure the effort cost of movement and sensitivity of movement to reward. Together, the results suggest that slower movements in older adults may be a rational economic response the brain is making to mitigate the elevated effort costs that accompany aging.

Keywords: movement vigor, reward, decision making, neuroeconomics

Short Bio: Dr. Alaa Ahmed received a B.Sc. in Mechanical Engineering from the American University in Cairo in 1999 and a Ph.D. in Biomedical Engineering from the University of Michigan at Ann Arbor in 2005. She spent one year as an NIH post-doctoral fellow at the University of Michigan Medical School. From 2006-2008, she was a Whitaker International Fellow and post-doctoral researcher in sensorimotor control at the University of Cambridge. In 2008, she joined the University of Colorado Boulder where she is currently a professor in the Department of Mechanical Engineering, and programs in Biomedical Engineering and Robotics. Her research program uses a neuroeconomic approach that combines techniques from neuroscience, economics, psychology and engineering to investigate the costs and constraints underlying human sensorimotor decision-making, learning, and control. Dr. Ahmed is the recipient of an NSF CAREER Award and a DARPA Young Faculty Award.

Relative contributions of corticospinal and reticulospinal tracts to control of the primate upper limb

Stuart N. Baker, PhD
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Abstract: In many mammals, the upper limb has an important role in reaching and grasping, especially to retrieve food; this has become dominant in bipedal humans. Research into primate arm and hand function has typically focused on the role of the cortex, and the corticospinal tract (CST). The reticulospinal tract (RST) originates in the brainstem, and projects to motoneurons controlling the upper limb. It receives input from the cortex, allowing it to act as an alternative pathway between cortex and spinal cord. However, it is difficult to go beyond existence proofs ('Both CST and RST control the upper limb'), and to estimate the relative importance of these two tracts during voluntary upper limb movements. Results from anaesthetised monkeys suggest that input from the CST to motoneurons is around five times greater than from the RST; however, this will be considerably affected by anaesthesia. In awake monkey, we made recordings of neural activity from both the primary motor cortex (M1) and reticular formation (RF) during a reaction time task. On some trials, the visual go cue was accompanied by a loud (startling) sound. As previously reported in human subjects, the loud sound shortened the reaction time. Neural activity from M1 was briefly suppressed by the sound; by contrast, activity from RF was facilitated. The experimentally-observed profiles of activity modulation were mixed in different ratios of M1:RF activity and used as input to a computational model of a motoneuron pool. This revealed that *shortening* of reaction time could only occur if more than half the drive to motoneurons arose from RF. If more input came from M1, it led to a *lengthening* of reaction time after a startling cue – contrary to experimental findings. Our results suggest that the majority of input to motoneurons during voluntary upper limb movements arises from the RST.

Keywords: reticulospinal, corticospinal, startle, voluntary movement

Short Bio: Stuart Baker is Professor of Movement Neuroscience at Newcastle University. His research interests include how cortical and sub-cortical systems (such as the brainstem and spinal cord) interact to coordinate voluntary movement. This has led him to an interest in functional recovery after damage, for example after stroke or spinal cord injury, when sub-cortical systems are often critical for restoration of function. He uses a wide range of experimental methods, including neural recordings in awake behaving monkey, and non-invasive electrophysiological measurements from healthy human subjects and patients. He has published over 150 papers in refereed journals.

The lens matters: walking recovery after pediatric spinal cord injury

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University of Louisville, USA
andrea.behrman@louisville.edu

Abstract: As clinicians, a top-down model of brain control for walking has dominated our clinical predictions and decision-making for walking ability after human spinal cord injuries (SCIs). Using the American Spinal Cord Injury Association Impairment Scale (AIS), manual muscle testing for voluntary motor control below the spinal lesion remains the predominant tool for predicting walking recovery after SCI and guides our rehabilitation choices. For those with severe, complete SCIs, the choices for mobility continue as compensation-based (e.g., wheelchair, braces, robotics) with no expectation for activation of paralyzed limbs. Basic scientists' discoveries of spinal cord level contributions to postural and walking control provide a new lens with which to assess sensorimotor capacity after SCI. These key discoveries: central pattern generation, automaticity for postural and walking control at the spinal level, the interplay of an ensemble of afferent information with the spinal cord (e.g., load and speed), and the necessary physiological state of the spinal cord for response to therapeutic interventions offer new possibilities for postural and locomotor control after SCI, rehabilitation and recovery. New rehabilitation approaches capitalize on our intrinsic biology and spinal neural networks resulting in unexpected, untapped capacity and walking recovery after upper motor neuron and lower motor neuron injuries. Examples of recovery from pediatric, human SCIs, test our assumptions and reveal alternative lenses for assessing motor control below the lesion. Each case presented is founded in scientific discoveries and principles for accessing the spinal networks to drive neuroplasticity via intense practice and engaging neuromotor capacity below the lesion, even in those with severe complete, chronic SCIs. Expanding our understanding of locomotor control beyond a single lens, i.e., manual muscle testing, to assessing the potential of neural networks in conditions affording access and illuminating capacity for those with SCIs may stimulate novel rehabilitation approaches and outcomes beyond our current view.

Keywords: human, locomotion, rehabilitation, recovery

Short Bio: Andrea Behrman is Professor and Kosair for Kids Endowed Chair in Pediatric Neurorecovery at the University of Louisville, Department of Neurological Surgery, Kentucky SCI Research Center, Louisville, KY. She is Director of the Kosair for Kids Center for Pediatric NeuroRecovery that, first, provides out-patient activity-based therapies to advance recovery from SCI in children and adolescents and second, conducts research aimed at whole-body function recovery after pediatric SCI to inform clinical practice. Her research focuses on developing therapeutic interventions, measurement tools, and the next generation of equipment promoting neuromuscular recovery after SCI using principles of activity-dependent plasticity and knowledge of the neurobiology of motor control. She served as Co-Director of the Christopher and Dana Reeve Foundation NeuroRecovery Network providing standardized activity-based therapies for individuals with SCI at six adult and two pediatric clinical sites. Her work has been funded by NIH; Craig H. Neilsen Foundation; Department of Defense; National Center for Neuromodulation for Rehabilitation; the Kentucky Network for Innovation and Commercialization (KYNETIC); Coulter Translational Award; Expediting Commercialization, Innovation, Translation & Entrepreneurship; the Helmsley Charitable Trust; the KY SCI Research Board; and Kosair for Kids.

Searching for new coordinative structures in degrees of freedom space

Raoul M. Bongers, PhD
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Anadi Mehta & Mart Bekker

Abstract: De-novo motor learning involves searching for novel coordinative structures in which the abundant degrees of freedom (DOF) of the movement system are organised. Coordinative structures are soft assemblies of DOF constrained to act as a task specific unit. In the current studies we take joint angles as the relevant DOF. Coordinative structures can be analysed through solution spaces in the state space spanned by the involved joint angles (DOF space), such as the Uncontrolled Manifold (UCM). Search for a novel coordinative structure implies moving through the DOF space to find the UCM, and on the UCM to incorporate task constraints. Variability orthogonal to the UCM over practicing indicates search for the UCM, whereas variability along the UCM over practicing indicates search to meet different task constraints. We aimed to characterise these search processes when learning a novel coordinative structure. The experiments employed a virtual lateral interception task using a body machine interface in which a novel redundant mapping was introduced between the upper limb joint angles and the virtual paddle position. In the experiments, participants had to learn this mapping, reflecting the novel coordinative structure to accurately control the paddle for interception. Results showed that with practice participants learned intercepting the ball. First, the coordinative structure only emerged after the proper perceptual information to guide the movement was picked up. Second, the novel coordinative structure was not present in the initial phases of training and formed over practicing. Third, search was larger for random practice schedules than for blocked practice schedules, and independent of participants' intrinsic variability. Fourth, during practicing homing in onto the UCM is faster than traversing along the UCM to meet more task constraints.

Keywords: coordinative structures, motor learning, action-perception learning, exploration, uncontrolled manifold

Short Bio: Raoul Bongers is Associate Professor at the Department of Human Movement Sciences of the University Medical Center Groningen and the University of Groningen in the Netherlands. His research focuses on action-perception learning and motor learning from a combined perspective of Ecological Psychology and a Dynamical Systems approach to motor coordination. The research concentrates on themes related to the learning of novel coordinative structures (sometimes called synergies in the literature) at the level of muscles and of joint angles, studied usually in the upper limbs. Main research questions revolve around how perceptual information constrains the emergence of coordinative structures, what is the relative importance of co-variation in maintaining functional integrity of coordinative structures, and what are the mechanisms underlying the organisation of degrees of freedom in coordinative structures. An important part of the research involves translating this knowledge into rehabilitation practice, in particular the rehabilitation training of upper limb prosthetics. This research line focuses on the development of training protocols of learning to use a hand prosthesis, exploiting serious gaming, virtual reality, and mixed reality, and on how knowledge of coordinative structures can be exploited to improve user intent detection algorithms. Raoul Bongers coordinates an MSCA ITN (www.repairs-etn.eu) and is editor of the journal Motor Control. More information about his research can be found at https://www.rug.nl/staff/r.m.bongers/.

Ataxic symptoms in essential tremor: can DBS help?

Evangelos A. Christou, PhD
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Abstract: Essential Tremor (ET) is characterized by bilateral upper limb action tremor. However, individuals with ET also experience additional motor symptoms consistent with ataxia (i.e. dysmetria, voice dysarthria, motor output inconsistency, gait and balance deficits). The standard treatment for upper limb tremor in drug-refractory ET is deep brain stimulation of the ventral intermedius thalamus (VIM DBS). Although VIM DBS has proven excellent in suppressing upper limb tremor, its effectiveness in suppressing ataxic symptoms in ET patients remains unknown. We stratified 16 ET patients undergoing VIM DBS into those who exhibited suppression of tremor and inconsistency with VIM DBS (N=8; termed $ET_{T\&I}$) and those who exhibited only suppression of tremor with VIM DBS (N=8; termed ET_{T}). We compared the participants' performance on various tasks with VIM DBS ON and OFF, performed in different days. Participants completed an upper limb postural task, an unloaded goal-directed ankle movement task attempting to match a 9-degree spatial target in 180 ms, speech tasks, the Timed Up-and-Go (TUG) test, a 15 m straight walk task, the Activities-specific Balance Confidence (ABC) questionnaire, Berg Balance Scale (BBS), tandem stance, tandem walk, and eyes-closed quiet standing. Our findings provide evidence that ataxic symptoms improved only for the $ET_{T\&I}$ group. Further, it appears that the location of the volume of tissue activated by VIM DBS differed for the two groups – possibly contributing to the effectiveness of the VIM DBS to suppress both tremor and ataxia in the $ET_{T\&I}$ group. These findings provide novel evidence that when VIM DBS is applied to a specific thalamic location it can suppress ataxic symptoms in addition to upper limb tremor.

Keywords: VIM DBS, balance, gait, speech, tremor, ataxia,

Short Bio: Evangelos A. Christou is a Professor in the Department of Applied Physiology and Kinesiology, a scientist in the Norman Fixel Institute for Neurological Diseases, and the director of the Human Motor Neuroscience Laboratory at the University of Florida. His research interests are focused on understanding the neurophysiological mechanisms that underlie motor deficits in neurologically impaired individuals with ataxia and tremor and develop effective rehabilitation protocols to counter these deficits. The productivity and impact of his work is demonstrated by over 120 publications in some of the leading journals in the field of movement neuroscience, including the Journal of Neuroscience and Annals of Neurology. His work has been continuously funded by NIH since 2004 with multiple R01 and R21 grants. In addition to research, Dr. Christou contributes to the field via teaching and mentoring. He has taught over 15 different courses, mentored 4 assistant professors, 10 post-doctoral fellows, chaired 15 Ph.D. students, and has served on over 50 graduate student supervisory committees. Dr. Christou has been awarded the 2014 College of Health and Human Performance Teacher of the Year, the 2018 University of Florida Dissertation Mentor Award, and has been inducted in the National Academy of Kinesiology in 2024. Dr. Christou has previously served as vice chair and graduate coordinator of the Department of Applied Physiology and Kinesiology at the University of Florida.

Body mapping and the development of goal-directed reaching in infancy

Daniela Corbetta, PhD
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Abstract: Our body is endowed with an amazing brain capable of dynamically sensing and orchestrating behavior in complex ways to achieve the most sophisticated tasks. Such capability, however, is far from the reality of young infants, whose movements appear initially disorganized, uncoordinated, and uncontrolled. How do infants develop basic patterns of sensorimotor organization that they can later harness into forming goal-directed movements? In this talk, I will present new data on spontaneous arm movements and self-generated touches to the body and surrounding surface that babies perform extensively in the 3- to 12-week-old period. Self-touch is one of the earliest forms of motor behavior that infants produce extensively from birth. Despite marking the beginning of aerial motor activity, the study of this behavior in human infants has been largely neglected in the medical, clinical, and movement neuroscience fields. I will illustrate through data how these early patterns of spontaneous movements and touches to the body, seemingly exploratory in nature, actually form the foundations from which later goal-directed movements such as reaching for objects emerge. Our data show that in their first postnatal months, infants produce an astoundingly high and widely distributed number of hand contacts to the body and surrounding surface over hours, days, and weeks. These movements are critical for the development of early body mapping, the process by which babies start to connect local skin sensations with specific body parts. Further, self-touch contributes to the delineation of somatosensory maps in the infant brain. Finally, as babies move their arms from touch to touch, they also gain a sense of which limbs are moving, in which direction they move, and how far and how fast they move. Such sensorimotor experiences constitute an elemental but necessary step in the development of motor control and set the stage for the development of goal-directed actions.

Keywords: body mapping, self-touch, reaching, infancy

Short Bio: Daniela Corbetta is a Professor in the Department of Psychology and the Director of the Infant Perception-Action Laboratory at the University of Tennessee, Knoxville. Her main research area is on the development of goal-directed behavior in young infants. Dr. Corbetta has 80 publications, many of which are the product of extensive longitudinal studies. She also edited 3 books. Her most recent one is on Reach-To-Grasp Behavior: Brain, Behavior, and Modelling Across the Life Span (2018). Dr. Corbetta is a Fellow of the Association for Psychological Science, and Fellow #574 of the National Academy of Kinesiology, she has been the president of the North American Society for the Psychology of Sport and Physical Activity (NASPSPA - 2017), the Editor-in-Chief of the Journal of Motor Learning and Development (2015-2021) and an Associate Editor of Frontiers in Movement Science and Sport Psychology and Frontiers in Developmental Psychology (2013-2022), she has served on the Editorial Boards of Developmental Psychology, Infancy, Infant and Child Development, and Developmental Psychobiology.

The dual roles of vestibulospinal reflexes: excitatory and inhibitory influences on limb muscle activity

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Abstract: Vestibular pathways project to multiple levels of the brainstem and spinal cord, significantly influencing motoneuron activity and playing a central role in postural control and coordination of head and eye movements. Emerging evidence suggests that altered vestibulospinal signaling may contribute to abnormal muscle coactivation and motor impairments in the upper limbs of stroke survivors. However, vestibulospinal influences on upper limb muscles remain poorly understood, adding the need on clarifying their role. Given the vestibular system’s primary role in posture, we first examined vestibular-originated reflex responses by comparing proximal and distal muscles in the upper limb, to then compare distal muscle responses between upper versus lower limbs. We hypothesized that larger responses would be observed in proximal versus distal muscles, and in lower compared to the upper limb. To investigate vestibular-originated reflex responses, we used vestibular evoked myogenic potentials (VEMPs) and galvanic vestibular stimulation (GVS) to evoke inhibitory and excitatory effects, respectively. VEMPs were elicited via tone bursts and recorded from ongoing EMG activity in preactivated muscles. Our findings indicate that magnitude and response probability were greater in proximal compared to distal upper limb muscles. To assess whether vestibular-originated signals influence lower limb motoneurons, we paired soleus VEMPs with its H-reflex. Timing the VEMP’s first peak with the H-reflex resulted in H-reflex suppression, suggesting a descending inhibitory effect from vestibular inputs. Excitatory vestibular-originated signals were further explored via cathodal GVS applied ipsilateral to the evaluated side. H-reflexes of the flexor carpi radialis and soleus were conditioned with GVS to examine differential effects across limbs. GVS enhanced H-reflex amplitudes in both muscles, with a greater increase observed in the soleus, supporting our hypothesis of stronger vestibular influence in the lower limb. These findings confirm our hypothesis and highlight limb and muscle specific vestibular modulation of spinal motor output in healthy individuals.

Keywords: vestibulospinal, vestibular-evoked myogenic potentials, galvanic vestibular stimulation, spinal reflexes.

Short Bio: Cristian Cuadra is an assistant professor in The State University of New York, at Buffalo where he directs the Neural Control of Movement and Neuromodulation Laboratory. Cristian obtained his PhD at Penn State University in Mark Latash Lab, and then a post-doctoral training with Drs. Mark Lyle, Richard Nichols, and Steve Wolf at Emory University. He studies the neural mechanism of movement control with a strong emphasis on the understanding of neuropathologies. His long-term research goal is to advance rehabilitation strategies for lower and upper limb function by understanding how movement disorders originate from neuropathologies and musculoskeletal conditions across the lifespan. Currently, his laboratory focuses on the study bulbospinal and spinal circuits and their contribution to goal-directed actions (grasping, reaching, and posture), and their potential for creating neuromodulatory interventions. He currently serves as the Rehabilitation Science PhD program co-director at SUNY Buffalo.

Hand control: intersection of biomechanics, motor control and implications for clinical practice

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Abstract: The intersection of biomechanics and motor control provides a critical framework for understanding and optimizing clinical outcomes in hand surgery and rehabilitation. The hand's complex structure requires precise coordination between mechanical function and neuromuscular control. This interplay becomes especially significant in conditions ranging from degenerative arthritis to traumatic injuries requiring finger or hand replantation. Advances in biomechanical analysis allow for detailed assessment of joint loading, tendon excursion, and muscular contributions during various tasks, while motor control studies highlight the brain’s adaptability and the role of sensory feedback in restoring function. In patients with arthritis, altered joint mechanics and pain disrupt normal motor strategies, necessitating targeted therapeutic interventions. Conversely, in replantation cases, rehabilitation must facilitate neuroplasticity and the re-establishment of sensorimotor integration to regain coordinated function. Integration of biomechanical principles with motor control theory leads to more effective surgical planning, individualized rehabilitation protocols, and improved patient outcomes. The clinical implications emphasize a shift toward functionally driven care that respects both the structural and control aspects of hand performance.

Keywords: hand anatomy, hand function, sensorimotor integration, hand rehabilitation

Short Bio: Dr. DaSilva is originally from Portugal and earned his B.A. in Biology with a minor in Music from Rhode Island College. He received his medical degree from the Alpert Medical School at Brown University and completed his orthopedic surgery residency at Rhode Island Hospital/Brown University. He went on to complete fellowships in Orthopedic Trauma at Rhode Island Hospital/Brown University and in Hand and Upper Extremity Surgery at the National Hand Center in Baltimore, MD. With 28 years of clinical practice, Dr. DaSilva has developed multiple minimally invasive techniques and has special expertise in Arthroscopic surgery. He is a co-founder of S2S Surgical - a medical device company and holds 8 US patents. He currently serves as an Associate Professor and Program Director for the Hand Surgery Fellowship at Rhode Island Hospital/Brown University.

Multimodal approaches for identifying lateralized motor learning mechanisms and their implications in early Parkinson's Disease

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Abstract: Initial Parkinson's Disease motor symptoms often present unilaterally, on the dominant side (~60% of cases) or non-dominant side (~40% of cases) of the body. These motor symptoms often manifest as tremors, bradykinesia, and/or dyscoordination. Notably, initial non-dominant side symptoms predict earlier diagnosis (relative to symptom onset) compared to initial dominant side symptoms. This suggests that non-dominant side PD presents with distinct functional impairments that may lead to earlier diagnosis. In this talk, I will discuss insights from our laboratory's recent work characterizing lateralized motor features in early Parkinson's Disease that may help to explain this discrepancy in diagnosis timeline. These preliminary findings suggest that individuals in the early stages of their diagnosis have significant deficits in stabilizing control mechanisms that do not correlate with current gold-standard Parkinson's Disease motor assessments scores. Additionally, I will briefly discuss our recent basic neuroscientific investigations identifying cortical and subcortical neuroanatomical mechanisms for visuomotor learning (specifically, visuomotor adaptation). This includes non-invasive neuromodulatory techniques, invasive stereotactic electroencephalographic recordings, and functional MRI investigations. Lastly, I will discuss the clinical implications of studying visuomotor learning and deficits using these multimodal approaches.

Keywords: motor control, motor adaptation, motor learning, parkinson's disease, lateralization

Short Bio: Brooke Dexheimer, PhD, OTD, OTR/L is an Assistant Professor and licensed occupational therapist at Virginia Commonwealth University. Her research surrounds the lateralized mechanisms underlying perception and motor learning and how these mechanisms may impact the symptom presentation and progression of Parkinson's Disease. Dr. Dexheimer completed her PhD in Kinesiology from Pennsylvania State University, along with a Graduate Certificate in Translational Science from the Pennsylvania State University Clinical and Translational Science Institute (CTSI). Prior to her PhD, she earned a doctorate in Occupational Therapy from Washington University in St. Louis, MO and a bachelor's degree in Movement and Exercise Science from the University of Northern Iowa.

Understanding lower-limb coordination deficits to facilitate gait recovery after stroke

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Abstract: Most persons with stroke (PwS) regain walking independence within the first few months post-stroke; however, many experience gait impairments that can increase fall risk, limit daily activities, and reduce quality of life. A critical factor for safe walking is the ability to stabilize foot placement despite environmental changes. Stable foot placement, in turn, requires the coordination of lower-limb segments (intersegmental coordination) to ensure that the swinging foot reaches the intended target. However, achieving this coordination is challenging due to motor variability—fluctuations in movement trajectories across gait cycles—inherent to the motor system. Motor control theories suggest that one strategy for achieving the coordination necessary for stable foot placement is selectively controlling motor variability components that are important for task success while allowing variability in other components (i.e., structuring motor variability). Structured motor variability is beneficial to walking stability because, in complex environments, uncontrolled variability affords flexibility. Despite its importance, most clinical assessment tools for lower limb function rely on time-based measures or ordinal scales, which fail to capture movement quality (i.e., how the task is performed). In recent studies, we characterized movement variability at different levels during precision-based lower limb tasks, comparing PwS and healthy controls. I will discuss how we may harness these findings to enhance our understanding of gait recovery post-stroke and direct interventions aimed at improving gait recovery.

Keywords: stroke, motor variability, precision, gait, kinematics.

Short Bio: Dr. Shirley Handelzalts is a Lecturer in Physical Therapy at Ben-Gurion University of the Negev (BGU), Israel, where she has been a faculty member since 2022. She earned her PhD from BGU in 2019 and was a postdoctoral fellow at the University of Michigan, USA. She leads the Neurorehabilitation Laboratory at BGU and the Gait Recovery Laboratory at Loewenstein Rehabilitation Medical Center (LRMC), Israel. With a strong clinical background as a physical therapist at LRMC, Dr. Handelzalts' research focuses on understanding the mechanisms of normal and impaired balance and gait control, particularly in individuals post-stroke. She investigates prognostic biomarkers of motor recovery and develops innovative interventions to improve rehabilitation outcomes, emphasizing balance and gait performances. Her multidisciplinary research team includes students from Physical Therapy, Engineering, and Cognition and Brain Sciences, all sharing a common interest in neurorehabilitation. Dr. Handelzalts also serves as the Israeli representative for the International Neurological Physical Therapy Association (INPA) and is a member of the science committees of the Israeli Association of Physical and Rehabilitation Medicine (IAPRM) and the Israeli Physiotherapy Society (IPTS).

Astrocytes bridging motor behavior and synaptic plasticity in Parkinson’s Disease

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Ryan Foremen, Giselle Petzinger, MD

Abstract: Astrocytes are emerging as critical components in regulating the link between motor behavior and synaptic plasticity and are considered a potential novel therapeutic target in treating neurological disorders like Parkinson’s disease. Through their end feet, astrocytes regulate the blood brain barrier, transporting critical factors from the body to the brain, while monitoring neurotransmission activity at the synapse. Recent studies in our group have focused on L-lactate and its role in regulating neuroenergetics and synaptogenesis in response to motor behavior, specifically exercise. With exercise, serum levels of L-lactate are significantly elevated. Several organs, including the brain, rely on L-lactate as a primary metabolic substrate even surpassing dependance on glucose. Elevated levels of L-lactate originate from both peripheral striated muscles via blood supply as well as through aerobic glycolysis in astrocytes converting glucose (from glycogenolysis or serum glucose) to L-lactate. Astrocytes primarily generate ATP through aerobic glycolysis, even when oxygen levels are normal and can be considered lacking the robustness of OXPHOS to generate ATP. L-lactate can act as both a metabolic substrate for energy production as well as a cell signaling molecule. Through the astrocyte-neuron-lactate shuttle (ANLS) L-lactate effluxes from astrocytes via the monocarboxylate transporter MCT-4 and is taken up by neurons via MCT-2 where it enters the Krebs cycle. Extracellular L-lactate also binds to the G-protein coupled receptor HCAR1 found on astrocytes and neurons. Signaling via HCAR1 on astrocytes leads to the expression of a molecular cascade that includes neurotrophic factors (including BDNF) and proteins involved in promoting synaptogenesis. Activation of astrocytes and the L-lactate shuttle through exercise occurs in a region and circuit specific fashion and is not a generalized brain phenomenon. Blocking MCT4 or HCAR1 attenuates exercise-dependent synaptogenesis in motor circuits. Studies in the lab are focused on understanding the molecular mechanisms linking astrocytes and neurons and to determine if administration of L-lactate or other small therapeutic molecules can mediate synaptogenesis in rodent models of Parkinson’s disease.

Keywords: neuroenergetics, mitochondria, L-lactate, glucose, metabolism, synaptogenesis, functional recovery.

Short Bio: Michael W. Jakowec is a Professor in the Titus Family Department of Clinical Pharmacy at the USC Alfred E. Mann School of Pharmacy and Pharmaceutical Sciences. He holds a BSc in Microbiology and Biochemistry from the University of Toronto, an MSc in Genetics from UC Davis, a PhD in Molecular Biology from USC, and completed postdoctoral training at Yale and Columbia in Neurology and Molecular Biophysics. Before joining USC, he was a Research Scientist at the Parkinson’s Institute in Sunnyvale, California. Along with Dr. Giselle Petzinger, he co-founded the USC Parkinson’s Disease Translational Research Program, focusing on animal models of neurodegenerative disorders, experimental therapeutics, and drug discovery. His research aims to understand the molecular mechanisms of neuroplasticity, particularly in the basal ganglia and prefrontal cortex, to develop improved therapies for Parkinson’s disease. For over two decades, his lab has studied the effects of exercise on synaptogenesis and disease progression, while also exploring pharmacological strategies to enhance brain repair. Recent work investigates astrocyte support of neuronal function and the role of mitochondrial integrity in restoring motor and cognitive behaviors. His ongoing collaboration with Dr. Petzinger focuses on translating preclinical findings into more effective clinical treatments.

Musical neurodynamics

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Abstract: A great deal of research in the neuroscience of music suggests that neural oscillations synchronize with musical stimuli. While neural synchronization is a well-studied mechanism underpinning expectation, it has even more far-reaching implications for music. This talk will describe how fundamental dynamical principles based on known neural mechanisms can explain basic aspects of music perception and performance, as summarized in neural resonance theory (NRT). Building on principles such as resonance, stability, attunement, and strong anticipation, I suggest that people anticipate events not through predictive neural models, but because brain-body dynamics physically embody musical structure. The interaction of certain kinds of sounds with ongoing pattern-forming dynamics results in patterns of perception, action, and coordination that we collectively experience as music. Statistically universal structures may have arisen in music because they correspond to stable states of complex, pattern-forming dynamical systems. I will discuss how this new analysis of empirical findings from the perspective of neurodynamic principles sheds new light on the neuroscience of music and on what makes music powerful.

Keywords: dynamical systems; music cognition; oscillation; synchronization; resonance

Bio: Ed Large has devoted more than 30 years to the study of how music entrains—or synchronizes—brain rhythms. A global thought leader in the psychology and neuroscience of music, he has pioneered an approach to understanding how music affects the brain, combining neural networks, nonlinear dynamics, neuroscience, and experimental psychology. Ed studied mathematics at Colorado College and classical guitar performance at Southern Methodist University. He earned his PhD in Artificial Intelligence and Cognitive Science from The Ohio State University. He has held faculty positions in Auditory Neuroscience at the University of Pennsylvania and in Complex Systems and Brain Sciences at Florida Atlantic University. Currently, he directs the Music Dynamics Laboratory and the Theoretical Neuroscience Laboratory at the University of Connecticut, where he is a professor in the departments of Psychological Sciences and Physics. His research is published in journals such as Nature Reviews Neuroscience, Journal of Neuroscience, Psychological Review, Physica D, and Music Perception. He holds several US and international patents. He has received a National Research Service Award, a National Science Foundation CAREER Award, and a Fulbright Chair in the Science and Technology of Music. He was the 2024 recipient of the Music Has Power Award from the Institute for Music and Neurologic Function. He is a past President of the Society for Music Perception and Cognition.

