Neurophysiological Bases of Human Movement

12 – 13 December 2023 | King's College London, UK

Abstracts

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SA01

Developing motor skill with a new body part

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We are witnessing the rise of novel augmentation technologies designed to extend the physical abilities of able-bodied individuals. However, whilst engineers are developing extra fingers and even entire arms aimed to augment our own, relatively little attention has been afforded to how the human brain will control them. Is it possible, from a sensorimotor perspective, to develop sensory and motor skill to control a new body part? Here, I will describe a series of studies that aimed to begin addressing these questions, where individuals were trained to use a toe-controlled extra robotic finger (the Third Thumb; Dani Clode Design), both in the lab and 'in the wild'. Our studies demonstrate that successful integration of a motor augmentation device can be readily achieved, with potential for flexible use, reduced cognitive reliance and increased sense of embodiment. To support this motor skill learning, participants will rely on a multitude of sensory cues arising both from the Third Thumb and from their own body. Importantly, we show that developing motor skill with the extra Thumb resulted in changed use and representation of the biological hand. Collectively these results demonstrate neurocognitive bottlenecks and opportunities for the successful realisation of robotic motor augmentation, with implications for related assistive technologies.

SA02

Motor cortex activity during action observation

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Pyramidal tract neurons (PTNs) within macaque rostral ventral premotor cortex (F5) and primary motor cortex (M1) provide direct input to spinal circuitry and are critical for skilled movement control, but can also be active during passive action observation. In M1, relatively reduced PTN activity during grasp observation may explain the lack of overt movement, and differences in the functional contributions of premotor and motor cortex between execution and observation could support the flexible generation or suppression of grasping movements during these two conditions. We recorded from single neurons, including identified PTNs in the hand and arm area of M1, and in premotor area F5 of two adult male macaques, while they executed, observed, or simply withheld (NoGo) reach-to-grasp and hold actions. Simultaneous electromyographic recordings from multiple arm and hand muscles confirmed that mirror activity during observation could not be attributed to small levels of muscle activity. Single neuron responses were heterogeneous, with classical and suppression mirror neurons (MNs) in both cortical areas. At the population level, F5 mirror activity was more sustained and similar in profile to execution activity. In contrast, although some neurons mirror during the grasp and hold, M1 population activity during observation contained signatures of a withholding state in the lead-up to observed movement onset. Thus, while F5 maintains a more sustained representation of grasping actions, M1 and its output population may dissociate signals required for the initiation of movement from those associated with the representation of grasp in order to flexibly guide behaviour.

SA03

Grasping the virtual world

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In the last few years, immersive virtual reality (iVR) has become a significant part of the entertainment industry. In parallel, there has been a significant uptake in iVR for training in the context of sports, medicine, and dangerous industries. This technology also has potential value for research into human behaviour, allowing for the strict control of sensory inputs in ecologically-valid tasks. In this talk, I will give an overview of some of our recent research in the context of perception and action, highlighting how iVR can be used to study human motor control, and discussing the potential pitfalls of this approach. In the last few years, immersive virtual reality (iVR) has become a significant part of the entertainment industry. In parallel, there has been a significant uptake in iVR for training in the context of sports, medicine, and dangerous industries. This technology also has potential value for research into human behaviour, allowing for the strict control of sensory inputs in ecologically-valid tasks. In this talk, I will give an overview of some of our recent research in the context of perception and action, highlighting how iVR can be used to study human motor control, and discussing the potential pitfalls of this approach.

SA04

Low intensity focused ultrasound for neuromodulation in human

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Low intensity transcranial focused ultrasound stimulation (TUS) is a novel non-invasive brain stimulation (NIBS) technique. Compared to commonly used NIBS techniques such as transcranial magnetic stimulation and transcranial direct current stimulation, TUS is much more focal and can reach deeper brain structures. The talk will focus on induction of plasticity or after-effects by TUS, since lasting effects are likely required for non-invasive treatment for neurological and psychiatric disorders. In human subjects, a theta burst TUS (tbTUS) protocol with TUS repeated at bursts at 5 Hz (theta frequency) for 80 s can increase motor cortical (M1) excitability for 30 min to 1 hour. Pharmacological studies showed that tbTUS plasticity is blocked by calcium channel and NMDA receptor blockers, and by benzodiazepine which enhances GABAergic transmission, consistent with a long-term potentiation-like mechanism. A magnetoencephalography study showed that TUS to the M1 led to widespread changes in connectivity between brain regions. tbTUS to the dorsal anterior cingulate cortex and posterior cingulate cortex increased functional connectivity of the target regions, and decreased GABA level in the posterior cingulate cortex. These findings are consistent with an excitatory effect of tbTUS in deep cortical structures. In Parkinson's disease (PD) patients off-medication, tbTUS induced plasticity in the M1 was diminished but was restored to levels similar to normal subjects in the on-medication state. In a pilot study, PD patients in the off-medication state received 3 sessions of bilateral M1 TUS in one day. The study was well tolerated and led to increased M1 excitability and non-significant improvement in PD motor signs. These findings suggest that multiple sessions of TUS can be further studied as novel non-invasive treatment for PD. TUS targeting of deep brain structures requires accurate modeling based on individual MRI/CT scan because ultrasound is absorbed and deflected by the skull. In normal subjects, a TUS study targeting the internal globus pallidus (GPi) showed widespread reduction in blood flow measured by MRI. TUS of the subthalamic nucleus (STN) and the anterior putamen but not the posterior putamen interfered with a stop-signal reaction time task. There are few TUS studies in patients and they are small, open-labeled studies. TUS of the central thalamus was associated with improvement in patient with acute or chronic disorders of consciousness. TUS of mesial temporal lobe in patients with intractable epilepsy was safe and the subsequently resected brain tissues did not show histological changes. Current studies in our laboratory includes targeting the GPi and STN in PD patients implanted with deep brain stimulation (DBS) device capable of chronic local field potential recordings to provide target validation of our ability to accurately target deep brain structures and to find stimulation parameters that can reduce beta oscillations, a reliable biomarker of PD motor symptoms. Other oning studies include TUS of the cerebellum to treat freezing of gait in PD, cervical dystonia and orthostatic tremor. TUS has the potential to be developed into a novel non-invasive DBS treatment for neurological and psychiatric disorders.

SA05

Neural control of upper and lower limb muscles: what can we learn from motor unit ensembles?

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Understanding the neural control of motor unit ensembles is a challenging task. Historically, this challenge has been addressed by studying 2-3 motor units concurrently in muscles from diverse compartments and during different voluntary tasks. However, due to the low number of decoded motor units, it was not possible to extract a more structured view of the synaptic inputs shared between motor units during voluntary movement. With the advent of novel intramuscular and surface EMG electrodes and decomposition techniques, it has been shown that motor units exhibit a high level of correlated activity during isometric contractions. In this talk, I will discuss the behaviour of motor units controlling the hand (first dorsal interosseous and thenar muscles) during concurrent index abduction and thumb flexion, and leg muscles (vastus lateralis and medialis) during knee extension isometric contractions.

By applying a factorization method directly to the motor unit discharge timings, we were able to study the neural dimensions that control a relatively large number of motor units in the hand and vastii muscles. We first validated the factorization method with synthetic motor unit discharge times generated using an integrate-and-fire model with known distributions of shared and independent synaptic inputs. Subsequently, in the experiments, we found that the factorization method extracted a single dominant common input that was muscle-specific. On average 75% of the motor units for the thenar muscles and first dorsal interosseus were dominated by a single common input that was specific for the muscle they resided. On the other hand, in the vastii muscles, although we also found two independent muscle-specific shared inputs, the motor units exhibited a continuous distribution of correlation with these two dominant muscle-specific common inputs. The proportion of the muscle-specific motor unit common input was 60% for vastus medialis and 45% for vastus lateralis. The other motor units were either correlated with both muscles (shared inputs) or belonged to the common input for the other muscle (15% for vastus lateralis). These results indicate that correlated discharge rates of motor units arise from at least two independent sources of common input among the motor neurons innervating synergistic muscles, and that the hand and leg muscles significantly differ in their distribution, likely due to anatomical constraints.

In the second part of the talk, I will discuss how we used the same methods applied to subjects with C3-C6 complete motor and sensory spinal cord injury and healthy individuals during dynamic hand movements. By recording the spared motor units from the forearm muscles, we found high correlations between these spared motor units' discharge timings and the kinematics of a virtual hand. We then studied the dimensions of these motor unit firing times in comparison to healthy subjects. The results showed that even after 15 years of chronic hand paralysis, there are still motor units encoding flexion and extensions of the paralyzed fingers. We then connected these motor units in real-time through a novel brain-computer interface software and demonstrated that these patients can reliably control a virtual hand and exoskeleton controlling the paralyzed hand.

The forces generated by agonist muscles during isometric contractions arise from motor unit synergies A Del Vecchio et al. Journal of Neuroscience 43 (16), 2860-2873 The human central nervous system transmits common synaptic inputs to distinct motor neuron pools during non-synergistic digit actions A Del Vecchio et al. The Journal of physiology 597 (24), 5935-5948

SA06

Investigating functional connectivity between the human brain and spinal cord using optically-pumped magnetometers

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Background: Traditionally, the brain and spinal cord have been studied as separate systems due to the challenges of simultaneously imaging their activity. However, optically pumped magnetometer (OPM)-based imaging is uniquely versatile, allowing flexible sensor placement on different parts of the body. Using OPMs, we have developed a novel system for concurrent imaging of brain and spinal cord activity (Mardell et al., 2022).

Aim: This preliminary work aimed to investigate endogenous interactions between the brain, spinal cord, and muscle involved in sensorimotor control during simple movement.

Methods: Healthy participants (*n*=3) performed a tonic contraction task with their right and left hands. We recorded brain and spinal cord activity using OPMs positioned on the head and neck, while also recording electromyography (EMG) data from the thumb abductor muscle. During the task, they were asked to follow a target contraction level (~10 % maximal voluntary contraction) with their rectified, smoothed EMG trace as precisely as possible. The data recorded from sensors over the neck were reconstructed in source space using a Bayesian minimum norm inversion (Litvak et al., 2011). Multiple linear regression and canonical variate analysis (CVA) were applied (Friston et al., 1996) to identify within- and cross frequency coupling between brain-EMG, brain-spinal cord, and spinal cord-EMG activity in the frequency range of 5-30 Hz.

Results: Reconstructed current flow showed patches of activity concentrated over the lower cervical region of the spinal cord source space in all participants during both right and left contractions. For brain-muscle functional connectivity, we found evidence for within-frequency associations in the beta band (15-30 Hz; family-wise error (FWE) corrected $p < .05$) as described previously (Conway et al., 1995) as well as cross-frequency interactions (CVA chi-squared $p <. 05$) in all participants. Interactions between the spinal cord and EMG were exclusively cross-frequency (CVA chi-squared $p < . 05$), whereas brain-spinal cord interactions showed both strong within- (FWE corrected $p < .05$) and cross-frequency (CVA chi-squared $p <. 05$), oscillatory functional connectivity. These results were consistent across participants.

Implications: Our results provide evidence for within- and cross-frequency oscillatory interactions between the brain, spinal cord, and muscle during voluntary movement. This

research demonstrates the utility of OPMs in studying endogenous spinal cord activity. Our OPM-based system, allowing concurrent imaging of the brain and spinal cord, opens new possibilities for advancing our understanding of how communication is coordinated in the central nervous system, both in health and disease.

Conway, B. A., Halliday, D. M., Farmer, S. F., Shahani, U., Maas, P., Weir, A. I., & Rosenberg, J. R. (1995). Synchronization between motor cortex and spinal motoneuronal pool during the performance of a maintained motor task in man. The Journal of Physiology, 489(3), 917–924. https://doi.org/10.1113/jphysiol.1995.sp021104. Friston, K. J., Stephan, K. M., Heather, J. D., Frith, C. D., Ioannides, A. A., Liu, L. C., Rugg, M. D., Vieth, J., Keber, H., Hunter, K., & Frackowiak, R. S. J. (1996). A Multivariate Analysis of Evoked Responses in EEG and MEG Data. NeuroImage, 3(3), 167–174. https://doi.org/10.1006/nimg.1996.0018 Litvak, V., Mattout, J., Kiebel, S., Phillips, C., Henson, R., Kilner, J., Barnes, G., Oostenveld, R., Daunizeau, J., Flandin, G., Penny, W., & Friston, K. (2011). EEG and MEG Data Analysis in SPM8. Computational Intelligence and Neuroscience, 2011, 1–32. https://doi.org/10.1155/2011/852961 Mardell, L. C., O'Neill, G. C., Tierney, T. M., Timms, R. C., Zich, C., Barnes, G. R., & Bestmann, S. (2022). Concurrent spinal and brain imaging with optically pumped magnetometers [Preprint]. Neuroscience. https://doi.org/10.1101/2022.05.12.491623

SA08

Sex Differences in Alpha-synucleinopathies

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Background: Past research indicates a higher prevalence, incidence, and severe clinical manifestations of alpha-synucleinopathies in men, leading to a suggestion of neuroprotective properties of female sex hormones (especially estrogen). The potential pathomechanisms of any such effect on alpha-synucleinopathies, however, are far from understood. With that aim, we undertook to systematically review the literature on sex differences in alpha-synucleinopathies, broadening our scope to sex-lineated assessments of prevalence, demographics, biomarkers, genetic factors, clinical features, neuroinflammatory and neurochemical responses, interventions, and quality of life themes.

Methods: In this systematic review, studies investigating sex and gender differences in alpha-synucleinopathies (Rapid Eye Movement (REM) Behavior Disorder (RBD), Parkinson's Disease (PD), Dementia with Lewy Bodies (DLB), Multiple System Atrophy (MSA)) from 2012 to 2022 were identified using electronic database searches of PubMed, Embase and Ovid.

Results: 162 studies were included; 5 RBD, 6 MSA, 20 DLB and 131 PD studies. Overall, there is conclusive evidence to suggest sex-and gender-specific manifestation in demographics, biomarkers, genetics, clinical features, interventions, and quality of life in alpha-synucleinopathies. Only limited data exists on the effects of distinct sex hormones, with majority of studies concentrating on estrogen and its speculated neuroprotective effects. Similarly, there are several methodological caveats that should be considered while evaluating preclinical and clinical studies, all of which are rarely systematically considered in their translational importance. For example, in majority, if not in all, analysed clinical and preclinical studies, there is a lack of focus on the synergistic and antagonistic effects of different sex hormones on various aspects of alpha-synucleinopathies. Most studies predominantly focus on one specific hormone (i.e., estrogen/progesterone), which makes it impossible to fully understand the pathomechanistic complexity.

Conclusion: There is urgent need for future studies to disentangle the underlying sex-specific mechanisms of alpha-synucleinopathies to systematically account for (1) a specific subtype and distinct phenotype of alpha-synucleinopathies (2) ethnicity and geographical location, (3) disease progression, rate and severity (i.e., early versus late onset), (4) monitoring menstrual cycle and endocrinology health in women, (5) direct quantification of sex hormones in both sexes, (6) medication history and responses (i.e., hormones replacement therapy) and (7) consideration of societal, cultural and gender factors that could impact treatment of alpha-

synucleinopathies. A comprehensive assessment of sex and gender differences in alpha-synucleinopathies holds promise for improving diagnosis and management, implementing prevention strategies, and developing treatments with optimal efficacy in both men and women.

Raheel, K., Deegan, G., Di Giulio, I., Cash, D., Ilic, K., Gnoni, V., ... & Rosenzweig, I. (2023). Sex differences in alpha-synucleinopathies: a systematic review. Frontiers in Neurology, 14.