Origins of processes within the uncontrolled manifold

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Abstract: The uncontrolled manifold (UCM) hypothesis has turned into a broadly used framework for analysis of performance-stabilizing synergies. Within this hypothesis, the apparent motor redundancy is viewed as an abundant tunable apparatus allowing to stabilize various salient variables in a task-specific way. Most commonly, studies within this framework quantify variance within the solution space for a salient performance variable (UCM) and orthogonal to that space. By definition, processes within the UCM have no effects on the salient performance variables. On the other hand, the amount of inter-trial variance within the UCM (V_{UCM}) changes with practice, aging, neurological disorder, and treatment. We have recently explored the relative importance of two hypothetical contributors to V_{UCM}. The first is feed-forward variable mapping between spaces of elemental variables and performance variables learned during practice. The second is feedback processes, both from sensory receptors and within the central nervous system. These experiments involved manipulation of targets for total force (performance variable) produced by two or four fingers and for individual finger and finger-pair forces. The results have shown that adding targets for elemental variables leads to a significant drop in V_{UCM} without affecting the apparently more relevant variance orthogonal to the UCM. These observations have been interpreted as pointing at two contributors to V_{UCM}: Inter-trial variance in the sharing of total force across fingers and negative covariation of finger forces seen over time in individual trials. Analysis of variance indices across samples selected from a single trial confirmed this conclusion. Using this method can distinguish between two potential contributors to the changes in performance-stabilizing synergies in patient populations: Deficits in facilitating variable sharing of salient performance variables across trials and in facilitative negative covariation in the contribution of elements to performance. Single-trial analysis is possible, but it provides information only on the latter contributor.

Keywords: stability, synergy, force production; abundance

Short Bio: Mark Latash is a Distinguished Professor of Kinesiology and Director of the Motor Control Laboratory at the Pennsylvania State University. His research interests are focused on the control and coordination of human voluntary movements, movement disorders, and effects of treatment. He is the author of “Control of Human Movement” (1993) “The Neurophysiological Basis of Movement” (1998, 2008, 2022), “Synergy” (2008), “Fundamentals of Motor Control” (2012), “Motor Control and Biomechanics: Defining Central Concepts” (with V.M. Zatsiorsky, 2016), “Physics of Biological Action and Perception” (2019), and “Seminars in Motor Control” (2025). In addition, he edited ten books. Two of those books contained translations of classical monographs by Nikolai Bernstein, “Dexterity and Its Development” (1996) and “Bernstein’s Construction of Movements” (2020). He also published over 450 papers in refereed journals. Mark Latash served as the Founding Editor of the journal “Motor Control” (1996-2007) and as President of the International Society of Motor Control (2001-2005). He organized the first two meetings “Progress in Motor Control” in 1996 and 1999. He has served as Director of the annual Motor Control Summer School series since 2004. He is a recipient of the Bernstein Prize in motor control (2007).

Translation of motor control principles to functional movement improvement after stroke

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Abstract: Understanding how to improve functional motor recovery remains a major scientific, clinical and patient priority in rehabilitation efforts. Yet, despite numerous studies attempting to identify the most effective rehabilitation interventions, sensorimotor recovery in people with central nervous lesions (CNS) such as stroke remains incomplete. The threshold control theory, an extension of the Equilibrium-Point Hypothesis of motor control provides a means by which rehabilitation approaches can be designed to improve functional motor recovery. The threshold control theory describes how central regulation of reflexes, including the stretch reflex, results in different motor actions, in particular, muscle relaxation, motion, and isometric torque production in single- and multi-joint systems. Control is exerted via descending systems mediating both direct and indirect influences on motoneurons. This control is manifested as the specification and regulation of Tonic Stretch Reflex Thresholds (TSRTs) in specific muscles. Injury in the CNS results in deficits in dynamic stretch reflex threshold (DSRT) and TSRT regulation leading to limitations in kinematic redundancy, the appearance of abnormal muscle activation in specific joint ranges, identified as 'spasticity zones', and the adoption of compensatory movements during task performance. These problems lead to decreased functional ability and a decreased ability to adapt movements to task requirements. For example, people with mild stroke using excessive shoulder-elbow (e.g., arm-plane) motion can still adapt motion to compensate for deficits in reaching, while those with more severe stroke may be unable to adapt such movements to improve reaching accuracy. The relationship between disordered threshold control leading to limitations in reflex modulation and the development of motor impairments of the upper limb will be discussed. The process by which these concepts have been implemented in clinical rehabilitation approaches will be illustrated.

Keywords: equilibrium-point model, threshold control, spasticity, stroke, biomarker

Short Bio: Mindy Levin is a Professor in the School of Physical and Occupational Therapy (SPOT), Faculty of Medicine and Health Sciences at McGill University in Montreal, Canada. She was Research Scholar of the Quebec Health Research Fund (1992-2004) and held a Tier 1 Canada Research Chair in Motor Recovery and Rehabilitation (2005-2019). She is currently a Distinguished James McGill Professor. She has over 200 peer-reviewed publications. Her research focuses on elucidating the mechanisms underlying sensorimotor deficits and their recovery in patients with central nervous system lesions. She has a strong background in motor control theory and the translation of motor control and motor learning principles into clinical rehabilitation applications to improve the lives of people with neurological lesions. Amongst her research methodologies are new technologies such as virtual reality and robotics. She is the current Past-President of the International Society of Motor Control and a Past-President of the International Society for Virtual Rehabilitation. She is also currently a Board member of the International Neurological Physiotherapy Association of WCPT and a member of the Scientific Advisory Committee of the International Stroke Recovery and Rehabilitation Alliance (ISRRA). She is past Editor-in-Chief of the journal "Motor Control".

2025 EARLY CAREER AWARD PRESENTATION

Decoding human motoneuron firing behaviour illuminates diversity in movement control

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Abstract: Movement is fundamental for human life, yet little is known about the neural code of human movement. Due to their direct connection to muscle fibres, which collectively form the motor unit, alpha motoneurons are the only cells in the central nervous system that can be routinely recorded in humans. Until recently, it was quite difficult to study motoneurons in humans due to the invasive procedures required to sample their behaviour. Now, we can routinely record tens of motor units at a time, which has provided us with incredible insights into the diversity in motoneuron properties innervating functionally distinct muscles in humans across the lifespan (i.e., ageing), between the sexes and in response to fluctuations in sex hormones, and in people with motor impairments (i.e., stroke, SCI, etc.). These insights have provided important guiding information required to rapidly advance therapeutic interventions, such as acute intermittent hypoxia.

Keywords: spinal motoneuron, motor unit, force control

Short Bio: Dr Gregory Pearcey is an Assistant Professor in the School of Human Kinetics and Recreation at Memorial University of Newfoundland (MUN) and holds a cross-appointment in the Division of BioMedical Sciences. He completed a Bachelor of Kinesiology and MSc in Exercise Physiology at MUN before pursuing a PhD in Neuroscience with Paul Zehr at University of Victoria. During his PhD, he studied how spinal reflexes are modified by sensory stimulation and rhythmic movement. He then trained under CJ Heckman and Zev Rymer during two postdoctoral fellowships at Northwestern University, where he acquired a newfound love for the analysis of human motor unit discharge behaviour in health and disease. He now directs the Neural Interface for Movement Lab and is interested in decoding the neural control of dynamic human movements. Dr Pearcey’s lab integrates neurophysiological tools such as high-density surface and intramuscular electromyography, percutaneous stimulation, dynamometry, and kinematic analysis to study motor unit behavior, spinal reflexes, and movement control. His work aims to understand and enhance neuroplasticity to improve motor function after injury or disease. He is particularly interested in how interventions like exercise, training, and acute intermittent hypoxia can modulate the nervous system to aid rehabilitation. Beyond his research, Dr. Pearcey is actively involved in the scientific community. He organizes and hosts the Motor Unit Group Seminar Series, fostering collaboration among researchers in the field. He also serves on the Board of Directors for the Canadian Society for Exercise Physiology and the Advisory Council of the International Society of Electrophysiology and Kinesiology.

Strategies to maximize functional restoration following spinal cord injury

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Abstract: Dr. Perez will review neurostimulation techniques and their effects on spinal pathways in individuals with spinal cord injury (SCI). She will discuss how Hebbian stimulation, based on the principles of spike-timing-dependent plasticity (“neurons that fire together, wire together”), enhances functional recovery and improves quality of life in individuals with SCI. Findings from proof-of-concept estudies to randomized clinical trials demonstrate that targeting spinal pathways with Hebbian stimulation and exercise is more effective than single-site stimulation alone. Additionally, combining Hebbian stimulation with 4- aminopyridine (4-AP, a potassium blocker) and exercise further accelerates locomotor recovery by increasing excitability in motor pathways and spinal circuits. The talk will highlight the need for combinatorial approaches and protocol optimization to maximize rehabilitation outcomes

Keywords: spinal cord injury, rehabilitation, neurostimulation, plasticity, recovery

Short Bio: Dr. Perez is the Scientific Chair of the Arms + Hands Lab at the Shirley Ryan AbilityLab, a Professor in the Department of Physical Medicine and Rehabilitation at Northwestern University, and a Research Scientist at the Edward Jr. Hines VA Hospital. She has studied neural mechanisms contributing to the control of voluntary movement in healthy humans and in people with spinal cord injury for over 15 years. Her research aims to understand how the brain and spinal cord contribute to the control of movement with the ultimate goal of using this mechanistic information to develop more effective rehabilitation therapies for people with spinal cord injury. This theme is mainly investigated from a neurophysiological point of view, using a combination of transcranial magnetic stimulation, magnetic resonance imaging, electrical stimulation, and behavioral techniques.

The Association of cognitive and motor performance in PD: understanding the role of cerebellum and related circuitry

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Dawn M. Schiehser, PhD, Andrew J. Petkus, PhD, D. Holschneider, MD, Zhuo Wang, PhD, Joseph O’Neill, PhD, Michael Jakowec, PhD, Benjamin T. Newman, PhD, John D. Van Horn, PhD

Abstract: Cognitive impairment is common in PD and is associated with deficits in motor performance, increased risk for falls and ultimately limiting rehabilitation approaches. In healthy individuals the cerebellum is proposed to play an important role in motor and cognition. The cerebellum has been shown to be affected in PD through DA loss and alpha synuclein deposition. However, its role in cognitive impairment and associated motor performance in PD remains largely unknown. Studies provide mixed evidence for its potential compensatory role for the damaged and dysfunctional striato-thalamo-cortical pathway, warranting new investigative approaches to better elucidate the cerebellum's role in alleviating cognitive deficits and related motor impairments as PD progresses. Combining global and domain specific cognitive testing and dynamic motor performance assessments we investigated the cross-sectional and longitudinal associations between motor and cognitive performance in individuals with PD. MRI volumetric and microstructural analysis, and tractography-DWI analysis of connectivity between cerebellum efferent/afferents to subcortical and cortical regions affected in PD were conducted to investigate the relationship between cognitive-motor performance and adaptive plasticity of cerebellar circuitry. Our investigation demonstrates strong associations between motor and cognitive performance over a two-year period. T1w MRI-derived volumes of several cerebellar lobes were positively associated with motor performance at 2-year follow-up. And the volume of the corpus medullare was associated with MOCA ($p<0.05$) and memory and visuospatial cognitive performance ($p<0.05$). From DWI, 3T-CSD microstructure was associated with motor performance across multiple cerebellar subregions. Using DWI tractography with cerebellar deep nucleus as seed, MOCA varied with structural connectivity of the left fastigial and dentate nuclei. Findings from these studies may provide critical insights into adaptive plasticity of cerebellum circuitry and its impact on cognition and related gait and motor performance which can be translated into practical applications for how PD is monitored and treated.

Keywords: adaptive plasticity, circuits, neuroimaging

Short Bio: Dr. Giselle M. Petzinger is a Movement Disorders Specialist and neuroscientist at the University of Southern California Neurology dept, at the Keck School of Medicine. She completed her MD at the University of Southern California, her Neurology Residency at Yale University, and Movement Disorders Fellowship at Columbia University. She divides her time between clinical care and research. Her research in Parkinson’s disease utilizes animal models of Parkinson’s Disease and human clinical studies to investigate mechanisms of exercise induce neuroplasticity and benefits on cognitive-motor function related circuitry. With a strong background in neuroimaging and neural circuitry, she has led multiple clinical and DoD-funded studies exploring how physical exercise can modify brain function and improve cog-motor outcomes in patients and in animal models of PD. Her expertise spans advanced imaging techniques, including multimodal MRI, MRS, and cognitive-motor metrics in PD to investigate compensatory and maladaptive neural changes. By elucidating the mechanisms of adaptive plasticity in critical brain regions, Dr. Petzinger has significantly contributed to identifying therapeutic targets that hold promise for enhancing patient rehabilitation and quality of life.

Motor control as a pathway to recovery in Neurorehabilitation

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Abstratct: Stroke remains a leading cause of long-term disability worldwide. Notably, one in four adults will experience a stroke in their lifetime, and 50–70% of survivors continue to have upper limb impairments even six months post-stroke. The most common sensorimotor disorders include spasticity and disrupted muscle activation, often leading to persistent functional deficits. Additionally, stroke survivors demonstrate significant alterations in movement variability compared to healthy individuals, resulting in reduced movement stability. While neurorehabilitation is crucial for supporting recovery in stroke survivors, its effectiveness remains suboptimal. Emerging approaches grounded in motor control theory have opened new avenues to enhance rehabilitation outcomes. In particular, impairment-based strategies informed by threshold control theory—which emphasizes the modulation of the tonic stretch reflex threshold—have been proposed to guide and promote recovery. From a *motor control* perspective, recovery can be investigated through a combination of movement performance metrics (e.g., accuracy, speed, trajectory straightness) and indicators of movement quality (e.g., spatiotemporal characteristics of joint motion and inter-joint coordination). Within this theoretical framework, novel clinical, neurophysiological, measures—such as Uncontrolled Manifold (UCM) analysis, stochastic models of variability, and the trunk-based Index of Performance (IPt)—are being explored as potential biomarkers to differentiate between true motor recovery and compensatory strategies. These tools may also inform the development of personalized rehabilitation approaches tailored to an individual's specific sensorimotor impairments. Preliminary evidence on the clinical application of UCM analysis during functional tasks and the IPt will be reviewed. UCM analysis shows promise in distinguishing recovery from compensation by examining task-relevant variability in spatial and temporal domains. However, its complexity and the requirement for multiple kinematic trials with specific constraints limit its current clinical feasibility. The IPt demonstrates promising metric properties and potential for clinical application, though further studies are needed to confirm its validity and reliability.

Keywords: stroke; neurorehabilitation, sensorimotor recovery

Short Bio: Daniele Piscitelli, PT, Ph.D., is an Assistant Professor at The University of Connecticut, USA., He is also affiliated with the University of Milano-Bicocca, Italy as a Researcher. From 2017 to 2022, he was a Post-Doc Fellow at McGill University (Canada). Dr. Piscitelli research focuses on understanding the neurophysiological mechanisms of motor control and how this knowledge can be translated into clinical research and clinical practice to promote recovery after brain lesions. Dr. Piscitelli has published several original papers and theoretical works as leading author in peer-review journals about the underlying motor control mechanisms in post-stroke recovery, despite a relatively young research-active career. In 2021, Dr. Piscitelli was the recipient of the Early Career Investigator Award by the International Society of Motor Control.

The undamaged motor cortex in stroke: friend or foe?

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Abstratct: The role of the contralesional (unaffected) motor cortex in post-stroke upper extremity (UE) recovery has long been debated—acting as either an inhibitory influence or a compensatory ally. In this talk, I will present evidence supporting a bimodal framework in which the contralesional cortex may function as a friend or foe, depending on the structural and functional integrity of the ipsilesional hemisphere. Across two studies in chronic stroke survivors, we integrated neurophysiological (TMS), neuroimaging (DTI), and clinical impairment data (UE Fugl-Meyer) to identify a reproducible threshold (UEFM ~42–43) that stratifies patients by their neuromodulation response. Individuals with milder impairment benefited from inhibitory stimulation of contralesional M1, while those with more severe impairment responded better to facilitatory stimulation of contralesional dorsal premotor cortex. These behavioral effects were mirrored by distinct patterns in interhemispheric inhibition and corticospinal excitability. Our findings support the "bimodal-balance recovery" model and inform the START (Stratification Algorithm for rTMS) framework—offering a personalized approach to non-invasive brain stimulation. This talk will explore when and for whom the unaffected motor cortex becomes inhibitory or supportive, advancing our understanding of individualized stroke rehabilitation.

Keywords: Stroke, rTMS, Inter-hemispheric Inhibition

Short Bio: Dr. Ela B. Plow, PT, PhD, FASNR is a physical therapist and neurophysiologist advancing motor recovery after stroke and spinal cord injury through innovative neuromodulation therapies. She serves as the Director of Research for Cleveland Clinic Rehabilitation Hospitals (CCRH) and holds faculty appointments at Case Western Reserve University and the Cleveland Clinic Lerner College of Medicine. A Fellow of the American Society of Neurorehabilitation (ASNR), Dr. Plow leads an NIH-, DoD-, and AHA-funded lab exploring brain-based biomarkers of recovery using tools such as fMRI, TMS, and functional electrical stimulation. She has authored over 80 peer-reviewed publications, including in Nature Medicine, Annals of Neurology, Neurology, Brain Stimulation, Stroke, and Neurorehabilitation and Neural Repair. Dr. Plow has mentored more than 50 emerging scientists and clinicians—several of whom have secured independent NIH R01, K99/R00, and NCMRR R03 awards. She is a standing member of the NIH’s Motor Function & Speech Rehabilitation (MFSR) Study Section and has served on grant review panels for the American Heart Association. She earned her PhD in Rehabilitation Science and Neuroscience from the University of Minnesota and completed her postdoctoral fellowship at Harvard Medical School’s Beth Israel Deaconess Medical Center.

Preparedness in thought and action

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Abstract: Progress in motor control can be made on many fronts. One front, illustrated in this talk, is psychology. In my psychology laboratory, we seek to understand the “software” of motor control, focusing especially on preparedness. Based on research in our lab, it appears that the key to preparedness is keeping options open. We have found that three main strategies serve this purpose: (a) Front-loading; (b) Mind-clearing; and (c) Energy-saving. Of these, the last is most familiar outside of psychology. The first two are less well known, partly because they have only recently been discovered. Front-loading is getting things done early if resources allow. Three examples are the end-state comfort effect (taking hold of objects in ways that facilitate comfort or control at the ends of object rotations), the grasp-height effect (taking hold of objects in ways that facilitate comfort or control at the ends of object lifts or lowerings), and pre-crastination (the tendency to expend extra effort to achieve goals or subgoals as quickly as possible). Pre-crastination (roughly the opposite of procrastination) has gotten a great deal of attention because of how widespread it is and because its costs and benefits can be dramatic. For example, in the study where pre-crastination was discovered, it was found that people who were invited to choose the easier of two tasks picked up and carried a near object over a long distance rather than a far object over a short distance. The main driver for pre-crastination in this and other contexts appears to be the desire for mind-clearing (being able to stop thinking about things that are distracting). Finding that motor-control phenomena reflect wider psychological tendencies is hardly surprising when one recalls that psychology is the science of mental life and behavior.

Keywords: pre-crastination, preparedness, psychology

Short Bio: David A. Rosenbaum (B.A. Swarthmore College, 1973; PhD., Stanford University 1977) has worked at Bell Laboratories (1977-1981), Hampshire College (1981-1987), the University of Massachusetts, Amherst (1987-1994), Pennsylvania State University (1994-2016), and the University of California, Riverside (2016-). He was Editor of Journal of Experimental Psychology: Human Perception and Performance (2000-2005. He has authored or co-authored several books, including Cognitive Science: An Introduction (MIT Press, 1987); Human Motor Control (Academic Press, 1991/2010); It’s A Jungle In There: How Competition And Cooperation In The Brain Shape The Mind (Oxford University Press, 2014); MATLAB for Behavioral Scientists (Routledge, 2007/ 2015); Knowing Hands (Cambridge, 2017); MATLAB Blues (Routledge, 2019); Action, Mind, and Brain – An Introduction (MIT Press, 2022); and Cognitive Control of Action. Selected Works of David A. Rosenbaum. World Library of Psychologists Series (Routledge, 2024). He is a Fellow of AAAS, the American Psychological Association, the Association for Psychological Science, and the Society of Experimental Psychologists, and was a Guggenheim Fellow in 2013-2014.

The potent vectors of the cerebellum

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Abstract: A principal puzzle in neuroscience is how to relate neuronal activities to control of behavior. To solve this puzzle, the leading theory posits that we can think of each neuron as having downstream connections that eventually reach the muscles, with the connection strengths to the various muscles represented as a set of weights. This is called the potent vector for that neuron. In this talk, I will present ideas on how we can take advantage of the climbing fiber input to estimate these vectors for the neurons in the cerebellum, and how the resulting potent vectors help reveal the computations that are taking place from the mossy fiber inputs, to the molecular layer interneurons, and finally the Purkinje cell outputs. The results show that many neurons in the cerebellum are active not to induce behavior, but to prevent the unwanted effects that the activities of other neurons would have on behavior.

Keywords: cerebellum, saccades, reaching, Purkinje cells

Short Bio: Reza Shadmehr was born in Iran and was lucky enough to be given a visa to come to the US when he was 14. He studied engineering at Gonzaga University, then Robotics at the University of Southern California (mentored by Michael Arbib), and finally human motor control at MIT (mentored by Emilio Bizzi). At MIT, he came up with the force field paradigm, something that has proven useful in the study of motor learning. He was subsequently appointed faculty at Johns Hopkins, where he has remained for his entire career. He has authored 3 books, with the latest titled: "Vigor: Neuroeconomics of movement control". He considers his greatest achievement to be his students, who have gone on to become productive scientists and good citizens.

Non-invasive neurobehavioral training to improve motor behaviors and functions of the targeted pathway in CNS disorders

Aiko K. Thompson, PhD
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Abstract: Over the past decade, neurobehavioral training methods, operant conditioning of spinal reflexes and motor evoked potentials (MEPs), have started to gain recognition as potential tools to enhance neurorehabilitation in people with CNS disorders. Through operant conditioning of stimulus triggered muscle responses such as spinal reflexes, a person learns and practices to produce a certain state and/or activity of a targeted neural pathway that is reflected in the size of the measured muscle response. Over time, through many repetitions, this leads to establishing a new habitual behavior of the targeted neural pathway and improving its general behaviors and functions. The following is the current core understanding of operant conditioning approach. Through *reflex operant conditioning*, the brain's descending influence over the targeted reflex pathway is modified, which in turn produces persistent changes in the reflex pathway and its activity and triggers wider plasticity in other spinal and supraspinal pathways. Thus, when applied appropriately, reflex conditioing can improve motor function. With MEP up-conditioning to increase the excitability of the targeted muscle's corticospinal pathway, plasticity can be targeted to the injury- (or disease-) weakened corticospinal drive to improve it, towards enabling more effective movement execution and inducing wider beneficial plasticity. Using several examples, what operant conditioning protocol may be applied to whom, why, and how will be discussed. In recent years, through multiple collaborations with multiple investigators, our lab has started applying various operant conditioning protocols to upper and lower extremities of people with spinal cord injury and other neurological disorders to improve sensorimotor function recovery. As we expand our effort in clinical translation of these methods, the critical importance of rigorous scientific bases and inter-disciplinary collaborations continues to become clearer.

Keywords: neural plasticity, spinal reflexes, spinal cord injury, motor evoked potentials, corticospinal tract

Short Bio: Aiko Thompson is a neuroscientist and a Professor at the College of Health Professions at the Medical University of South Carolina. She did her Ph.D. with Dr. Richard Stein at the University of Alberta, Canada, and then did a postdoc training with Dr. Jonathan Wolpaw at the Wadsworth Center in Albany, NY. During her Ph.D., she was engaged in non-invasive human neurophysiology / plasticity research related to the use of functional electrical stimulation; she also started investigating normal and abnormal spinal reflex modulation during walking and other dynamic movements in people with and without chronic CNS disorders. During her postdoc, she developed the human H-reflex operant conditioning protocol. Since establishing her own lab in 2007, she has been studying CNS plasticity in human sensorimotor control and how to guide the plasticity to help restore useful sensory and motor function in people with spinal cord injury (SCI) and other neuromuscular disorders. Her research focuses on investigating functional roles of sensory afferents and spinal reflexes and evaluating the CNS plasticity associated with operant conditioning of stimulus-triggered muscles responses (e.g., spinal reflexes) in people with SCI and other neuromuscular disorders.

The role of posterior parietal cortex in motor learning and adaptation

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Abstract: Adapting to novel environments is a hallmark characteristic of the human sensorimotor system. While the role of posterior parietal cortex (PPC) as a hub for sensorimotor integration is known, its role in motor learning and adaptation has been sparsely studied. In a series of experiments, we causally investigated bilateral PPC involvement in adaptation using high-density transcranial direct current stimulation (HD-tDCS) and transcranial magnetic stimulation (TMS). In one set of experiments, right-handed participants received anodal or sham HD-tDCS during a center-out visuomotor rotation adaptation task performed with their right arm or left arm. Anodal HD-tDCS to left PPC facilitated right-to-left transfer of motor adaptation, while left-to-right transfer was inhibited by HD-tDCS to both left and right PPC. These findings demonstrate a possible lateralized contribution of PPC to motor-memory consolidation. We then asked whether this involvement may be driven by PPC’s role in governing motor planning as opposed to error detection processes. Thus, in a second set of experiments using the same task, we delivered double pulse TMS to left PPC either during the movement planning (pre-movement) or error detection (end of movement) phases. Our findings indicated that PPC may have unique contributions to movement planning and error detection, evidenced by early TMS modulating the initial adaptation whereas late TMS modulating overall learning rate and completeness of adaptation. Overall, our work suggests that the left PPC plays a particularly important role during visuomotor adaptation, consolidation, and transfer, which may have important clinical applications. Furthermore, the role of the left PPC seems to contrast and complement some of the research exploring cerebellum’s and M1’s roles in learning and adaptation, thus adding to our foundational knowledge of the broader cortical circuits supporting our ability to learn and adapt our motor skills.

Keywords: motor learning, posterior parietal cortex, lateralization, motor planning, error detection

Short Bio: Gene Tunik is a professor of Physical Therapy, Movement, and Rehabilitation Sciences and is co-director of the Movement Neuroscience Laboratory at Northeastern University. He studies neural control of movement using techniques that include measurement of kinematics and kinetics, muscle and brain electrophysiology, and non-invasive brain stimulation. Dr. Tunik earned a Bachelor of Science in Physical Therapy from Northeastern University, a PhD in neuroscience from the Center of Molecular and Behavioral Neuroscience at Rutgers University and completed a fellowship at the Dept. of Psychological and Brain Sciences at Dartmouth College. At Northeastern, he currently serves as the Director of the AI + Health & Human Performance division at the Institute for Experiential AI and as Senior Associate Dean of Research and Innovation at the Bouvé College of Health Sciences. Dr. Tunik serves as the president of the International Society of Motor Control and is an active member of the American Physical Therapy Association.

Locomotor coordination, shock attenuation and dynamic visual acuity

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C. Dane Napoli, M.S., Hwigeum Jeong, M.S., Joseph Hamill, Ph.D.

Abstract: To ensure optimal perception of visual information, the locomotor system employs multiple strategies to stabilize the visual field. These include the attenuation of impact shock arising from foot-ground contact as well as compensatory coordinative head pitch rotations in response to movements of the body. The attenuation of impact shock can occur through passive and/or active mechanisms. Passive mechanisms include mechanical deformations of tissue while active mechanisms include adjustments in joint stiffness and changes in segment geometry such as greater knee flexion. While these attenuation and compensatory mechanisms serve to stabilize head motion and support visual information pick up in response to altered gait parameters, the inverse, how the body adapts to meet the different degrees of head stability demands under different visual task constraints is less clear. The purpose of this presentation is to: 1) review active impact shock attenuation and compensatory coordination mechanisms that provide stable body and head movement, and 2) assess how different visual and locomotor task demands alter these active attenuation and compensatory mechanisms. Although some of the compensatory strategies in the lower and upper body under different locomotor task demands have been investigated, less is known about the role of multi-segment foot dynamics during foot-ground contact throughout the stance phase in maintaining head stability. In particular, we examine the role of multi-segment foot coordination in adjusting to different locomotor speeds and how these relate to head stability. Finally, while these compensatory strategies are usually effective, we have previously demonstrated that constraining individuals to locomotor asymmetries reduces shock attenuation and results in decreased visual task performance. We will review how individuals adapt to these locomotor asymmetries through modifications in active attenuation and compensatory mechanisms.