SA10

Stepping into Independence: How Children Learn to Walk

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Walking, a seemingly effortless human skill, involves the intricate coordination of numerous muscles. With over 50 muscles in each leg, at least half of them actively contribute to the complex task of leg movement during walking. The notion that the central nervous system simplifies this complexity through the use of functional units, known as locomotor primitives, has garnered significant attention.

Our research delves into the modular organization of human locomotion, focusing on the development of walking in children. Newborns, when supported under the armpits with their feet touching a surface, instinctively exhibit a 'stepping reflex.' This innate behavior is hardwired into our neural circuitry. However, typically developing children only attain the ability to walk independently around one year later. The question arises: How do infants progress from these rudimentary movements to mastering the art of walking? And how do toddlers' initial steps transform into the refined walking patterns seen in adults? In this presentation, we will explore how the number and nature of locomotor primitives undergo changes as independent walking emerges in typically developing children and in those with neurodevelopmental disorders, such as cerebral palsy. Finally, we will shed light on the selective interactions between the human cortex and these primitives during walking in typically developing toddlers and adults.

SA11

Implantable modular neuroprostheses to understand and restore neural functions

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Neuroengineering is a novel discipline combining engineering including micro and nanotechnology, electrical and mechanical, and computer science with cellular, molecular, cognitive neuroscience with two main goals: (i) increase our basic knowledge of how the nervous system works; (ii) develop systems able to restore functions in people affected by different types of neural disability. In the past years, several breakthroughs have been reached by neuroengineers in particular on the development of neurotechnologies able to restore sensorimotor functions in disabled people.

In this presentation, I will provide several examples on how implantable interfaces can be used to restore sensory (tactile, position and thermal feedback for hand prostheses, vision), motor (grasping, locomotion), and autonomic functions (for type 2 diabetes and cardiovascular problems) and how they can be used also to understand cognitive functions such as language and decision making.

C01

Manipulating cortico-cortical plasticity in motor control brain regions changes neural excitability and interregional oscillatory communication

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Introduction:

Voluntary motor control is subserved by a neural network involving the interaction between the two primary motor cortices (M1). It is well established that the pathway connecting the right and the left M1 has a very important role in movement execution allowing single muscle control. Specifically, the contralateral M1 exerts a powerful inhibitory influence over the ipsilateral M1 through transcallosal connections and it is functionally relevant and correlated with motor control. Moreover, the pathway can be examined in humans; by stimulating the contralateral M1 shortly (6 to 8 ms) before the ipsilateral M1, it is possible to influence how activity in the ipsilateral M1 evolves. When this is done repeatedly, the influence that contralateral M1 exerts over ipsilateral M1 is modulated. Such a procedure is often referred to as corticocortical paired associative stimulation (ccPAS).

Aim:

In this study we used ccPAS over the right and the left M1, to selectively manipulate synaptic plasticity in the pathway connecting such regions, and then measured changes in cortical excitability and oscillatory connectivity in the human brain of 37 healthy adults (aged 18-40 years). All participants had no personal or familial history of neurological or psychiatric disease, were right-handed and gave written informed consent (Department of Psychology Research Ethics Committee, - ref numb: ETH2324-0189)

Methods:

In two separate blocks, we stimulated over the left and the right M1 with either single pulse TMS, paired pulse TMS (12ms inter-pulse interval - IPI), or dual-site paired pulse TMS over both left and right M1 (8ms IPI) and measured the levels of motor-related M1 excitability, from the first dorsal interosseous muscle with electromyography. Moreover, we measured motor electrophysiological (EEG) responses at rest. Between the two blocks, we applied the ccPAS protocol by repeatedly stimulating over left and right M1 with the same 8ms IPI at 0.1Hz during a 15minture interval. This ccPAS protocol is proven to evoke synchronous pre- and post-synaptic activity and to strength interregional connectivity between the left and right primary motor cortex in a Hebbian-like manner.

Results:

The results of the study showed selective changes in the motor-evoked potentials (MEPs) and EEG oscillatory activity after applying ccPAS over the left and then the right M1 (8ms IPI); we observed an enhancement of local right M1 excitability ($F_{1,36} = 4.12$, $p < 0.05$). However, no changes in cortical inhibition were observed ($p > 0.05$). The changes in cortical excitability were observed in tandem with an increase of phase synchrony in beta (Monte Carlo p value < 0.01), while no phase changes were observed in the alpha or theta bands ($p > 0.05$). Conversely, administration of the control ccPAS protocol (1ms IPI) showed no alterations neither in EEG phase activity nor in M1 cortical activity.

Conclusions:

These findings demonstrate a clear link between physiology of the motor control network and the resonant frequencies mediating its interactions.

C02

Accurate detection of spared hand motor functions after cervical spinal cord injury through latent manifold analysis based on high-density electromyograms

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Individuals with motor complete cervical spinal cord injuries [1] (SCI) typically lose all motor control of their hands, which has a significant impact on all daily living tasks. We recently found through surface electromyography (EMG) [2], [3] that some motor units (MUs) below the injured area remain unaffected and can generate task-specific signals controlling paralyzed hand motions. Based on this discovery, we hypothesize that these preserved signals can be utilized to predict the kinematics of hand movements. This prediction could empower patients to regain some degree of hand function through exoskeletons or other assistive systems.

To investigate this hypothesis (Fig. 1), we used two datasets consisting of 13 healthy and 8 motor complete chronic (C4-C6) SCI subjects (Table 1). Each subject followed and attempted to mimic a digitally displayed hand performing individual finger flexions, grasps, and 2- or 3-finger pinches, while we recorded the sEMG of their forearm using 320 electrodes. Our previously published AI [4], capable of real-time hand kinematics prediction, was then trained for each subject individually (Fig. 2A). For an explainable classification between SCI and healthy subjects or between the different movements performed (Fig. 3A), we projected the high-dimensional model latent spaces using UMAP [5] into a discernable 2D space. To make the projections between each other comparable, we automatically align the latent spaces during the projection stage together.

We found that our deep learning model was capable of making proportional hand kinematic predictions for healthy individuals, but when applied SCI patients it could, as expected, only predict a subset of movements, with a predominant focus on grasping and pinching actions (Fig. 2B & C, $p < 0.001$, $n = 60480$ predictions; 2880 per subject). Interestingly, we could classify the movements performed by SCI patients with an accuracy exceeding 92% and those performed by healthy individuals with an accuracy surpassing 97% (Fig. 3B & C, $p = 0.054$, $n = 21$ accuracy scores). By applying UMAP to the latent space, we visualized the spared motor functions that are still present in the electromyogram with clear distinctions between already recoverable and not recoverable motor functions. Utilizing these projections, we developed a classification algorithm that achieved an accuracy rate of 95%, with a single outlier injured subject being misclassified. Upon examination of this outlier, it was plausible to speculate that this subject may have the potential for complete hand recovery.

Although the results have been tested on offline data and online assessment is now in progress, we believe that such latent space analysis can provide valuable rehabilitation prospects for clinicians and patients alike and could help pinpoint the exact spared motor dimensions that are still present in the electromyograms. Lastly, the proposed AI system can proportionally predict in some cases more than half of the attempted movements which demonstrates that our solution can become a viable kinematics decoder for SCI patients.

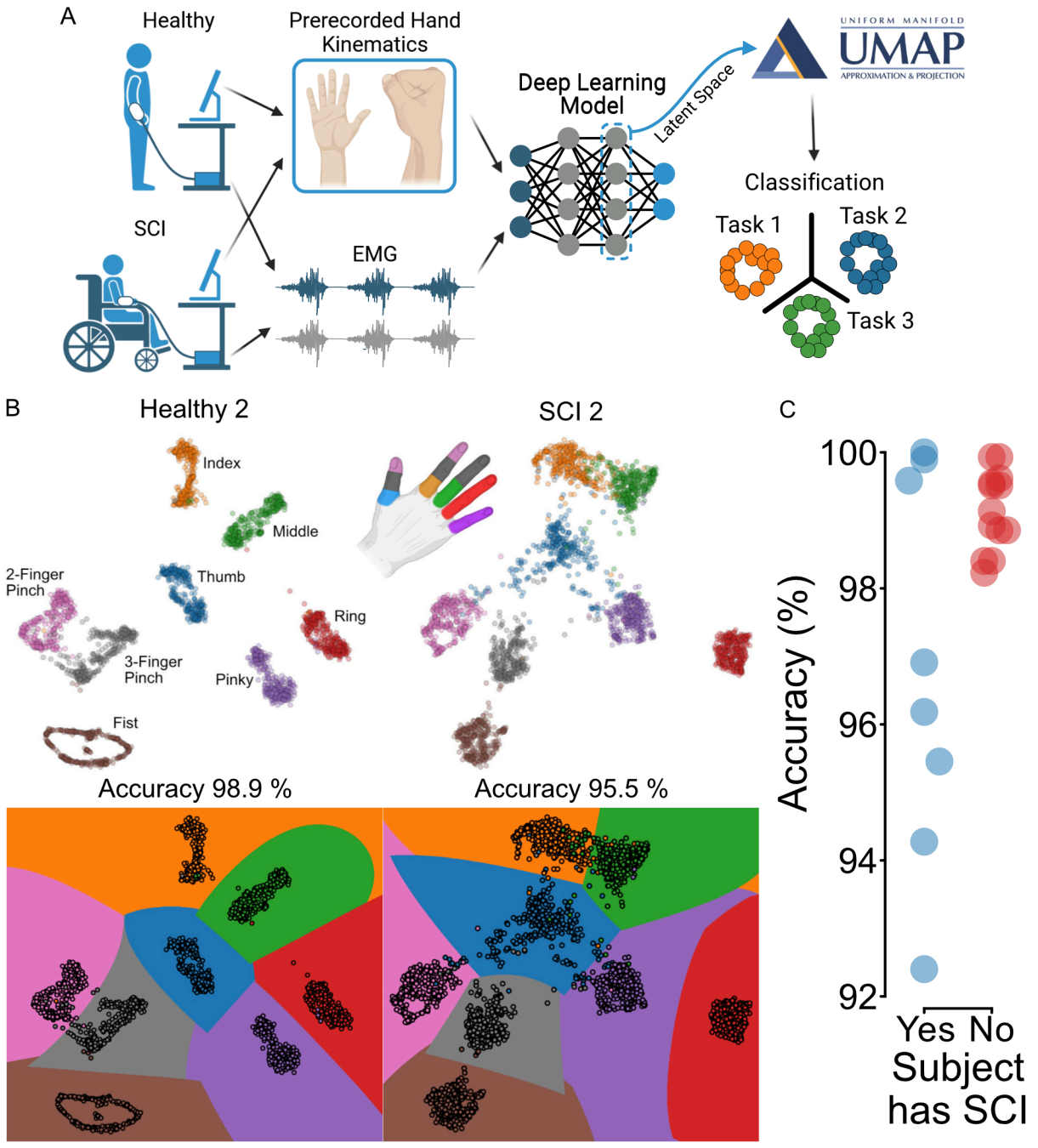

Fig. 3 **A.** We trained our previously published deep learning model capable of real-time accurate hand kinematics prediction on 8 subjects with and 13 subjects without a spinal cord injury. Each model is trained individually for each subject and can output all 21 joints of the hand in 3D space. Using UMAP, a dimensionality reduction technique, we projected the latent space vectors into 2D and use them to classify different movements from each other. **B.** Example of UMAP projections for the 2nd healthy subject and the 6th SCI patient. The hand at the top has the fingers colored in order to display which finger executes which movement. The classification boundaries achieved by an SVM trained on the UMAP projections are drawn in the bottom panels. **C.** Classification accuracy for all subjects, which resulted in a total of 21 data points. To determine if the results were statistically significant, we conducted an independent Welch's t-test. The p-value was 0.054, which was not statistically significant.

Subject	Age range (years)	Gender	Injury level	AIS	Wrist movement	Time since injury (years)
S1	36-40	M	C6	B	yes	18.8
S2	31-35	M	C5	B	yes	9.1
S3	41-45	F	C6	B	yes	24.2
S4	36-40	F	C5	A	yes	24.2
S5	31-35	M	C4	A	no	22.2
S6	56-60	M	C5	A	no	6.9
S7	41-45	M	C6	C	no	18.2
S8	36-40	F	C5	B	yes	5.0

Table 1 SCI patient characteristics reproduced with permission from Souza de Oliveria *et al.* [3]. Injury level represents the lowest spinal cord segment that still posses intact sensory sensation and can produce muscle forces to counteract gravity (NIL in ASIA guidelines [1, p. 17]). The AIS column shows the degrees of the **A**SIA **I**mpariment **S**ale [1, p. 18]. In this scale, an A grade indicates a **motor complete** injury, signifying the absence of any motor function in the sacral section. A B grade represents a **sensory incomplete** injury, where sensory information in the sacral region is preserved, but there is no motor function. Lastly, a C grade denotes a **motor incomplete** injury, indicating the presence of residual motor function in the sacral region.

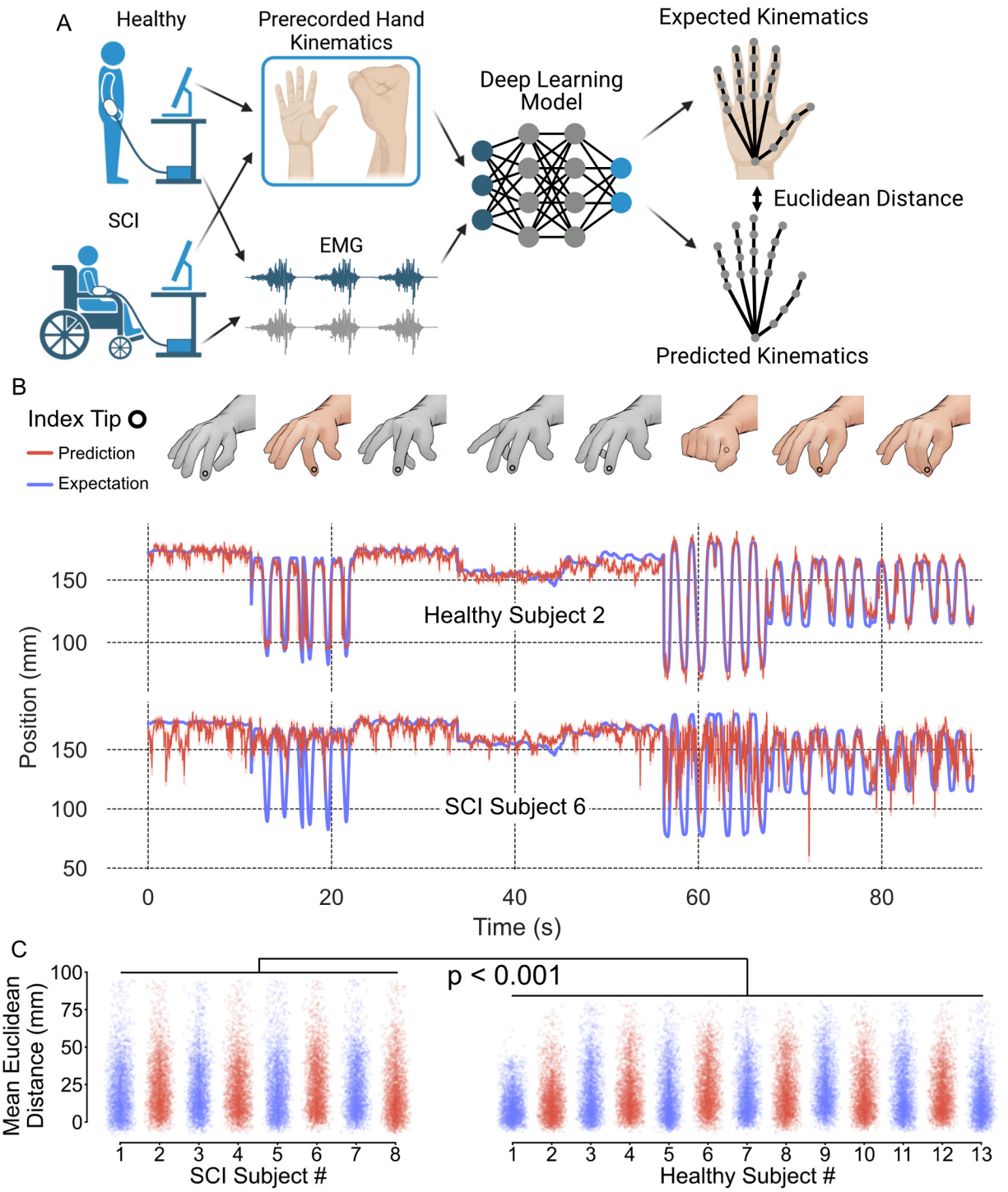

Fig. 2 **A.** We trained our previously published deep learning model capable of real-time accurate hand kinematics prediction on 8 subjects with and 13 subjects without a spinal cord injury. Each model is trained individually for each subject and can output all 21 joints of the hand in 3D space. We then compare the predictions against the prerecorded movements by computing the Euclidean distance. **B.** Example of index tip position during all 8 executed movements for the 2nd healthy subject and the 6th SCI patient. The hands at the top are colored if the index finger plays an active role in a movement and are grey if not. **C.** Euclidean distance results for all subjects computed between the predicted and expected joint positions for each time point. The results are averaged across all 21 joints, resulting in a total of 2,880 data points per subject or 60,480 in total. We assessed the statistical significance using an independent Welch's t-test and obtained a highly significant p-value smaller than 0.001.