Keywords: coordination, shock attenuation, visual perception, multi-segment foot, asymmetry

Short Bio: Dr. Richard E.A. van Emmerik is a Professor and Chair in the Department of Kinesiology at the University of Massachusetts Amherst, USA. He received his undergraduate degree in Movement Science from the Vrije Universiteit in Amsterdam, the Netherlands, and his Ph.D. degree in Kinesiology from the University of Illinois at Urbana-Champaign, in the USA. In his research, he applies principles from complex and nonlinear dynamical systems to the study of posture and locomotion, with a focus on coordinative processes underlying expert performance as well as movement disorders. The research in his laboratory is integrative and focuses on the interaction between mechanical, neural and perceptual factors underlying the control of posture and gait, with applications to aging, rehabilitation, and optimal performance. His research on coordination addresses both expert and impaired movement and the role of adaption. The work on movement disability examines the role of coordinative variability as it relates to postural and gait stability and adaptability, while his research with the Department of Defense is aimed at establishing a better understanding of how head-mounted loads impact soldier performance and perception under various environmental conditions and challenges. He is a member of the Royal Dutch Academy of Arts and Sciences, the American National Academy of Kinesiology (NAK), and serves on the editorial boards for Human Movement Science, Motor Control, Kinesiology Review, and the Brazilian Journal of Motor Behavior.

Effects of multi-day state-dependent parietal intermittent theta burst stimulation on the motor control network

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Abstract. Transcranial magnetic stimulation (TMS) can differentially alter cortical excitability and functional connectivity within the motor control network, depending on the brain’s activation state during stimulation. Our group and others have demonstrated context-dependent functional interactions between the parietal and frontal motor areas in the motor control network derived from dual-site TMS. Here, I demonstrate how controlling behavioral state during circuit-targeted theta burst TMS to the parietal cortex can enhance the specificity of neuromodulatory action among the distributed brain regions involved in grasping. Our results indicate that: 1) controlling the brain state with a grasping task during parietal stimulation over multiple days induces immediate changes in the motor cortex and improves manual dexterity; 2) state-dependent parietal stimulation produces sustained facilitation of motor cortical excitability, as motor evoked potentials (MEPs) remained significantly higher than baseline after a week of multiple-day stimulation sessions; 3) parietal-motor resting-state connectivity and parietal-motor network task-evoked fMRI activity increased after state-dependent stimulation, both immediately following the final stimulation session and one-week post-intervention. We conclude that multiple sessions of state-dependent TMS induce immediate and long-lasting plasticity-like effects within the targeted cortical grasp control network. These findings have implications for developing stimulation-based interventions for sensorimotor disorders.

Keywords: transcranial magnetic stimulation, state-dependency, manual dexterity, functional connectivity, plasticity, theta burst stimulation, posterior parietal cortex, motor cortex

Short Bio. Dr. Michael Vesia holds a BPHE from the University of Toronto and an MSc and Ph.D. in Kinesiology and Health Sciences from York University (Canada). He completed his post-doctoral training at the University of Waterloo and the University of Toronto's Krembil Brain Institute. In 2017, he joined the School of Kinesiology at the University of Michigan as an assistant professor, where he currently serves as the director of the Brain Behavior Laboratory. Dr. Vesia's research integrates electrophysiology, noninvasive neuromodulation, neuroimaging, and behavior to understand the mechanisms of human movement in both health and disease. He has authored over 40 papers in refereed journals, including the Journal of Neuroscience, Journal of Neurophysiology, Brain Stimulation, Experimental Brain Research, Nature Human Behaviour, and Clinical Neurophysiology. He aims to develop drug-free neuroscience therapeutics to assist individuals with sensorimotor disorders.

Heksor: the CNS substrate of a skilled behavior

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Abstract: Recognition that the CNS remains plastic through life requires a new paradigm to explain how skills are acquired and maintained in a changing CNS. The paradigm's core is a newly recognized CNS entity, now called a "heksor" from the ancient Greek "hexis" (JPhysiol 2022 DOI:10.1113/JP283291). A heksor is a distributed network of neurons and synapses that may extend from cortex to spinal cord. It has two unique properties. First, it changes itself as needed to maintain the key features of its skill, the attributes that make the skill satisfactory. Thus, the CNS activity, muscle activity, and kinematics of locomotion may change, but its key features (e.g., upright posture, good balance, right/left symmetry, acceptable metabolic cost) are maintained. Second, through their concurrent changes, the many heksors that share the CNS negotiate the properties of the neurons and synapses they all use. Heksors keep the CNS in a negotiated equilibrium that enables each to maintain its skill. While a heksor's neurons and synapses change continually through life, the key features of the skill the heksor produces do not change. These key features are the memory of the skill; it is recognizable in the skill the heksor produces. As the CNS changes with new learning, growth, aging, and other events, the plasticity of the heksor ensures the stability of the memory. Animal and human studies support this paradigm; and it explains otherwise inexplicable results. It underlies new therapies now proving successful in people with spinal cord injury, stroke, and other disorders. Furthermore, the paradigm offers new answers to questions such as the generation and function of spontaneous neuronal activity, the etiology of muscle synergies, and the control of homeostatic plasticity. It makes predictions that can be tested in humans and/or animals. The first tests are yielding positive results.

Keywords: motor skill; memory; plasticity; heksor; negotiated equilibrium

Short Bio: Dr. Wolpaw is a neurologist who has spent nearly 50 years exploring spinal cord and brain plasticity in animals and humans. His lab pioneered the operant conditioning of spinal stretch reflexes, revealing complex spinal and brain plasticity underlying this seemingly simple learning. They demonstrated that reflex conditioning improves walking in rats and, with Dr. Aiko Thompson, in people with spinal cord injury. This work introduced a new paradigm for understanding skill acquisition and maintenance in the pervasively plastic CNS, leading to promising new therapeutic strategies. Dr. Wolpaw has also been a leader in brain-computer interface (BCI) research. With Dr. Dennis McFarland, he first demonstrated the use of EEG sensorimotor rhythms for BCI-based communication and multidimensional control. Their group led the first multicenter trial of a home-use BCI for people with severe disabilities and developed the widely used BCI2000 software platform, which has supported over 2,500 peer-reviewed studies. They organized the first four international BCI conferences, co-authored the first BCI textbook (Wolpaw & Wolpaw, 2012), and are now editing its second edition. Dr. Wolpaw's research has been continuously supported for over 40 years by NIH, the VA, DARPA, and private foundations. He is Director of the NIBIB/NIH-funded National Center for Adaptive Neurotechnologies (NCAN) and Professor of Biomedical Sciences at the State University of New York. His work has been widely published, presented, and internationally recognized. He has mentored numerous students and postdocs and has served the scientific community through advisory roles, review panels, and as the first president of the BCI Society.

Measuring corticospinal recruitment gain with TMS

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Abstract: Modulation of the relationship between descending neural drive and motor output (corticospinal recruitment gain) is considered an essential property of motor control. Task dependent modulation of this input-output relationship has been empirically demonstrated using invasive techniques in animal preparations using direct neural measurements coupled to force output. To date, description of input-output modulation using non-invasive techniques in humans remains limited. I will overview our work exploring modulation of corticospinal recruitment gain using novel paradigms that measure motor outputs in response to transcranial magnetic stimulation (TMS) applied during voluntary activation. I will present evidence of modulation of corticospinal recruitment gain in healthy individuals, individuals with amyotrophic lateral sclerosis, and individuals with weakness due to knee osteoarthritis. Empirical findings from these studies demonstrate that corticospinal recruitment gain: 1) is reflected in the size of the TMS-evoked motor response, 2) is strongly modulated during voluntary contractions, 3) exhibits a strong dependency on the yank (force time derivative) and that yank-dependent modulation of outputs is limited by motor unit availability. I will also discuss our recent work examining how corticospinal recruitment gain is modulated by electric stimulation of the target muscle. Finally, I will present several new hypotheses and directions emerging from the collective empirical findings across these different populations and tasks.

Keywords: transcranial magnetic stimulation, neuromodulation, corticospinal recruitment gain

Short Bio: Dr. Mathew Yarossi is an Assistant Professor at Northeastern University jointly appointed in the Department of Physical Therapy, Movement and Rehabilitation Sciences and Deparment of Electrical Engineering where he co-directs the Movement Neuroscience Laboratory. He currently serves as director of the Northeastern University Signal Processing, Imaging, Reasoning, and Learning Center. Dr. Yarossi's research bridges the fields of sensorimotor neuroscience, neurostimulation, and engineering to explore neural mechanisms of sensori motor control and create innovative interventions for persons with motor deficits. His prior work has focused on understanding the motor physiology that subserves motor control and motor learning in both the upper and lower limbs, including the structure-function relationships that underlie performance in healthy individuals and impairment and recovery in stroke, spinal cord injury, and ALS. Dr. Yarossi completed his bachleor's degree in biomedical engineering from Northwestern University and master's degree in biomedical engineering from New Jersey Institute of Technology. He received his doctoral degree in biomedical engineering Rutgers University in 2017. Following his doctoral degree he performed post-doctoral training at Northeastern University prior to becoming faculty. His work has been funded by the NIH, NSF, DOD.

POSTER PRESENTATIONS

POSTER INDEX

Posters in numerical and session order along with presenting author.

SESSION I (Monday 06/30)

Poster#	Name
P1-01	Kaner, Aleksandra
P1-02	Herzog,Michael
P1-03	Mukamel, Roy
P1-04	Kim, Kwang S.
P1-05	Prado-Rico, Janina M.
P1-06	Trewartha, Kevin M.
P1-07	Walia, Pushpinder
P1-08	Darendeli, Abdulkerim
P1-09	Kelley, Christopher
P1-10	Hibino, Hidetaka
P1-11	Wang, Yuxuan
P1-12	Wijffels, Joey
P1-13	Srinivasan, Manoj
P1-14	DiCarlo, Julie A.
P1-15	Dusang, Aliceson N.D.
P1-16	Shin, Narae
P1-17	Opesade, Oluwatobi S.
P1-18	Lokesh, Rakshith
P1-19	Jin, Rifeng J.
P1-20	Yuk, Jisung
P1-21	Engstrom, Cassandra J.
P1-22	McLinden, John
P1-23	Juras, Grzegorz
P1-24	Khan, Saad
P1-25	de Freitas, Paulo B.
P1-26	Dias, Mateus S.
P1-27	Byrd, Charisma E.
P1-28	Krotov, Aleksei
P1-29	Eckstein, Noah I.
P1-30	Cetera, Anna
P1-31	Shu, Liqi
P1-32	Piscitelli, Daniele

SESSION II (Wednesday 07/02)

Poster#	Name
P2-35	Grover, Francis M.
P2-36	Jurkojć, Jacek
P2-37	Reedich, Emily J.
P2-38	Serré, Hélène
P2-39	Kanekar, Neeta
P2-40	Gonzalez, Elian E.
P2-41	Riley, Michael A.
P2-42	Słomka, Kajetan J.
P2-43	Mena Avila, Elvia
P2-44	Riehm, Christopher D.
P2-45	Frazier, Megan E.
P2-46	Oh, Jinseok
P2-47	Michalska, Justyna
P2-48	Buscaglione, Silvia
P2-49	Akbas, Anna
P2-50	Curuk, Etem
P2-51	Pawłowski, Michal
P2-52	Kolmodin, Caroline
P2-53	Desabhotla, Krishna S.
P2-54	Brachman, Anna
P2-55	Schmitz, Xenia M.
P2-56	Ornstein, David
P2-57	Novoa-Cornejo, Ignacio J.
P2-58	McPhee, Kylie N.D.
P2-59	Cavanagh, Sarah K.
P2-60	Montgomery, Lynnette R.
P2-61	Aquino, Mariana R.C.
P2-62	Foster, Tyler

AUTHOR INDEX

The alphabetical order of all presenting authors by last name including poster number.

ABSTRACT COMPENDIUM

The abstracts have been organized in alphabetical order based on the first author’s last name. The author’s name that is underlined identifies the presenting author. The email of the presenting author has also been provided along with all affiliations for all authors.

Motor asymmetries in virtual reality reach-to-grasp tasks (P2-49)

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Background: Reach-to-grasp coordination relies on intricate interactions between transport and grasp components, both governed by distinct yet complementary neural mechanisms. While previous studies support the dynamic dominance hypothesis—asserting that the dominant and non-dominant limbs are specialized for different control strategies—comparative data on their behavior in varied task contexts remains limited, particularly in immersive virtual reality (VR) settings.
Objective: The present study aimed to investigate how hand dominance, object size, and distance influence reach-to-grasp behavior in a validated haptic-free VR environment, utilizing both kinematic and electromyographic (EMG) data.
Methods: Twelve right-handed healthy adults performed 216 reach-to-grasp trials (108 per hand), interacting with virtual objects of three sizes and distances. Kinematic markers tracked wrist, thumb, and index finger motion, while EMG was collected from eight upper limb muscles. Analyses focused on transport and grasp kinematics (e.g., movement time, peak aperture, peak transport velocity) and phase-specific integrated EMG (iEMG) values.
Results: Results confirmed that object properties robustly modulated reach-to-grasp behavior. Increasing distance led to longer movement durations, higher peak transport velocities, and increased EMG activation in proximal muscles, especially the biceps and anterior deltoid. Larger objects elicited wider grip apertures and delayed peak aperture timing. Comparing hands, the non-dominant hand (NDH) exhibited significantly greater peak transport velocity and acceleration, along with higher trajectory variability in the wrist, thumb, and index finger. This pattern suggests a more variable, potentially feedback-driven strategy rather than one optimized for trajectory stability. In contrast, the dominant hand (DH) showed more consistent kinematics and higher early-phase activation of the anterior deltoid, indicative of greater reliance on predictive control mechanisms. Despite these differences, grasp-related kinematics and muscle activity were largely similar between hands, and no significant differences emerged in coordination metrics such as movement time or the temporal gap between peak transport and grasp.
Conclusion: These findings refine the understanding of functional lateralization by showing that DH and NDH employ distinct neuromuscular strategies under the same task demands. Rather than reflecting simple superiority of one hand, the results align with the complementary dominance model, suggesting that each limb contributes differently to motor control—with the DH favoring efficiency and predictive control, and the NDH relying more on online adjustments. This study extends these theoretical frameworks into a VR context and underscores the value of combining kinematic and EMG analyses to explore sensorimotor asymmetries. The findings have implications for motor rehabilitation and training paradigms targeting hand function and bilateral coordination.

Changes in joint and coordination regularity following running distinguished runners who sustained an injury within six-months (P2-61)

Mariana R C Aquino[1], Richard E A van Emmerik[2], Priscila Albuquerque de Araújo[1], Thales R Souza[1], Michael A. Busa[2,3], Juliana M Ocarino[1], Sérgio T Fonseca[1]

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Background: Running-related injuries are multifactorial processes often resulting from the inability to overcome and recover from a repeated demand imposed during exercises. Running induces fatigue and changes in joint and coordination patterns, which is associated with injuries. However, studies investigating movement patterns as risk factors for running-related injuries and the time to recover from exercise have provided inconsistent results. Recognizing that it is impossible to obtain sufficient information about the many factors related to injury occurrence, applying tools and concepts from complex dynamical systems could improve understanding of the role of movement changes in response to exercise and help forecast injuries
Objective: Investigated whether acute and prolonged changes in joint and coordination regularity during a single-leg squat task following a high-intensity running distinguished runners who sustained an injury within six months from those who did not. We hypothesized that joint and coordination patterns would become more regular in both groups immediately after running, but the increased regularity would be greater and for longer in the injured group.
Methods: Thirty healthy recreational runners (11 women, 19 man) were evaluated pre, post, 24h, and 48h during a 60-second single-leg squat task after running at high intensity (4x15min, 85%VO_2max) or rest (i.e., control). After six months of the assessments, runners were divided into two groups based on whether they did or did not report injuries within this period. A three-way ANOVA compared the percent change of joint (ankle, knee angles) and coordination (ankle-knee relative phase) regularity (multiscale entropy) between groups (injured, non-injured), times (%Post, %Post24h, %Post48h), and protocols (high-intensity, control). Additionally, one sample t-test compared if the magnitude of relative changes were significant for each group across times.
Results: Increased regularity was observed in the injured (13 runners, 25.8%) and non-injured (17 runners, 14.5%) groups after running, but the increase was greater (p=.015) and persisted after 48h (14.5%) only in the injured group. The injured runners also increased knee regularity at 24h (11.3%) and 48h (10.9%) after running, while the non-injured decreased ankle (-12.6%) and knee (-13.5%) regularity on the post-test. In this context, changes in ankle-knee entropy (%Post) were inversely and highly correlated with changes in joint entropy only in the non-injured group ($p < .001$, $r = -0.85$). No changes were observed after the control protocol or at the pre-test. **Conclusion:** Runners who sustained an injury within six-months after assessments increased joint and coordination regularity and required more time to recover than non-injured runners. These results suggest a reduced capacity of injured runners to adapt and recover from high-intensity activities before the injury occurs. Additionally, the non-injury runners seem to adopt more adaptable behavior in the joints to compensate for the more constraint coordination induced by the high-intensity run, which may be related to an ability to mitigate the deleterious consequences of exercise-induced fatigue and reduce the occurrence of injuries. Monitoring changes within individuals during a functional task may provide valuable early warnings about a reduced adaptive and recovery capacity to deal with training and exercises.

Gait stability in older adults after tripping simulated perturbation – a pilot study (P2-54)

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Background: The literature indicates that locomotor adaptability in general, and anticipatory and reactive adaptation in particular, remain largely intact in the elderly. Therefore, experiencing near-fall situations in a safe environment can facilitate reactive balance control in everyday life situations and increase fall prevention. Various methods have been used to generate perturbations in the laboratory. Terrestrial systems can have a high similarity to real-world conditions, however, induced perturbations tend to occur in a fixed location and may result in a loss of 'unpredictability'.

Objective: Our aim is to verify our prototype and create a protocol for assessing gait stability after perturbation which as much as possible resembles a trip in natural conditions. We hypothesize that older adults have worse stability after perturbation when compared to healthy young adults. We also hypothesize that gait is more stable after perturbing dominant leg when compared to non-dominant leg in both groups.

Methods: We developed a prototype for walking while using a mechanical treadmill. It includes a braking element that blocks foot movement during the swing phase. A handle allows for free plantar and dorsal flexion, external and internal foot rotation. The braking module is synchronized with the beginning of the swing phase through footswitch sensors. Both the delay time and duration of the perturbation are controlled by a microcontroller. Participants walk for 10 minutes at their preferred speed to acclimate to the device and treadmill gait. The preferred walking speed is individually adjusted to ensure that participants can walk comfortably (0.42 to 0.32 times the Froude velocity). Each subject experiences seven perturbations, the first perturbed leg being the dominant one. The remaining six perturbations are administered randomly to both legs. Each perturbation is given in the first one third of the swing phase and lasts until the perturbed leg lands on the treadmill. Between each perturbation there is a 2min washout phase. To measure gait stability, we use the margin of stability (MoS) in the anteroposterior direction using a simplified kinematic model. Kinematic data during walking are recorded with Innovision Motion Systems, utilizing six cameras and a Zebris FDM-T treadmill at a frequency of 100 Hz.

Results: We are currently in the process of gathering data; therefore, we cannot present any results at this time. So far, we have confirmed that our system is capable of measuring MoS when the perturbation device is mounted to participants' feet. The results during unperturbed gait are similar to those reported in previous research. The sample results for the three consecutive baseline steps during touchdown:

P_{Tro} (m)	V_{Tro} (m/s)	V_{C7}(m/s)	XCoM (m)	toe projection (m)	MoS (m)
0,177	0,006	0,078	0,2520	0,34	0,088
0,176	0,06	-0,042	0,2411	0,337	0,096
0,168	0,042	0,024	0,2403	0,332	0,092

Conclusion: As new solutions are still being sought worldwide, our goal is to verify our prototype. This is a necessary and initial stage for subsequent stages, such as creating training procedures to improve gait stability in various groups of people at risk of falling.

Holding hands in a challenging postural balance task (P2-48)

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Background: From infancy onwards, maintaining an upright posture represents a significant challenge as it requires complex neuromuscular control. With ageing or neuromechanical impairments, postural stability often declines, increasing the risk of falling. Understanding the neural mechanisms governing balance is essential for predicting and preventing falls. Previous studies established that even a light touch of a stable surface reduces postural sway. Yet, the benefits of haptic touch between individuals, such as when holding hands, remain largely unexplored. Insights into partner support could inform rehabilitation strategies and inspire the design of assistive devices.

Objective: This study examined the effect of 'holding hands' on postural balance between two partners with different skill levels, professional ballet dancers and naïve individuals. In addition to expecting better performance from the ballet dancers, we hypothesized that same-skilled partners would enhance each other's balance, while an expert paired with a novice would be perturbed.

Methods: We challenged participants by asking them to stand in a tandem stance on a narrow beam (width 3.65cm, height 7.62cm). Ballet dancers (n=14) executed the task alone, coupled with novices, and coupled with an expert. Novice undergraduate students (n=10) performed alone and with a novice partner. During the coupled conditions, both participants stood side by side on the beam, facing forward, while holding the same handle of a compliant robot. The vision of the partner was occluded. We recorded the whole-body kinematics of the focal participant to calculate the center of mass (CoM), ground reaction forces, and the robotic handle force. Performance was assessed by the percentage of time they stepped off the beam, the CoM sway, and CoM velocity. Additionally, we quantified movement coordination between partners by correlating their CoM movements through mutual information analysis. Lastly, to gain insight into participants' control strategies, we developed a biomechanical inverted two-link pendulum model and used it to estimate the stiffness of the arm.

Results: As expected, in the single conditions, novice participants stepped off the beam more frequently than experts and exhibited greater CoM velocity and sway. Yet, when 'holding hands' with a novice partner, all performance measures improved, reaching expert values. Counter expectations, all metrics of the experts remained unaffected by physical coupling, indicating that experts were neither perturbed by a novice partner nor stabilized by another expert. Further, the movements of two novices executing the task together were more correlated than those of two experts. These findings demonstrated that novices benefit from haptic interaction with another novice, while experts maintain their stability, regardless of their partner's skill level.

Ongoing analyses of the model results focus on arm stiffness modulation as a mechanism that individuals could use to regulate how interaction forces are transmitted from the hand to the body. Higher stiffness maximizes force transfer for support, while lower stiffness filters the force, allowing partial rejection of perturbing forces.

Conclusion: These results highlight the importance of haptic sensation in postural balancing and the central nervous system's ability to effectively utilize haptic information, suggesting the need to better incorporate haptic communication for balance assistance.

Hand dominance influences spatiotemporal finger coordination in precision grip, not finger individuation (P1-27)

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Background: The ability to execute complex, precise hand movements is a hallmark of human dexterity. Handedness—the consistent preference for using one hand over the other—has traditionally been defined by preference (Corey et al., 2001), skill (Annett, 1970; Flowers, 1975), or strength (Chau et al., 1997); however, this semantic ambiguity underscores the need to investigate its influence on fine motor control. While minimal literature reports hand dominance differences in individuated finger movements (Abolins and Latash, 2021), dexterity asymmetries appear more pronounced in tasks requiring multiple finger coordination, e.g., found in thumb-to-finger opposition (Reilly and Hammond, 2004). While the previous studies focused on individuation without examining coordination, our study fills this gap by investigating both aspects of dexterity.
Objective: Here, we assessed finger individuation and precision grip using a dual-task approach to test whether handedness selectively affects distinct aspects of dexterity.
We hypothesized that (1) finger individuation is unaffected by handedness, (2) spatiotemporal coordination across multiple effectors, crucial for precision grip ability, is the key feature that distinguishes the superior dexterity in the dominant hand, and (3) individuation ability may interact with coordination during precision grip tasks.
Methods: Participants completed finger individuation and precision grip tasks using a novel hand device with highly sensitive 3D isometric fingertip force measurements (Xu et al., 2023) in a virtual environment. The individuation task required force generation with an instructed finger along six directions in the virtual 3D space while keeping the non-instructed fingers inactive. The precision grip task involved thumb-to-finger opposition to grasp a small object in the virtual space with a high demand for accuracy. Three separate experiments evaluated individuation (Exp 1: n=16, 20±1.46 years, 15 right-handed, 12 female), precision grip abilities (Exp 2: n=22, 24±5.55 years, 22 right-handed, 10 female), and both across hands (Exp 3: n=18, 20±2.04 years, 17 right-handed, 13 female), with handedness assessed via the Edinburgh Handedness Inventory. Finger individuation was quantified using a 3D Individuation Index (Xu et al., 2023), while precision grip performance was assessed using grip angle, touch desynchronization, and force trajectory synchronization.
Results: Linear mixed-effects models were used to analyze dexterity measures, accounting for within-subject variability where appropriate. Significant handedness effects were observed in precision grip, particularly in touch desynchronization (Exp 2&3: $p<0.05$) and trajectory synchronization (Exp 2&3: $p<0.01$), suggesting that superior dexterity in the dominant hand is present in multiple finger coordination. Grip accuracy differed between hands for Experiment 2 ($p<0.01$) and not for Experiment 3 ($p=0.741$). No handedness effects were found in finger individuation from both Experiments 1 and 3 (all $p>0.05$), aligning with prior literature. However, in the precision grip task, better individuation ability in the dominant hand was associated with greater difference in active-passive finger coordination between the dominant and non-dominant hand ($p<0.05$), suggesting that individuation ability interacts with coordination in tasks that demand spatiotemporal precision.
Conclusion: The results suggest hand dexterity asymmetries across the dominant and non-dominant hands primarily emerge in tasks requiring precise spatiotemporal coordination rather than tasks focused on isolated finger control.

Three-dimensional evaluation of upper limb joint coupling after chronic stroke (P2-59)

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Background: Stroke commonly disrupts upper limb motor coordination, resulting in abnormal joint coupling, or the inability to independently control joint movements. Joint coupling has been measured with individuation tasks (isolated movement of a single joint within one plane). Previous work has demonstrated that joint coupling during individuation relates to functional task performance. However, joint coupling is typically only assessed in the sagittal plane and quantified based on synergistic in-plane movements, overlooking the contribution of out-of-plane movement. A three-dimensional analysis of joint movement is needed to capture multi-plane couplings and clarify their relationship with functional deficits.
Objective: This study aims to quantify upper limb joint coupling in 3D and its relationship to functional task performance in chronic stroke survivors. We hypothesized that (1) stroke survivors exhibit out-of-plane joint coupling during sagittal plane shoulder, elbow and wrist flexion/extension individuation tasks, (2) joint coupling also occurs during individuation movements outside of the sagittal plane (i.e., transverse and frontal planes), and (3) accounting for joint coupling beyond the sagittal plane explains additional variance in performance of functional tasks.
Methods: Eighteen chronic stroke participants with upper limb motor impairment (Upper Extremity Fugl-Meyer Assessment [FMA-UE] range: 15-55, without reflex items) performed individuation tasks and a functional reaching task with marker-based optical 3D motion capture. Individuation tasks included shoulder, elbow and wrist flexion/extension (sagittal), shoulder horizontal abduction/adduction, ulnar/radial deviation (transverse), shoulder internal/external rotation and forearm supination/pronation (frontal). Range of motion (ROM) across all seven upper limb degrees of freedom (DOFs) was derived and normalized by its instructed movement range. Joint coupling was quantified as the sum of normalized ROMs of non-instructed DOFs divided by the sum of normalized ROMs of both instructed and non-instructed DOFs (joint coupling ratio, JCR). The JCR was computed separately using in-plane or out-of-plane non-instructed DOF movement. Functional reaching task performance was evaluated by movement smoothness (quantified with spectral arc length). Differences between paretic and non-paretic limb JCRs were analyzed with Wilcoxon signed-rank tests. The relationship between JCR and FMA-UE and between JCR and reaching smoothness were examined by a Spearman correlation and linear regression, respectively.
Results: Significantly more in-plane ($p<0.001$) and out-of-plane ($p=0.001$) joint coupling occurred in the paretic limb during flexion/extension tasks compared to the non-paretic limb. Greater motor impairment (lower FMA-UE scores) was associated with increased out-of-plane joint coupling ($\rho=-0.77$, $p<0.001$), indicating more severely impaired individuals exhibit coupling beyond the flexor synergy pattern. There was significantly more paretic arm 3D joint coupling across all seven individuation tasks compared to the in-plane joint coupling during only flexion/extension tasks ($p<0.001$). Finally, in-plane joint coupling during flexion/extension tasks explained 32% of reaching smoothness variance; in-plane and out-of-plane coupling from all individuation tasks increased the variance explained to 63%.
Conclusion: This study highlights the importance of 3D joint coupling for evaluating stroke-related upper limb motor impairment. Individuals post-stroke exhibit significant joint coupling beyond the sagittal plane, and these out-of-plane movements relate to functional reaching task performance. Future work will quantify how joint coupling at each DOF explains functional task performance variance.

Decoding motor intent from planning-phase EEG using graph neural networks for goal-driven rehabilitation (P1-30)

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Background: Understanding how large-scale brain dynamics evolve between motor planning and execution is fundamental to advancing both motor control theory and neuroadaptive rehabilitation. For individuals with spinal cord injury (SCI), who retain cognitive motor intent despite the inability to produce voluntary movement, brain-computer interfaces (BCIs) that operate during the planning phase offer a promising path toward restoring purposeful interaction. However, how visuomotor pathways such as the vision-based grasping network emerge at the macroscopic level in noninvasive EEG remains unclear. By investigating how visuomotor pathways emerge during the planning phase, we aim to decode motor intent as the brain formulates motor commands prior to movement onset, enabling the development of a proactive rehabilitation system—one that anticipates user intent and delivers adaptive assistance before physical movement occurs. Driven by this goal, we are developing two complementary systems: a neural decoding framework that predicts motor intent from EEG, and a robotic control architecture that translates intent into adaptive motor assistance using a 3-DOF planar rehabilitation robot.