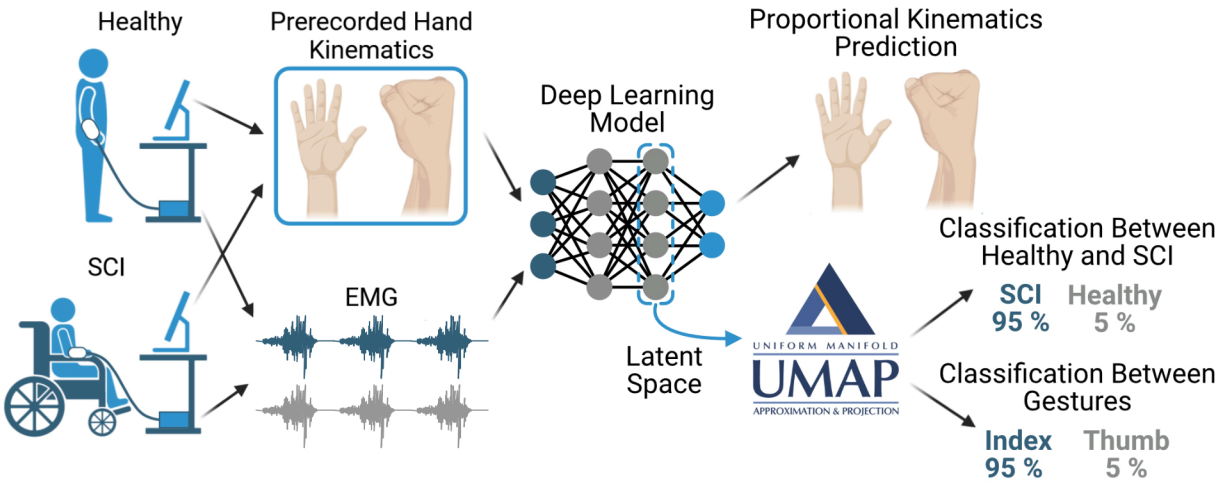

Fig. 1 We collected surface Electromyography (EMG) data from a group of 8 individuals with spinal cord injuries (SCI) and 13 individuals without. During the data collection process, participants were asked to attempt to replicate prerecorded hand movements displayed on a screen. Using this collected data, we trained individual deep learning models for each subject that are capable of proportionally predicting hand positions in 3D space. Additionally, we applied a dimensionality reduction technique called UMAP to transform the latent space of our models into a 2D representation. The 2D projections can be used to distinguishing between SCI and healthy subjects or between different hand movements. This has the potential to offer individuals with SCI the ability to control and perform multiple (in this study 8) different movement again.

[1] R. Rupp et al., "International Standards for Neurological Classification of Spinal Cord Injury: Revised 2019," Top Spinal Cord Inj Rehabil, vol. 27, no. 2, pp. 1–22, 2021, doi: 10/gsb3c3. [2] J. Ting et al., "A wearable neural interface for detecting and decoding attempted hand movements in a person with tetraplegia," in Proceeding of the 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Berlin, Germany: IEEE, Jul. 2019, pp. 1930–1933. doi: 10/gnp6g3. [3] D. Souza de Oliveira et al., "You Will Grasp Again: A Direct Spinal Cord/Computer Interface with the Spared Motor Neurons Restores the Dexterous Control of the Paralyzed Hand after Chronic Spinal Cord Injury." medRxiv, Sep. 10, 2022. doi: 10.1101/2022.09.09.22279611. [4] R. C. Sîmpetru, M. März, and A. Del Vecchio, "Proportional and Simultaneous Real-Time Control of the Full Human Hand From High-Density Electromyography," IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 31, pp. 3118–3131, Jul. 2023, doi: 10/gsgk4s. [5] L. McInnes, J. Healy, and J. Melville, "UMAP: Uniform Manifold Approximation and Projection for Dimension Reduction," arXiv:1802.03426 [cs, stat], Sep. 2020.

C03

Can the somatosensory system integrate a tactile model for an extra robotic body part?

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Augmentation technology is a rapidly expanding field, and with it there is growing interest in how such devices interface with the body. When learning to control augmentation devices, one important sensory input is the tactile feedback received from where the device is worn on the body, described as intrinsic touch. We asked whether the brain gathers information from intrinsic tactile inputs to construct an internal representation of the device. We particularly wanted to determine whether the brain integrates intrinsic touch inputs with the somatosensory inputs from the biological fingers.

To investigate such changes in somatosensory processing, we are using a supernumerary robotic finger (the Third Thumb, Dani Clode Design). The Third Thumb is worn on the ulnar side of the hand and controlled by pressure sensors underneath the big toes. In our ongoing study, we are assessing changes to inter-finger sensory representations before and after a week of altered finger-synchronisation motor training: either due to extended Third Thumb training, or training to play the keyboard (n=50 in total). We are using fMRI to study the representational similarity patterns across the biological fingers and Third Thumb (via intrinsic touch) before and after training using a soft pneumatic actuator stimulation system. We are also using a psychophysics paradigm to explore changes in sensory integration, examining tactile temporal order judgements involving the biological fingers and the Third Thumb.

Our fMRI results so far suggest that Third Thumb training has the largest impact on the biological finger representation. Following training, we see a collapsing of the canonical finger representation, not seen to the same extent in our active control group, and replicating previous results obtained from an active movement paradigm[1]. We then wanted to investigate whether the intrinsic touch inputs from the Third Thumb are represented differently from merely stimulating the side of the hand where the Third Thumb is worn (the 'palm'). Preliminary findings suggest there may be some small shifts in the way the somatosensory system mediates this intrinsic touch information compared to just palm stimulation after Third Thumb training. However, when considering the whole hand representation, it appears shifts in the Third Thumb and palm are likely tied to shifts in the finger representation.

Overall, these early findings suggest that the brain is more likely to change the representation of the biological body to account for the use of an additional limb, rather than creating an independent representation of the technology. If these results withstand, this could produce important considerations for how to safely integrate such technologies with our body in the future. The next steps for this work will be to use markerless tracking data to precisely investigate how co-usage of the Third Thumb with the biological fingers shapes their neural representation.

Kieliba, P., Clode, D., Maimon-Mor, R. O., & Makin, T. R. (2021). Robotic hand augmentation drives changes in neural body representation. https://doi.org/10.1126/scirobotics.abd7935

C04

EEG Neural Markers for Parkinson's Disease Symptom Fluctuation during Daily Life Activities

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Parkinson's disease (PD) is characterised by enhanced synchronisation of beta (13-30Hz) oscillations in the motor cortex and basal ganglian networks. A slowing EEG rhythm characterised by an enhanced alpha (8-12 Hz) peak in PD at 8 Hz has also been observed as a marker of cognitive decline as indicated by ACE scores. Current literature focusses mostly on observations from subcortical activity during hand movements or cortical measurements at rest. Here, we investigate movement and cortical neural activity using real world neuroscience, recording PD patients in a domestic environment.

We observed participants' (13 PD, 24 control) gait dynamics during walking and whilst they made a cup of tea. PD patients repeat the tasks a few hours apart to capture the natural fluctuations of their medication schedule. We observe elevated low beta power (13-20 Hz) in PD participants OFF medication compared to ON and age matched controls, but not between ON and controls. Conversely, we observe elevated alpha power both OFF and ON relative to controls, but not between the ON and OFF conditions indicating distinct motor and cognitive functions for alpha and beta power.

Alpha power for ON and OFF were both significantly higher than controls during walking ($t = 3.5$, $p=0.006$; $t=2.6$, $p=0.02$) and during the tea task ($t=4.2$, $p = 0.001$; $t=2.7$, $p=0.02$). Low beta power was greater for OFF vs ON and OFF vs controls during walking ($t=2.9$, $p=0.02$; $t=2.3$, $p=0.03$) and during the tea task ($t=3.2$, $p=0.007$; $t=2.5$, $p=0.025$). No significant difference was found between ON and controls, suggesting beta levels are restored to a healthy level. ACE scores correlated negatively with low alpha (7-10Hz) power during the 4m walk ($r=-0.49$, $p=0.03$), indicating a negative association with cognitive abilities. These results are in line with previous studies suggesting that beta power is modulated by medication and suggest that alpha power is elevated in PD patients relative to controls but not modulated by medication. We also observed a case study patient across 7 monthly visits. Beta power and UPDRS scores were elevated OFF medication for 6 of 7 visits. We also analysed the gait stages during walking calculating the power ratio between the support and swing phases of the gait cycle which showed a greater beta ratio ON medication. This indicates greater desynchronisation of beta during movement, reflective of healthy physiological gait.

Our results suggest that digital neural markers can be reliably measured during free behaviour to capture both motor and cognitive functioning. Furthermore, they indicate the potential of tracking neural markers relative to individual baseline fluctuations. Here we observe a snapshot of the average power, but future research can look at the temporal dynamics of the tea making task to uncover the interactions between alpha and beta power changes across the task's many sub-elements.

C05

Excitatory/inhibitory modulations reflect the simultaneous processing of top-down and bottom-up information during Joint Action coordination.

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Joint actions (JA) are an essential component of animal behavior as they require to coordinate with others in space and time. The optimization of mutual motor adaptations must be based on the simultaneous analysis and integration of signals across multiple temporal scales. In this context, a JA motor plan has to incorporate cues specifying partners' actions (bottom-up) and prior knowledge (top-down). Therefore, the motor system must be "prepared" to predict - from minimal kinematic cues - which effect the partner's action will have and to rapidly integrate this data with prior information. From a neurophysiological perspective, the behavioral co-regulation emerging during JA can be reduced to a continuous and dynamic process of action selection and execution. In fact, the integration of bottom-up and top-down information to deliver the most appropriate course of action boils down to the fine equilibrium between excitatory and inhibitory signals in sensorimotor circuits. We designed a transcranial magnetic stimulation (TMS) protocol to investigate the neurophysiological fingerprints of the two inferential processes (top-down and bottom-up) naturally at play during human motor coordination.

Here we used a typical bimanual task – reaching/grasping for a bottle – and adapted it to become a unimanual JA task: the participant is asked to hold a bottle (JA) while the other member of the dyad (the confederate) has to reach either for the JA-bottle or for another bottle stabilized by a mechanical clamp (No_JA). We manipulated priors' availability (K vs. No_K) to introduce the necessity for the participant to differently weight top-down or bottom-up processing. In summary, the confederate could reach the bottle either held by the participant (JA) or the mechanical clamp (no_JA), and the participant could either know (K) or not know (no_K) the target bottle in advance. In no_K trials, the participant could only rely on partner's kinematic cues to decode which bottle he was pointing toward and, therefore, whether it was a JA or a no_JA trial. In K trials, by contrast, this information was provided explicitly by prior information. We use single pulse TMS to investigate corticospinal excitability (CSE) and cortical silent period (cSP) from participants' opponens pollicis (OP). TMS was delivered at four timings: rest, onset of confederate's movement, pre-shaping, grasping.

Our results show that JA generally produce larger CSE and longer cSPs. At the same time, the two neurophysiological indexes seem to reflect two temporally dissociable processes. CSE was modulated early on before the action started if prior information about confederate's choice is available. Differently, cSP modulation emerged during the reaching action -regardless prior information- only when kinematic features are accessible. These two indexes could thus reflect the concurrent elaboration of contextual priors (top-down) and the online sampling of kinematic cues (bottom-up).

Here, by showing a temporal dissociation between excitatory and inhibitory indexes and differential dependence on prior information and partner's kinematics, we present new evidence that specific neurophysiological modulations may represent the fingerprints of the natural unfolding of top-down and bottom-up complementary inferential processes which contribute to the optimization of social motor interaction.

- Derosiere, G. and Duque, J. (2020) 'Tuning the Corticospinal System: How Distributed Brain Circuits Shape Human Actions', Neuroscientist. SAGE Publications Inc., pp. 359–379. - Friston, K. (2010) 'The free-energy principle: A unified brain theory?', Nature Reviews Neuroscience, pp. 127–138. - Pezzulo, G. et al. (2019) 'The body talks: Sensorimotor communication and its brain and kinematic signatures', Physics of Life Reviews. Elsevier B.V., pp. 1–21. - Sebanz, N., Bekkering, H. and Knoblich, G. (2006) 'Joint action: Bodies and minds moving together', Trends in Cognitive Sciences, pp. 70–76. - Spampinato, D.A. et al. (2023) 'Motor potentials evoked by transcranial magnetic stimulation: interpreting a simple measure of a complex system', The Journal of Physiology, pp. 1–25.

C06

Effects of theta-gamma transcranial alternating current stimulation on motor skill acquisition in young healthy volunteers and stroke patients

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Introduction: Theta-gamma (θ-γ) phase amplitude coupling is a widespread phenomenon across the cerebral cortex associated with various aspects of memory and learning (1), but also with motor skill acquisition (2,3). Applying transcranial alternating current stimulation (tACS), a technique thought to entrain oscillations in targeted brain regions (4), with a peak-coupled θ-γ waveform, Akkad et al. enhanced motor skill acquisition in a thumb acceleration task in healthy participants (3).

Objectives: We aim to further investigate if θ-γ tACS enhances motor skill acquisition in healthy individuals by re-studying the idea of Akkad et al. (3) in an extended thumb movement task. Moreover, we study the effect of θ-γ tACS in chronic stroke patients with a history of impaired hand motor function.

Methods: We conducted two randomized, triple-blinded, sham-controlled studies, including 78 healthy volunteers and 20 chronic stroke patients. In our motor skill acquisition task, participants repeatedly pressed a sequence of buttons with their thumb as fast as possible [Fig.1B]. After a pre-tACS baseline, they received peak-coupled θ-γ tACS (TGP) or sham stimulation over M1 throughout 6 task blocks. An active control group in the healthy cohort received trough-coupled θ-γ tACS (TGT) [Fig.1A]. For exploratory analyses, we measured the thumb acceleration. Our primary outcome measure *motor skill acquisition,* the relative reduction of the performance measure *movement duration* over the task, was compared between conditions using unpaired t-tests or Wilcoxon rank-sum tests. The effects of *condition* and *block* on *movement duration* and *peak acceleration* were analyzed in linear mixed-effects models (LME). At the date of abstract submission, the authors are blinded to the tACS conditions. The studies were pre-registered on https://osf.io/mqwt5 and clinicialtrials.gov (Identifier: NCT05576129).

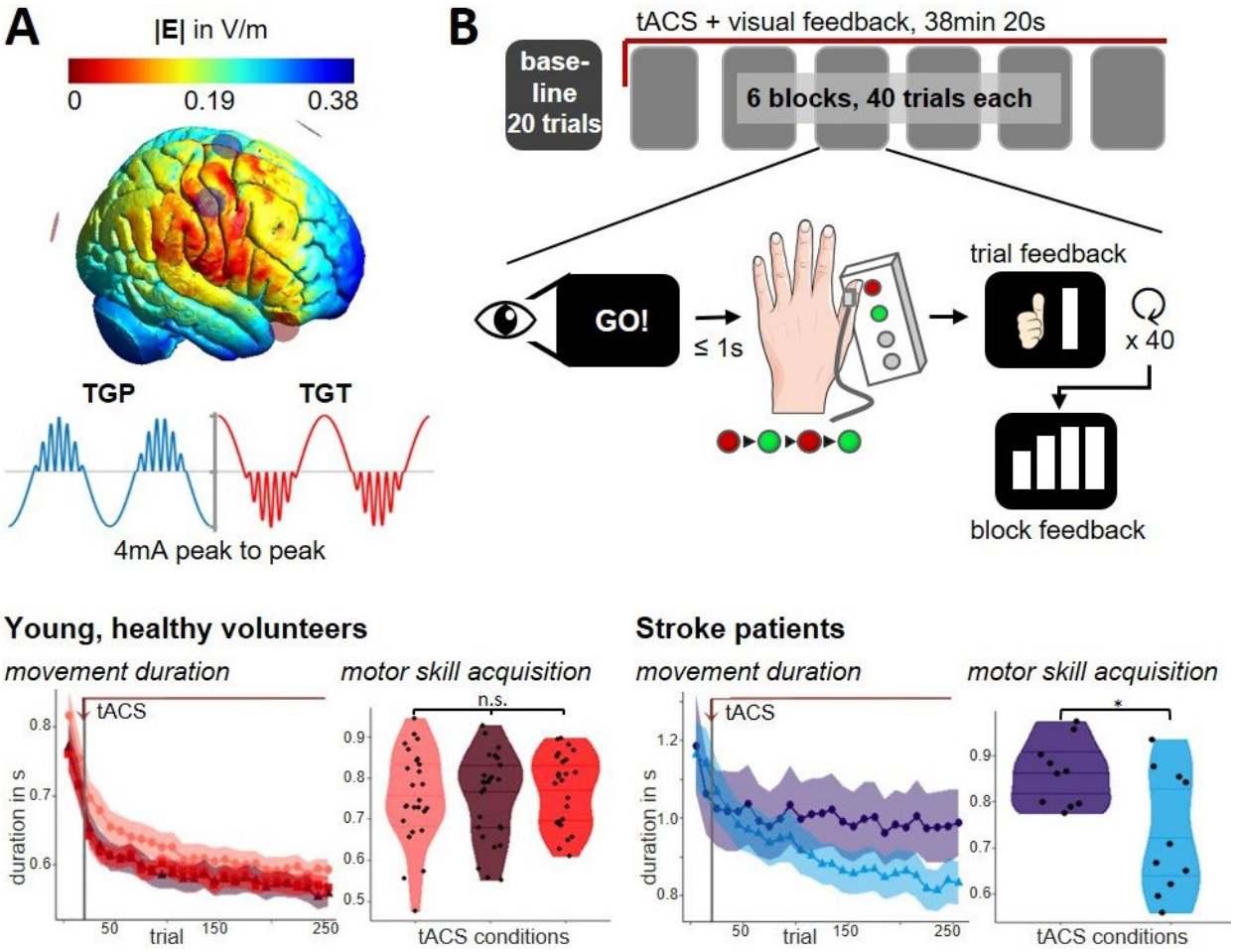
Results: In both cohorts, participants showed an improvement in *movement duration* over the task. The primary outcome measure *motor skill acquisitio*n differed significantly between tACS conditions in stroke patients ($t(13.7)=2.71$, $p=0.017$), but not in the healthy cohort (all uncorrected $p>0.05$) [Fig.2]. Coherently, the *condition* x *block* interaction effect on *movement duration* was significant (likelihood ratio test (LRT): $X^2(1)=13.5$, $p<0.001$) with post-hoc analyses revealing a difference in slopes between conditions ($p<0.001$, 95% CI [13.3, 39.6]) in stroke patients but not in the healthy cohort (LRT: $X^2(2)=2.36$, $p=0.31$). In contrast, in an exploratory

analysis, we found a significant effect of *condition* on *peak acceleration* in the healthy (LRT: $X^2(2)=10.15$, $p=0.006$), but not in stroke patients (LRT: $X^2(1)=0.07$, $p=0.79$).

Conclusion: Theta-gamma tACS impacted how much chronic stroke patients improved their performance while practicing a thumb movement task, but did not show this effect in young healthy individuals. However, only in healthy participants, but not in stroke patients, θ-γ tACS modulated thumb acceleration. The observed qualitatively different effects may help to draw conclusions on neurophysiological differences between optimally functioning and lesioned networks relevant to motor skill acquisition.

Figure 1 Experimental design. (A) Top: electric field simulation from SimNIBS (5), below: tACS waveforms. (B) Motor skill acquisition task.

Figure 2 Results. *Movement duration:* timeline for each tACS condition. *Motor skill acquisition*: statistical significance of the pairwise comparisons indicated (n.s.: not significant, *: $p<0.05$).



1. Lisman JE & Jensen O (2013). Neuron 77(6), 1002-1016 2. Dürschmid S et al. (2014). PLoS One 9(2), e89576 3. Akkad H et al. (2021). eLife 10, e67355 4. Wischnewski M et al. (2023). Trends Cogn Sci 27(2), 189–205 5. Thielscher A et al. (2015). Annu Int Conf IEEE Eng Med Biol Soc, 222-225

C07

Differential effect of age on implicit and explicit motor learning processes

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It is well established that older adults experience deficits in motor control, but how aging impacts motor adaptation remains a subject of considerable debate. Some studies suggest prominent learning impairments; however, others have shown no age-related differences. These mixed results may be explained by the fact conventional adaptation tasks engage both implicit and explicit learning processes, with aging having a differential impact on each process. Moreover, previous studies have typically involved small sample sizes reducing sensitivity to detect possible effects of aging.

To address these two concerns, we re-examined this question using methods that isolate either implicit or explicit learning processes in visuomotor rotation tasks (Experimental protocols were approved by UC Berkeley's IRB). In Experiment 1, we used clamped feedback to isolate implicit adaptation and collected a large sample using a web-based crowdsourcing approach (n = 100; 50/group). Participants reached to one of four targets and during the perturbation block, the cursor always following an invariant trajectory, rotated by 45º from the target position (non-contingent). Despite being asked to ignore the cursor, participants in both groups exhibited implicit adaptation in the opposite direction of the cursor. Strikingly, the results show that implicit adaptation was enhanced with age: Whereas the younger participants adapted 17.8° (sd=1.6°), the older participants adapted 24.4° (sd=1.5°) ($t(97) = 3.0$, $p = 0.004$). In Experiment 2, we used delayed feedback to isolate explicit re-aiming (n = 200; 100/group). Specifically, participants reached to one of three targets, receiving endpoint feedback, with the cursor appearing after an 800 ms delay. During the perturbation block, the cursor position was rotated by 60º from the actual hand position (contingent). Strategic re-aiming was attenuated in the older participants. At the end of the perturbation block the younger participants had adapted 33.3° (sd=3.6°) whereas the older participants had adapted 20.2° (sd=3.7°) ($t(98) = 2.6$, $p = 0.01$).

We complemented these experiments with a meta-analysis, focusing on 60 studies that have reported data relevant to the question of the effect of aging on motor adaptation. We focused on two key dependent variables: Late adaptation, a measure that likely reflects the contribution of both implicit and explicit processes, and the aftereffect, a measure of implicit adaptation. Across studies, the aftereffect was enhanced in older adults (0.4 (95% CI = [0.2, 0.6]; positive = greater in older adults). Late adaptation showed the opposite effect, with this measure attenuated in older adults (mean effect size [CI]: -0.4 [-0.6,-0.2]). Assuming this attenuation is likely driven by an explicit re-aiming deficits in older adults, the results of the meta-analysis converge with our experimental results, pointing to a differential effect of age on implicit and explicit motor learning processes.

C08

EFFECTS OF EXTRINSIC REWARD ON MEASURES OF MOTOR EXCITABILITY DURING MOTOR SKILL LEARNING

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INTRODUCTION: Motor learning is the process by which movements can be improved with practice. A large amount of research has demonstrated that this process strongly relies on reduction of movement errors based on sensory feedback (Shadmehr et al., 2010). In the recent years, studies have also shown that reinforcement feedback (providing knowledge of performance) and reward (in the form of extrinsic motivation), can also impact motor learning (Vassiliadis et al., 2021; 2022).

OBJECTIVE: Despite its potential clinical relevance for motor rehabilitation, the underlying neurophysiological mechanisms remain largely unexplored. Specifically, whether reward affects the excitability of motor structures during motor learning remains unclear.

METHODS: 65 healthy right-handed participants (44 Females; 23.85 ± 3.22 yr old) divided in 3 groups performed a right-hand pinch-grip motor skill learning task (6 training blocks of 40 trials) with sensory feedback only (GroupS), sensory and reinforcement feedback (GroupSR) or with both feedbacks combined with monetary reward (GroupSRR). Study was approved by University Ethical Committee.To probe the excitability of motor structures, we applied transcranial magnetic stimulation (TMS) on the left motor cortex (130% of resting motor threshold of Flexor Policis Brevis muscle) before, during and after training (pre, intra and post training blocks) in the three groups. This allowed us to evaluate the effects of learning on corticospinal (CS) excitability (measured as Motor Evoked Potentials- MEPs), GABA-ergic short-intracortical inhibition (SICI) and use-dependent plasticity (UDP assessed by considering directional changes in TMS-evoked movements). Here our main goal was to assess the impact of reward at the neurophysiological level by assessing and comparing the MEPs (mean amplitude and variability measured as coefficient of variance (CV)), SICI and UDP of the 3 groups (GroupS, GroupSR, GroupSRR) during the 2 training blocks (intra, post blocks {normalized and expressed in percentage of pre-training block}).

RESULTS: At the behavioral level, motor learning was clearly higher in the group who received reward (GroupSRR) compared to the two other groups who only received feedback (GroupS and GroupSR). Next, we found that motor training was associated with a general increase in corticospinal excitability as well as clear signs of UDP that were equivalent in all groups. Further, we did not find any significant effect of training or group on SICI measures. Yet interestingly for CV MEPs, we noted a group effect (no training or trainingXgroup effect) with the group who learned with reward (GroupSRR) displayed a lower variability of CS-excitability compared to the other groups- CV of MEPs (normalized to pre-training) was 93% for Group SRR, 101.8% for GroupSR and 118.69% for GroupS. Currently, we are performing further statistical and exploratory analyses to evaluate if there is an association between training-related changes in CS-excitability variability and performance error, as well as individual scores

of Sensitivity to Punishment and Sensitivity to Reward (SPSRQ Questionnaire {Lardi et al., 2008; Torrubia, 2001} completed by each participant at the beginning of our experiment).

CONCLUSION: Our current results indicate that the observed facilitatory effect of reward on motor learning (reduction in errors) may be driven by a reduction in variability of cortico-motor excitability.

1. Shadmehr, R., Smith, M. A., & Krakauer, J. W. (2010). Error correction, sensory prediction, and adaptation in motor control. Annual review of neuroscience, 33, 89-108. 2. Vassiliadis, P., Derosiere, G., Dubuc, C., Lete, A., Crevecoeur, F., Hummel, F. C., & Duque, J. (2021). Reward boosts reinforcement-based motor learning. Iscience, 24(7). 3. Vassiliadis, P., Lete, A., Duque, J., & Derosiere, G. (2022). Reward timing matters in motor learning. Iscience, 25(5). 4. Lardi, C., Billieux, J., d’Acremont, M., & Van der Linden, M. (2008). A French adaptation of a short version of the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ). Personality and Individual Differences, 45(8), 722-725. 5. Torrubia, R., Avila, C., Moltó, J., & Caseras, X. (2001). The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) as a measure of Gray's anxiety and impulsivity dimensions. Personality and individual differences, 31(6), 837-862.

C09

Management of Myalgia Encephalomyelitis/Chronic Fatigue Syndrome in Older Adults: A Comprehensive systematic Review of ClinicalTrials.gov

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Background: Myalgia Encephalomyelitis/Chronic Fatigue Syndrome (ME/CFS) is a complex, debilitating neuro disorder affecting multiple body systems and roughly 50 million individuals worldwide. It is a complex physiological phenomenon that arises during sustained or repetitive muscular activity, limiting an individual's capacity to perform physical tasks. This debilitating condition is primarily attributed to the inability of muscle fibers to contract effectively. Despite its significant global health impact, our understanding of ME/CFS's causes and pathophysiology is incomplete.

Methods: A search on ClinicalTrials.gov was performed on August 03, 2023, using "chronic fatigue syndrome." Four independent reviewers screened trials matching specified eligibility criteria. Criteria included relevance to CFS, completion status, interventional design, inclusion of older adults, and a defined phase. Key trial data, such as intervention details, therapeutic mechanisms, primary endpoints, participant numbers, study duration, and outcomes, were retrieved for evaluation.

Results: The initial search of the database retrieved 191 clinical trials. Following the screening that excluded incomplete, non-geriatric, and non-interventional studies, 45 trials were shortlisted. Further filtration led to the final selection of 32 clinical trials. Most trials utilized randomized allocation (69.7%) and parallel assignment (69.7%). The most common masking method was open-label (36.4%), and the United States emerged as the leading study host (36.4%). Herbal/Dietary supplements were the most common interventions, accounting for 36.4% of the trials. Prisma flow chart was created to identify the process.

Conclusion: This systematic review aims to provide a comprehensive overview of clinical trials related to the management of ME/CFS in older adults, utilizing data from ClinicalTrials.gov. By systematically reviewing the available evidence, this study contributes to a better understanding of ME/CFS management strategies for older populations, potentially informing clinical practice and future research in this area.

Keywords: Myalgia Encephalomyelitis, chronic fatigue syndrome, movement, neurology, Neurophysiology.

[1] Er U, Js L, Dj B, Cw L, Al K, A N, et al. CDC Grand Rounds: Chronic Fatigue Syndrome - Advancing Research and Clinical Education. MMWR Morb Mortal Wkly Rep 2016;65. https://doi.org/10.15585/mmwr.mm655051a4. [2] Tate WP, Walker MOM, Peppercorn K, Blair ALH, Edgar CD. Towards a Better Understanding of the Complexities of Myalgic Encephalomyelitis/Chronic Fatigue Syndrome and Long COVID. Int J Mol Sci 2023;24:5124. https://doi.org/10.3390/ijms24065124. [3] Słomko J, Newton JL, Kujawski S, Tafil-Klawe M, Klawe J, Staines D, et al. Prevalence and characteristics of chronic fatigue syndrome/myalgic

encephalomyelitis (CFS/ME) in Poland: a cross-sectional study. BMJ Open 2019;9:e023955. https://doi.org/10.1136/bmjopen-2018-023955. [4] Centers for Disease Control and Prevention. ME/CFS: Making strides to enhance the lives of those living with ME/CFS | Blogs | CDC 2017. https://blogs.cdc.gov/publichealthmatters/2017/05/me-cfs/ (accessed August 5, 2023). [5] Cortes Rivera M, Mastronardi C, Silva-Aldana CT, Arcos-Burgos M, Lidbury BA. Myalgic Encephalomyelitis/Chronic Fatigue Syndrome: A Comprehensive Review. Diagnostics 2019;9:91. https://doi.org/10.3390/diagnostics9030091.