Objective: This study aims to develop and evaluate a graph-based neural decoding framework (P2M-GAT: Planning-to-Movement Graph Attention Network) that predicts movement intent from planning-phase EEG and to integrate this framework with a modular robotic system to support closed-loop motor rehabilitation.

Methods EEG data were recorded from one participant performing 150 plan-to-grasp tasks (16-channel, 256 Hz), segmented into planning and execution phases. Each phase was modeled as a graph representation of the respective brain activity: nodes captured spectral (5 frequency bands) and time-domain EEG features, and edges were computed via top-5 Pearson correlations. We implemented P2M-GAT, consisting of: (1) a Planning Graph Encoder, which applies multi-head GAT layers to extract node embeddings during the motor planning phase; (2) a Movement Graph Predictor, which predicts movement-phase graph representation from planning-phase embeddings; and (3) a Predicted Graph Classifier, which applies GAT layers to the predicted movement graph to classify grasp type. In parallel, a 3-DOF planar rehabilitation robot with force sensing and joint-space EKF-based admittance control was developed for responsive motor assistance.

Results: P2M-GAT achieved 63.3% accuracy on a held-out test set for binary classification (power grasp vs. no movement) using predicted graphs. Predictive alignment was strongest in the beta band ($r = 0.15$), consistent with its role in motor planning. The robotic system demonstrated compliant motion in response to force input, enabling adaptive movement trajectories via a virtual mass-damper-spring model.

Conclusion: While these components were developed independently, they are designed to be interoperable. The end goal is to integrate real-time motor intent decoding from the P2M-GAT model with the robot’s EKF-admittance control architecture, forming a closed-loop neuroadaptive rehabilitation platform. This integration would allow the system to transition from reactive to predictive assistance, aligning robot support with inferred motor intent during the pre-movement phase. Future work will extend both systems—multi-class grasp decoding on the neural end, and task-specific adaptation on the robotic end—to enable more intuitive, patient-specific therapy for motor recovery.

Contributions to ankle clonus in individuals with SCI (P2-50)

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Background: Clonus is an involuntary, rhythmic muscle contraction commonly observed in humans with spinal cord injury (SCI). Recent evidence indicates that increased excitation in spinal reflex pathways and decreased descending inhibition following the injury may contribute to the generation of clonus. In addition, motoneuronal hyperexcitability has been attributed to the recovery of persistent inward currents (PICs), resulting in uncontrolled muscle contractions and exaggerated cutaneous reflexes. However, the exact neural mechanisms of sustained clonus are not fully understood.
Objective: Our study aims to explore the existence of sustained ankle clonus and its potential relationship with motoneuron excitability following SCI in humans. We hypothesized that SCI individuals with sustained clonus would demonstrate a prolonged cutaneous reflex (long-lasting reflex; LLR), a greater soleus (SOL) H/M ratio, and a different motor unit behavior.
Methods: Individuals with SCI (>1-year post-injury) were divided into two groups: those with sustained clonus (n=18) and those without clonus (n=10). Ankle clonus was assessed using clinical measurements, such as the leg drop and manual stretch tests; both were applied on separate days. Cutaneous reflex was elicited by electrical stimulation through the medial plantar nerve, and the LLR was recorded from the tibialis anterior (TA) muscle. The SOL H-max and M-max were measured to evaluate motoneuron excitability through the tibial nerve over the popliteal fossa. TA and SOL motor unit (MU) behaviors were characterized in individuals with voluntary ankle control (n=5, SCI with sustained clonus; n=5, SCI without clonus) and healthy controls n=5). High-density surface electromyograms were obtained during isometric dorsiflexion and plantarflexion, and blind source separation was used to identify MU spike times. Maximal voluntary contractions (MVCs) were used to normalize the target amplitude of submaximal 20-second triangular ramp contractions (30% MVC) across participants. Firing rate hysteresis was calculated using the paired-MU analysis technique (ΔF) to provide an estimate of PIC magnitude.
Results: Our results demonstrated good reliability in clonus assessments (ICC=0.76), excellent reliability for the manual stretch test across days (ICC=0.99), and moderate reliability for the leg drop test (ICC=0.69). Participants with sustained clonus showed a significantly prolonged LLR duration (1.51±0.86 ms) compared to those without clonus (0.31±0.08 ms) ($p<0.05$). Furthermore, the H/M ratio for the SOL was significantly higher in individuals with sustained clonus (0.58±0.16) than in those without (0.21±0.23) ($p<0.05$). Preliminary MU analysis found individuals without clonus had significantly higher ΔF in the TA muscle (TA: 4.13±0.502 pps; SOL: 1.90±0.504 pps, $p<0.05$) compared SOL muscle (TA: 1.6±1.0 pps; SOL: 1.5±1.3 pps). In contrast, individuals with clonus did not show significant differences between muscles (TA=3.00±0.463 pps; Sol=1.69±0.482; $p>0.05$). Additional MU analyses and participant recruitment are ongoing.
Conclusion: Our findings are the first to establish the association between prolonged ankle clonus, elevated motoneuron excitability, and differences in motor unit firing behaviors, suggesting that all may contribute to the development of sustained clonus in humans following SCI. The importance of our findings would provide

important insights into the underlying mechanisms of ankle clonus and may guide the improvement of more effective rehabilitation strategies for individuals with SCI.

Task demands dictate the control of motor units (P1-08)

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Background: A motor unit (MU), consisting of a motor neuron and the muscle fibers it innervates, is the final output responsible for muscle contraction. Traditional understanding asserts that MUs share a common synaptic input for efficiency. Although there is considerable support for this hypothesis, it needs to be tested across diverse force profiles, as recently done in macaques.
Objective: The main purpose of our study was to investigate whether the control of MUs is rigid (fixed function of a common command) or flexible in humans. A second objective was to model recruitment threshold (RT) of single MUs as a function of muscle length and time derivative of force (yank).
Methods: Young, male participants (n=10) performed isometric finger abduction across various force profiles (slow ramp, fast ramp, static, and chirp) and muscle lengths (short and long). High-density surface electromyography signals were recorded and decomposed to identify discharge times of single MUs. We used displacement metric that assumes rigid control hypothesis. Monotonic increases or decreases in firing rates across units will yield 0 displacement. We fit linear mixed models to reveal how the muscle length and yank within 20 ms prior to RT influence the RT (%MVC) of single motor units across six ramp-up contraction trials (n=3 for short muscle length), accounting for random effects of *subject*, *repetition*, and *MU*.
Results: In total, 308 first dorsal interosseous (FDI) MUs were identified and tracked across force profiles. Displacement was near zero when only a single force profile was included in the calculation. It increased significantly (departure from rigid control) with the inclusion of all force profiles and further increased when muscle lengths were also considered. Muscle length and yank explained the variance in RT.
Conclusion: We found that, even during a simple task, FDI MUs are flexibly controlled in humans. Within the same condition (e.g., 4 s ramp-up or static), however, MU control is constrained by common inputs. These results indicate that diverse behaviors involve greater flexibility in cortico-spinal activity than previously thought. The second part of our experiments indicated that the recruitment of single MUs is determined by muscle length and yank during 4s ramp-up contractions.

The impact of feedback type on rate of force development scaling factor (rfd-sf) during rapid submaximal force production (P1-25)

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Background: The rate of force development scaling factor (RFD-SF) offers a functionally relevant alternative to traditional rate of force development (RFD) measures by assessing how quickly force is produced at submaximal levels. Unlike the maximum RFD value, which reflects maximal explosive capacity, RFD-SF captures the ability to generate rapid and precise force, as required in daily activities such as balance recovery or reaching to grab a falling object. It is calculated as the slope of the relationship between peak force and peak RFD across a series of brief submaximal pulses, typically ranging from 20% to 80% of maximal force. Visual feedback is commonly used to guide pulse generation and ensure a proper range of submaximal force levels. However, it remains unclear whether the presence or type of visual feedback influences the magnitude of RFD-SF and the consistency of the relationship between peak force and peak RFD.

Objective: To investigate whether visual feedback availability and type influence the magnitude of RFD-SF and the consistency of the relationship between peak force and peak RFD during submaximal isometric grip force (GF) exertion.

Methods: Twelve healthy, right-handed young adults (6 males, 6 females; aged 20–40 years) participated in the study. Each held an instrumented handle using a power grip and completed two tasks: (i) maximal grip force (GF_{Max}), and (ii) a brief force pulse (BFP) protocol. The highest GF value from two trials was used to define submaximal targets. In the BFP protocol, participants performed approximately 120 pulses under three feedback conditions: (1) no feedback (always performed first), (2) a moving line indicating force level (line), and (3) a vertical-moving circle representing applied force (circle). During feedback conditions, force targets were displayed within three bands: low (20–40% GF_{Max}), moderate (40–60%), and high (60–80%). Each condition included six 32-second trials. A metronome set at 40 beats per minute paced the pulses, providing a 1.5-second interval between each pulse. At the end, participants reported their preferred feedback condition. RFD-SF was calculated as the slope of the linear relationship between pulse peak force and corresponding RFD peak. The consistency of this relationship was assessed using the coefficient of determination (R^2). A one-way ANOVA tested the effect of feedback on RFD-SF, and the Friedman test assessed R^2 differences.

Results: ANOVA revealed a significant effect of feedback on RFD-SF ($p = 0.028$). Pairwise comparisons showed a trend toward higher RFD-SF in the circle condition versus no feedback ($p=0.092$), with no differences between other conditions. The Friedman test revealed an effect of feedback on R^2 ($p=0.013$). Post-hoc Wilcoxon tests reviewed lower R^2 in the no-feedback condition compared to both feedback conditions, which did not differ from each other. Eleven of twelve participants preferred the moving line feedback.

Conclusion: Our findings suggest that feedback is a key element in the BFP protocol. The absence of feedback impairs the ability to scale RFD to force magnitude. Although both feedback types were effective, participant preference favored the moving line, making it the preferred option when using the BFP protocol.

Force modulation in interactions with a complex object: insights from healthy and post-stroke individuals (P2-53)

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Background: Force production and modulation are necessary when interacting with everyday objects during daily activities. Numerous studies have examined manipulation of rigid objects, typically evaluating kinematics. However, when the object is non-rigid and has internal degrees of freedom, the forces applied to the object must preempt or compensate for internally generated forces. To examine such dynamically complex interactions, we developed an experimental paradigm, motivated by 'carrying a cup of coffee'.

Objective: We aimed to shed light on force production and modulation in healthy individuals and those with neurological injury by using a previously proposed paradigm.

Methods: The experimental task of transporting a cup of coffee was simplified into planar movements of a 3D-printed cup with a ball rolling inside, modeled as a cart with a suspended pendulum. The cup and ball's geometries were based on the spherical cart-pendulum model, which enabled estimation of force from recorded kinematics without added force sensors. We collected data from healthy (n=24) and post-stroke (n=18) individuals with a range of upper limb motor impairment (Fugl-Meyer upper extremity range 30-66). Participants moved the cup-and-ball on a horizontal table between two targets by extending and flexing the elbow, while an overhead camera captured cup and ball kinematics. Participants complete 10 trials with each upper extremity. Based on the measured cup and ball kinematics, smoothness of the movement was calculated using frequency spectrum analysis. Mutual information between the ball force and applied force assessed the predictability between these two quantities. In addition, the forces generated by the participant and the ball were derived using spherical pendulum model. To characterize the different strategies, we evaluated the similarity of the phase progression of the fluctuating signal between: (1) applied force and cup velocity, (2) ball force and cup velocity, and (3) applied force and ball force. Greater similarity in phase indicated greater influence between two variables.

Results: The movements of healthy participants were significantly smoother than those of post-stroke patients. Trials with greater smoothness exhibited stronger phase alignment between the applied force and cup velocity, while trials with less smoothness revealed stronger alignment between ball force and applied force or cup velocity. This suggests that in less smooth trials, the ball force had a more direct influence on the system kinematics and dynamics. In contrast, in smoother trials, the lower alignment between the ball force and both the applied force and cup velocity indicated that the ball had a smaller impact on the overall motion. Smoother trials were significantly correlated with higher mutual information, indicating that participants may predict or preempt the ball force to generate smoother trajectories.

Conclusion: These findings highlight force modulation strategies underlying distinct observed kinematics when manipulating a complex object that provide insights into motor control strategies. The focus on force modulation is even more relevant to gain insights into control strategies in patients with impaired force production, such as individuals post-stroke.

Stabilization of lead-limb foot trajectory by multi-joint synergies during single-step ascent (P1-26)

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Background: Step ascent is a common locomotor activity in daily life that demands precise control of the lead-limb foot trajectory. Inadequate control (e.g., moving the foot too close to the step or lifting it excessively high) can increase the risk of tripping or compromise balance and energy efficiency. We propose that the foot trajectory in both the anterior-posterior (AP) and vertical directions would be stabilized by multi-joint synergies that coordinate the co-variation among lower-limb joints and pelvis motion. We hypothesize that such synergies are especially prominent during critical events as the lead-limb moves toward the step: (i) anterior-posterior clearance (C_{AP}), when the foot crosses the upper edge of the step; (ii) vertical clearance (C_V), as it passes over the front edge; and (iii) the point of maximum foot heigh (H_{MAX}).

Objective: To investigate the presence of multi-joint synergies stabilizing foot position at C_{AP}, C_V, and H_{MAX} during single-step ascent and to compare the strength of these synergies across the three critical events.

Methods: Sixteen healthy, right-footed young adults (20-40 years old) performed 60 repetitions of a single-step ascent onto a 17×100×120 cm (H×W×L) step. All trials began from a self-selected, comfortable starting position and ended with both feet on top of the step. Kinematic data were recorded to compute the lead-limb foot trajectory (AP and vertical) and joint angles (ankle, knee, hip in the sagittal plane; pelvis in frontal and transverse planes). Multi-joint synergies stabilizing foot position were assessed using the Uncontrolled Manifold (UCM) at C_{AP}, C_V, and H_{MAX}. Elemental variables included sagittal joint angles and either pelvis transverse (C_{AP}) or frontal (C_V, H_{MAX}) angles (N=4). Variance components were computed: V_{UCM} (variance in joint space that does not affect foot position) and V_{ORT} (the variance affecting foot position). The synergy index, ΔV_Z (the normalized difference between V_{UCM} and V_{ORT}) was then calculated. One-sample t-tests assessed whether ΔV_Z differed from zero. Repeated measures analyses of variance tested for differences in ΔV_Z, V_{UCM}, and V_{ORT} across events.

Results: ΔV_Z was significantly greater than zero at C_{AP} (mean±SD, 0.39±0.27), C_V (0.50±0.32), and H_{MAX} (0.85±0.43), indicating the presence of stabilizing synergies. ΔV_Z was higher at H_{MAX} compared to C_{AP} and C_V, driven by greater V_{UCM} at H_{MAX}. V_{ORT} did not differ across events.

Conclusion: Our findings indicate that the central nervous system (CNS) organizes multi-joint synergies to stabilize the AP foot position when crossing the upper edge of the step and vertical foot position when crossing the front edge and reaching maximum foot height. The stronger synergy at H_{MAX}, caused by increased V_{UCM} rather than reduced V_{ORT}, suggests different control strategies. When the foot is moving rapidly near the step edges, the CNS minimizes overall joint variance to reduce tripping risk. At H_{MAX}, when foot vertical speed is near zero, the CNS maintains low joint variance that affects foot position (V_{ORT}), while allowing greater joint variance along the UCM. This strategy enhances flexibility and adaptability, potentially supporting proper responses to perturbations as the foot approaches the step.

The impact of attention control demands on upper limb motor performance (P1-14)

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Background: Upper limb motor function depends not only on the transmission of motor commands from motor cortical regions to the muscles but also on higher-order cognitive processes such as attention control. The impact of cognitive processes on motor performance remains understudied; for example, increased attentional demands may interfere with upper limb motor function.
Objective: In this study, we aimed to examine how varying levels of attentional control demands affect upper limb motor performance.
Methods: We used a cognitive-motor dual-task (CM-DT) paradigm. Sixty healthy adults performed a goal-directed upper limb motor task under single-task and dual-task conditions. Secondary cognitive tasks included an auditory Stroop task (low and high attention control demands) and a non-attention control processing speed task. In a repeated-measures design, we found a significant effect of cognitive load on goal-directed motor performance.
Results: Post hoc comparisons revealed significantly worse performance during Stroop-High compared to both the single-task ($p < .001$) and processing speed ($p < .001$) conditions, and during Stroop-Low compared to both the single-task ($p = .004$) and processing speed ($p = .006$) conditions. Stroop reaction times also slowed under dual-task conditions.
Conclusion: These findings suggest that attention control plays a selective role in upper limb motor function. The results have important implications for understanding cognitive-motor interactions underlying upper limb function and informing rehabilitation approaches for individuals with cognitive-motor impairments such as stroke or Parkinson's disease.

Pre-movement beta oscillations and peak velocity in healthy adult planar reaching (P1-15)

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Background: Beta-band neural oscillations (15–30 Hz) observed prior to movement onset have been shown to provide meaningful insight into subsequent motor behavior, particularly during reaching tasks. Specifically, increased pre-movement beta power has been associated with slower reaction times. This suggests that beta activity reflects a mechanism of motor inhibition or a modulating gateway of sensory information. While faster reaction times have been linked to greater peak velocity on a trial-by-trial basis, the direct relationship between pre-movement beta dynamics and peak velocity has not yet been established. Understanding the relationship between pre-movement beta activity and peak velocity could yield new insights into the neural processes underlying motor control.

Objective: This study aims to examine the link between pre-movement beta power and peak velocity during a reaching task, addressing a key gap in our understanding of how preparatory neural activity shapes subsequent movement execution.

Methods: Twenty-one healthy adults (ages 18–75) participated in a 2D reaching task while high-density electroencephalography (hdEEG) was recorded. Participants completed 120 paired center-out/center-in reaches in eight uniformly randomized directions using their dominant arm on the InMotion robot. Velocity profiles were calculated from end-effector position data sampled at 200 Hz by the robotic system. Peak velocity was calculated as the maximum velocity observed during the movement period. Pre-movement beta power was computed from hdEEG data using a time window from -500 ms to movement onset, averaged across contralateral sensorimotor electrodes. Trials contaminated by false starts or EEG artifacts were excluded from analysis. To assess the relationship between neural and behavioral measures, we employed multilevel modeling to account for the nested structure of the data (trials within subjects). Specifically, we examined whether pre-movement beta power predicted subsequent peak velocity while accounting for inter-individual variability.

Results: As expected, faster reaction time was significantly associated with greater peak velocity ($t = -4.25$, $p < .001$). However, we did not find evidence for a significant relationship between pre-movement beta power and reaction time ($t = -1.90$, $p = .06$). Interestingly, higher pre-movement beta power significantly predicted higher peak velocity ($t = 2.17$, $p = .03$), suggesting a direct relationship between neural preparatory activity and subsequent movement vigor.

Conclusion: Our findings reveal a marginal relationship between pre-movement beta power and reaction time, yet a significant relationship between beta power and peak velocity. These results could align with dynamical systems theory, suggesting that elevated pre-movement beta reflects optimized preparatory states that establish initial conditions for efficient motor execution, extending beyond traditional inhibitory frameworks. This perspective reframes beta activity as potentially facilitative when aligned with task demands. Future studies should incorporate time-resolved and causal methodologies (e.g. TMS) alongside expanded motor parameter analyses to investigate the specific contributions of beta oscillatory dynamics to distinct components of movement planning and execution.

Dice stacking is mostly open-loop: a case study on highly under-actuated dynamic manipulation (P1-29)

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Background: Humans' ability to grasp and dynamically manipulate objects with their hands and fingers is not fully understood and is unmatched by current robots. To better understand human dynamic manipulation, we studied dice stacking, a task in which humans form a vertical stack from a set of initially unstacked playing dice using an overturned cup and the surface of a table. This task is highly under-actuated, meaning the number of degrees of freedom to be controlled (which includes the many dice) far exceeds the number of degrees of freedom directly controlled by the human. This makes it appear like a very difficult task.

Objective: We aimed to determine the degree to which dice-state feedback is necessary for dice stacking as a way of understanding the capabilities of the human state estimation and motor control system. Based on videos available online showing people forming stacks tens of dice tall using very tall cups, and our own personal experience learning to form stacks in the space of a few minutes, we hypothesized the task is feasible without any dice-state feedback.

Methods: We tested various humanly realizable open-loop control strategies (i.e., cup trajectories) using both MuJoCo and a bespoke simulation framework we designed in MATLAB. To verify the results from our simulations, we tested a subset of our cup trajectories using a simple two-axis robot.

Results: For a wide range of dice-state-independent cup trajectories corresponding to simple sinusoidal oscillations of the hand and forearm, a set of four playing dice will converge to a vertical stack inside of the cup from random initial conditions. This result is robust to imperfect realizations of the identified trajectories, changes in the geometry of the cup, and changes in the contact physics.

Conclusion: Dice stacking can be done robustly with simple open-loop controllers. Alongside the apparent ease with which humans can learn and execute the task, this suggests that humans easily discover open-loop control strategies for dice stacking. Future work should investigate the extent to which the human motor learning algorithm is biased toward open-loop strategies for under-actuated tasks like dice stacking.

Navigators trade off proximal and distal energy minimization strategies in uncertain environments (P1-21)

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Background: When navigating through an unfamiliar maze or field of barriers, humans may employ strategies that utilize local perceptual information to approximate an optimal path in lieu of global path planning algorithms. For instance, humans may attempt to reduce the turning angle and distance travelled to proximal decision nodes, both of which reduce per-decision energy expenditure. However, these strategies don't always generate globally optimal routes because they don't consider the direction of the final goal. Other strategies, despite occasionally being locally suboptimal, take such information into account, potentially producing more direct routes. For instance, humans may minimize the angular deviation between route options and the distal goal.

Objective: We endeavored to characterize human path choices and whether they followed proximal or distal strategies. Specifically, by putting proximal variables, such as distance (d) and turn angle (γ) to the next node, in conflict with distal variables, such as angular deviation of a path option from the goal direction (θ), we hypothesized that humans would prefer the latter.

Methods: We tested human route choices in naturalistic virtual environments. Humans were free to walk around a 13x13m room wearing a Meta Quest Pro headset.

Experiment 1: Participants navigated through mazes comprised of 3 parallel walls, each with two doors. Door positions were randomized between trials, and participants could not see into the next layer. In experiment 1A (n=17), participants were asked to navigate towards a beacon that was visible above the walls. In experiment 1B (n=17), the beacon was truncated 2s after trial start, forcing participants to navigate using memory.

Experiment 2: Participants were asked to walk on a rectangular sidewalk around a courtyard to a 'clocktower' on the diagonally opposite corner. The two possible routes were equal in length. One group (n=14) started at the corner from rest, initially facing in different directions, while another group (n=13) entered the sidewalk from an on-ramp in matched directions.

Results: Experiment 1: Door choices were best predicted by a combination of minimum angular deviation of the door from the goal (θ) and minimum turn angle to each door (γ). When the beacon was visible, the distal variable (θ) had greater predictive value; when the beacon was hidden, the proximal variable (γ) had greater predictive value. In simulation, we found that a pure θ-minimizing agent discovers the shortest and metabolically optimal route most often.

Experiment 2: Participants primarily minimized the turn angle of the route from their initial heading (γ). They were not influenced by the angular deviation from the clocktower (θ).

Conclusion: Humans utilize a combination of perceptually-based wayfinding strategies that either reduce energy expenditure immediately or over the course of an uncertain route. Distal strategies are preferred when environment structure is unknown as in random barrier configurations. However, proximal strategies are preferred when there is uncertainty about the goal direction (given a hidden beacon) or when global routes are known to be equal.

Reliability and validity of modified upper quarter y-balance tests: potential as new clinical tools (P2-62)

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Background: Clinically applied upper extremity performance measures are limited, with rehabilitation often guided by impairment-based metrics such as range of motion, strength, or patient-reported outcomes. The Upper Quarter Y-Balance Test (UQ-YBT) is one of the few established performance-based functional tests for the upper limb; however, its clinical utility may be constrained by its difficulty and limited accessibility

Objective: (1) to evaluate the reliability of the modified UQ-YBTs, (2) to examine associations between UQ-YBT and position-modified UQ-YBT performance as well as participants' anthropometric and demographic characteristics, and (3) to determine the relationship between hand strength (grip and pinch) with performance on both versions of the UQ-YBT.

Methods: Sixteen healthy individuals (8F, 23.8 ± 4.3 years; 8M, 23.3 ± 2.7 years), with no history of upper extremity injury, participated in the test-retest study following informed consent. Anthropometric data, grip, and pinch strength were recorded. Each participant completed two testing sessions, one week apart. During each session, participants performed a series of reaches in two position-modified versions of the UQ-YBT: a quadruped version (qUQ-YBT) and a standing version (sUQ-YBT) with the upper extremity supported against a wall. Test-retest reliability was assessed using the intraclass correlation coefficients (ICC).

Results: Both position-modified UQ-YBT (qUQ-YBT and sUQ-YBT) demonstrated at least moderate reliability (ICC ≥ 0.5) with one repetition, achieving excellent reliability (ICC ≥ 0.9) by three repetitions across all reach directions for both upper extremities. Minimal detectable change ranged from 3.4 to 8.1 cm, depending on the test and reach direction. The original UQ-YBT correlated significantly with the qUQYBT bilaterally (DH: $r = 0.66$, $p < 0.01$; NDH: $r = 0.57$, $p = 0.02$) but not with the sUQ-YBT. Strong positive correlations existed between qUQ-YBT and sUQ-YBT performance for both hands (DH: $r = 0.70$, $p = 0.02$; NDH: $r = 0.72$, $p < 0.01$). Significant directional correlations were found between UQYBT and qUQYBT in the dominant hand's medial ($r = 0.68$), inferolateral ($r = 0.52$), and superolateral ($r = 0.64$) reaches (all $p < 0.01$). The sUQ-YBT's superolateral reach was also correlated with the qUQ-YBT ($r = 0.57$, $p < 0.01$). UQYBT composite scores were negatively associated with age, weight, and BMI, while qUQYBT scores were negatively associated only with weight. The sUQ-YBT showed no significant correlations with these variables. There was no relationship between grip/pinch strength and the UQYBT.

Conclusion: The position-modified UQ-YBT (qUQ-YBT and sUQ-YBT) are reliable functional performance measures. First, both modified versions showed high test-retest reliability, supporting their use as consistent assessment tools. Second, results indicate that performance on the original UQYBT is related to age, weight, and BMI, while only weight is related to qUQYBT performance, and sUQYBT was unrelated to anthropometric or demographic factors. Finally, grip and pinch strength were not related to performance on any version, suggesting that none of the UQ-YBTs are not solely strength-dependent. Together, these findings support the potential of position-modified UQ-YBTs as accessible, scalable clinical tools to assess functional performance, track rehabilitation progress, and potentially screen for injury risk.

Sway characteristics in adults with neuromuscular conditions (P2-45)

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Background: Adults with cerebrovascular accident (CVA) use distinct compensatory strategies to maintain balance, partly due to challenges related to spasticity and visual changes. Physical therapists often use clinical outcome measures such as the modified Clinical Test of Sensory Integration and Balance (mCTSIB) to examine balance in older adults with neuromuscular disorders. However, these measures lack the precision to differentiate specific balance metrics. Inertial measurement units (IMUs) offer a portable, cost-effective solution for detecting subtle balance deficits in clinical settings, providing detailed data on sway characteristics that traditional assessments may overlook.

Objective: To measure differences in the sway characteristics between adults with chronic CVA and adults with other neurologic disorders.

Methods: Eight participants (7M/1F; 52-90 years old) were recruited from a student physical therapist organized exercise program. Diagnoses included CVA (n=4), neuropathy (n=3) and multiple sclerosis (n=1). Balance was measured using four Mobility Lab™ Opal IMUs (APDM, Inc., Portland, OR, USA) at the sternum, lumbar spine and bilateral feet while performing the mCTSIB protocol. This protocol requires subjects to stand quietly for 30 seconds in 4 conditions: eyes open (EO) and eyes closed (EC) on both firm (FI) and foam (FO) surfaces. Additional outcome measures included the Montreal Cognitive Assessment (MOCA), the 10-meter walk test (10MWT), the Functional Gait Assessment (FGA), and Activities Specific Balance Confidence Scale (ABC). All measurements were taken at the beginning and end of the 8-week exercise program. Data were compared between participants with stroke (CVA group, n =4) and those with other neurologic diagnoses (NCVA group, n=4) using independent t-tests.

Results: Groups were similar in baseline walking speed (CVA=0.72±0.32 m/s; NCVA=0.65±0.0.06 m/s), cognition (CVA=22.5±3.54; NCVA=21.25±4.43), balance confidence (CVA=68.13±11.43, NCVA=61.50±6.34), and functional balance (CVA=18.25±6.7, NCVA= 16.25±4.86). In the EO/FI condition, significant differences were observed at post-testing in sway area (CVA=0.236±0.023 m/s^4, NCVA=0.756±0.020 m/s^4, p=0.014) and frontal plane range (CVA=0.131±0.092 m/s^2, NCVA=0.258±0.045 m/s^2, p=.048). In the EC/FI condition, significant sway differences were found in the frontal plane area at both baseline (CVA=0.048±0.038 m/s^2, NCVA=0.167±-.086 m/s^2, p=0.044) and post-testing (CVA=0.041±0.008 m/s^2, NCVA=0.126±0.029 m/s^2, p=0.008), in frontal plane velocity (CVA=0.016±0.003 m/s, NCVA=0.067±0.021 m/s, p=0.014) and in range (CVA=0.126±0.016 m/s^2, NCVA=0.322±0.067 m/s^2, p=0.008) at post-testing. No group differences were observed in foam conditions.

Conclusion: Subjects with CVA exhibited decreased sway range, velocity and radius in the frontal plane when compared to subjects with non-CVA neuropathologies. Further research is necessary to determine the sensitivity and specificity of IMU balance outcomes to CVA populations.

Modulating motoneuron activity to influence neuromuscular junction maturation in a model of cerebral palsy (P2-40)

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Background: Cerebral palsy (CP) is a neurodevelopmental disorder that is often associated with hypoxia-ischemia (HI) injury to the developing brain, leading to motor impairments and lifelong disability. When HI injury occurs during a critical period of development in late gestation or early childhood, it can disrupt normal neuromuscular development. Neuromuscular junction maturation is highly activity-dependent, relying on precise patterns of motoneuron activity to shape synaptic structure and function.
Objective: We hypothesize that HI-induced alterations in motoneuron activity disrupt neuromuscular junction development, leading to a delay in the transition between poly- to mono-innervation, and an immature morphology when mono-innervation is finally achieved.
Methods: To test this hypothesis, we use a rabbit model of CP, which closely mimics the motor deficits and neurophysiological alterations seen in human CP. We will employ AAV-based gene delivery in neonatal HI rabbits and sham controls to selectively modulate motoneuron activity using Designer Receptors Exclusively Activated by Designer Drugs (DREADDs). This approach allows us to precisely control motoneuron excitability and examine its effects on neuromuscular junction structure and function. By comparing neuromuscular junction morphology and innervation pattern using immunofluorescence in normal and CP-affected animals with and without DREADD-induced activity modulation, we aim to determine the extent to which altered motoneuron activity drives neuromuscular junction dysfunction in CP. We performed initial experiments in which we injected the DREADD AAVs in the lumbricals and Levator Auris Longus (LAL) at post-natal day 1 (P1). The lumbricals, small intrinsic muscles of the paw, and the LAL, a muscle involved in ear movement, were chosen due to their small size for whole-mount analysis.
Results: Our findings show successful transduction of a subset of motoneurons as early as postnatal day 5, with sustained expression at P8 and P11.
Conclusion: Our findings will provide critical insights into the role of motoneuron activity in neuromuscular junction development and offer potential therapeutic strategies for improving neuromuscular function in CP.

Movement amplification during locomotor training improves the dynamic stability of center of mass control for people with incomplete spinal cord injury (P2-35)

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Background: A recent randomized clinical trial tested the efficacy of a cable-driven robot amplifying lateral pelvis movements during locomotor training (movement amplification environment; MAE) to improve functional walking in people with incomplete spinal cord injury (iSCI). Following 20 training sessions, all participants (those training in the MAE and those training in an unmodified, i.e., natural, treadmill environment) similarly improved in functional walking assessments and standard measures of gait (stride characteristics). However, for participants training in the MAE, patterns in whole-body center of mass (COM) trajectories over time appeared to increase in *dynamic stability*—cycle-to-cycle variations in COM decreased and exhibited less drift across gait cycles. This could suggest the balance control mechanism underlying walking was different for those who trained in a MAE compared to those who trained in a natural environment.

Objective: The objective of the study was to quantify the dynamic stability of mediolateral COM trajectories during steady-state walking before, during, and after training. We used recurrence quantification analysis (RQA), which quantifies a signal's dynamic stability in terms of its recurrence (revisiting positions in phase space). Moments of recurrence are plotted as “points” on a recurrence plot. When recurrence points fall along diagonal lines, they indicate continued recurrence, which indicates dynamic stability. We hypothesized that participants in the MAE group (N=15) would exhibit greater increases in dynamic stability (via increases in diagonal lines on recurrence plots) compared to a Null group (who trained in the natural environment; N=14).

Methods: We assessed kinematic data from participants with iSCI who completed 20 sessions of training. COM trajectories were extracted via motion capture from steady-state walking trials recorded at baseline, midpoint (10 sessions), and post training intervention. Two RQA measures were assessed: Determinism (DET; the percentage of points that fall on diagonal lines), and mean line length (MeanL), which both quantify the dynamic stability of a system's recurrence.

Results: RQA diagonal line measures increased with training in the MAE group; both DET ($p < .001$) and MeanL ($p < .05$) increased with training (ANOVA). RQA measures did not increase with training for the Null group, all $p > .05$ (ANOVA).

Conclusion: Locomotor training with the MAE enhanced the dynamic stability of COM control for individuals with incomplete spinal cord injury (iSCI). While both groups exhibited similar improvements in functional walking assessments and standard quantitative measures of gait, only the group who trained with the MAE exhibited improved dynamic stability of their COM control. These findings suggest MAE is a promising intervention for improving dynamic stability during gait training in individuals with iSCI. For people with gait impairments, increased dynamic stability could represent improved control over step-to-step dynamics, more effective sensory feedback utilization, and greater central nervous system involvement in regulating locomotion. Future research is needed to investigate explicit links between improved dynamic stability and functional outcomes of locomotor training.

Force field adaptation requires specific muscle synergies (P1-02)

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Background: Humans can adapt their motor commands in response to errors. During force field adaptation, they adapt to perturbing forces exerted by a robotic manipulandum and ultimately reach targets with trajectories similar to those from unperturbed reaching. Force field adaptation has been studied thoroughly in terms of endpoint kinematics and kinetics, i.e., at a task level. However, how its coordination is represented at a muscular level remains unanswered. In particular, it is unclear how force field adaptation affects muscle synergies, groups of co-activated muscles that the CNS might organize to simplify the control of excessive degrees of freedom. In isometric visuomotor rotation, a related paradigm, synergies from unperturbed reaching could account for adaptation. Studies on the activation of a few muscles in force field adaptation suggest that muscles acting in the force field's opposite direction are activated early in the movement, and that co-contraction occurs when the force field is experienced for the first time and remains throughout the adaptation phase.

Objective: To test whether combinations of unperturbed reaching muscle synergies can account for force field adaptation or if specific muscle synergies are required. We hypothesized (1) that combinations of baseline reaching synergies were sufficient to explain adapted reaching with the alternative (2) that additional specific muscle synergies were necessary.

Methods: Thirty-six healthy young male volunteers performed reaching movements (15 cm) with a KINARM End-Point manipulandum. After unperturbed reaching to targets at -90°, -45°, 0°, 45°, and 90°, they were exposed to a viscous force field reaching to the 0° target. Twelve EMG electrodes captured muscle activity of the trunk and arm muscles. Spatial muscle synergies were extracted from the baseline with NMF and fitted to the EMG of the last 20 trials of the force field exposure ("adapted state"). Hypothesis 1 was tested using the fit's reconstruction quality (R^2). To test hypothesis 2, shared-and-specific muscle synergies were extracted using a bootstrap procedure from the baseline and the adapted state simultaneously. This procedure can distinguish between differences in the two EMG datasets, baseline and adapted state, due to noise and due to structural differences.

Results: Participants adapted to the force field. Muscle synergies from unperturbed baseline reaching could not explain the muscle patterns of the adapted state, with R^2 values 0.98 ± 0.69 lower for the adapted state than for the cross-validated baseline EMG (t-test: $p < 0.05$). We, therefore, rejected hypothesis 1. 1.47 ± 0.74 synergies were found to be shared between the baseline and adapted state, and 1.92 ± 0.60 adapted state-specific synergies were necessary to explain the muscle patterns of the adapted state. We therefore accepted hypothesis 2.

Conclusion: Force field adaptation requires structural changes in muscle synergies. While EMGs of individual muscles resemble those described in the force field adaptation literature, we provide a novel characterization of the underlying coordination at a muscular level. In contrast to isometric visuomotor rotation, structural changes observed in force field adaptation highlight the neuromechanical differences between the two related paradigms.

Timing-dependent posterior parietal cortex contribution in adaptation and transfer (P1-10)

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Background: Visuomotor adaptation is attributed to numerous cortical mechanisms including memory-driven updating of a motor plan and sensory-feedback-driven online correction. While compelling evidence demonstrates posterior parietal cortex (PPC) involvement in movement planning and online correction, the respective contributions of these distinctive cognitive processes governed by PPC in adaptation are poorly understood.

Objective: We causally investigated PPC involvement in adaptation and motor-memory consolidation by delivering transcranial magnetic stimulation (TMS) to the left PPC at either the motor planning or online correction phases during a visuomotor rotation adaptation task.

Methods: 54 healthy righthanded participants (age: 23.6 ± 5.4, 26 males) were recruited and randomly assigned to one of three groups: No TMS, Prior-To-Movement TMS (Early TMS), and Later-In-Movement TMS (Late TMS) following IRB approved informed consent. All participants completed four blocks in which they reached to one of eight pseudorandomly presented targets 12 cm away from a fixed central point: 1. Left-Arm Baseline, 2. Right-Arm Baseline, 3. Right-Arm Visuomotor Rotation Adaptation (Adaptation), and 4. Left-Arm Interlimb Transfer (Transfer). The cursor representing the hand position was veridically matched to hand motion during Baseline blocks and deviated 30° counterclockwise during Adaptation and Transfer blocks. During the Right-Arm Baseline and Right-Arm Adaptation blocks, Early TMS and Late TMS groups received double-pulse TMS (50ms ISI) after target presentation (Early) or when the hand was 8 cm from the starting point (Late). The absolute value of angular difference between the line connecting the center point and the target and the line connecting the center point and the hand position at peak acceleration was used to quantify the angular error ($|AE|$). Baseline-normalized $|AE|$ ($|AE|\Delta$) was calculated by subtracting the mean $|AE|$ of the last 8 trials of Right-Arm and Left-Arm Baselines from that of each trial in the Adaptation and Transfer blocks, respectively. For each group, we fitted an exponential decay function with limit to the learning curves during Adaptation and Transfer and compared the estimated parameters ($|AE|\Delta$-intercept, learning rate, and learning limit) between groups via a bootstrap confidence interval method.

Results: While reaching error during Left-Arm and Right-Arm Baseline blocks was comparable regardless of TMS intervention, adaptation during Adaptation and Transfer blocks was TMS-timing dependent. Specifically, compared to No TMS, Early TMS exhibited lower $|AE|\Delta$ at the beginning of Adaptation ($p < 0.05$), whereas Late TMS exhibited a higher learning rate and a lower learning limit ($p < 0.05$). Additionally, during Transfer, Late TMS had a higher learning rate compared to No TMS ($p < 0.05$).

Conclusion: The study causally revealed that PPC contribution in adaptation and motor-memory consolidation is timing-dependent such that the contribution of PPC in adaptation through motor planning is immediate, but not progressive, whereas its contribution through sensory-feedback-driven online correction is progressive, but not immediate. This timing-dependent PPC involvement in adaptation and motor-memory consolidation may be exploited for development of evidence-based therapeutic interventions for noninvasive brain stimulation to

left PPC after injury to facilitate motor adaptation, and may facilitate further understanding in the neuromechanisms underlying adaptation and motor-memory consolidation

TMS-induced I-wave characteristics are associated with impairment severity in chronic post-stroke hemiparesis (P1-19)

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Background: Volitional movement relies on high-frequency communication between subcortical, higher motor areas, and the motor cortex, all of which are modulated by cortico-cortical circuits. In neurologically intact individuals, the facilitation of cortico-cortical circuits is important for movement initiation and the recruitment of spinal motor neurons. Paired-pulse transcranial magnetic stimulation (TMS) at precise intervals provides insights into cortico-cortical circuit excitability, a method known as short-interval intracortical facilitation (SICF). Cortico-cortical facilitation is reflected by increased motor evoked potential (MEP) amplitudes corresponding to later indirect (I1, I2, and I3) waves. Previous studies have shown that the modulation of cortico-cortical circuits is disrupted in various movement-related disorders, worsening impairment and functional deficits. However, the impact of stroke on cortico-cortical circuits and its relationship to motor deficit severity remains understudied.

Objective: To investigate the cortico-cortical excitability in participants with chronic post-stroke-related hemiplegia and its associations with motor impairments across varying motor severities.

Methods: Ten chronic post-stroke hemiplegic participants with mild-to-severe impairments were recruited (Upper-Extremity Fugl-Meyer (UEFM): 34±12, range: 14-51). TMS was delivered to the ipsilesional and the contralesional primary motor cortex (M1), targeting the extensor digitorum communis muscle. SICF stimulation of the M1 was delivered using a test stimulus that elicited 50% of the maximal MEP amplitude, followed by a conditioning stimulus at 90% of the resting motor threshold. Interstimulus intervals (ISI) from 0.9 ms to 5.9 ms in steps of 0.2 ms were used to cover the range of the first three I-wave peaks. Ten paired-pulse stimulations were delivered for each ISI condition (random order), and 52 single-pulse stimulations were randomly delivered throughout the protocol.

Results: The excitability of cortico-cortical circuits differs between the ipsilesional and contralesional hemispheres at a group level. Ipsilesional I2-, I3- peak excitability is diminished (I2: -23.5 ± 27.4% | $p < 0.05$; I3: -20.9 ± 19.6% | $p < 0.05$), and I1-, I2- peaks are delayed (I1: 1.26 ± 0.45 ms | $p < 0.001$; I2: 0.74 ± 0.44 ms | $p < 0.001$). In the ipsilesional hemisphere, greater excitability of I1- and I3-peaks correlated with less impairment (UEFM, I1: $r^2 = 0.49$ | $p < 0.05$; I3: $r^2 = 0.51$ | $p < 0.05$). Additionally, greater excitability of the I3-peak in the contralesional hemisphere was correlated with less impairment (UEFM, I3: $r^2 = 0.47$ | $p < 0.05$).

Conclusion: Our findings suggest a group-level decrease and delay in I-wave dynamics of ipsilesional compared to the contralesional hemispheres. Early I1-peak excitability may predict recovery, reflecting the direct engagement of residual excitatory inputs within the ipsilesional primary motor cortex. I3-peak excitability from both hemispheres predicted impairment severity, suggesting that interhemispheric interactions, mediated by cortico-cortical projections, may reflect an adaptive mechanism that supports post-stroke motor recovery.

Postural control in parkinson's disease: analyzing wearable sensor data using trend change indexes (P2-36)

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Background: Evaluating postural balance in patients with Parkinson's disease is essential however, the reliable differentiation between healthy individuals and patients at different disease stages remains challenging. The Trend Change Analysis (TCA) method relies on detecting significant corrections in signal trends (described in other our publications – based on techniques commonly used in financial market analysis that reflect quick postural adjustments (TCI – number of corrections in time) signals and can be used as a new method offering improved insight into the mechanisms underlying the maintenance of postural balance.
Objective: The primary objective was to assess the effectiveness of the TCA using wearable sensors to differentiate healthy individuals and Parkinson's disease patients in ON and OFF states, as well as to compare the TCA parameters with traditional postural balance parameters.
Methods: Participants were divided into three groups: young adults (YO, n=40), older adults (OA, n=21), and Parkinson's disease patients (PD, n=29). Mean ages were 29.5±8.5 (males) and 27.5±7.1 (females) for YO, 72.5±5.9 (males) and 70.9±6.0 (females) for OA, and 63.2±11.7 (males) and 68.0±7.3 (females) for PD. All participants were recruited from the University Hospital Schleswig-Holstein (UKSH), Kiel, Germany. Participants were excluded when their fall risk was determined to be too high (> 2 falls in the previous week), corrected visual acuity was below 60%, they scored ≤ 15 points in the Montreal Cognitive Assessment (MoCA).
The experimental procedure involved a 10 seconds static balance task. Data were collected using inertial measurement units (Noraxon USA Inc., myoMOTION, Scottsdale, AZ, USA) that were attached to the head (HEAD), sternum (STERNUM), and sacrum at S1 (PELVIS) using elastic straps. The analyses encompassed conventional parameters such as jerk, acceleration range, root mean square of acceleration, surface area of the sway ellipse, path length, and mean velocity. Additionally, Trend Change Indices (TCI, TCI_dT, TCI_dS, TCI_dV) were calculated based on acceleration signals across three axes.
Results: No differences were observed between the cohorts for all parameters except for TCI, which specifically enabled the differentiation of patients in the OFF state.
An independent analysis of each sensor demonstrated differences across all parameters between the head-mounted sensor and the other two sensors. In this case, no significant differences were found between the head and the rest of the body, suggesting less head motion.
Conclusion: The conducted analyses confirm the applicability of the newly developed method for enhanced assessment of postural balance. The ability to distinguish patients in the OFF state from those in the ON state, as well as from healthy individuals, highlights its potential for objective balance evaluation. The observed lower head motion during quiet standing in OFF-state patients—highlighted by the absence of differences in the TCI parameter between the head, pelvis, and sternum—is consistent with previously described motor dysfunctions

characteristic of Parkinson’s disease. The capacity for objective quantification and monitoring of this phenomenon may contribute to improved diagnostic support for the disease.

Effect of visual time perception on the control of standing balance (P2-39)

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Background: Accurate perception of timing is critical for motor control. While recent evidence suggests that perception of time may be expanded or contracted by concurrent movements, how our judgment of elapsed time may itself affect control of movements is poorly understood. This is particularly important in the context of standing balance control, impairments of which are a key determinant of falls with aging and disease. Maintenance of postural stability entails continuous monitoring and correction of the body's position, requiring precise time perception, often in the millisecond range. Yet, how judgements of time affect balance control is not known.

Objective: The present study investigated the bidirectional relationship between human time perception and balance control. Specifically, whether perception of time distorts during standing and how the act of processing time in the sub-second range affects postural stability were examined. We hypothesized that competition for attentional resources may result in distortion of perceived time and poor postural control. On the other hand, shared neural circuitry between postural control and precise timing may result in facilitation of balance.

Methods: Ten healthy young adults (mean age 27.6 years; 6 females) participated in a cognitive-motor dual-task protocol. The seated single cognitive (first) block involved three cognitive tasks (visual stimulus, verbal response): temporal bisection task (TBT), simple reaction time, and 0-back (latter two as control tasks), order pseudo-randomized. TBT involves participants judging the duration of a given visual stimulus in comparison to a previously anchored duration. The single motor (second) block required maintaining balance while standing on a firm or foam surface (order counterbalanced). The cognitive-motor dual (third) block involved maintaining standing balance while concurrently performing the given cognitive task (order pseudo-randomized), under the two support-surface conditions (counterbalanced). Percent accuracy, reaction time, and psychophysics measures on cognitive tasks and center of pressure (COP) metrics with their cognitive and motor costs were computed. 2x2 repeated-measures ANOVAs with factors: task [single, dual] and support-surface condition [firm, foam] along with post-hoc tests were conducted for each measure, and costs across support-surface conditions were compared with paired t-tests.

Results: There were no differences between single and dual-task performance on any measures of TBT, under firm and foam conditions; with no differences in cognitive costs across support-surface conditions [all $p>0.05$]. However, mean COP displacements in the sagittal [$F=11.12$, $p<0.01$, $\eta p^2=0.55$] and frontal planes [$F=6.73$, $p<.05$, $\eta p^2=0.42$] revealed a significant main effect of task during TBT; COP displacements, during dual-tasking were lower than single task (for both firm and foam conditions), with no differences between motor costs across support-surface conditions [$p>0.05$].

Conclusion: Time perception was preserved during standing, even under challenging balance conditions without additional cognitive costs. Moreover, sub-second level processing of time during standing seemed to improve postural stability, across balance threats without added motor costs. Collectively, these findings suggest a pattern of motor facilitation resulting in improved balance during the performance of a concurrent time perception task, probably due to shared neural circuitry and ensuing synchronization; with important implications for investigations of age-related decline in postural control and balance rehabilitation.

Effects of increasing movement variability on motor learning (P1-01)

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Background: Movement variability is a phenomenon when no two identical movements can be performed. It has long been described as “noise” that should be reduced to achieve more accurate movements. The views on movement variability have changed over time. It can enhance motor learning, predict adaptability, and improve performance. However, the role of movement variability and its effects on the motor learning process remain controversial.

Objective: The aim of this study was to investigate whether increasing variability during training impacts the motor learning process and immediate motor learning outcomes. We hypothesized that repetition of the same movement might promote improved learning in the initial stages of training, but increasing variability during training may help perform more varied tasks more effectively and apply the skill learned to variations of the exercises.

Methods: 38 healthy right-handed adults, both male and female, participated in the experiment. They performed a challenging motor task involving moving a cursor through a channel without touching borders controlled by movements of the left wrist within a target duration. The task included pretest, training, posttest, and transfer. Participants were divided a control group who had the same semicircle channel throughout training, and the study group who had the same semicircle channel during pretest and posttest, and three more semiellipses with different axis ratios during training. In the transfer task, both groups had a same new semi-ellipse. The primary outcome was accuracy (% of time within the channel). Also, movement time, number of submovements, and distance from the midline were calculated.

Results: Mixed design ANOVAs were used to compare differences in the outcomes at different time points. Both groups, study and control, showed some enhancement in accuracy ($p = 0.032$) at the transfer point, without a significant difference between groups ($p = 0.437$). There was a significant decrease in movement time from pretest to posttest ($p = 0.037$) and to the transfer ($p < 0.001$) for both groups. Analyses of all results showed that the study group performed the task faster than the control group ($p = 0.012$). Also, both groups shortened the distance from the midline ($p < 0.001$) and reduced the number of submovements ($p < 0.001$) following training without any significant difference between groups.

Conclusion: We examined the effects and immediate outcomes of increased variability during training on motor learning. The study group demonstrated faster task completion, suggesting that variability may enhance speed without compromising accuracy and can be an optimization factor in the execution of the movement. Further studies should be conducted to explore long-term outcomes, different types of variability and their effects on different populations.

A high-level computational model of parkinson's disease motor symptoms (P1-09)

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Background: Parkinson's disease (PD) includes several motor symptoms with varying expression among patients. The characteristic symptom "triad" includes bradykinesia, rigidity, and tremor. Typically, at least two of these three symptoms are present for a PD diagnosis. Dopamine depletion is the key neural dysfunction in PD. However, it remains unclear whether this dopamine depletion produces all three symptoms, especially with tremor contrasting the other two inhibitory symptoms. Other neurotransmitter systems are affected by PD and likely modulate symptom expression. Still, degradation of dopamine centers seems to be necessary to produce the classical motor symptoms. Improved understanding of the mechanisms underlying these motor symptoms could help inform PD treatment strategies.

Objective: Develop and analyze a computational model based on high-level motor control and potential dysfunction in PD, with simulations evaluating the ability of the model to capture previously recorded PD movement characteristics.

Methods: The proposed model incorporates prospective control-system roles of brain regions to simulate healthy motor control with compensation for feedback delays. This low-order model captures qualitative behavior of human upper-limb movements at low computational cost. The key effect of dopamine depletion is a reduction in an action gating parameter based on the "gating" model of basal ganglia control of the thalamus. Simulations explore the effects of different model parameters on the characteristics of symptom expression.

Results: Simulations of the computational model recreate the key motor symptoms along with several previously recorded movement characteristics for PD patients. All three of bradykinesia, rigidity, and tremor are driven by simulated dopamine depletion. Unstable feedback is the key factor that enables decreased signal levels to produce tremor. Modulating parameters likely affected by neurotransmitters other than dopamine affects symptom expression. Finally, controller parameters are a greater driver of symptom expression than biomechanics parameters.

Conclusion: The developed model demonstrates how bradykinesia, rigidity, and tremor may all stem from the characteristic dopamine depletion in PD. High-level control system parameters encoded by dopamine translate into the range of observed motor symptoms. Parameter studies demonstrate how similar dysfunctions could produce different symptom expression across patients, potentially contributing to the existence of disease subtypes. Future work aims to implement human movement studies to further evaluate model efficacy.

Inter-trial and intra-trial analysis of force stabilization in multi-finger tasks: the role of visual feedback (P1-24)

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Background: This study explored the multi-finger synergies during force production in isometric conditions. In particular, we assumed that variance component with no effect on total force produced by a set of effectors, fingers or finger pairs, (i.e., variance along the UCM, V_{UCM}) had two contributors. One of them, $V_{UCM\text{-}SH}$, defines inter-trial variance in the sharing of total force between the effectors in a feed-forward way, based on practice trials. The other contributor, $V_{UCM,CoV}$, is covariation of the force by the effectors based on salient feedback that is reflected in both inter-trial and intra-trial variance indices.

Objective: We analyzed inter-trial and intra-trial variance during multi-finger force production tasks to explore the contributions of feed-forward control and salient visual feedback to force-stabilizing synergies. We hypothesize that V_{UCM} is influenced by both inter-trial variance in force sharing and covariation of element contributions based on feedback.

Methods: Young healthy subjects performed four-finger force production tasks using the index and middle fingers of both hands. Subjects were presented with targets for total force (F_{TOT}), individual finger pairs (F_{PAIR}), or both ($F_{TOT+PAIR}$). Feedback on force magnitude was either continuous (FB_{ON}) or provided only when cursors were outside the targets (FB_{OFF}). For each feedback condition, participants completed series of 24 trials (10-s each) for each target condition and three 60-s trials with varied initial force sharing between the finger pairs (75:25, 50:50, and 25:75). In those trials, force sharing feedback was frozen after 5 s, while force magnitude feedback remained for the duration. Inter-trial variance along the UCM (V_{UCM}) and orthogonal to it (V_{ORT}) were quantified using averages from steady-state intervals. Intra-trial variance was quantified across 0.1-s steady-state windows spaced by 1-s interval. Synergy index (ΔV) was calculated as the normalized difference between V_{UCM} and V_{ORT}.

Results: Inter-trial analysis showed positive ΔV values for variables with explicit targets across all conditions. ΔV values were higher in the FB_{ON} condition compared to FB_{OFF}. Variables without visual feedback showed $\Delta V \approx 0$. Under the $F_{TOT+PAIR}$ condition, all $\Delta V > 0$ but were reduced compared to the F_{TOT} and F_{PAIR} conditions. These effects were primarily due to changes in V_{UCM}. Intra-trial analysis showed significantly smaller ΔV for the 50:50 sharing condition, while ΔV was significantly higher for the 75:25 and 25:75 sharing conditions.

Conclusion: The results support the hypothesized two contributors to V_{UCM} and their importance in force-stabilizing synergy. Continuous visual feedback is crucial for these synergies. There's a trade-off between synergies at the level of two hands and finger pairs between hands, although they can coexist. Intra-trial analysis provides information on only one component of V_{UCM}, $V_{UCM\text{-}CoV}$. Combining inter-trial and intra-trial analyses can provide deeper insights into impaired synergies in neurological disorders.

The structure of variability during unperturbed speech production does not predict speech motor adaptation in perturbed trials (P1-04)

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Background: The critical role of movement variability in motor adaptation is well established. While practicing movement in novel circumstances, errors are used to improve performance over repeated trials. However, an open question is whether the variability of unperturbed movements is related to the adaptation to those movements in altered environments.

One study on arm reaching suggested that sensorimotor adaptation may be associated with motor variability measured during unperturbed trials. Participants with larger task-relevant variability (movement variations that affect outcomes) and task-irrelevant variability (movement variations that do not affect outcomes) during unperturbed reaching movements showed greater adaptation to visuo-motor rotations and viscous force fields. However, in the case of speech production, previous studies did not find a relationship between task-relevant variability during baseline trials (with unperturbed auditory feedback) and speech adaptation when feedback was altered. However, task-irrelevant variability or the stability of the movements during baseline may be associated with adaptation. We want to know whether movement variability and its structure during unperturbed trials are predictive of sensorimotor adaptation in perturbed trials of speech production.

Objective: Our aim was to determine whether the task-relevant and task-irrelevant variances in lip, jaw and tongue kinematics during baseline correlated with motor adaptation during subsequent perturbed speech trials. We also aimed to determine whether the synergy index, a measure of the stability of the unperturbed movements, predicted adaptation.

Methods: We asked eighteen adult participants to read "talk," "tech," and "tuck" in a pseudo-random order while sitting in the electromagnetic articulograph (Carstens, AG501). The first 90 trials were baseline, followed by 90 perturbation trials during which formant frequencies in the auditory feedback were increased to induce adaptation. The articulatory kinematic data during the baseline trials were used to identify four principal components. Then the Jacobian that mapped small changes in the principal components to changes in corresponding formant frequencies was obtained via regression. The principal components were projected onto the null and range spaces of the Jacobian. Task-relevant and -irrelevant variances and the synergy index were computed from the projections. Motor adaptation during perturbed trials was quantified as the change in formant frequency between the last unperturbed trial and the average of the last ten perturbed trials. The analyses were performed separately for each word.

Results: We observed a statistically significant correlation between adaptation and task-irrelevant variance for “tuck” (R^2=0.4; p<0.01), but this significance disappeared once the p-value is corrected for multiple tests. There was no significant correlation for any other variance type and synergy index for any word (p>0.1).