C10

Adaptation of the human reticulospinal tract in untrained participants to a 6-week isometric resistance training intervention; preliminary data.

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Introduction. Non-human primate research has highlighted the reticulospinal tract (RST) as a likely site of adaptation to resistance training (Glover & Baker, 2020) however, longitudinal observations in untrained humans have yet to be performed. This study examined the possible time-course adaptations of the RST over a 6-week resistance training intervention.

Methods. Eight untrained (age: 28 ± 5 years) and six untrained (age: 31 ± 4 years) participants were pseudo-randomly assigned into training and control groups, respectively. The isometric resistance training intervention consisted of 4 sets of 8 repetitions at 80% maximal voluntary contraction (MVC) of the dominant elbow flexor, twice weekly for 6-weeks. Neuromuscular assessments were performed at baseline and end of weeks 1, 2, 3 and 6 in both training and control groups. The neuromuscular assessments consisted of measures of cortical function; short-interval cortical inhibition (SICI) intra-cortical facilitation (ICF) and voluntary activation (V-wave), assessment of corticospinal tract (CST) excitability through motor evoked potentials (MEP) and motoneuronal function through silent period cervico-medullary stimulations (spCMEP). RST function was indirectly inferred from responses to cervico-medullary stimulations ($CMEP_{CON}$) and transcranial magnetic stimulation (TMS_{CON}), paired with a conditioning startling auditory stimuli of ≥ 110 dB, either 80 ms ($CMEP_{CON}$) or 50 ms (TMS_{CON}) apart (Furubayashi et al., 2000). Conditioned responses were expressed as a percentage of the unconditioned response. Evoked responses were recorded at 10% MVC with surface electromyography. The *StartReact* protocol, which assess reaction times in response to visual (VRT), auditory (VART), and startling auditory stimuli (VASRT) was also employed (Baker & Perez, 2017). RST gain, an index of RST function, was quantified as the difference in VRT and VASRT with respect to the difference in VRT and VART.

Results. Training group strength increased compared to controls following the 6-week isometric intervention (11 ± 4% vs. 4 ± 4%, $p = 0.006$). Of the measures of RST function, compared to control there was a training group interaction effect with *StartReact* VASRT decreasing at week 2 (−12 ± 8%; $p = 0.029$), week 3 (−22 ± 10%; $p = 0.003$) and week 6 (−25 ± 12%; $p = 0.004$) compared to baseline. RST gain was also greater at week 1 compared to baseline (44 ± 32%; $p = 0.043$). There were no interaction effects found in the control group ($p = ≥0.055$). $CMEP_{CON}$ facilitation, and TMS_{CON} inhibition were not different following the intervention ($p = ≥0.43$). No differences in SICI, ICF, V-Wave, MEPs or spCMEP ($p = ≥0.48$) were found across both groups following the intervention.

Conclusion. Elbow flexor strength, *StartReact* rection times and RST gain all improved in the training group following the isometric resistance training intervention but not in the control group. This, along with the lack of cortical or CST changes, strongly indicates that RST adaptations drive initial increases in strength when beginning a resistance training programme.

Baker SN & Perez MA (2017). J Neurosci, 37(40), 9778-9784. Furubayashi, T et al. (2000). Clin Neurophysiol, 111(1), 178-183. Glover IS & Baker SN (2020). J Neurosci, 40(30), 5820-5832.

C11

Conditioning corticospinal excitability to the anticipation of noxious stimuli

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Environmental stimuli may acquire threat-related properties through pairing with an aversive event, and exert a powerful influence on behaviour. Nevertheless, the extent to which the human cortical motor system learns to prepare to aversive events remains largely unexplored. Here, in two experiments on two independent groups of healthy individuals (exp. 1: N=28, exp. 2: N=30) we investigated whether and how changes in corticospinal excitability mark the acquisition of threat learning. In both experiments, participants completed a Pavlovian threat learning task in which two different neutral stimuli (coloured dots) acquired threat-related value by predicting a lateralized aversive shock, either to the left (left conditioned stimulus, CS+L) or right (CS+R) arm (Exp.1) or hand (Exp.2). Another stimulus (CS-) never predicted shock. Electrodermal activity (SCR) was collected to characterize changes in autonomic response between CSs. Critically, changes in corticospinal excitability were assessed by acquisition of motor-evoked potentials (MEP) recorded from two right hand and arm muscles (FDI and ECR muscles, respectively), and elicited by transcranial magnetic stimulation (TMS) applied to the left primary motor cortex. We found increased SCR for CS+R and CS+L compared with CS-, which did not distinguish the laterality of impending shock. In contrast, a lateralized inhibitory effect emerged for corticospinal excitability. Indeed, we found a reduction in the FDI MEP amplitude for CS+R, compared with CS+L and CS-. By tracking the development of the conditioned corticospinal response, we then revealed that the presentation of a conditioned stimulus triggers corticospinal inhibition in anticipation of the delivery of a noxious somatosensory outcome, which is mapped relative to the body part where the outcome is expected. This work advances the mechanistic understanding of Pavlovian learning and threat anticipation, showing that a motor representation of the outcome is part of the learning content, even though the outcome occurs unconditional to any overt motor response.

C12

Using transcranial magnetic stimulation for rapid cortical mapping of multiple muscles: Feasibility in spinal cord injury

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Introduction

There is increasing interest in the role of neurophysiological tools in early assessment of neurological conditions. Techniques such as transcranial magnetic stimulation (TMS) give insight into the neurophysiology underpinning functional deficits and may support improved prognostics, personalised treatment approaches and stratification for clinical trials[1]. TMS can be used to produce cortical maps, which give information about corticospinal drive to muscles post injury and the extent of post injury cortical reorganisation[1]. Being able to comprehensively map multiple upper limb muscles innervated at different spinal levels would be useful in neurological assessment, since functional tasks require synergistic use of multiple muscles and joints. This is particularly true in spinal cord injury (SCI) where differences in level and extent of damage lead to significant heterogeneity in impairments below the level of injury. Recently developed protocols allow for rapid production of cortical maps[2], potentially supporting clinical use. However, these protocols still involve lengthy procedures to determine stimulation parameters (e.g. threshold) for each muscle of interest, such that producing cortical maps for multiple upper limb muscles remains time-consuming. Therefore, we investigated TMS mapping protocols which enable simultaneous mapping of multiple upper limb muscles.

Methods

Nine healthy participants and 5 people with cervical SCI participated in our pilot study. Neuro-navigated, single-pulse TMS was used with surface EMG recording to produce cortical maps for 8 upper limb muscles on one side of the body for each participant (>80 stimuli per map). For healthy participants, 2 stimulation intensities were determined, separately, for 'distal' and 'proximal' muscles. Maps for all 8 muscles were recorded at each of the 2 intensities. For participants with SCI, a single stimulation intensity was used to produce all 8 maps. Standard clinical assessments of upper limb power were also performed for participants with SCI.

Results

For healthy participants, somatotopic distribution of the centre of gravity (CoG) for proximal vs distal muscles was observed (see table 1). CoGs were not different between those obtained with the 'distal' vs 'proximal' stimulation intensities: CoG was preserved irrespective of stimulation intensity (see table 1). Volume of cortical map for each muscle decreased predictably from distal to proximal at both stimulation intensities (see table 2). For participants with SCI, we observed a relationship between cortical map volume for a given muscle and muscle power ($r^2 = 0.21$, $p = 0.009$). As has previously been demonstrated[3], somatotopic distribution of CoGs was altered in people with SCI compared with healthy participants.

Conclusion

Rapid production of cortical maps from multiple muscles simultaneously is feasible in healthy participants and in people with SCI. This method could be used to perform rapid neurophysiological assessment of the upper limb in people with cervical SCI, enabling correlation with clinical measures and potentially giving insight into recovery of function.

Table 1

	Lateral distance from vertex, mm: mean (SD)			**Posterior** distance from vertex, mm: mean (SD)		
	All sessions	High Intensity (proximal target)	Low Intensity (distal target)	All sessions	High Intensity (proximal target)	Low Intensity (distal target)
Proximal muscles	**41.9 (6.5)**			10.7 (6.0)		
Distal muscles	**47.4 (6.0)**	47.2 (6.0)	47.6 (7.0)	8.1 (6.0)	8.3 (5.5)	7.9 (6.6)

Table 1: Results from healthy participants only. Lateral and posterior distance of CoGs from vertex for proximal muscles (anterior deltoid, biceps brachii, triceps brachii) or distal muscles (first dorsal interosseous, abductor pollicis brevis, abductor digiti minimi, extensor digitorum communis, flexor digitorum superficialis). Comparisons of CoGs for proximal vs distal muscles revealed significant ($p < 0.001$) differences in lateral distance (noted in bold in the table), but not for posterior distance ($p = 0.06$). Comparisons of CoGs for high vs low intensity stimulation revealed no differences for either lateral distance ($p = 0.78$) or posterior distance ($p = 0.80$). Proximal muscle CoGs were not compared across the two intensities since typically no responses were recorded from them at the lower intensities used for the hand muscle maps.

Table 2

	Volume, $mV \cdot mm^2$: mean (SEM)	
	High intensity (proximal target)	Low intensity (distal target)
First dorsal interosseus	10663 (1698)	4290 (1672)
Abductor pollicis brevis	8862 (1952)	2861 (895)
Abductor digiti minimi	5996 (1182)	1799 (804)
Extensor digitorum communis	2105 (441)	655 (133)

Flexor digitorum superficialis	2148 (465)	857 (341)
Triceps brachii	324 (70)	
Biceps brachii	802 (240)	
Anterior deltoid	172 (42)	

Table 2: Cortical motor map volume for different muscles at different stimulation intensities. Volumes were higher for distal vs proximal muscles. Proximal volumes were not included for the distal muscle mapping session since typically no responses were recorded from them at the lower intensities used for the hand muscle maps.

1. Arora T, Desai N, Kirshblum S, Chen R. Utility of transcranial magnetic stimulation in the assessment of spinal cord injury: Current status and future directions. Front Rehabil Sci. 2022;3:1005111. doi:10.3389/fresc.2022.1005111 2. van de Ruit M, Perenboom MJ, Grey MJ. TMS brain mapping in less than two minutes. Brain Stimul. Mar-Apr 2015;8(2):231-9. doi:10.1016/j.brs.2014.10.020 3. Freund P, Rothwell J, Craggs M, Thompson AJ, Bestmann S. Corticomotor representation to a human forearm muscle changes following cervical spinal cord injury. Eur J Neurosci. Dec 2011;34(11):1839-46. doi:10.1111/j.1460-9568.2011.07895.x

C13

From experimental pools of discharging motor units to computational predictions of muscle force: a novel motoneuron-driven neuromechanical muscle model

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Introduction

The dynamics of human voluntary muscle contraction are commonly investigated with a mathematical Hill-type model that transforms a single bipolar EMG signal into whole muscle force. However, this single-input single-output approach limits the comprehensive description of muscle internal dynamics, like the recruitment and discharge dynamics of the muscle's individual motor units (MUs), as reviewed [1]. Here, we propose a novel and validated mathematical model [2] that takes as input a vector of experimental motoneuron (MN) spike trains to control, in MN-driven simulation of human voluntary muscle contractions, the force-generating dynamics of a population of individual MUs.

Methods

The model is built as a population of Hill-type actuators, each of which describes the force-generating dynamics of an individual MU. This approach is MN-driven: the pool of Hill-type MUs transforms a vector of binary MN spike trains into a vector of continuous MU forces, that sum into the predicted whole muscle force (Figure 1). By using a musculoskeletal model derived from segmented medical images, carefully-selected experimental biophysical parameters from previous literature, and advanced modelling techniques, the MU forces are derived from the input spike trains with subject-muscle-specific models of the dynamics of free calcium concentration, concentration of calcium-troponin molecules, MU active state, and other MU mechanical properties. Note that no parameter calibration was performed.

The input vector of MN spike trains was derived from blind source separation of HDEMG signals (Figure 1A, B) acquired during an isometric trapezoidal contraction up to 30% of the maximum force of the tibialis anterior (TA) muscle of a healthy subject (male, 26 years old, 170 cm, 52 kg) [3]. The sensitivity of the model performance to the experimental motoneuronal data was assessed by varying the size and the density of the grids of EMG electrodes [3] and by reconstructing the discharge activity of the complete MU pool with computational methods (Figure 1C) [4,5].

To evaluate the prediction accuracy of the multi-MU model, eight validation metrics, including the normalized root-mean-squared error (NRMSE) and coefficient of determination (r^2), were computed between the predicted and measured muscle forces.

Results and Discussion

The best prediction accuracy was obtained when the input vectors of MN spike trains were representative of the full spectrum of discharging MUs and accurately approximated the true

neural drive to muscle. Yet, few to no early-recruited MUs are usually identified with HDEMG decomposition. This experimental limitation was addressed by using large and dense grids of EMG electrodes (10x3.6cm, 256 electrodes) (Figure 1B) [3] or by computationally reconstructing the whole MU population (Figure 1C) [4,5]. In the best conditions, the predicted and measured TA forces (Figure 1E) were in remarkably good agreement (r^2=0.99, NRMSE=6%).

Conclusions

This state-of-the-art neuromuscular model samples the predicted whole muscle force into individual MU dynamics controlled by specific experimental spike trains. As opposed to single-actuator bEMG-driven Hill-type models, this comprehensive description of the MU recruitment and discharge activity in human voluntary contraction finds dedicated applications in the control of neuroprosthetics, the investigation of neural synergies, and volumetric muscle modelling.