Conclusion: These results extend previous speech research by demonstrating that speech adaptation correlates with neither task-relevant nor task-irrelevant variability. Furthermore, the synergy index, reflecting the stability of articular motions during baseline, was also not related to subsequent motor adaptation. Overall, our findings are consistent with the evidence that speech adaptation may be fundamentally different from adaptation in the upper-limb domain. In addition, our results add to the skepticism that the structure of variability of natural, unperturbed motions is predictive of motor adaptation.

Altered gait among people with multiple sclerosis during a prolonged walking bout (P2-52)

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Introduction: People with Multiple Sclerosis (PwMS) report fatigue as well as gait and balance dysfunction as major factors that reduce their quality of life. MS-related fatigue is defined as a lack of physical and/or mental energy, and is exacerbated by physical exertion. Given that postural stability worsens with fatigue among people with MS, it is plausible that prolonged walking could exacerbate gait instability among this population.

Purpose: To analyze the effects of a prolonged walking bout on MS-related fatigue, spatiotemporal gait parameters, and gait stability across multiple walking speeds in PwMS compared to healthy controls (CON) was assessed.

Methods: Fifteen participants (7 MS; 8 CON) performed a 30-minute treadmill walking bout during which speed was manipulated (0.6, 1.0, 1.4 m/s), repeated for 2 minutes each at three timepoints (early, mid, late), with the first and last three minutes of the bout performed at self-selected pace. Reflective markers were affixed to the body, recorded using 8 infrared cameras (Qualisys Inc.) and used to generate a seven-segment 3D model. Spatiotemporal gait parameters (step and swing time, stance width) were assessed as well as average and minimum Time to Contact (TtC) values of the body center of mass (CM) to evaluate gait stability. Left-right asymmetry index and covariance was computed for all variables. A visual analog fatigue scale (VAFS) assessed changes in physical fatigue pre/post. Mixed-model repeated measures ANOVA (group, speed and time factors) analyzed variables of interest; preferred speed group comparisons were assessed using independent samples t-tests ($p<0.05$).

Results: Effects of prolonged walking on stride parameters and TtC were most pronounced at the slow and medium walking speeds. PwMS exhibited shorter step and swing times than CON, as well as greater swing time variability at medium and slow speeds, which decreased over time. Average TtC decreased with increasing walking speed, with no group or timepoint differences. Asymmetries were evident for TtC with group by time differences on the left leg; PwMS demonstrated lower or equivalent minimum TtC values to CON at the initial timepoint that increased for middle and final timepoints (left foot). TtC variability was higher in PwMS across speeds (middle timepoint -trend only), decreasing over time (left foot). Fatigue increased similarly in both groups, although PwMS had a higher baseline.

Conclusions: PwMS appeared to adopt a cautious gait strategy for medium and slow walking speeds, with shorter steps that became less variable over time. PwMS increased their TtC over time suggesting an effort to enhance stability, although this was found only on the left side. Decreased variability of TtC and stride parameters suggests a compensatory strategy that may limit adaptability and could increase fall risk as fatigue progresses. These effects, most pronounced at slow

Embodiment and control of a complex object: hitting a target with a whip (P1-28)

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Background: When rhythmically hammering a nail into a wall, the hand can move along multiple trajectories even if the hammer always hits the nail. For such movements, without a tool or with a rigid one, high task accuracy is generally associated with low variability in both in the hand and the tool. Manipulation of complex objects or ‘tools’, such as clothes or ribbons, has received less attention, despite their abundance in daily life.
Objective: Our research explores interaction with an extreme example of complex tools, a bullwhip, in a task of hitting a target. We examine how variability of the body and the whip evolves during attempts to hit the target. We hypothesize that the task configuration and the whip dynamics would result in a spatiotemporal organization of variability.
Methods: Subjects used a 1.6-m whip to repeatedly hit a target at 2.2-m distance, with 30 trials per block. 16 and 16 novices practiced the task either in 5 or 35 blocks, respectively, and an expert practiced the task in 5 blocks. Arm and whip kinematics were recorded via 3D motion capture. A throw interval was defined from the instance when the hand was the farthest away from the target until the instance when the tip of the whip was the closest to the target. Variability throughout the throw interval was quantified for each marker as cross-sectional area of its repeated trajectories within each block. To examine the contribution of object extension to its variability, a “normalized” variability was additionally found. To this end, the coordinates were normalized by each marker’s mean distance travelled before determining cross-sectional variability.
Results: Expectedly, experts hit the target in 90% of the trials, and novices scored 5-60%. Between-participant variability was larger than the within-participant one. In addition, the results suggested an emerging spatiotemporal structure of variability:

- Variability was lower in the experts than in novices and reduced with practice in novices.
- In all subjects, the tip of the whip reached minimum variability when it extended backwards before each throw and when it was closest to the target, and its variability was considerably larger during the rest of the throw.
- In all subjects, the hand reached minimum variability at the time of its maximum velocity, the whip unfolded smoothly following that, and low variability propagated from the hand to the tip of the whip.
- In all participants, variability increased from proximal to distal markers. However, when normalized by marker path travelled, variability decreased from proximal to distal markers.

Conclusion: In agreement with task requirements and our previous findings, variability was reduced at the times and locations most relevant for the task: preparing the whip and then transferring energy from the hand through the whip to its tip using the emerging “unfolding” regime of the whip. Assuming low variability reflects a focus of control, this control point appeared to shift from the hand towards the tip of the whip, suggesting embodiment of even such a complex tool as a whip.

Impedance preparation and modulation when interacting with dynamically complex and uncertain objects (P1-18)

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Background: Manipulating complex objects is ubiquitous in our daily activities, such as tying shoelaces, donning a jacket, or carrying a cup of coffee. However, such non-rigid objects present complex dynamical challenges: When carrying a cup of coffee, the coffee develops unpredictable dynamics and generates forces acting on the hand and that can lead to spilling the coffee - instability. Previous research has shown that humans ensure stable dynamics by preparing the system's initial conditions and selecting appropriate interaction frequencies. However, it remains unclear how these strategies adapt when the physical properties of the object, like the amount of liquid, are uncertain or difficult to estimate.

Objective: We hypothesize that humans optimize mechanical impedance by preparing and interacting with objects that have nonlinear dynamics and uncertain properties.

Methods: Extending our previous work, the task of transporting a ‘cup of coffee’ was simplified to transporting a cup with a rolling ball inside, modeled as a cart with a suspended pendulum. Participants translated the virtual cup and ball on a horizontal line displayed on a screen via a robotic manipulandum. Participants were instructed to 'jiggle' the cup to prepare the cup and ball's states for the ensuing continuous rhythmic movement at their preferred frequency. The isometric grip force on the robot handle served as a proxy for the mechanical impedance of the arm. To introduce uncertainty regarding object properties, we manipulated the pendulum's length in two conditions performed by two groups of subjects: i) random condition, the length changed randomly from trial to trial without explicit cues, and ii) blocked condition, the length remained constant across trials. To evaluate human strategies, we measured the ball's angle at the end of the preparation phase and the cup's oscillation frequency during the rhythmic portion of the trial. Stability was defined as the variability of the relative phase between the cup and ball. Using stochastic open-loop optimal control simulations we solved for time-dependent impedance and force under the two conditions imposed in the experiment.

Results: In both conditions, participants controlled the relative phase to either in-phase (0°) or anti-phase (180°) before starting the rhythmic task. Despite the uncertainty in dynamics, they maintained comparable stability of relative phase in both conditions. While the ball's initial angle and the cup's frequency varied among participants, the nonlinear covariation of the two variables stabilized the cup-ball dynamics in both conditions, as predicted by the forward simulations. These simulations confirmed that maintaining stability was prioritized over other control objectives, such as minimizing applied force, smoothness of force, or the risk of losing the ball. While the net force applied on the cup was similar between the conditions, the grip forces indicative of mechanical impedance were higher in the random condition. Optimal control simulations corroborated these findings, further revealing that participants selected preparation and interaction frequencies that effectively minimized mechanical impedance.

Conclusion: Humans covary preparation and interaction strategies to optimize mechanical impedance and stability of interactions when faced with uncertain and nonlinear dynamics.

Cortical hemodynamic responses in auditory processing and the influence of transcranial direct-current stimulation (P1-22)

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Background: Although neuromodulatory approaches, such as transcranial direct-current stimulation (tDCS), have garnered considerable interest in the treatment and understanding of neurological diseases and disorders, their influence on the cortical hemodynamic correlates of neural activity remain under-characterized. In particular, the concurrent use of tDCS and functional near-infrared spectroscopy (fNIRS) is of particular interest due to their mutual compatibility and portability. Understanding the effects of tDCS on neural responses to auditory stimuli could inform future treatment approaches to conditions affecting auditory processing, such as schizophrenia, while providing a lens to better understand cortical function during auditory processing and other neural processes.

Objective: In this study, we attempt to characterize hemodynamic responses to blocks of auditory stimuli and the potential modulatory role of tDCS in these responses.

Methods: A total of 10 healthy participants (age 27.01±5.07, 4 female) were enrolled in this study. One participant was removed from the analysis due to inadequate fNIRS signal quality. After an initial neuroimaging-only session, participants completed two experimental sessions during which fNIRS signals were recorded from 12 channels Frontal (F), Left Auditory (LA), and Right Auditory (RA) regions of interest (ROIs) along with a set of 8 short-separation channels while auditory stimuli (500ms duration 40 Hz white noise click trains) were presented in 15s blocks followed by 15s resting-state blocks. Experimental runs (24 of each block per run) were collected before, during, and after tDCS was administered in one of two configurations: Left Hemisphere (LH; anode: AF3, cathode, CP5) and Right Hemisphere (RH; anode: AF4, cathode, CP6) counterbalanced across sessions. Stimulation was administered for 20 minutes at 2 mA. A general linear model (GLM)-based first-level analysis approach was applied within experimental runs using a canonical hemodynamic response convolved with boxcar representations of the Task and Rest blocks as functional regressors and retained short-channels and a set of drift regressors as nuisance regressors. A linear mixed-effects model (LME) was used to determine the relevant regressor/ROI pairs to analyze. Once identified, a set of LME models was used to determine the influence of tDCS within sessions and across the results of the post-stimulus runs corresponding with the two tDCS configurations.

Results: Second-level analysis identified significant negative Rest coefficients for oxygenated hemoglobin concentration change (ΔHbO_2) in the LA ($\theta = -3.92$, $p = 0.001$) and RA ($\theta = -2.47$ $p = 0.033$) ROIs. No significant effect of run type (pre-stimulation vs. post-stimulation) was observed on these regressor fits (LA: $\theta = -0.14$, $p = 0.948$; RA: $\theta = 0.92$, $p = 0.72$). Similarly, no effect of stimulation configuration (LH vs. RH) was observed on these regressor fits (LA: $\theta = 2.27$, $p = 0.10$; RA: $\theta = 1.08$, $p = 0.58$).

Conclusion: A bilateral negative response to the Rest period was observed in both auditory cortices. tDCS condition and configuration had no significant influence on this negative response. Further work may be required to optimize extraction of task-related hemodynamic responses. A larger sample size may enable us to observe subtler interactions in this ongoing study.

Assessing the differences between fine wire and surface electromyography in the infraspinatus muscle during active range of motion movements (P2-58)

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Background: The rotator cuff (RC) is a unique muscular structure made up of four muscles originating at the scapula and attaching at the head of the humerus. Each of the four muscles can act as primary movers of the upper extremity; however, the essential function of this musculature is to stabilize the humerus to the scapula during upper extremity movements during daily tasks such as reaching and grasping. Traditionally, non-invasive surface electromyography (EMG) has been used to measure the electrical activity of the rotator cuff muscles and has been deemed the gold standard to capture muscle activation. The structure of the RC, however, is only partially superficial (infraspinatus and teres minor) and larger and more superficial muscles such as the trapezius or deltoid interfere with clean signals from the deeper RC muscles - the subscapularis and the supraspinatus. This requires the use of fine wire intramuscular electrodes to quantify the muscle activation patterns of these muscles.

Objective: This project aims to investigate the differences in infraspinatus muscle activity during upper extremity movement, comparing signals recorded with indwelling fine wire electrode and surface electrodes.

Methods: Four healthy participants with no history of injury to the shoulder or upper extremity were enrolled in the study. Once consented, the infraspinatus was palpated on both the left and right side. A surface electrode was placed on the infraspinatus inferior to the scapula and an indwelling fine wire electrode was inserted into the muscle belly adjacent to the indwelling electrode insertion point. Participants completed a series of movements involving external rotation of the shoulder, a primary action of the infraspinatus. Muscle activity was recorded during external shoulder rotation from neutral and at 90 degrees of abduction. EMG signals were filtered, rectified and enveloped in MATLAB to assess differences between the indwelling and surface electrode amplitude and timing.

Results: Intramuscular electromyography demonstrated a greater amplitude compared to surface electromyography predominantly due to the penetration of the sensor into the muscle tissue. Muscle activation patterns were similar between the two electrodes with the peak amplitude occurring at approximately the same time frame.

Conclusion: Indwelling fine wire EMG sensors provide more specific and localized measurement of muscle activity. These electrodes are ideal for investigating the deeper muscles of the rotator cuff without distortion from the activity of the trapezoid or deltoid muscles often seen when using surface electrodes. Further investigation is necessary to determine if a proportional relationship exists between the two signals and whether signals from one type of electrode can be reliably scaled to the other electrode signal using a fixed multiplication factor. The results demonstrate the potential of indwelling electrodes for muscle rehabilitation, training, and performance analysis. However, the fine wire sensor's invasive nature requires a trained professional and a detailed protocol to ensure accurate readings. Future research should aim to standardize data collection protocols and safety procedures for intramuscular EMG to enhance reproducibility and promote clinical adoption.

Primary afferent depolarization and hyperreflexia in cerebral palsy (P2-43)

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Background: Cerebral palsy (CP) is the most common cause of physical disability in children and results from various perinatal insults. Spastic CP, the most prevalent form, is associated with motor dysfunction such as hypertonia and hyperreflexia. These features are traditionally attributed to corticospinal tract (CST) damage leading to disinhibition of spinal motoneurons; however, the specific spinal mechanisms underlying this disinhibition have not been directly tested. In the spinal cord, primary afferent depolarization (PAD) is a form of presynaptic modulation mediated by GABAergic interneurons (GABApre) that receive convergent input from both CST axons and peptidergic nociceptors and effectively control spike conduction of Ia afferents at axonal branch points. How this circuitry is altered following perinatal injury is not well understood, but the circuit is poised to impact Ia afferent spike conduction, or in other words reflex irradiation.

Objective: We hypothesize that in CP, CST injury leads to expansion of nociceptive input onto GABApre neurons, resulting in increased Ia afferent spike conduction and reflex irradiation, contributing to hyperreflexia.

Methods: Prenatal hypoxia-ischemia (HI) was induced in pregnant New Zealand White rabbits near term (70-80% gestation) by occluding the uterine arteries with a Fogarty balloon catheter for 40 minutes under anesthesia. Sham animals received anesthesia without HI. Electrophysiological recordings were performed in midsagittal hemisected spinal cords from neonatal rabbits (postnatal days 1–5) of both sexes. Dorsal root potentials (DRPs) and monosynaptic reflexes (MSRs) were evoked by stimulation of dorsal roots. Multiple dorsal and ventral roots were recorded simultaneously to assess the extent of reflex irradiation.

Results: HI animals exhibited enhanced intersegmental spread of DRPs and increased MSR irradiation in response to low-threshold stimuli compared to sham, indicating hyperexcitability of spinal circuits. These preliminary findings suggest that perinatal HI injury results in aberrant sensorimotor integration within the spinal cord.

Conclusion: Our findings highlight maladaptive spinal plasticity as a contributing factor to hyperreflexia in CP. These results underscore the importance of investigating spinal mechanisms and suggest that targeting spinal circuits could offer novel therapeutic strategies to mitigate motor impairments in CP.

A virtual representation of the fear of falling – pilot study (P2-47)

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Background: One of the early indicators of postural control issues is the presence of a fear of falling. Unfortunately, all current measures of this phenomenon are based on qualitative and subjective data. It is crucial to assess postural control in the presence of an actual postural threat. This goal can be achieved through the use of virtual reality (VR), in which postural threat is simulated as if it were real.

Objective: The primary aim of the study was to induce a postural threat through VR and examine the resulting changes in postural control.

Methods: Twenty elderly subjects (10 females and 10 males) participated in this study (age > 60 years). The testing procedures involved force plate measurements (Limit of Stability test – LOS test) in a VR environment using HTC Vive Pro goggles. The virtual scenarios were designed to simulate standing at different heights. In the first scenario, participants stood at ground level in the laboratory. The second scenario simulated standing at a height of one meter. The final, extreme scenario simulated standing on top of a skyscraper. The LOS test consisted of three distinct phases. The first phase involved quiet standing (QS) for 10 seconds. In the second phase, after an auditory signal, subjects leaned forward as quickly and as far as possible. The third phase required subjects to maintain the inclined position until the test ended. Repeated measures ANOVA was used to compare the velocity of leaning (B2), the range of maximum forward lean (R1), and sample entropy (SampEn) between different levels of postural threat.

Results: In the second phase of the LOS test, there were significant differences in the mean value of B2 between the GROUND (7.13 ± 5.7) and EXTREME (4.5 ± 2.27) conditions ($F = 5.43$, $\eta p^2 = 0.22$, $p < 0.01$). Additionally, subjects exhibited significantly higher R1 values in the GROUND (5.56 ± 1.24 cm), HIGH (5.51 ± 1.4 cm), and EXTREME (4.88 ± 1.61 cm) conditions ($F = 5.64$, $\eta p^2 = 0.23$, $p < 0.01$). In the first phase of the LOS test, which corresponded to QS before the leaning movement, significant differences in SampEn in the AP plane were observed between the GROUND (0.09 ± 0.03), HIGH (0.10 ± 0.03 cm), and EXTREME (0.13 ± 0.06) conditions ($F = 6.55$, $\eta p^2 = 0.26$, $p < 0.01$). In the third phase of the LOS test, which corresponded to standing at the stability boundary, subjects exhibited higher SampEn values during the EXTREME (0.17 ± 0.03) condition compared to the GROUND (0.13 ± 0.05) condition ($F = 4.29$, $\eta p^2 = 0.18$, $p < 0.01$).

Conclusion: Through VR, we can safely introduce postural threat situations. Scenarios simulating standing at different heights led to changes in participants' postural control. This approach opens new possibilities for a more objective and quantitative assessment of the fear of falling. Funding: RID/SP/0053/2024/01.

Kinematic Data Gathered via OpenPose and Machine Learning Classifier for Distinguishing Between Normal Gait and Toe-Walking: A Pilot Study (P1-32)

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Background: Autism Spectrum Disorder (ASD) is one of the clinical conditions where altered gait patterns, such as toe walking (TW), are present, and it affects approximately 20%-30% of individuals. The quantification of TW has the potential to provide valuable insights into gait abnormalities and inform targeted interventions. A recently proposed video-based coding protocol enables TW quantification in natural settings, but it requires manual video review by an operator. However, a markerless gait analysis system (MGAS) could address the challenges of non-acceptance in individuals with ASD and intellectual disabilities, enabling automated kinematic analysis and the detection of uncommon gait patterns, such as TW, with minimal operator involvement during data processing.

Objective: This study aimed to develop a novel method for detecting TW using the OpenPose module.

Methods: The present study involved 15 subjects with neurotypical development (mean age 10.3 ± 3.1 years; age range: 6.5–16.1 years; 6 males) who simulated TW. All participants were administered a validated video-based coding protocol using standardised video recordings to quantify toe-walking. The test consisted of transporting an object (e.g.,Lego®) from a physiotherapist to a playing table located 3 meters away and back again 10 times. All tests were conducted without shoes, with socks. Sagittal-plane video recordings of the walking trials were collected for each participant. Skeletons were extracted in the sagittal plane via the OpenPose module, and gait kinematics were computed. The TWIST algorithm was applied to identify the most significant features and create two balanced subsets to optimize training of various machine learning algorithms. These selected features then trained supervised neural networks (NNs), which were evaluated for accuracy, sensitivity, specificity, and area under the curve (AUC).

Results: A total of 1,793 steps, including 825 tip-toe gait samples, were used to train four neural network classifiers based on 14 selected features. These included three biomechanical dimensions: spatial (n=2; vertical distances between the malleolus and toes), angular (n=11; joint angles and range of motion at the hip, knee, and ankle, plus toe-off alignment angles), and temporal (n=1; stance phase duration) features. Performance was evaluated using leave-one-out cross-validation, repeated 19 times. The Support Vector Machine (SVM) classifier achieved the best performance, with an accuracy of 89.8%, sensitivity of 94.8%, specificity of 95.1%, and an AUC of 0.944. K-Nearest Neighbors (KNN) showed comparable results, with 89.4% accuracy, 93.0% sensitivity, 96.4% specificity, and an AUC of 0.935. The Bayesian classifier followed with 84.9% accuracy, 88.6% sensitivity, 96.3% specificity, and an AUC of 0.932. Random Forest (RF) yielded the lowest performance, with 54.6% accuracy, 57.3% sensitivity, 97.3% specificity, and an AUC of 0.598.

Conclusion: The proposed method offers the potential for automated detection and quantification of toe walking in standardised protocols and settings. This approach provides detailed kinematic data using a fully non-intrusive method, not requiring the patient's instrumentation. The following research steps will be dedicated to studying a larger group of subjects to further validate the findings of this preliminary study and in other populations.

Contributions of the vestibular system to the stance phase of gait during downhill walking (P2-60)

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Background: Recently it has been shown that adding downhill gait training to a rehabilitation program following spinal cord injury (SCI) leads to improvements in gait. In our lab preliminary findings indicate that these improvements are most striking in the stance phase of gait, particularly during yield when weight is shifted onto one leg as the other leaves contact with the ground. This period of gait is important as it is often difficult to target during rehabilitation due to the complex biomechanical demands and neural control required. Walking downhill increases the biomechanical demands on the stance leg resulting in a more pronounced knee and ankle flexion during yield. Though the biomechanical requirements of downhill walking have been detailed, the underlying neural mechanisms that drive these changes are still unknown. There is indirect evidence that sensory information from neck proprioceptors and the vestibular organs provide inputs to the central nervous system that facilitate the biomechanical changes observed during downhill walking but the degree to which each of these contributes remains undetermined. Here we present our findings on the role of vestibular inputs on hindlimb biomechanics during level and downhill walking. Understanding the neural components that control the hindlimb during downhill walking will provide valuable information to guide the development of rehabilitative interventions that specifically target this phase of gait to improve functional outcomes for individuals with SCI and other neurological diagnoses.
Objective: Investigate the contributions of the vestibular system on the biomechanics of walking on level and downhill surfaces particularly during the stance phase of gait.
Methods: Adult, female Wistar rats (n=6) were trained to walk overground (OG) on level and declined surfaces (up to -20°). Following kinematic data collection using the Vicon 3D motion capture system on these tasks to establish baseline measures, animals received bilateral intratympanic injections of gentamicin (GENT), an ototoxic drug that destroys vestibular hair cells. After receiving GENT, kinematic data was collected again on the same tasks at two and seven days post-injection and then weekly for three weeks.
Results: We found that prior to GENT injections there was greater yield in the ankle during stance when walking on -20° compared to 0° OG. Following bilateral GENT injections there was significantly greater yield at the ankle on -20° compared to 0° OG by day 7 post-injection. Ankle yield on -20° was also significantly greater at day 7 when compared to ankle yield on -20° OG prior to GENT. By 3 weeks post-injection this significant change in yield was less apparent as the rats developed compensatory mechanisms to overcome the loss of vestibular inputs.
Conclusion: We conclude that vestibular inputs are an important component of the neural control of walking downhill and that disruption of vestibular information leads to altered stance biomechanics with greater ankle yield which can lead to gait instability in stance.

Kinematic adaptation to expected sensory feedback in single- and double-tap actions (P1-03)

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Background: Motor 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 feedback actively shapes the kinetics of motor execution. For example, the force profile of a simple act of pressing a button is different depending on whether it is expected to trigger a sound or not, and comparison of force profiles shows that participants apply less force when the action is associated with an auditory outcome. Nevertheless, what attributes of action outcome are embedded in action kinetics and how, is not well understood.
Objective: In the current study, we set to characterize how expected attributes of stimulus outcome (intensity) shape the kinetics of the triggering action (applied force), even when action kinetics have no causal effect on this attribute. Specifically, (1) whether the amplitude of expected stimulus outcome modulates action kinetics; (2) whether such modulations are related to foreknowledge (prediction) of the outcome stimulus amplitude; and (3) whether such force modulations permeate to kinetics of early actions embedded in an action sequence.
Methods: We used a force-sensitive plate to measure the force profiles of right index finger taps while the contingency between finger-presses and auditory outcome (300ms, 1kHz pure tone at either 73 or 23 dB SPL) was manipulated.
Results: Healthy, young participants (N = 24) tapped to trigger an auditory sound of either high or low amplitude across experimental conditions. Results show an inverse relationship such that when outcome amplitude is known in advance, participants applied more force when the expected intensity of the outcome was low (vs. high intensity outcome). However, when sound amplitude could not be predicted, no modulation of applied force was found. In another group of participants (N = 24) we further show that flipping the causal order between action and sound abolishes force differences related to sound amplitudes. In other words, when participants tap in response to high/low amplitude sounds (instead of generating them), they applied similar force levels. The results of these studies show that predicted attributes of stimulus outcome are embedded in action kinetics. We also examined whether such predictions affect the kinetics of early actions within an action sequence. To this end, participants (N = 40) performed single or double taps which generated (or not) a sound immediately following the last tap in the sequence. Sound-dependent force modulations were seen also 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. Thus, even though the first tap is temporally and causally separate from the actual sound event, it is still affected by expected future outcome.
Conclusion: Taken together, our results demonstrate that prediction of future action-outcome attributes shapes action kinetics in early stages of movement. We are now examining this in bimanual actions.

Galvanic vestibular stimulation modulates upper and lower limb spinal reflexes: comparison between wrist and ankle a muscles (P2-57)

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Background: Vestibular pathways project to various levels of the spinal cord and significantly influence motoneuron activity, primarily contributing to postural control, balance, and coordination of head and eye movements. While these pathways have been extensively studied about lower limb function, their effects on upper limb motoneuron pools remain incompletely characterized. Galvanic vestibular stimulation (GVS) provides a non-invasive method to activate vestibular afferents, offering an opportunity to investigate vestibulospinal influences across different spinal segments.

Objective: This study aimed to investigate the effects of galvanic vestibular stimulation (GVS) on spinal excitability in the flexor carpi radialis (FCR) muscle of healthy adults, comparing these effects with those in the soleus (SOL) muscle. We hypothesized that cathodal GVS would facilitate H-reflex amplitude in both muscles, with larger effects expected in the lower limb.

Methods: Eight healthy volunteers (7 male, aged 24-34 years) participated in this study. H-reflex recruitment curves were recorded to identify optimal stimulus intensities. The protocol included 20 control trials at 50% H-max intensity followed by 20 trials with cathodal GVS (200-ms duration with 100ms interstimulus interval with H-reflex). Recruitment curve parameters (H-reflex threshold currents, H-max, and slope) were analyzed. Paired comparisons between control and GVS conditions were tested using t-tests or Wilcoxon signed-rank tests.

Results: Cathodal GVS significantly facilitated H-reflex amplitude in both FCR and SOL muscles ($p=0.0225$ and $p=0.0482$, respectively), with comparable facilitation observed between upper and lower limb muscles, contrary to our hypothesis of greater lower limb effects. Recruitment curve analysis revealed a significantly increased slope during GVS stimulation. No significant differences were found in H-max values. Threshold currents decreased significantly during GVS, particularly in the SOL muscle (mean change: -14.3%, $p=0.0282$), suggesting preferential effects on smaller motoneurons.

Conclusion: Our research challenges the traditional understanding of vestibulospinal pathways by demonstrating that their influence extends throughout the spinal cord, with comparable facilitation observed in FCR and SOL. The significant decrease in threshold current, especially in SOL, suggests vestibulospinal inputs may preferentially affect smaller motoneurons, reflecting altered post-synaptic excitability and modulation of inhibitory mechanisms. The pattern of widespread facilitation across functionally distinct muscles provides compelling evidence for vestibulospinal pathways' role in coordinating movements across multiple body segments, with potential implications for rehabilitation strategies in patients with motor impairments.

Building a normative dataset of infant leg movements using wearable sensors (P2-46)

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Background: Spontaneous leg movement patterns change across infancy, providing key insights into early motor development and likely reflect changes in central and peripheral nervous system development. Traditional assessments, although informative, are limited. Observational methods are episodic and limited by subjectivity, training needs, and lack of quantification of movement dynamics. Advances in wearable sensor technology offer a continuous, objective way to capture detailed quantitative movement characteristics such as frequency, amplitude, and patterns in spontaneous infant leg movements across days. This study uses wearable sensors (accelerometers and gyroscopes) to collect days data, offering a precise, quantitative approach to tracking motor behaviors that may indicate neurodevelopmental trajectories. This method could enhance early detection of atypical development, impacting pediatric care and developmental research by aiding in the creation of early intervention strategies.

Objective: Our objective is to develop a normative dataset of infant leg movement characteristics.

Methods: Observational data are being collected from 7000 infants, recruited from 27 research sites, as part of the HEALthy Brain and Child Development (HBCD) study. Infants will wear a wearable sensor on each ankle for 72 continuous hours, secured in legwarmers. Caregivers will be instructed to continue their typical daily activities with the infants in a natural setting. We will use a validated threshold-based algorithm to identify and quantify each leg movement, capturing its duration, peak acceleration, and average acceleration. The algorithm also estimates sleep time, physical activity intensity, and calculates an hourly leg movement rate for awake periods. Finally, we will calculate sample entropy of the movement acceleration time-series, measuring the variability among the acceleration values. We will analyze data from the first public data release of HBCD data (originally planned for January 2025 - postponed) to provide descriptive data from the leg movements of infants collected at visit 2 (ages 0-1 month).

Results: Based on our group's previous small sample study, we estimate the sample median leg movement rate to be 1,200 movements/hour awake with an interquartile range (IQR) of 300 movements/hour awake. The sample medians for peak and average acceleration per leg movement are expected to be 2.6 m/s^2 (IQR: 0.3) and 1.3 m/s^2 (0.15), respectively. The median movement duration is projected to be 0.4 seconds (IQR: 0.04).
Regarding physical activity intensity, we expect that approximately half of the recording period will be classified as sedentary. Of the remaining time, two-thirds is anticipated to be light activity, with the rest categorized as moderate-to-vigorous (MV) activity. Sample entropy values depend on the choice of parameters, but we expect the sample median to fall within the range of 1.25 and 1.5.

Conclusion: Our findings will provide an unprecedented normative dataset of infant movement patterns and physical activity levels based on 72 continuous hours of wearable sensor recordings collected across the United States. This dataset will serve as a benchmark for understanding typical physical motor activity in early infancy. Future analyses will explore associations between movement characteristics and concurrent measures from the

HBCD study, including brain development, cognitive function, and language skills. These insights may contribute to early identification of neurodevelopmental differences and inform early intervention strategies.

Activity of V3 neurons in swing and stance phases of fictive locomotion and in fictive scratching (P1-17)

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Background: Coordinated rhythmic movement of the limbs during locomotion is primarily controlled by the central pattern generators (CPGs) within the spinal cord. Sim1-expressing V3 neurons are part of the CPGs and are classified into subpopulations based on electrophysiological and spatial distribution properties. Research indicates that silencing V3 neurons impairs high-speed locomotion in mice, disrupts interlimb coordination, and alters homolateral and diagonal phase relationships between fore- and hindlimbs at low and medium speeds.
Objective: In this study, we aim to define the phase of the locomotion cycle during which V3 neurons are active, if the different subpopulations of V3 neurons are active at different times, and if the neurons are also active in unilateral movements like scratching. We hypothesize that V3 neurons will be primarily active during the stance phase of locomotion, as preliminary mouse studies indicated that brief optogenetic activation of these neurons induced coordinated bilateral standing. Based on this, we also hypothesize that V3 neurons are minimally active in fictive scratching, given that scratching is a flexor-dominant and unilateral behavior that likely does not require the bilateral coordination mediated by V3 neurons.
Methods: To study this, we will perform fictive locomotion and fictive scratching experiments in adult mice and the electrical activity of a large number of spinal neurons will be recorded using Neuropixels electrodes. Data acquired will be processed with Kilosort and interpreted using Python.
Results: Electroneurogram recordings of the triceps and deep peroneal nerves will be used to identify the different phases of the locomotor pattern and to construct polar plots of the neuronal activity. V3 neurons will be identified using optotagging in Sim1-cre::ChrimsonR mice. ChrimsonR is a channelrhodopsin activated by red light and will be specifically expressed in V3 neurons, allowing us to identify these neurons in our recordings by their time-locked response to pulses of light applied to the spinal cord.
Conclusion: This work will deepen our understanding of the role of V3 interneurons in the spinal cord, which has important implications for disorders affecting spinal networks, such as spinal cord injury.

The comparison of lower extremity muscle activation and kinematics during lunging and step negotiation between those with and without total knee arthroplasty (P2-56)

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Background: Over 700,000 total knee arthroplasty (TKA) surgeries are performed yearly in the U.S. 20% of people with TKA have persistent pain and impaired function. The forward lunge, step up, and step down are commonly used clinical tests to evaluate function. Research on how lower extremity electromyography (EMG) and knee kinematics differ during lunging, step up, and step down between adults with and without TKA is limited.

Objective: To compare lower extremity EMG and knee joint kinematics during three functional tasks between adults with TKA and without TKA (control group). We hypothesized that individuals with TKA would exhibit significantly lower EMG activity in the lower extremity muscles and significantly reduced peak knee flexion compared to the Control group across all tasks.

Methods: Thirty adults, 60-80 years old participated in the study, including 13 individuals 6-36 months post-total knee arthroplasty (TKA) and 17 healthy controls. After providing informed consent, participants underwent assessment of demographics, anthropometrics, knee flexion passive range of motion (PROM). Surface EMG sensors were placed bilaterally on the vastus lateralis (VL), vastus medialis (VM), semitendinosus (ST), and biceps femoris (BF) following SENIAM guidelines. Integrated EMG (iEMG) was calculated for group comparisons. Four inertial measurement units (IMUs) were placed bilaterally on the midthigh and calf. Participants completed one familiarization trial and four repetitions of each functional task (lunge, step-up, and step-down), leading twice with the surgical/non-dominant leg and twice with the contralateral leg. Lunge distance and step height were standardized to individual leg length. Group differences were analyzed using independent t-tests with alpha set at 0.05.

Results: There were no significant differences in age, height, weight, or gender between the TKA and control groups. As hypothesized, the TKA group demonstrated significantly reduced peak knee flexion across all three functional tasks: step-up (80° vs. 95°), step-down (48° vs. 58°), and lunge (68° vs. 90°), with all p's < 0.001. Consistent with these findings, iEMG revealed greater VL activation in the control group during the step-up ($p = 0.006$) and lunge ($p = 0.01$) tasks. However, contrary to expectations, the TKA group exhibited significantly higher muscle activation in the step-down task for the BF, $p < 0.001$; ST, $p = 0.003$, and VM, $p < 0.001$, suggesting possible compensatory recruitment strategies during descent.

Conclusion: In conclusion, individuals with TKA demonstrated reduced peak knee flexion and altered muscle activation patterns during functional tasks, with lower VL activation in ascent tasks and unexpectedly higher hamstring and VM activation during descent. These findings suggest compensatory neuromuscular strategies that may impact movement efficiency and rehabilitation focus in individuals with 6-36 months of TKA.

Effects of the different types of fatigue on muscle synergies (P1-23)

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Background: The notion of muscle synergies is widely recognized as one of the key concepts in contemporary motor control research. It suggests that the central nervous system controls not the coordinated activity of singular muscles but their specific sets to facilitate efficient and precise movement. Despite of novelty of technologies and research methods, this process remains only partially understood, with numerous gaps in our knowledge, especially regarding the role of fatigue factor. How are people able to maintain fine motor control over extended time? It is still not fully understood how does a driver maintain precise control of a vehicle after long hours ride, how does watchmaker handle tiny components with excellent precision and why does the performance of line workers remain consistent despite prolonged muscle work?
Objective: To explore presented problem, our study aims to identify muscle synergies that emerge in the upper limbs in a bilateral force production task in the elbow joints. We planned to evaluate the changes in muscle synergies following different types of fatigue. By analyzing these synergies, we would like to seek to deeper understanding of how the nervous system adapts to fatigue and maintains quality of movement performance.
Methods: Thirteen adult men participated in the study, undergoing two types of fatigue. Their fatiguing task was based on bilateral force production at the intensity of 85% of maximal voluntary force as long as possible and performing repeated arm flexion exercise with a barbell loaded to 85% of their maximum load. We recorded kinetic (upper limb forces) and bioelectric variables (muscle activity) from five muscles within each upper extremity: the biceps brachii, brachialis, brachioradialis, flexor carpi radialis and flexor carpi ulnaris. To extract muscle synergies, we performed two well-established methods widely used in the literature: Principal Component Analysis and Nonnegative Matrix Factorization algorithms.
Results: Despite experiencing fatigue, all participants successfully completed the bilateral force production task as intended. Regardless of the method used to extraction muscle synergies, two of them were identified with explanation of more than ninety percent of emerged variability in our data. Furthermore, the type of the fatigue didn't affect the identified number of muscle synergies. However, we were not interested only in the number of muscle synergies but also in the contribution of each muscle's into specific synergy. At this level of analysis, we reported a different structure of synergies in relation to the specific fatigue protocol.
Conclusion: Obtained results contradict our basic hypothesis, that dynamic type of fatigue will cause extraction of more muscle synergies than in static protocol of fatigue. As an additional aspect, our project seems to show whether one of the synergy extraction methods could be more effective for assessing the fatigue aspect in motor control research.

Age-related characteristics of unintentional force drift: a pilot study (P2-51)

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Background: The aging process is one of the most significant factors affecting movement control. Do adolescents, adults, and older individuals control the movement execution and force production in the same manner? Consider how a child applies toothpaste to a toothbrush, how an adult navigates skiing in foggy conditions, or how an older person adapts when transitioning from a brightly lit room to a darker environment. The observed variability in their motor behavior may have its origin from differences in sensory processing, motor learning, or neuromuscular function. One of the well-known phenomenon in the field of motor control, particularly related to force production and perception, is unintentional force drift. This refers to the involuntary decline in force output during sustained muscle contractions when visual feedback is removed—potentially reaching reductions of up to 30%. Current research on unintentional force drift largely focuses on activities involving the upper limbs, particularly fingers or toes.

Objective: However, it remains unclear how the use of larger body segments, such as arms or forearms, may influence the characteristics of this involuntary drop in force output. Furthermore, existing studies have almost exclusively examined adult populations, leaving a gap in understanding how this phenomenon manifest across the lifespan. How does unintentional force drift differ between younger and older individuals? In light of these gaps, the present pilot study aims to characterize unintentional force drift across different age.

Methods: Participants were asked to perform isometric force production tasks by using their elbow flexors in both upper limbs. The experimental protocol consisted of several tasks, designed to assess different aspects of force production: 1) First, maximal voluntary force of the bilateral elbow flexion was performed, 2) Second, participants were instructed to produce and maintain force at the intensity of the 20% of their maximum magnitude for 25 seconds in six consecutive trials, using both limbs simultaneously, 3) Third, participants executed a matching task, where one limb match the perceived level of force from other one. Each of them was performed under two conditions: with and without visual feedback about actual magnitude of produced force in real time. All measurements were obtained using a dynamometer equipped with two linear force sensors, allowing for independent assessment of generated force from each upper limb. Participants performed all the tasks in isometric condition in seated position, with their arms supported on a dedicated gym bench.

Conclusion: We hypothesized that individuals from different age would exhibit distinct characteristics and varying levels of accuracy in force production tasks. Findings from this pilot study may contribute in the future to the development of age-specific rehabilitation protocols and in the high-performance environments such us competitive sports.

Force-stabilizing synergies at the neural control level: a comparison of Parkinson's disease and essential tremor (P1-05)

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Background: Parkinson's disease (PD) and essential tremor (ET) both affect motor coordination. ET primarily involves postural and kinetic tremor in the upper limb, whereas PD tremor is mainly postural and resting, lacking a kinetic component. Previous studies have examined impaired action stability in PD, but the synergic control of multi-finger forces in ET remains unexplored. We investigated force-stabilizing synergies in PD and ET in spaces of neural control variables based on spatial referent coordinates (RCs), where the R-command regulates RCs for the effectors (fingers), and the C-command (k) modulates the system's apparent stiffness.
Objective: To examine synergies at the level of neural control variables level and examine finger forces matching in individuals with PD, ET, and healthy age-matched controls (AMC).
Methods: Participants [13 PD (Hoehn & Yahr stages I–II) on PD medication; 11 with ET; thirteen AMC] performed a two-fingers (index and middle) pressing task. Participants pressed sensors with their task hand (right or left) to move a cursor to a target set at 10% of their maximal two-fingers force. This was first completed with task hand, and then participants matched the force with the opposite hand. After 10 s, the force sensors were lifted by 1 cm over 0.5 s while participants were instructed not to react to any force changes. We calculated the intercept and slope of the force-coordinate linear regression (RC and k, respectively) in each trial, and R^2 coefficients from hyperbolic regression analysis of {RC; k} pairs across trials to assess the covariation of {RC; k} along the solution space. Differences in RC (ΔRC), k (Δk), and total force (ΔF) between the task and matching hands were analyzed. Statistical comparisons (ANOVA) were conducted to assess group differences.
Results: The matching condition impacted the task performance across both hands (LH and RH) for all groups. All participants tended to overshoot the force by a similar magnitudes, (≈ 5% MVC). This was associated with larger absolute RC magnitudes in the ET group compared to AMC when the LH was the task hand. PD values were between ET and AMC without significant differences from either group. No group differences were observed for k values in both task and match hands. The index of force-stabilizing synergy (z-transformed R^2 for the hyperbolic regression in the {RC; k} space) was smaller in the ET group compared to AMC ($p < 0.01$) for both LH and RH tasks. PD values were intermediate, without significant differences from either groups. The matching hands showed significantly smaller z-transformed R^2 values across all groups, with no group differences.
Conclusion: ET participants exhibit impaired force-stabilizing synergies at the neural control level, particularly when performing with the left hand. PD-related deficits appear more subtle, possibly due to medication effects, especially in the early stages. These results provide insights into the neurological mechanisms underpinning ET and PD, shedding light on how these disorders affect neural control of force and motor coordination. Tailored interventions based on distinct needs will be crucial for improving motor function.

Motor unit development in a rabbit model of cerebral palsy (P2-37)

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Background: Cerebral palsy (CP) is the most common motor disability in children, occurring in 1:500 live births. The mechanisms through which CP-causative injuries like hypoxia-ischemia (HI) cause motor deficits remain unresolved. Motor unit development occurs in the perinatal period when CP-causative injuries occur, and depends on motoneuron activity, which is increased in the HI rabbit model of CP.
Objective: We hypothesize that prenatal HI injury dysregulates neuromuscular junction maturation and disrupts motor unit development.
Methods: To test our hypothesis, we are using immunofluorescence to track the emergence of mono-innervation at the neuromuscular junction, an anatomical hallmark of maturity. This process is driven by the developmental switch from synchronous to asynchronous motoneuron activity. We are therefore analyzing the synchronicity of motor unit activity recorded in awake rabbits across neonatal development using Myomatrix array electrodes. In addition, we are using immunostaining to label type I, IIa, IIx, and IIb myofibers and are evaluating differences in fiber type distributions of sham-operated control and HI rabbit muscles in order to assess their force-generating capacity and fatigability.
Results: Our preliminary data suggests that neuromuscular junctions undergo delayed maturation in HI rabbit skeletal muscle and indicates that in the third postnatal week when poly-neuronal innervation is eliminated, HI muscle has a slower, weaker, and less fatigable fiber type profile than that of typically developing rabbits. This may reflect chronic, low frequency motor unit activity consistent with CP.
Conclusion: Overall, this work suggests aberrant motor unit development after prenatal HI injury contributes to motor dysfunction in the rabbit model of CP.

The Dynamic Assessment of Sensorimotor Health (DASH): Preliminary Results from A Virtual Reality Behavioral Testing Platform (P2-44)

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Background: Sensorimotor control supports sustained healthy function across the lifespan. Nearly all activities of daily life require effective coordination of body movements guided by complex multisensory information. Emerging research methodologies highlight the importance of ecologically valid tasks and nuanced time series data analysis for characterizing healthy and pathological sensorimotor control. Advanced tools and techniques, such as 3D motion capture, virtual reality (VR) immersion, and non-linear time series analysis, are often not considered for clinical workflows due to the time investment required or a lack of access to technology or analytical expertise. Further, many researchers aiming to characterize sensorimotor mechanisms and dynamic behavioral patterns are resource limited and would benefit from a pre-built, customizable software tool to facilitate such work. For this purpose, we have developed the Dynamic Assessment of Sensorimotor Health (DASH). This VR application captures and processes movement data across a growing library of standardized sensorimotor tasks, allowing for customizable audiovisual manipulations and synchronization with external sensors (e.g. EEG, EMG, or IMU).

Objective: Large scale testing was performed to assess DASH’s ability to discriminate groups based on underlying health related factors, like their history of concussion. Specifically, we hypothesized that those who have previously received a clinically diagnosed concussion would exhibit altered sensorimotor control pattens.

Methods: Large-scale group testing was conducted with a cohort of 298 students (53% female; age, M = 15.30 y, SD = 1.14; height, M = 66.35 in, SD = 4.11; weight, M = 146.65 lb, SD = 37.19) across four area high schools over multiple testing days. The testing protocol consisted of VR-based trail making, sound localization, reaction time, smooth pursuit (eye tracking), single-leg balance, and tandem gait tasks. During the single-leg balance task, two conditions were presented. One condition manipulated optic flow by adjusting the head movement gain, while the other condition maintained canonical optical parameters. For all tasks, positional and rotational measurements of head movement were recorded using the Meta Quest Pro’s internal sensors at a rate of 72 Hz. All participants also completed demographic and health status questionnaires, including a survey of their history of concussions. Preliminary analyses were performed to determine if performance of the DASH single-leg balance task could differentiate those who had indicated a history of concussion from those who did not.

Results: ANCOVA analyses revealed significant differences in single leg balance performance, controlling for task condition, between participants with and without a clinical concussion history for sample entropy (anteroposterior direction; $F[1,595] = 3.89$, $p = .049$) and detrended fluctuation analysis (mediolateral direction;

$F[1,595] = 6.35$, $p = .012$). Participants with a history of concussion had higher sample entropy values (less regular postural sway) and lower DFA exponents (weaker long-range temporal correlation).

Conclusion: These results indicate that the DASH system is promising for differentiating injury-specific (e.g., concussion history) sensorimotor control processes (i.e., visually manipulated postural control) in a portable and easy-to-administer form factor. Future analyses using the DASH protocol should aim to expand to include analyses from all tasks, along with an expanded set of outcome metrics.

Contribution of postural-respiratory synergy dysfunction to postural control deficits in adults with chronic obstructive pulmonary disorder (P2-41)

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Background: Adults with chronic obstructive pulmonary disease (COPD) have greater postural sway and a greater risk of falling than adults without COPD. Many COPD patients' long-term corticosteroid use increases their risk of osteoporosis and thus of fall-related fractures. While many factors likely lead to balance deficits in COPD, one may be that individuals with COPD cannot compensate for balance perturbations resulting from altered ventilatory mechanics arising from COPD. Typically, the *postural-respiratory synergy* prevents ventilation from substantially impacting balance by offsetting ventilatory movements via counter-rotations about (primarily) the lower-extremity joints. Altered ventilation due to COPD may disrupt this compensatory mechanism.

Objective: To characterize postural control and postural-respiratory synergy function in adults with COPD compared to young adult and age-matched controls without COPD.

Methods: Fourteen adults (63.8 ± 8.9 yrs old) diagnosed with COPD (recruited from a university medical center pulmonology clinic), 14 adults (59.9 ± 7.3 yrs) without COPD, and 21 young adults (21.1 ± 0.94 yrs) without COPD participated in this IRB-approved study. Participants were free of neurological or musculoskeletal conditions impacting balance, and controls were non-smokers without asthma, COPD, or other pulmonary conditions. Postural center of pressure (COP) data, 3D movement kinematics, and respiratory amplitude data were respectively collected using two AMTI force platforms, an 18-camera Qualisys Arqus A5 motion capture system tracking 17 retro-reflective markers on the body, and Biopac respiratory inductance plethysmography belts worn at the abdominal and thoracic levels. After completing demographic and medical questionnaires each participant's spontaneous respiratory rate was measured while standing. Participants then performed eight one-minute trials involving standing with feet shoulder width apart (each foot on a separate force platform) while fixating an anterior visual target. On half the trials participants were instructed to breathe normally (spontaneous condition) while on the other half (paced condition) their breathing was paced by an auditory metronome set to 120% of their spontaneous rate. Condition order was randomized.

Results: Mixed-design 2 × 3 (respiratory task × group) ANOVA revealed a significant group effect on COP path length ($p < .05$) with Bonferroni-corrected post-hoc tests revealing significantly greater path length for COPD patients compared to young and old controls (both $p < .0167$), who did not differ significantly from each other. No significant effect of breathing task (spontaneous vs. paced) was found for COP path length. Preliminary cross-spectral coherence analysis results indicated that the respiratory frequency dominated the COP signals of patients but not controls.

Conclusion: The results provide preliminary evidence of compromised postural-respiratory synergy functioning in adults with COPD. This result points toward a potential strategy for reducing fall risk in adults with COPD by training them to compensate for how their altered ventilatory mechanics impact balance. Yoga, by virtue of focusing on both breathing and balance, could be a fruitful type of balance training intervention for individuals with COPD.

Anticipatory Postural Adjustments for Voluntary Arm Movements in Children with ASD (P2-55)

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Background: While difficulties in voluntary movements, such as catching a ball, are common in individuals diagnosed with autism spectrum disorder (ASD), they remain excluded from the DSM-5 diagnostic criteria. Coordinated movements rely on a forward model that predicts sensory outcomes of actions and updates based on sensory feedback. Such sensorimotor integration is critical for compensating for perturbations, even when they result from one's own actions. A hypothesis with increasing support suggests that *differences in predictive abilities* may underpin the spectrum of atypicalities of the autism phenotype, including motor control challenges.
Objective: This study investigated anticipatory postural adjustments (APAs) required for maintaining postural balance while raising one's arms above the head, comparing autistic and non-autistic (allistic) children. Voluntary arm movements generate shifts in the center of mass, requiring an anticipatory shift toward the opposite direction to prevent loss of balance. According to previous studies in allistic adults, APAs activate before significant upper-limb action to maintain postural stability. To test if predictive impairments exist in autistic children, we hypothesized that APAs should be reduced or absent in autistic individuals.
Methods: We recruited 22 allistic and 14 autistic children (minimum non-verbal IQ: 86) aged 7-13 years. Participants performed repeated arm raises in the sagittal plane, starting with their arms hanging loosely by their side and quickly lifting their arms to a vertical position above their head. We collected kinematic data, ground reaction forces, and muscle activity (EMG) from major muscle groups. This task requires adjustments in: 1) the center of pressure within one's base of support and 2) the activation of several trunk muscles required to compensate for postural instability.
Results: Using a triple-inverted-pendulum model, with shoulder, hip, and ankle joints and a triangular foot, we simulated the effects of self-generated arm raises on postural stability. Joint angle trajectories were fed into the model to obtain the corresponding center of pressure (CoP) profile without incorporating predictive adjustments prior to onset. The center of pressure profile from this simulation extended beyond the base of support, indicating postural instability in the absence of APAs.
Variability in the directionality of CoP velocity was quantified by computing Shannon entropy across 3 phases: preparation, early movement, late movement. The ASD group showed significantly greater variability during both preparation and late phases. This increased variability suggests decreased postural stability in autistic children. Experimental recordings of trunk, arm, and lower leg muscles revealed between group differences in muscle activation that persisted across trials and subjects: Most prominently, autistic children exhibited significantly later activation of the latissimus dorsi that were not explained by differences in movement speed.

Conclusion: This delayed activation of trunk muscles and increased variability in directionality of the CoP velocity in autistic children provides evidence for altered predictive motor control in autism. These findings support the hypothesis of differences in predictive abilities in autistic individuals.

Unifying reinforcement learning and feedback control to predict multi-timescale adaptation (P1-13)

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Background: Humans seamlessly adapt their movements to changing conditions, yet the underlying computational principles remain elusive, particularly how stability is maintained while improving task performance. We address this gap in understanding how different adaptation mechanisms are integrated across multiple timescales, i.e., from seconds to hours, by putting forward a novel theoretical framework that unifies reinforcement learning and feedback control.
Objective: The primary objective of this study is to develop and validate a theoretical framework and a formal computational model that unifies reinforcement learning with stabilizing feedback control to predict how humans adapt their locomotion across multiple timescales and diverse environments. The central hypothesis is that this unified model can predict multi-timescale phenomena including initial fast reactions, slower performance improvements, savings, and generalization.
Methods: A hierarchical computational model was developed combining feedback control, reinforcement learning, and memory, interfacing with a physics-based bipedal agent. The model consists of: (i) an inner-loop stabilizing feedback controller that maintains balance, reacting quickly to perturbations; (ii) an outer-loop reinforcement learner that gradually tunes the feedforward components of this controller to optimize performance objectives, primarily energy minimization with a minor cost for asymmetry, through exploration-driven policy gradient learning, and (iii) a memory module that stores and recalls learned control strategies, facilitating multi-timescale adaptation phenomena like savings. The model's ability to predict experimental phenomena was tested by comparing its outputs to findings from ten prior experimental studies and two prospective experiments involving split-belt treadmills, asymmetric loading, and exoskeletons.
Results: This unified model successfully predicted multi-timescale adaptation across various locomotor tasks. It replicated the fast initial responses due to the feedback controller, and subsequent slow performance transients due to the reinforcement learner. The critical role of the feedback controller in generating fast-timescale transients and stable exploration was demonstrated via simulated lesions. The memory component of the model accounted for faster de-adaptation, savings and generalization phenomena, consistent with prior experiments. The model makes testable predictions about adaptation in the presence of device noise and anterograde non-interference, which were confirmed by prospective experiments. Comparing to other hypothesized learning rules in the literature like minimization of sensory error, task error, or proprioceptive realignment did not predict the observed phenomena as well as this unified model.
Conclusion: This work demonstrates that unifying reinforcement learning and feedback control in a hierarchical framework provides a powerful computational basis for multi-timescale adaptation. The model captures how humans learn and refine walking patterns stably and efficiently across various conditions and timescales, from immediate reactive adjustments to long-term learned optimizations. A key contribution of this unified model lies in its ability to explain a wide array of behaviors including behavioral transients, performance transients, savings, and generalization. Such a predictive model of adaptation has implications for developing targeted rehabilitation strategies and more intuitive assistive devices by enabling design that is cognizant of the multiple learning processes that underlie motor performance in a novel environment.

Stability in emergent vs enforced motor patterns and its effect on time perception (P2-38)

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Background: The human capacity to perceive and process time may be acquired through movement. When exposed to an auditory rhythm, the coupling between auditory and motor processes enables time prediction, strengthened by practice, like playing a musical instrument. The link between auditory and motor timing has mainly been studied in the context of music production. Does the interaction between perceptual and motor timing also occur in activities that do not require explicitly timed actions? For example, when bouncing a ball, motor timing arises from complex neuromotor systems in concert with the dynamic properties of the object. Over time, stable spatiotemporal patterns emerge, which can be interpreted as the visible realization of ‘dynamic primitives’. Does time sensitivity increase with the emergence of stable patterns?

Objective: The overall hypothesis is that dynamically stable motor rhythms act as dynamic primitives that entrain time perception. More specifically, 1) practicing at one’s own pace leads to more stable timing patterns than practicing with an implicit timing enforcement. 2) More dynamically stable motor patterns lead to higher effects on time sensitivity close to these stable rhythms.

Methods: The experiment consisted of five practice sessions over five days in which 51 participants used a paddle to bounce a virtual ball shown on a screen (6 blocks of 5 trials, 30s, per day). 29 participants, the emergent group, bounced the ball at their own pace to allow emergence of a spontaneous stable pattern. Stability in the motor rhythm was indicated based on the paddle acceleration at ball impact (see earlier work Sternad et al., 2001). 22 participants, the enforced group, bounced the ball to reach a given target line turning green if the ball’s maximum amplitude was close enough to the target. This height specification enforced a 600ms bouncing period and, due to the success feedback, an error-correction strategy, rather than allow a stable pattern to emerge. Following this motor practice, participants were tested in a psychometric task, listening to a rhythmic tone sequence and identifying whether one of the intervals was shorter or longer than the others. Three standard intervals were tested, one corresponding to the bouncing period of the participant, the other two higher and lower than the motor-derived period, outside of the range of their bouncing period.

Results: In the motor task, acceleration at impact decreased over days and became negative from day 2 onwards, suggesting that participants developed stable motor patterns. The emergent group displayed a significantly lower acceleration at impact, leading to a more stable pattern. In the perception task, regardless of the group, Weber Fraction decreased significantly faster over days on the interval related to the bouncing period than on the other two unrelated intervals, suggesting that even when not explicitly timed, motor practice sharpens time sensitivity around the related motor timing patterns.

Conclusion: These findings shed light on the fundamental role of dynamic stability and motor primitives for processing auditory rhythms. The results also suggest opportunities to improve time sensitivity beyond music practice, as may be relevant for some neurological disorders.

Restricting variability in task space hinders effective skill acquisition (P1-16)

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Background: Motor skill acquisition relies on variability in movement, which can be classified into two types: **task space variability** which refers to variations in movements that directly contribute to task performance and **redundant space variability** which involves variations in non-essential degrees of freedom that do not directly impact the task outcome. Bernstein's theory of motor control suggests that in the early stages of acquiring a movement skill, the coordination problem is simplified by initially freezing certain degrees of freedom, which are gradually released as learning progresses. However, it remains unclear which type of variability, whether in task space or redundant space, plays a key role in facilitating skill acquisition. In this study, we examined the effect of constraining certain degrees of freedom during the learning of a redundant virtual task by intentionally restricting movement in task space.