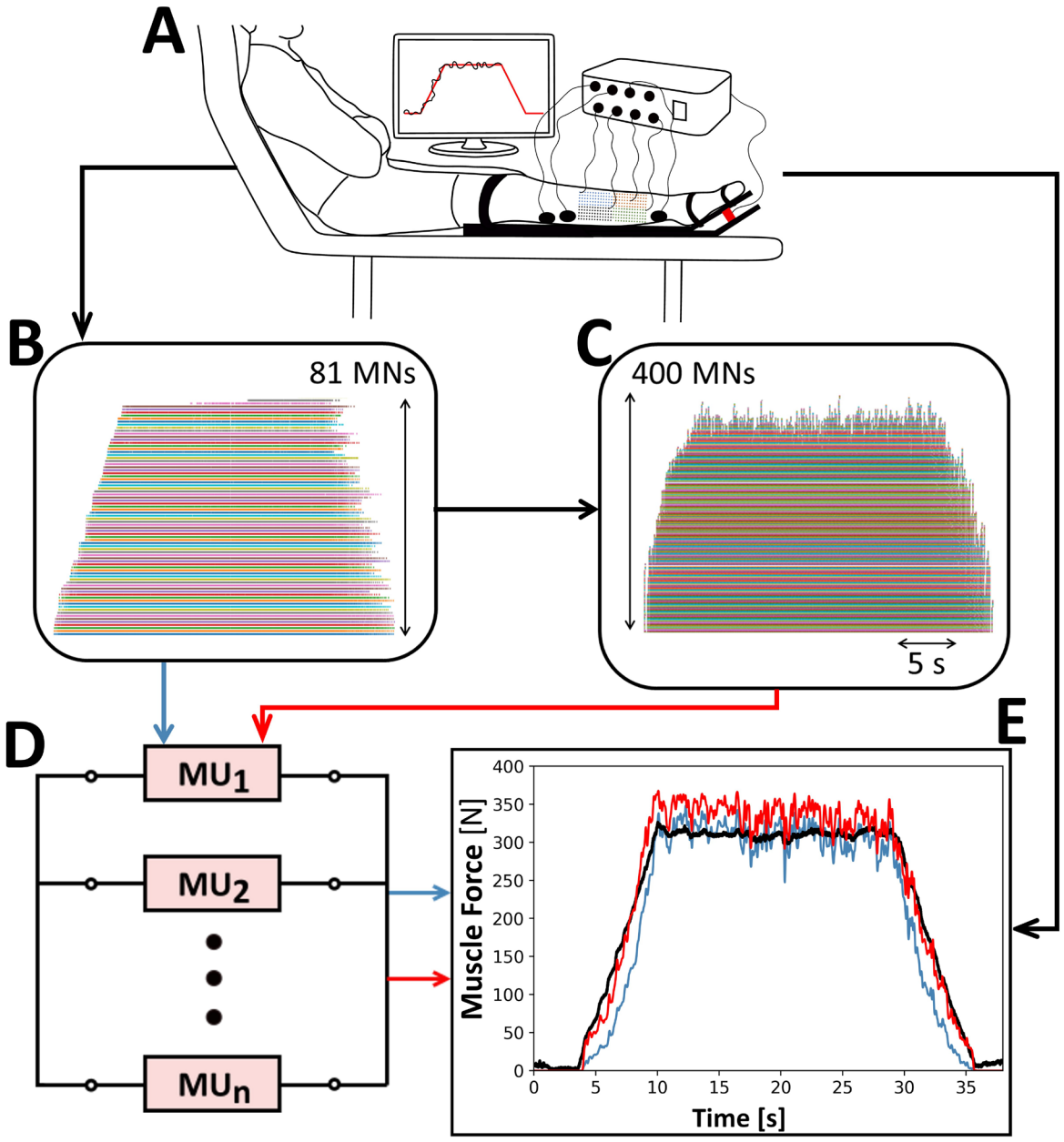

Figure 1: (A) Isometric recordings: TA HDEMG, antagonist and agonist bEMG, ankle torque. (B) 81 identified MN spike trains obtained from HDEMG decomposition [3]. (C) 400 spike trains obtained from (B) and computational MN pool reconstruction [4,5]. (D) MN-driven model of Hill-type MU actuators [2]. (E) Validation of the predicted muscle forces (blue: 81 identified MNs; red: reconstructed pool) against experimental TA force (black) [2].

[1] Caillet et al. (2022). BioRxiv, doi: https://doi.org/10.1101/2022.10.14.512218 [2] Caillet et al. (2023). BioRxiv, doi: https://doi.org/10.1101/2023.06.03.543552 [3] Caillet et al. (2023). eNeuro, 10 (9) ENEURO.0064-23.2023 [4] Caillet et al. (2022). Plos Comp Biol, 18(9), e1010556 [5] Caillet et al. (2022). eLife, 11, e76489

C14

Explainable Deep Learning for Localizing Cortical Physiomarkers from Deep Brain Stimulation

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Deep Brain Stimulation (DBS) is a common procedure in people with severe movement disorders – such as Parkinson's Disease (PD), Essential Tremor (ET) and Dystonic Tremor (DT) – once symptoms are no longer manageable with medications. DBS consists in stimulating specific areas of the patient's brain through an implanted electrode. However, stimulation approaches are still rudimentary. Reliable physiomarkers for discriminating neural response from the stimulation are needed to enable a closed-loop adaptive DBS system for personalised therapy.

Here, a deep learning model for agnostic physiomarker search in EEG recordings is presented. Our Convolutional Neural Network (CNN) is based on the EEGNet structure [1], and our proof-of-concept work of classifying EEG activity during DBS [2]. Our Siamese CNN (Figure 1) was created for the EEG-based distinction of different DBS settings (same vs different). In addition, an explainability method based on ablation studies is proposed for identifying the spectral location of the features utilized by the model [2], which can be used as physiomarkers. All work presented here was conducted on a labelled EEG dataset of 1 DT and 1 PD patient recorded during their initial DBS monopolar review.

For the DT patient, cross-validation accuracies of 86% and 71% were achieved for the left and right contact respectively and, for the PD patient, accuracies of 75% and 63% were achieved. With the ablation studies (Figure 2), we found that, for both patients, features in the theta band (4-8Hz) and narrow-band gamma (NBG) band (60-90Hz) were the main contributors to the accurate classification of the data. The theta band was attributed to the patients' tremor and the NBG band was identified as a potential physiomarker for DBS response in EEG data. The channel-wise ablation studies (Figure 3) revealed that, as expected, different channels were used for the classification task for the different DBS leads (left vs right), and overall, it showed that most channels were not used for the accurate classification of the stimulation.

The difference in accuracy between contact points was attributed to the monopolar review protocol which started with the left DBS and left it on while reviewing the right, presumably making it more difficult to classify changes in the stimulation from the right lead. It is also interesting to note that the DT patient in our study was not taking dopaminergic medicines, which's intake has been recently seen as significant for detecting NBG physiomarkers [3]. Overall, our findings are in line with recent research in the field, which suggests the potential of

the proposed approach in local field potential-based physiomarkers search [3, 4]. We have here provided a proof-of-concept of EEG-based DBS setting discrimination and have reaffirmed the recent shift in research from beta band (13-30Hz) physiomarkers to physiomarkers in the NBG range. Future work from our team will include a sample-size increase for statistical significance as well as making a patient-independent classifier with methods of transfer learning.

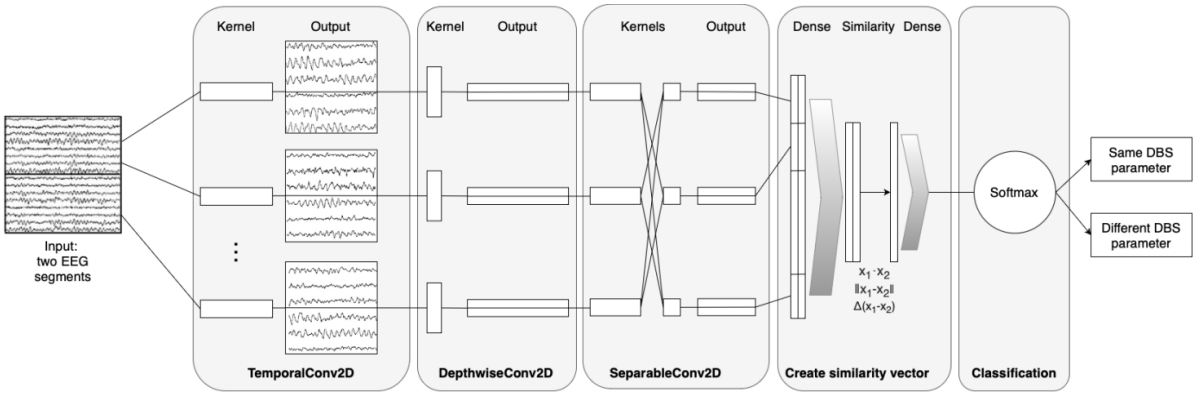

Figure 1. Siamese Convolutional Neural Network, based on the EEGNet architecture

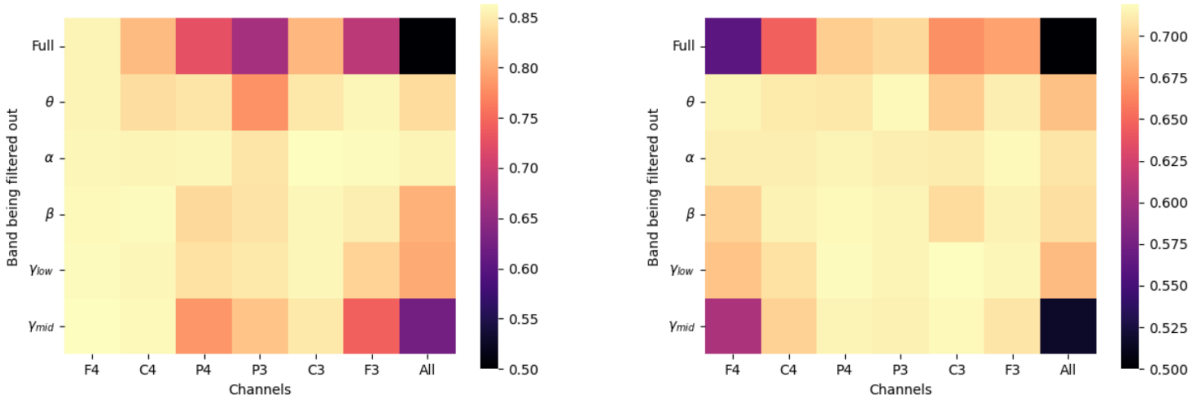

Figure 3. Frequency-Channel Heatmaps for (a) the left and (b) the right electrode on the DT patient

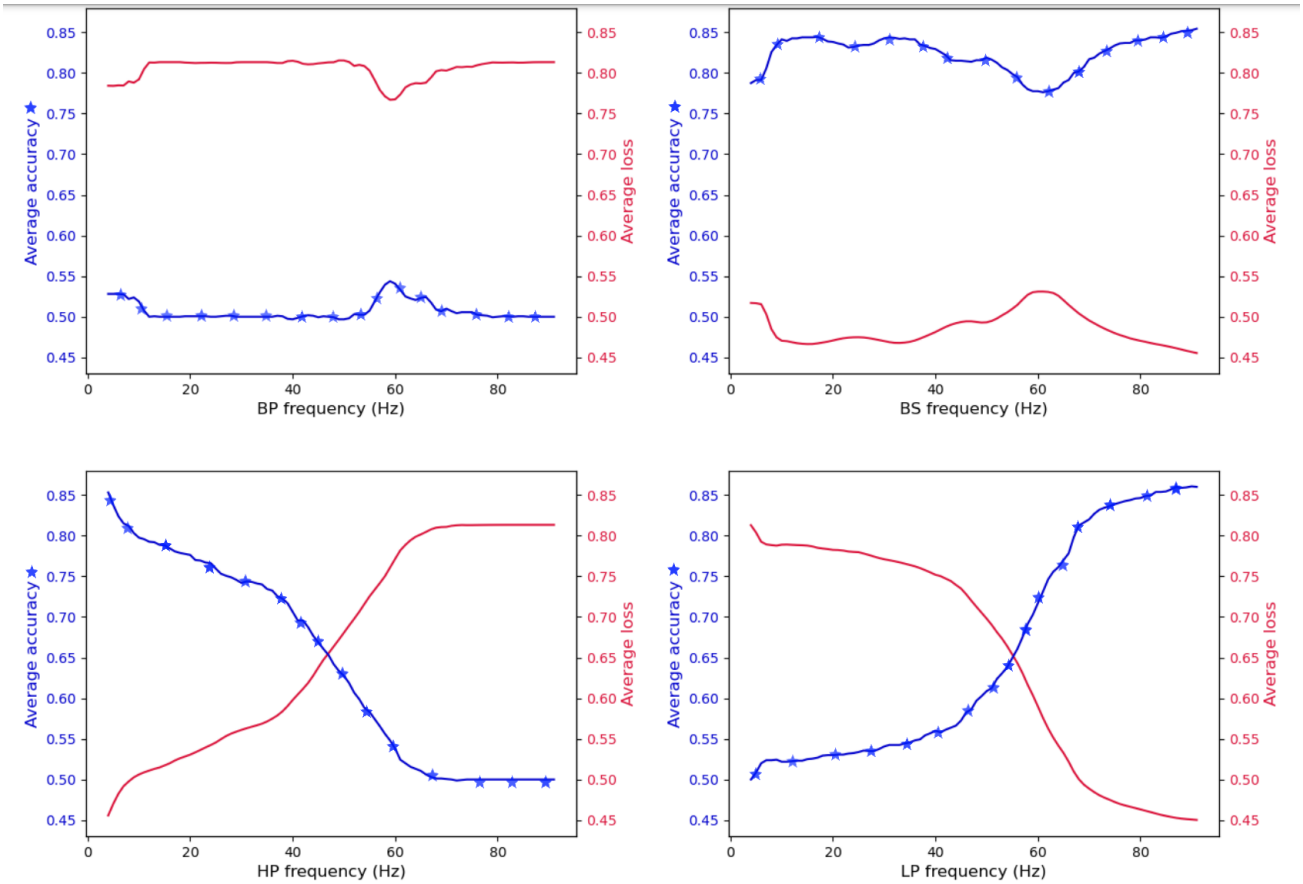

Figure 2. Accuracy (blue and star) and Loss (red line) for the frequency-band ablation studies in the DT patient
BP: Bandpass | BS: Bandstop | HP: Highpass | LP: Lowpass

1. Ruimin Peng, Changming Zhao, Jun Jiang, Guangtao Kuang, Yuqi Cui, Yifan Xu, Hao Du, Jianbo Shao, and Dongrui Wu. TIE-EEGNet: Temporal information enhanced EEGNet for seizure subtype classification. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 30:2567–2576, 2022. 2. Mathias R Haugland, Anastasia Borovykh, Yen Tai, and Shlomi Haar. Explainable deep learning for arm classification during deep brain stimulation - towards digital biomarkers for closed-loop stimulation, Conference on Cognitive Computational Neuroscience, 10.32470/CCN.2023.1368-0, Aug 2023 3. Carina R Oehrn, Stephanie Cernera, Lauren H Hammer, Maria Shcherbakova, Jiaang Yao, Amelia Hahn, Sarah Wang, Jill L Ostrem, Simon Little, and Philip A Starr. Personalized chronic adaptive deep brain stimulation outperforms conventional stimulation in parkinson's disease. Aug 2023. 4. Nicole C Swann, Coralie de Hemptinne, Margaret C Thompson, Svjetlana Miocinovic, Andrew M Miller, Ro'ee Gilron, Jill L Ostrem, Howard J Chizeck, and Philip A Starr. Adaptive deep brain stimulation for parkinson's disease using motor cortex sensing. Journal of Neural Engineering, 15(4):046006, May 2018.

C15

Markerless full-body tracking of motor fluctuations in Parkinson's Disease

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Continuous assessment and monitoring of symptom fluctuations and disease progression in Parkinson's Disease (PD) can improve treatment and provide robust outcome measures for clinical trials, making them faster and more conclusive. Despite impressive progression over the past decade, this remains a challenge, and the gold standard for clinical trials is still clinical assessment based on the Unified Parkinson's Disease Rating Scale (UPDRS), which is subjective and conducted at scattered intervals, failing to adequately capture daily symptoms fluctuations in symptoms experienced by patients.

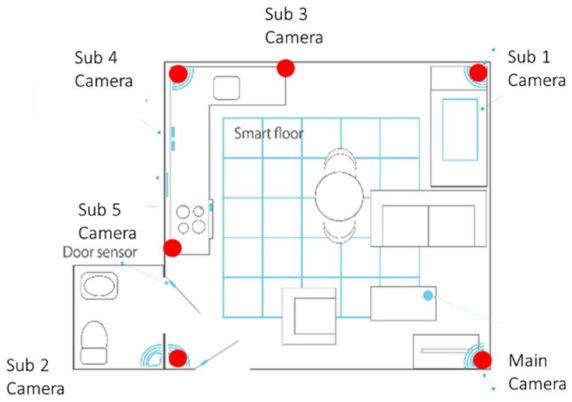
Markerless Motion Capture (MMC) can track full-body movement and posture to measure motor fluctuations during everyday activities, with the potential for deployment in people's homes, enabling continuous and objective measurement of PD's severity [1,2]. In this project, which is part of the Living lab Study [3], we present a proof of concept for measuring symptom fluctuations and disease progression using passive sensors in domestic settings during activities of daily living (ADL). MMC using multiple Microsoft Kinect depth sensors have been used for tracking full-body movements of PD participants (N=12) as they perform mobility tests and ADLs in a living-lab environment. The participants performed the tasks once shortly after taking medication, while their symptoms were controlled (On state) and again a few hours later, before the next medication intake, when symptoms started to fluctuate (Off state). A case study participant attended seven visits over nine months. Features of their movement and posture were extracted and used to predict their UPDRS scores using multivariate linear regression models. The spine curvature and shoulder slope during walking, and centre of mass deviation during sit-to-stand were common features within the best subset for prediction in both data groups.

Feature selection was performed separately for the group and the case study. In the case study, a model based on features identified for this patient performed very well ($R^2 = 0.96$) while using the features identified for the group reduced the model's performance ($R^2 = 0.76$). Interestingly, when applying the case study's optimal features to the group, there was a substantial drop in R^2 from 0.76 to 0.38.

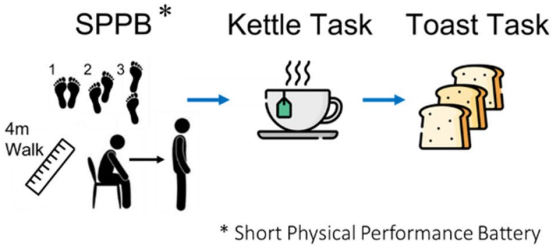
Next, a classification between patients' On and Off states based on their daily medication cycle was performed. A Support Vector Machine (SVM) model was used to train two models, one on the case study and another on the group. For the case study, their personalised model outperforms the group's model with perfect classification vs AUC of 0.82. For the group data, the model performed well with an AUC of 0.85. Interestingly, the best outcomes for the case study were obtained using only features from the instructed tasks (4-metre walk and sit-to-stand), whereas the group obtained the best results by using only features from the ADLs (making tea and toasts).

This preliminary analysis suggests that MMC techniques could potentially be a reliable approach for monitoring and evaluating PD motor symptoms.By effectively addressing fluctuations, these techniques could offer valuable insights into optimizing medication dosages and tailoring patient care requirements, reinforcing the importance of personalized medicine in managing the evolution of this disease.

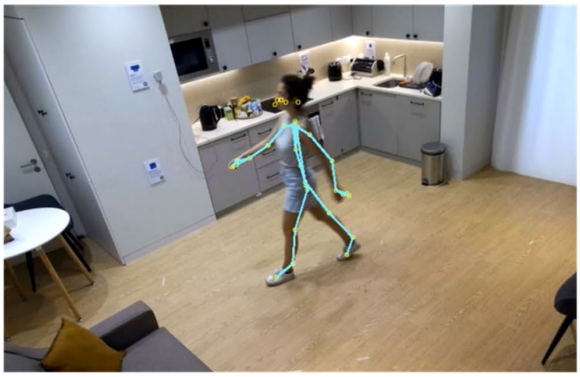
- Azure Kinect DK



Home-like setting: Living Lab Layout



* Short Physical Performance Battery



4m Walk Recording Task

1. Jeyasingh-Jacob J, Crook-Rumsey M, Shah H, Joseph T, Abulikemu S, Daniels S, Sharp DJ, and Haar S. (2023). Markerless Motion Capture to quantify functional performance in neurodegeneration: A systematic review, MIR Preprints. 08/09/2023:52582 2. Carpio Chicote A, Jeyasingh-Jacob J, Abulikemu S, and Haar S. (2023). Computational Tracking of Parkinsonian Motor Fluctuations in a Real-World Setting: a case study, Conference on Cognitive Computational Neuroscience, 10.32470/CCN.2023.1420-0 3. Crook-Rumsey, M., Daniels, S. J., Abulikemu, S., Lai, H., Rapeaux, A., Hadjipanayi, C., ... & Haar, S. (2023). Multicohort cross-sectional study of cognitive and behavioural digital biomarkers in neurodegeneration: the Living Lab Study protocol. BMJ open, 13(8), e072094.

C16

Corticospinal excitability is correlated with rate of force development in rapid muscle contractions.

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Introduction

Rate of torque development (RTD) is essential in everyday tasks and athletic endeavours (1). RTD is strongly correlated with the number of motor units recruited and their discharge rate at the start of contraction (2), but corticospinal mechanisms underpinning this relationship remain unclear. In this study, we superimposed rapid voluntary contractions with transcranial magnetic stimulation (TMS) to elicit motor-evoked potentials (MEPs) and silent periods (SP), to assess corticospinal excitability and inhibitory processes during the contractions. The aim was to assess the relationships between RTD and both MEP amplitude and SP, within a group of healthy young adults and within individuals of that same population.

Method

Fourteen participants (five females) performed multiple 1-second isometric rapid (push 'fast and hard') voluntary contractions and multiple 3-second isometric maximal (push 'hard') voluntary contractions (MVCs) of the knee extensors. During these contractions, electromyography (EMG) from the vastus medialis (VM), vastus lateralis (VL), and rectus femoris (RF) muscles. Some rapid contractions were superimposed with TMS applied to the leg representation in the motor cortex and set at 140% of the active motor threshold. The TMS stimulation generated motor-evoked potentials (MEP) and silent period (SP) responses at approximately 45 (early), 115 (middle), or 190 (late) ms after the EMG onset. RTD was recorded up to 45, 115, and 190 ms from torque onset in rapid contractions without TMS (for within-group correlations) and at 30 ms (just prior to MEP onset) in the early phase of contractions with TMS (for within-individual correlations). For within-group correlations, RTD in contractions without TMS were normalised to MVC torque and MEP amplitudes were normalised to resting maximal M-waves (Mmax). Pearson's bivariate correlations assessed the relationships between normalised RTD and normalised MEP amplitude and SP for each phase. MEPs and SPs in the middle and late phases first averaged with those of the preceding phases. For within-individual correlations, we used repeated measures correlations (3) for the early phase only to assess the relationship between absolute torque and absolute MEP amplitude, MEP amplitude normalised to RMS EMG in the preceding 20 ms (MEP:RMS), and SP.

Result

At the group level, the correlation between normalised RTD and normalised MEP amplitude was small in the early ($r=0.43$, $p=0.12$), moderate and significant in the middle ($r=0.56$, $p=0.036$), and small in the late ($r=0.21$, $p=0.48$) phases. Normalised RTD was unrelated to SP at any

phase ($r<0.13$; $p\geq0.67$). Within individuals, early phase RTD was correlated with MEP amplitude ($r=0.43$, $p\leq0.001$), but not MEP:RMS ($r=0.00$, $p=0.093$), nor silent period ($r=0.00$, $p=0.99$).

Conclusion

In conclusion, corticospinal excitability (assessed via MEP amplitude) is correlated with RTD during the early and middle phases of rapid contraction, both within a group of people and between contractions within a person. However, given RTD was not correlated to MEP:RMS within individuals, it seems the variance in MEP amplitude during the early phase of rapid contractions is reflected in the amplitude of the preceding voluntary EMG signal. Corticospinal inhibition (assessed via SP duration) was not associated with RTD.

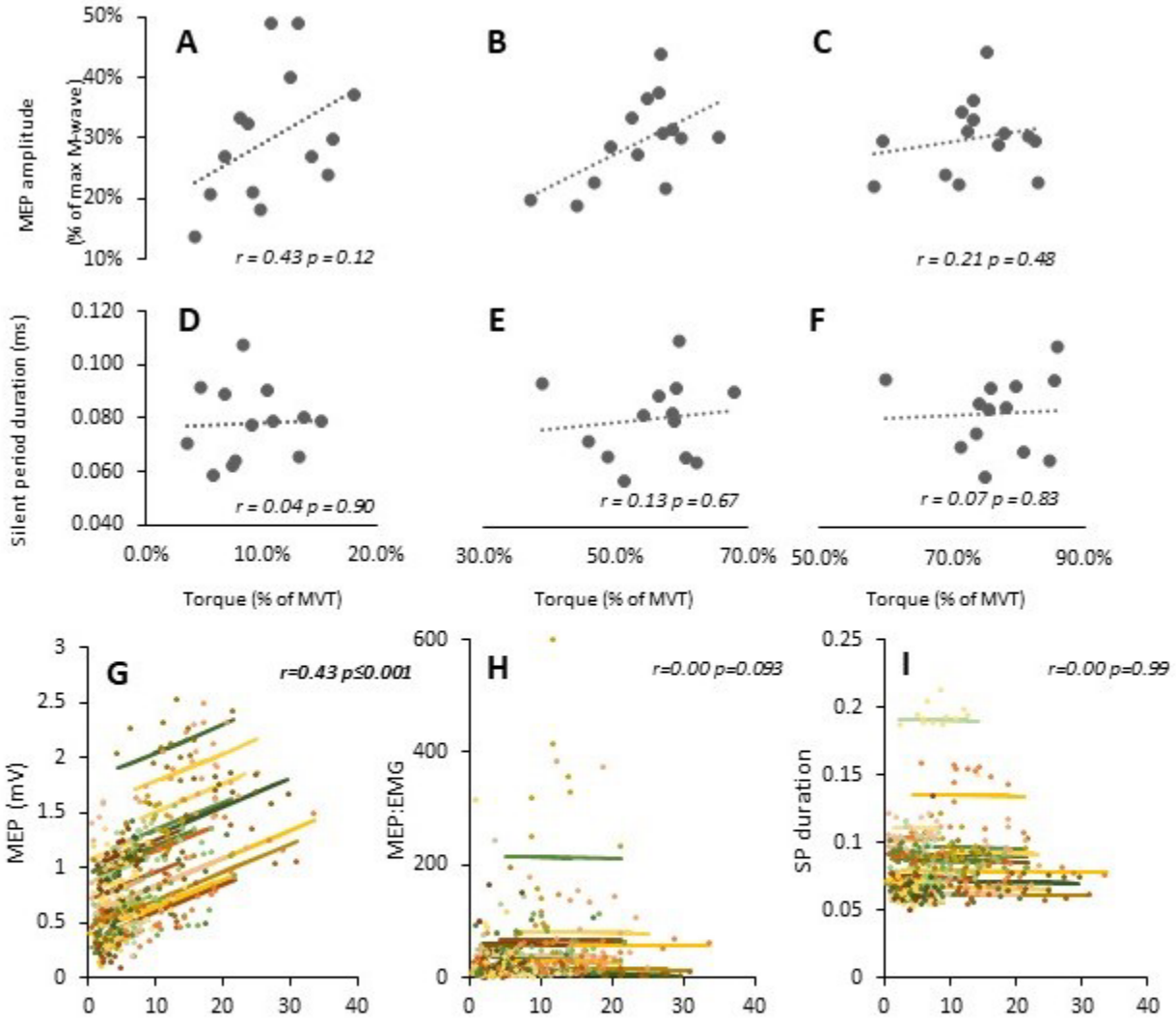

Figure 1 . Top panel: Pearson's r bivariate correlations between normalised (to MVT) torque and MEP amplitude normalised (to maximal M-wave (M_{max})) at early (A), middle (B), and late (B) time points during rapid voluntary contractions. Correlations are on a group-level, with each data point a separate participant (n=14).

Bottom panel: Repeated measures Correlations between torque at 30 ms during a rapid voluntary contraction, and MEP amplitude, MEP:EMG (B), and silent period (C), recorded straight after torque in the same contraction. Correlations are on an individual level, with each data point representing a single contraction and each best-fit line representing a separate individual.

Correlation coefficients r and p-values for all correlations are presented for each correlation. Level of significant p≤0.05.

(1) Maffiuletti et al. (2016) Eur J Appl Physiol, 116(6), 1091–1116. (2) Del Vecchio et al. (2019) J Physiol, 597(9), 2445–2456. (3) Bakdash & Marusich (2017) Front. Psychol. 8:456.

C17

Effect of reward and caution on corticomotor indicators of urgency during decision making.

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INTRODUCTION: Recent models of decision making support the existence of an urgency signal shaping neural activity during deliberation (Cisek & Thura, 2022). In a past study using transcranial magnetic stimulation (TMS), we were able to show that high urgency materializes into two main adjustments of motor neural activity: a broad facilitation and a surround inhibition (around the index prime mover) (Derosiere et al., 2022). Notably, urgency is often treated as a uniform phenomenon, when in fact, it is more likely to be shaped by several influences, with potentially opposing effects modelling its ultimate strength. For instance, reward, which is known to invigorate action, is a likely promoter of urgency while influences supporting caution will rather counteract this effect. Here, we tested the hypothesis that motor adjustments observed in high urgency contexts result from these contrasting regulators, with surround inhibition boosted by influences promoting urgency, such as reward, and broad facilitation reflecting a weak recruitment, in such settings, of (inhibitory) influences promoting caution.

METHODS*:* 13 young healthy right-handed participants (23 ± 3.0 years old; 10 women) were tested in this ongoing study spanning over two days (target sample size n=20, planned completion Dec-2023). We recorded motor evoked potentials (MEPs) to TMS over primary motor cortex while subjects performed an index finger variant of the Tokens task with low or high reward trials (randomized low or high monetary precue), which were grouped in blocks requiring either low (majority of easy trials) or high (minority of easy trials) caution (8 or 9 blocks of 40 trials for each level of caution, in a counterbalanced order). On two separate days, the TMS coil position was adapted to obtain MEPs in finger muscles (as a probe of surround inhibition; total of 16 blocks) or in leg muscles (as a probe of broad facilitation; total of 18 blocks).

RESULTS*:* Behaviour in the task was clearly influenced by the reward landscape and the caution requirements. As expected, subjects were overall faster to decide in low than high caution blocks (in 13/13 subjects; paired-$t_{(12)}$=5.5, $p<0.001$), consistent with a greater urgency in the former block type. Yet, rather than a boosting effect, high reward generally tended to slow down decisions (in 9/13 subjects; paired-$t_{(12)}$=1.9, $p=0.08$ when compared to low reward trials), possibly because reward outcome was largely contingent on accuracy in our task design. Interestingly though, as evident when considering finger MEPs, high reward trials still tended to be associated with greater surround inhibition (i.e. lower ΔMEP [thumb-index]), compared to low reward trials (in 11/13 subjects; paired-$t_{(12)}$=1.345 $p=0.203$). Preliminary inspections of leg MEPs are consistent with a broad facilitation of motor neural activity during deliberation, although more subjects are required to determine how this effect interacts with urgency as a function of caution and reward.

CONCLUSION: Our preliminary data provide evidence for the view that surround inhibition can be increased by reward landscape and that broad facilitation can be observed during decision making, possibly related to caution level as will be further examined with a larger sample size.

- Cisek, P., & Thura, D. (2022). Oxford University Press. - Derosiere, G., Thura, D., Cisek, P., & Duque, J. (2022). PLoS Biol, 20(4), e3001598.

C18

Stretchable surface electromyography electrode array patch for tendon location and muscle injury prevention

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Intro: Non-invasive measures of muscle activity are still limited to being used in research environments, although its usefulness in diagnosis and therapeutics is well accepted. One of the factors that might improve its acceptance is ease of use, reliability and reusability without sacrificing ability to capture high-quality data for continuous monitoring.

Aim: We set out to develop a non-toxic, conformal dry electrode using tannic acid, polyvinyl alcohol, and PEDOT:PSS (TPP), as well as a metal-polymer electrode array patch (MEAP) with liquid metal (LM) circuits and TPP electrodes. We then explored the advantageous skin conformability of this array and investigated its potential for recording muscle and tendon location.

Method: The MEAP fabrication uses screen printers and ovens, ensuring precision and consistency. With use of biocompatible adhesives, the LM circuit were protected within a PDMS casing, with only the TPP electrodes making direct contact with the skin. To test for conformability, we compared our 64 channel MEAP with an identical commercial array (CA) of Ag/AgCl electrodes on a polyimide substrate (Neuracle, China). Data was obtained from five male subjects (23.4 ± 1.9 years). For Ultrasound imaging a Mindray L14-6NE probe (Lysis, Austria) was used.