Methods: Participants completed a two-dimensional cursor control task wearing a cyber glove, aiming to match a target using finger movements. They were randomly assigned to one of two groups; 1) in the resistance group, a haptic glove applied resistance to restrict the movement of specific fingers that did not directly contribute to cursor movement in the target direction, thus constraining the degrees of freedom in task space, and 2) in the non-resistance group, participants performed the task without any movement restrictions, allowing free exploration of the task space.

Results: The manipulation-check confirmed that the variance in movement was significantly lower in the resistance group when constraints were applied to certain fingers, indicating that the glove successfully restricted movement in the corresponding directions. Both groups demonstrated successful skill acquisition, evidenced by a reduction in the time taken to complete the task. However, the resistance group exhibited lower movement efficiency after training, suggesting that restricting variability in task space is less effective for skill acquisition than allowing free movement, as seen in the non-resistance group.

Conclusion: This study suggests that constraining degrees of freedom in task space can simplify movement patterns during skill acquisition. While both groups successfully learned the task, the resistance group exhibited less movement efficiency, indicating that allowing variability in task space may better facilitate motor learning. The results suggest that free exploration of task space, rather than restricting it, may enhance skill acquisition and lead to more efficient motor performance.

A data-driven assessment of planar reaching movement: Intuition and analysis in context of upper extremity stroke hemiparesis (P1-31)

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Background: Traditional kinematic metrics used in stroke rehabilitation assessments, such as path deviation, movement time, peak velocity, and smoothness, typically focus on isolated aspects of motor performance and thus fail to fully capture the multidimensional nature of motor impairments. This limitation can hinder comprehensive clinical evaluations. Examining the pattern of kinematic deviations was recently proposed using Principal Component Analysis combined with Mahalanobis Distance (PCA-MD). This approach has shown promise in quantifying overall movement abnormalities following stroke, but its intuition, application, and interpretation have not been clarified.

Objective: To evaluate the interpretability, sensitivity, and clinical utility of PCA-MD in characterizing spatial and temporal variability of upper-extremity motor impairment following stroke, compared with conventional kinematic measures.

Methods: First, planar reaching trajectories were generated with systematically manipulated spatial and temporal deviations, involving movement fragmentation, deflection of each fragment from a straight line, and temporal deformations of a generic bell-shaped velocity profile. A low-variability set of trajectories was used as a "healthy" reference, and PCA was run on that set to establish a normative reference space. Following that, all trajectories were projected onto that space. Variance unaccounted for (VUF) during projection, and the MD (PCA-MD) between each trajectory and the reference cluster were determined to elucidate the method's intuition and sensitivity to temporal and spatial deviations. Subsequently, real-world reaching data were collected from stroke survivors (n=25) and healthy controls (n=32) using an InMotion robotic arm system. The PCA-MD method was similarly performed on the healthy control data, and then on all subjects' trajectories. Spearman correlations were employed to explore relationships among the resulting VUF, PCA-MD, conventional kinematic metrics, and clinical severity as measured by the Upper Extremity Fugl-Meyer Assessment (FMA-UE).

Results: The simulation showed that the first principal component is likely to capture most of the spatial deviation in the data, with the second and third PCs capturing subtler temporal distortions. Both metrics scaled with increased variability: VUF primarily increased with temporal variability reflecting the complexity of deviation pattern with increased movement fragmentation, while MD was sensitive to both spatial and temporal variabilities. In the healthy controls data, the first three PCs captured 71, 20, and 5% of variance. Stroke survivors exhibited progressively increased VUF from mild (12.6%) to severe impairment (29.3%), reflecting the emergence of distinct abnormal features as impairment severity increased. Despite these variations, the top three principal components remained capable of capturing majority of the motor kinematics in stroke patients. PCA-MD correlated strongly with conventional metrics, notably path deviation ($\rho=0.62$, $p<0.05$).

Conclusion: PCA-MD effectively quantifies overall movement abnormalities by capturing both spatial and temporal components of variability. Importantly, even severely impaired stroke survivors exhibited motor variance predominantly represented within normative able-bodied trajectories. PCA-MD's strong correlation with multiple conventional kinematic metrics underscores its potential as a comprehensive measure of impaired

motor control. Future research should explore PCA-MD’s relationship with established clinical outcome measures and extend its application to quantify 3-dimensional functional movement deficits post-stroke. Understanding PCA-MD’s capacity to capture complex motor deficits may significantly enhance clinical assessments of upper-extremity impairment post-stroke.

Innovative use of trend change index in assessing functional stability: comparing older and younger adults (P2-42)

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Background: Maintaining postural control is critical for preventing falls, particularly among older adults. However, traditional center-of-pressure (COP) analyses often fail to detect subtle balance impairments that precede falls. The Trend Change Index (TCI), adapted from stock market technical analysis, provides an innovative approach for assessing these subtle dynamic shifts in balance.
Objective: To compare the sensitivity of the Tiptoe Rising Test combined with TCI analysis against conventional Limits of Stability (LOS) tests using standard COP measures in distinguishing functional stability differences between healthy older and younger adults.
Methods: Twenty-four older adults (aged 65+ years) and twenty younger adults (aged 18–30 years) performed both the Limits of Stability and the Tiptoe Rising tests. COP data were continuously recorded using a force plate. Conventional COP parameters (e.g., sway range, velocity, standard deviation) and TCI metrics (TCI_dT, TCI_dS, TCI_dV, and TCI_per_s) were calculated. Group comparisons employed independent-samples t-tests and Mann–Whitney U tests, with effect sizes (Cohen's d, r) computed to quantify observed differences.
Results: Standard COP analyses showed limited ability to detect differences between younger and older adults during the LOS test, particularly in less dynamic phases. In contrast, the TCI-derived indices demonstrated moderate to large effect sizes, especially during the dynamic Tiptoe Rising Test. For instance, significant differences in TCI metrics (e.g., TCI_per_s[j]AP, TCI_dV[mm/s]AP) between groups revealed subtle but important age-related impairments not evident in conventional COP analyses.
Conclusion: Integrating TCI analysis with dynamic postural assessments, such as the Tiptoe Rising Test, significantly enhances sensitivity in detecting age-related functional stability impairments. This novel approach could improve early detection of balance deficits and inform targeted interventions aimed at fall prevention among the elderly.

Age differences in long-term retention of visuomotor adaptation (P1-06)

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Background: Sensorimotor adaptation has been studied using two primary paradigms: force-field adaptation and visuomotor rotation. Both forms of learning rely on the combined contributions of multiple memory systems. In particular, the literature shows that sensorimotor adaptation is supported by explicit and implicit memory processes. Aging is associated with diminished learning and retention during sensorimotor tasks, due in part to age-related cognitive declines, and that the explicit and implicit contributors may be differentially affected. Much of the work on age differences in sensorimotor adaptation has investigated learning and retention during a single session. Little is known about the long-term retention of sensorimotor adaptation in older adults. This knowledge is important for our understanding of how older adults learn new motor skills and adapt their movements during rehabilitation.

Objective: Given that long-term memory processes in general, and specifically explicit long-term memory processes are known to decline with aging, it is important to investigate whether older adults differ from younger adults in the long-term retention of an adapted movement. Long-term retention, or savings, has been shown to be robust across different training periods and retention intervals in younger adults for sensorimotor adaptation tasks. Here, we used a visuomotor adaptation task to test the hypothesis that older adults exhibit weaker savings in sensorimotor adaptation than younger adults.

Methods: An a priori power analysis based on the effect size of age differences in acquisition of a visuomotor rotation from a previous study in our lab, alpha = 0.05, and power = 0.95, indicated that a sample of 10 participants per group would be sufficient. Consistent with previous studies, we recruited 21 healthy younger (M = 19.57, SD = 1.21, 10 females) and 22 healthy older adults (58-80 years old, M = 67.73, SD = 5.93,14 females) to complete a visuomotor adaptation paradigm over two consecutive days. On the first day they learned a 45-degree visuomotor rotation in a center-out reaching task to four radial targets. After a wash-out period during which the rotation was turned off, the participants returned 24-hours later to repeat the same task.

Results: We calculated the angular error from the target of the participants' reaching movement on each trial and averaged every four consecutive trials into epochs. We then compared the learning curves of younger and older adults in an epoch by age group ANOVA. There were no differences between the groups in initial acquisition of the visuomotor rotation, with younger and older adults producing similar learning curves. However, younger adults showed significant savings, with faster learning on Day 2 compared to Day 1, whereas older adults showed no differences in learning curves between the two days.

Conclusion: The results of this study show that long-term retention in sensorimotor adaptation is affected by aging and that there may be larger age differences in long-term retention than initial learning. These data suggest that while we can learn new motor skills throughout the lifespan, aging is associated with declines in retention of those motor skills over a 24-hour retention period. These findings have implications for rehabilitation of movements after injury in later adulthood.

Effects of transcranial magnetic stimulation waveform shape and pulse width on corticospinal excitability (P1-07)

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Background: Transcranial magnetic stimulation (TMS) pulse parameters such as phase and directionality have been shown to influence neuronal populations activated during stimulation. Controllable pulse TMS (cTMS) provides greater control of the stimulus waveform and therefore may enable more selective stimulation though a greater understanding of stimulus-response characteristics is needed.

Objective: In this study, we investigated how variations in pulse width (PW) and phase balance (M-ratio) modulate motor evoked potential (MEP) recruitment in two intrinsic hand muscles: the first dorsal interosseous (FDI) and the abductor digiti minimi (ADM).

Methods: Using controllable pulse TMS, we systematically varied PWs (40, 60, 80, 100, and 120 μs) and M-ratios (0.2, 0.4, 0.6, and 0.8) to assess their effects on MEP input–output (IO) curves.

For each PW and M-ratio combination, we collected Input-Output (IO) curves and fit them using a sigmoidal function to extract two key parameters: x50, the stimulus intensity required to evoke 50% of the maximum MEP amplitude, and the slope at x50 (x50slope), which reflects the gain of motor unit recruitment. These parameters were analyzed using linear mixed-effects models to account for within-subject variability.

Results: Our results revealed a consistent and significant leftward shift in IO curves with increasing pulse width in both FDI and ADM muscles. This was quantified by a significant reduction in x50 values ($p < 0.0001$), indicating that wider pulses require lower stimulus intensities to reach threshold response. Additionally, slope values increased with PW, indicating enhanced recruitment gain at wider pulse widths. We also observed distinct effects of M-ratio across the two muscles. In the FDI, M-ratio had a significant effect on both x50 ($p = 0.04$) and slope ($p = 0.022$), suggesting that M-ratio tuning can modulate excitability and recruitment gain in this muscle. In contrast, ADM showed no significant main effect of M-ratio on x50 ($p = 0.92$), but a significant interaction between PW and M-ratio was found for slope ($p = 0.03$), highlighting muscle-specific differences in response to combined modulation of these parameters. The consistency of trends across participants reinforces the robustness of the observed effects.

Conclusion: These findings emphasize the importance of considering both pulse width and M-ratio in neuromodulatory protocols. Wider pulses appear to engage more excitable cortical circuits, while M-ratio modulation may provide an additional dimension for fine-tuning recruitment properties. The differential responses observed between FDI and ADM suggest that muscle-specific circuit properties influence how pulse parameters shape IO dynamics. Overall, this study contributes to a more detailed understanding of how TMS pulse shaping can be leveraged to modulate cortical excitability in a targeted and individualized manner. These insights may have future applications in developing optimized stimulation protocols for motor rehabilitation and neurotherapeutic interventions.

Comparing physiological recruitment during neuromuscular electrical stimulation and volitional contraction (P1-11)

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Background: Neuromuscular electrical stimulation (NMES) faces limited clinical adoption despite its proven effectiveness for quadriceps strengthening,[1] primarily due to patient discomfort at therapeutic intensities.[2,3] Multiple-path NMES (MP-NMES), which distributes current across pathways via several large electrodes, reduces discomfort and fatigue while increasing torque-to-current ratio compared to the spatially-fixed current path of conventional NMES (C-NMES).[4] Whether MP-NMES achieves its relative effectiveness by better approximating natural central recruitment patterns remains unexplored. Understanding central recruitment patterns in MP-NMES and C-NMES would provide fundamental insights into NMES mechanisms and inform development of more effective, physiologically representative stimulators.
Objective: To compare recruitment patterns of quadriceps torque production during MP-NMES, C-NMES, and voluntary activation. We hypothesize that quadriceps MP-NMES produces a more physiologically representative contraction pattern than C-NMES, resembling voluntary activation.
Methods: Following IRB-approved informed consent procedures, participants were seated in a dynamometer with 60° knee flexion. In randomized order, participants completed six experimental conditions: voluntary activation (VA), conventional NMES (C-NMES), and four distinctively focused multipath configurations: vastus lateralis-dominant (VL-NMES), vastus medialis-dominant (VM-NMES), hamstrings-dispersion (HS-NMES), and full quadriceps (FQ-NMES). Torque was incrementally increased in 10% steps of either maximal voluntary isometric contraction (MVIC) for voluntary trials or percentage of maximum stimulator output for NMES conditions until participant tolerance was reached. At each intensity level, participants performed three 3-5 second contractions. During the force plateau of each contraction, we delivered transcranial magnetic stimulation (TMS) to the motor cortex at 120% of active motor threshold. We recorded TMS-evoked torque, which serves as an indicator of central recruitment and estimates the population of near-threshold motor units at stimulation time. For each configuration, we analyzed three key parameters: max NMES-evoked torque, max TMS-evoked torque, and torque at max TMS-evoked torque.
Results: Nine subjects participated (5 females, 24.1±4.6 years, 62.5±10.1 kg). VA showed the greatest max TMS-evoked torque (11.3 %MVIC) and torque at max TMS-evoked torque (49.5 %MVIC). Within the NMES configurations, FQ-NMES and VM-NMES showed greater max NMES-evoked torque (FQ: 40.7; VM: 36.7; C:35.7 %MVIC), max TMS-evoked torque (FQ: 3.6; VM: 5.5; C: 2.9 %MVIC), and torque at max TMS-evoked torque (FQ: 29.2; VM: 24.5; C: 17.0 %MVIC) than C-NMES.
Conclusion: Compared to C-NMES, two MP-NMES configurations (FQ-NMES and VM-NMES) elicited recruitment patterns more closely resembling physiological activation. Of these, VM-NMES produced the highest max TMS-evoked torque among all NMES conditions, possibly suggesting a greater number of larger-sized motor units were near recruitment threshold. Notably, max TMS-evoked torque occurred at ~60% of max NMES-evoked torque in FQ-NMES and VM-NMES, closely mirroring VA. Although limited by small sample size, our data supports the need for further studies into the mechanisms of MP-NMES to optimize NMES therapeutic efficacy.

Prior motor learning constrains optimal behavior under altered precision constraints (P1-12)

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Background: In tasks requiring high precision (such as surgery), humans are able to adapt movements to task-specific precision demands, enhancing accuracy when necessary while exploiting redundancy to buffer noise. Optimal Feedback Control (OFC) explains this via the minimum intervention principle, predicting that variability is minimized only in task-relevant dimensions. Yet, empirical findings often show an overall reduction in variability with learning, suggesting convergence onto a stable nominal trajectory. One potential source for this discrepancy is that classical OFC does not account for learning history.

Objective: We sought to determine whether prior motor learning influences variability when precision demands are altered after learning. If variability patterns purely reflect optimal responses to current task demands, then prior motor learning should have no effect.

Methods: Participants (n = 12) trained in a VR environment on a sinusoidal via-point task with five 3D cylindrical targets. We manipulated the location of task-relevant precision demands while keeping the spatial path constant. The target diameter (task-relevant dimension) was varied between groups while the target depth (task-irrelevant or redundant dimension) remained constant between groups. One group trained with precision requirement early in the sequence, whereas a second group trained with precision requirement late. After training, participants in both groups were transferred to a common via-point task where the same average path was maintained as in training, but with an intermediate precision requirement. This transfer task allowed us to examine if the reduction in variability that is typically observed after learning is indicative of a nominal trajectory, or whether variability in fact remains flexible and capable of adjusting to new task demands.

Results: First, we examined how positional variability is distributed in the task-relevant and irrelevant dimensions. We found that in the task relevant dimension, variability was higher "in between" via points compared to at the via-points throughout learning. This is consistent with OFC's prediction of strategic variability modulation by minimum intervention. Second, we examined how learning changes variability in both dimensions. We found that both components of variability reduced with learning, consistent with prior work showing that there is a global reduction in variability with learning. Finally, we examined the performance of both groups in the common transfer test. We found that contrary to classical OFC, there was an influence of prior training on performance, indicating that participants had learned a feedforward strategy that carried over to their performance in the transfer test.

Conclusion: Overall, these results suggest that motor system prioritizes retaining prior learned coordination strategy over reorganizing to new constraints. This challenges the original formulation of OFC, which does not account for the influence of learning history on control policy. New models should incorporate this influence of prior learning, acknowledging that what is optimal from the viewpoint of the task can differ from what is optimal for the system as a whole.

Adaptive roles of corticospinal excitability and intracortical inhibition at rest and during movement initiation in chronic post-stroke hemiparesis (P1-20)

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Background: Excitation and inhibition of intracortical neurons are dynamically modulating during motor tasks. In neurologically intact individuals, the motor system is generally in a state of inhibition at rest but decreases (i.e. disinhibited) during movement planning and execution. Further, intracortical inhibition increases in a muscle-specific manner to suppress unwanted activation of nearby muscles, supporting precision of desired movements. Paired-pulse transcranial magnetic stimulation (TMS) can be used to characterizes intracortical inhibitory circuits through short latency intracortical inhibition (SICI), a widely used measure of GABAergic inhibitory mechanisms in the primary motor cortex (M1). After stroke, early phase of recovery results in disinhibition of the intracortical ipsilesional motor network at rest and during movement preparation, which is thought to promote motor recover. By the chronic phase, SICI abnormalities at rest and during movement preparation tend to normalize in some but persist in others. It remains unclear whether abnormal SICI in chronic stroke is adaptive.

Objective: To investigate corticospinal excitability (CE) and intracortical inhibition at rest and during movement preparation and their associations with chronic post-stroke motor impairments across varying motor severities.

Methods: Eleven chronic post-stroke hemiplegic participants were recruited (Upper-Extremity Fugl-Meyer (UEFM): 31.6 ± 12.9, range: 14-51; Box-and-Block Test (BBT): 13.3 ± 15.0, range: 0-36). TMS was used to examine CE and SICI in the ipsilesional M1 (iM1) and contralesional M1 (cM1), targeting the extensor digitorum communis. Resting SICI recruitment curve was evaluated with a test stimulus at 50% of the maximal MEP amplitude and a conditioning stimulus (CS) at 60%-100% (10% steps) of the resting motor threshold, with 2.5ms interstimulus interval. For movement-related SICI, CS was set at an intensity that suppressed corticospinal output by ~50%. SICI was examined during early and late phases of movement preparation in a simple reaction time paradigm. MEPs from unconditioned stimulus were used to assess CE. UEFM and BBT scores assessed motor impairment and gross manual dexterity of the paretic upper-limb.

Results: At rest, CE and SICI were reduced in the iM1 compared to the cM1. Greater iM1 disinhibition (reduced SICI) correlated with less impairment (UEFM, $r2 = 0.44$, $p = 0.04$) and better gross manual dexterity (BBT, $r2 = 0.58$, $p = 0.01$). During movement preparation, CE was facilitated from early to late phases ($p = 0.04$), with greater facilitation in iM1 ($p = 0.03$). Greater iM1 facilitation correlated with reduced impairment (UEFM, $r2 = 0.71$, $p = 0.004$) and better gross manual dexterity (BBT, $r2 = 0.52$, $p = 0.02$). SICI in the cM1 showed gradual disinhibition, while the iM1 remained disinhibited with no modulation ($p = 0.021$). The abnormal ipsilesional SICI pattern was not associated with severity of motor deficits.

Conclusion: Our results suggest that resting disinhibition may serve as an adaptive neuroprotective mechanism, but movement-related SICI modulation does not predict motor deficits. Instead, CE facilitation during preparation is important for effective motor function. The mechanism promoting CE facilitation during movement preparation is unclear. Ongoing data collection will clarify if resting disinhibition contributes to CE facilitation during movement preparation and execution.

POSTER SUBMISSIONS

The posters have been divided into two sessions. The authors in each session are responsible for presenting between 1:00 pm and 3:00 pm on each day. Posters are displayed on the day they are assigned and removed at the end of the day. The poster numbers are divided first by session and then with a sequential serial number.

POSTER SESSION 1

Monday, June 30, 2025
1:00- 3:00 pm

Theme 1: Neural and Biomechanical Mechanisms of Motor Control and Adaptation

This theme includes studies focused on the neural control of movement, motor learning and adaptation, muscle synergies, sensorimotor integration, and computational modeling of motor behavior.

P1-01 Effects of increasing movement variability on motor learning

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P1-02 Force field adaptation requires specific muscle synergies

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P1-03 Kinematic adaptation to expected sensory feedback in single- and double-tap actions

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P1-04 The structure of variability during unperturbed speech production does not predict speech motor adaptation in perturbed trials

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P1-05 Force-stabilizing synergies at the neural control level: a comparison of parkinson’s disease and essential tremor

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P1-06 Age differences in long-term retention of visuomotor adaptation

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P1-07 Effects of transcranial magnetic stimulation waveform shape and pulse width on corticospinal excitability

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P1-08 Task demands dictate the control of motor units

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P1-09 A high-level computational model of Parkinson's disease motor symptoms

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P1-10 Timing-dependent posterior parietal cortex contribution in adaptation and transfer

H. Hibino*, B. Uitz[1], A. Akbas[2], J. Kogan[3], T.E. Murphy[4], M. Yarossi[1,5], R.L. Sainburg[6,7], & E. Tunik[1]
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P1-11 Comparing physiological recruitment during neuromuscular electrical stimulation and volitional contraction

Y. Wang[1], S. Hornsby[1], K.D. Deegan[2], B.M. Caulfield[2], D.A. Sherman[1,3], J. Stefanik[1], Mathew Yarossi[1,3]
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P1-12 Prior motor learning constrains optimal behavior under altered precision constraints

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P1-13 Unifying reinforcement learning and feedback control to predict multi-timescale adaptation

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P1-14 The impact of attention control demands on upper limb motor performance

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P1-15 Pre-movement beta oscillations and peak velocity in healthy adult planar reaching

A.N. Dusang[1,3,4], R. Hardstone[1,4], S. Cavanagh[1,4,5], J.A. DiCarlo[1], L.R. Hochberg[1,2,3,4], D.J. Lin[1,2,4]
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P1-16 Restricting variability in task space hinders effective skill acquisition

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P1-17 Activity of V3 neurons in swing and stance phases of fictive locomotion and in fictive scratching

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P1-18 Impedance preparation and modulation when interacting with dynamically complex and uncertain objects

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P1-19 TMS-induced I-wave characteristics are associated with impairment severity in chronic post-stroke hemiparesis

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P1-20 Adaptive roles of corticospinal excitability and intracortical inhibition at rest and during movement initiation in chronic post-stroke hemiparesis

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P1-21 Navigators trade off proximal and distal energy minimization strategies in uncertain environments

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P1-22 Cortical hemodynamic responses in auditory processing and the influence of transcranial direct-current stimulation

J. McLinden[1], B. Adeli[1], A. Cerullo[1], M. Shao[2], K.M. Spencer[3], M. van ‘t Wout-Frank[4], Y. Shahriari[1]
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P1-23 Effects of the different types of fatigue on muscle synergies

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P1-24 Inter-trial and intra-trial analysis of force stabilization in multi-finger tasks: the role of visual feedback

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P1-25 The impact of feedback type on rate of force development scaling factor (rfd-sf) during rapid submaximal force production

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P1-26 Stabilization of lead-limb foot trajectory by multi-joint synergies during single-step ascent

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P1-27 Hand dominance influences spatiotemporal finger coordination in precision grip, not finger individuation

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P1-28 Embodiment and control of a complex object: hitting a target with a whip

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P1-29 Dice stacking is mostly open-loop: a case study on highly under-actuated dynamic manipulation

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P1-30 Decoding motor intent from planning-phase EEG using graph neural networks for goal-driven rehabilitation

A. Cetera[1], B.S. Ghafoori[2], C.C. M.P. Furmanek[3], Y. Shahriari[4], M. Alvarez[5] & R. Abiri[6]
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P1-31 A data-driven assessment of planar reaching movement: Intuition and analysis in context of upper extremity stroke hemiparesis

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P1-32 Kinematic Data Gathered via OpenPose and Machine Learning Classifier for Distinguishing Between Normal Gait and Toe-Walking: A Pilot Study (P1-32)

L.E. Molteni[1], G. Valagussa[2,3], M. Boccotti[2], G. Purpura[3], C. Perin[3], A. Crippa[1], G. Andreoni[1,4], E.Grossi[2], D. Piscitelli[3,5]
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POSTER SESSION 2

Wednesday, July 2, 2025
1:00- 3:00pm

Theme 2: Clinical and Functional Applications in Motor Impairments and Rehabilitation

This theme includes work on rehabilitation, motor impairments, clinical populations (e.g., stroke, Parkinson's, CP, SCI), wearable sensors, and functional assessments.

P2-35 Movement amplification during locomotor training improves the dynamic stability of center of mass control for people with incomplete spinal cord injury

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P2-36 Postural control in parkinson's disease: analyzing wearable sensor data using trend change indexes

J. Jurkojć[1], M. Chmura[2], C. Hansen[3], E. Warmerdam[4], R. Romijnders[3], M. A. Hobert[3], W. Maetzler[3], K. Cygoń[5], P. Wodarski[6]
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P2-37 Motor unit development in a rabbit model of cerebral palsy

E. Reedich[1,2], E. Mena Avila[1,2], L. Genry[1,2,3], E. Gonzalez Sanchez[1,2,3], B. Moline[1,2], C. Kramer[1,2,3], K.A. Quinlan[1,2,3], M. Manuel[1,2,3]
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P2-38 Stability in emergent vs enforced motor patterns and its effect on time perception

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P2-39 Effect of visual time perception on the control of standing balance

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P2-40 Modulating motoneuron activity to influence neuromuscular junction maturation in a model of cerebral palsy

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P2-41 Contribution of postural-respiratory synergy dysfunction to postural control deficits in adults with chronic obstructive pulmonary disorder

M.A. Riley[1], M. Wilson[1], M. Bennett[1], Z. Webb[1], H. Samad[1], P-H Liu[1,2,3], H. Gallardo[4], R. Brackman[4], D. Goodman[4], K. Qualls[4], K. Horan[4], E. Ireland[4], J. Oney[4], A. Siddiqi[4], J. Pugh[4], E. Roth[4], B. Kelsey[4], C. Bonn[4], T. Santos Moreira[5], S. Dugan[1], N. Kuznetsov[1], R. Burkes[6]
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P2-42 Innovative use of trend change index in assessing functional stability: comparing older and younger adults

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P2-43 Primary afferent depolarization and hyperreflexia in cerebral palsy

E. Mena Avila[1,2], E. J. Reedich[1,2], L. T. Genry[1,2,3], M. A. Gorassini[4,5,6], D. J. Bennett[6,7], K. A. Quinlan[1,2,3]
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P2-44 The Dynamic Assessment of Sensorimotor Health (DASH): preliminary results from a virtual reality behavioral testing platform

C.D. Riehm[1,2,3], S. Bonnette[8], A.L. McPherson[1,2,3], B.L. Nelson[1,2,3], K.M. Stahl[1,2,3], F.M. Grover[9], B.Foss[1,2,3], J.A. Diekfuss[1,2,3,4], G.D. Myer[1,2,3,4,5,6,7]
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P2-45 Sway characteristics in adults with neuromuscular conditions

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P2-46 Building a normative dataset of infant leg movements using wearable sensors

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P2-47 A virtual representation of the fear of falling – pilot study

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P2-48 Holding hands in a challenging postural balance task

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P2-49 Motor asymmetries in virtual reality reach-to-grasp tasks

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P2-50 Contributions to ankle clonus in individuals with SCI

E. Curuk[1], A. Benedetto [1,2,4], M. T. Farley[1,2], G. E. P. Pearcey[6], C.J. Heckman[2,3,5] M. A. Perez[1,3,4]
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P2-51 Age-related characteristics of unintentional force drift: a pilot study

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P2-52 Altered gait among people with multiple sclerosis during a prolonged walking bout

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P2-53 Force modulation in interactions with a complex object: insights from healthy and post-stroke individuals

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P2-54 Gait stability in older adults after tripping simulated perturbation – a pilot study

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P2-55 Anticipatory postural adjustments for voluntary arm movements in children with ASD

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P2-56 The comparison of lower extremity muscle activation and kinematics during lunging and step negotiation between those with and without total knee arthroplasty

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P2-57 Galvanic vestibular stimulation modulates upper and lower limb spinal reflexes: comparison between wrist and ankle muscles

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P2-58 Assessing the differences between fine wire and surface electromyography in the infraspinatus muscle during active range of motion movements

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P2-59 Three-dimensional evaluation of upper limb joint coupling after chronic stroke

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P2-60 Contributions of the vestibular system to the stance phase of gait during downhill walking

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P2-61 Changes in joint and coordination regularity following running distinguished runners who sustained an injury within six-months

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P2-62 Reliability and validity of modified upper quarter y-balance tests: potential as new clinical tools

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