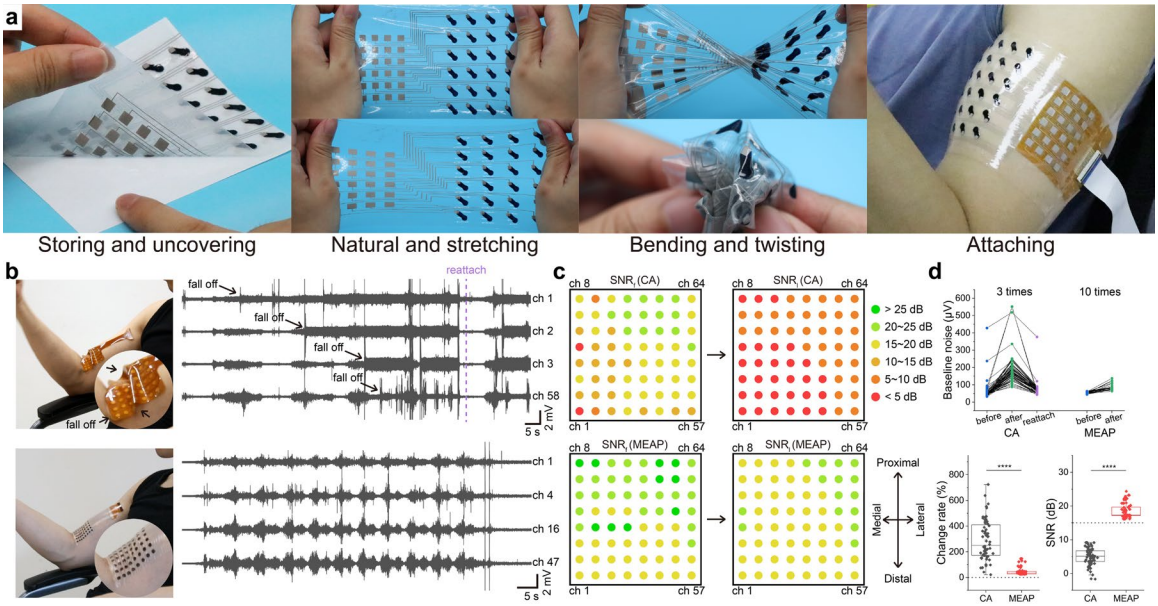
Subjects performed a biceps brachii isometric task, of holding the dumbbell for 30 seconds, with the forearm parallel to the ground forming a right angle with their upper arm. For the dynamic task they performed biceps curl, ranging from full extension to flexion. Subjects were instructed to control the curl speed at approximately 4.5 rad/s for five sessions, with loads ranging from 1 to 5 kg. Tendon strain was calculated as per Walton 2015 (Walton et al 2015) using the distal biceps tendon length. All studies were approved by the Medical Ethics Committee of Southern University of Science and Technology (approval no. 2021SYG049). n=64 for each measurement in Fig.1**d**; n=15 for Fig.2**b**, **c** and **e** (isometric and dynamic tasks x3, 5 subjects).

Results: Our findings indicate that MEAP exhibits remarkable flexibility, stretchability, and user-friendliness (Fig.1a). When affixed to the muscle-tendon junction, MEAP maintained conformal contact even with skin deformation, contrasting with the noticeable mismatch observed in the case of CA (Fig.1b). This difference in attachment performance was directly reflected in the surface electromyography (sEMG) signals (Fig.1b). MEAP was significantly better than CA for

recording sEMG, based on SNR mapping, this is primarily owing to its improved contact even in the presence of substantial skin deformation (Fig1c, d).

Tendon displacement, at the biceps, was quantified using the frequency component of the signal captured by the MEAP, further verified using ultrasound images in an isometric task (Fig.2a, b). Real-time tendon displacements during dynamic tasks were recorded using the MEAPs too (Fig.2c). Each MEAP channel consistently recorded significantly distinct signal in every subject (Fig.2d-f).

Conclusions: These MEAPs, manufactured using scalable screen-printing techniques, feature a completely stretchable material and array architecture, enabling real-time monitoring of muscle stress, fatigue, and tendon displacement. Their potential to reduce muscle and tendon injuries and enhance performance in daily exercise and professional sports holds great promise.



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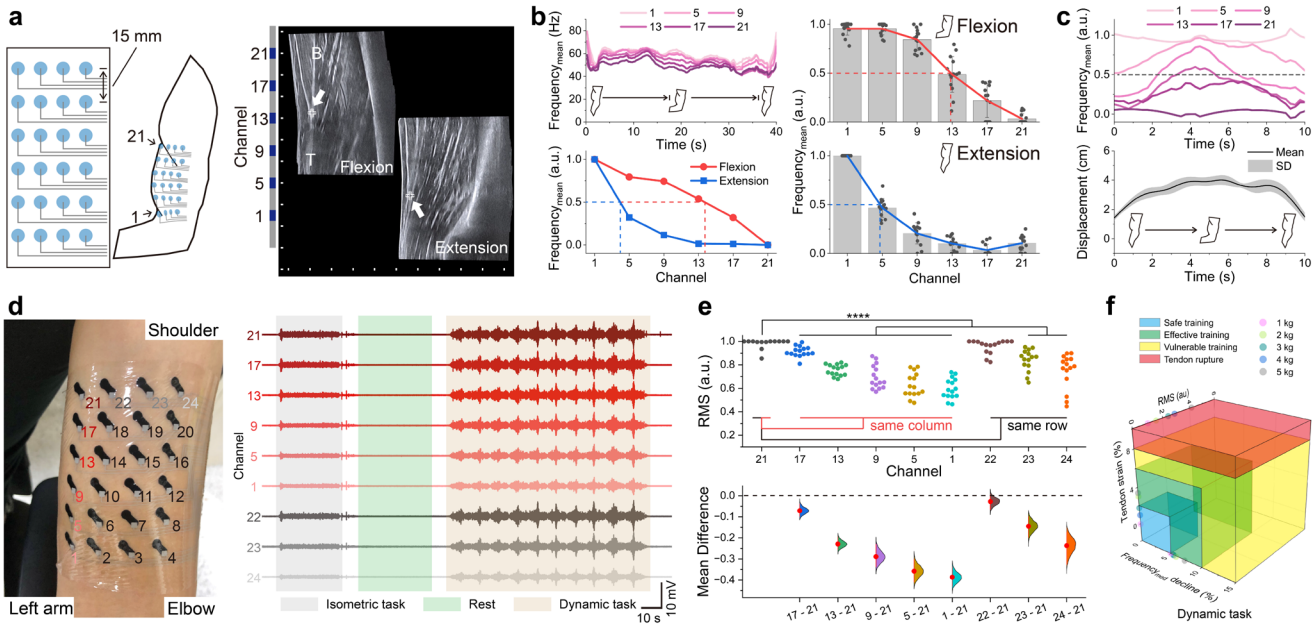

Walton, C. et al. (2015) 'A 3-dimensional anatomic study of the distal biceps tendon', Orthopaedic Journal of Sports Medicine, 3(6), p. 232596711558511. Available at: https://doi.org/10.1177/2325967115585113.

C19

Hand muscle activity patterns during fatigue inducing isometric exercise

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Muscle fatigue is referred to as a progressive reduction of force generated during muscle exertion due to any physical activity or exercise[1]. To compensate for the decline in force capacity of agonist muscles during sustained submaximal isometric contraction (sIMC), the net excitatory input to the motoneurons pool is increased to recruit additional motor units to maintain the force level until task failure. This common control of coactivation can lead to disproportionate rise in antagonist muscle activity[2]. Hand grip is commonly studied in non-fatigue tasks, and the most common synergistic pattern observed is coactivation of agonists and antagonists[3]. However, it remains unexplored if this activation pattern is affected.

In this study we used, the commonly used fatigue indicators root mean square (RMS), and median frequency (MDF)[4], parameters of surface electromyographs (sEMG), to examine the process of failure during a sIMC task. Having established fatigue, we identified the pattern activity of hand and forearm muscles during the task.

Method: 5 healthy participants (aged 31.2 ± 6.41 years) performed a sIMC protocol to induce fatigue until failure of task, preceded by them generating maximal grip force (MGF) (3s) using their dominant hand. A Bluetooth-enabled handgrip dynamometer (SQUEGG, USA) was used to record the MGF, and to provide feedback to the subject when performing the sIMC task. The posture and position of the hand was maintained as recommended by the American Society of Hand Therapists[5]. Participants performed the sIMC maintaining a target force at 50% of MGF for 5 minutes with visual feedback. This was repeated twice with a 5-minute rest between each repetition. sEMG signals from 7 hand and forearm muscles was recorded. Each sIMC was split into two epochs of 30s each: early (the first 30s) and, final (the last 30s from the time of failure). All data is presented as mean ± standard error.

Results: The sIMC led to muscle fatigue causing a 27% drop in MGF ($P < 0.05$), (fig1 A). The MDF of FDI decreased, while its RMS increased suggesting fatigue. In addition, the FDS, FCU, and FCR also exhibited change during sIMC. ECR and BR muscles also showed change in both fatigue indices, (fig1 B). Fig1 C illustrates interactions among forelimb muscles, BR demonstrates a stronger correlation with ECR (R=0.5), as well as with FCR and FCU (R=0.45), and FCR and FDS (R=0.37) during the AF2-2 phase, as compared to AF1-1.

Discussion and conclusions: The MGF for all subjects decreased following the fatigue task, similar to previous reports[1]. While FDI was expected to be fatigued, the fatigue indicators for finger flexors (FDS, FCU, and FCR) and ECR also suggested them being fatigued, especially in the final epoch. Forearm muscles were coactivated throughout the fatiguing task. This preliminary study suggests that the slight alteration in the pattern of activity of the forearm muscles might contribute to the individual's ability to maintain force output until failure during sIMC.

Keywords: Synergistic pattern, Maximal grip force, sustained isometric contraction, Coactivation

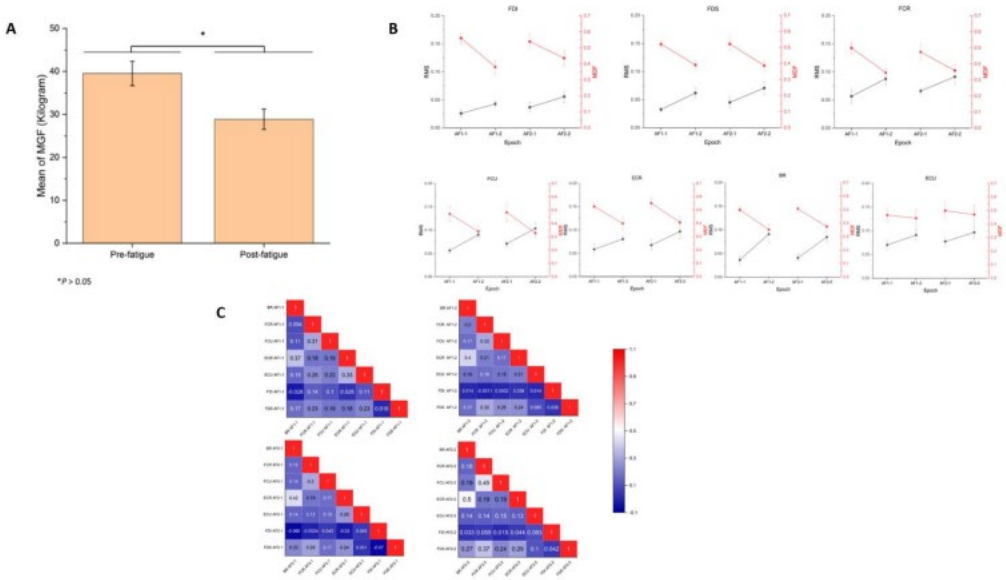

Figure 1 Epoch abbreviations: AF1-1 for the early epoch of the 1st sIMC, AF1-2 for the final epoch of the 1st sIMC, AF2-1 for the early epoch of the 2nd sIMC, and AF2-2 for the final epoch of the 2nd sIMC. Muscle abbreviations: Brachioradialis (BR), Flexor carpi radialis (FCR), Flexor carpi ulnaris (FCU), Extensor carpi ulnaris (ECU), Extensor carpi radialis (ECR), The first dorsal interossei (FDI), and Flexor digitorum superficialis (FDS).

1. GANDEVIA S. (2001). Spinal and supraspinal factors in human muscle fatigue. Physiological Reviews 81, 64. 2. Duchateau J, and Baudry S. (2014). The neural control of coactivation during fatiguing contractions revisited. J Electromyogr Kinesiol 24(6):780-8. 3. Marina M, Torrado P, Bou-Garcia S, Baudry S, and Duchateau J. (2022). Changes of agonist and synergist muscles activity during a sustained submaximal brake-pulling gesture. J Electromyogr Kinesiol 65:102677. 4. De Luca CJ. (1997). The use of surface electromyography in biomechanics. J Appl Biomech 13 (2): 135-163. 5. Mathiowetz V, Weber K, Volland G, and Kashman N. (1984). Reliability and validity of grip and pinch strength evaluations. J Hand Surg 9(2): 222–6.

C20

A cross-section study of the normative data of the side-to-side soleus Hoffmann reflex from the calf muscle in healthy individuals in the lying down position.

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Introduction: To obtain an H-reflex response, impulses enter the motor neuron reservoir (alpha-motor neurons) (Schieppati M. et al., 1987). This reflex is used to determine the excitability of the spinal reflex (Kimura J. et al., 1984). We have taken the normative data of M-Latency, H-Latency, M-Amplitude, H-Amplitude, and H/M Ratio in the left and right legs, respectively, so that it can be compared in disease states like cerebral spastic hemiparesis, polyneuropathy, and nerve root damage (S1, C6, C7).

Objective: The goal of this study was to determine what a normal H-reflex is in a group of healthy adults based on measurements taken from the calf muscle.

Material and method

Subjects: The research included 119 healthy male volunteers aged 30.40 years (mean SD: 6.78 years), height 173.11 ± 4.98 cm, with no background or clinical proof of peripheral or central nervous system illness (Table 1).

Method: The subjects were instructed to lie face down with one leg bent to one side (the Sims posture), with the angles of the knee and ankle being approximately 154°–164° and 95°–105°, respectively. The limb position was slightly modified (semi-prone) to place the electrode according to Braddom and Johnson's approach(***Braddom and Johnson***, 1974). In the soleus muscle, the recording surface electrode was placed 2 cm distally to the medial gastrocnemius, and the reference electrode was placed at the location of the Achilles tendon insertion. A ground electrode was mounted between the active and reference electrodes (Figure 1). The H-reflex test was performed with stimulation of the posterior tibial nerve in the popliteal fossa (mid-popliteal crease) while maintaining the anode distally. All participants signed an informed consent form before the examination, and the Institute research board and ethical committee (IMO 320) approved this research.

Results: 111 participants (93.3%) were 40 or younger, with the mean age (in years) being 30.40 ± 6.78. The average weight (kg), height (cm), and limb length (cm) were 173.11 cm, 10.48 cm, and 94.28 cm, respectively (Table 1). The mean latencies of the H reflex were (SD = 30.93 ± 4.42) and (SD = 31.01 ± 5.21) milliseconds in the right and left legs, respectively (Table 2). Leg length and H reflex latency were significantly correlated (r = 0.55, P 0.05) (Figure 3). There was no discernible correlation between age and the H reflex latency (Table 3).

Conclusion: The results of this study mostly agree with other studies (Fisher MA et al., 1992). (Jankus WR et al., 1994) A positive relationship was found between H-latency and patient height, which aligns with many other studies. The variables age group, weight, H-amplitude (left and right), and H-latency (right) were all significantly associated (p =.05) with the variable "H-

latency" (mV). (Table3) Future research in other age groups and grading of the reflex in terms of mild, moderate, and severe will look at how these findings may be compared to the disease state for the management of the patients.

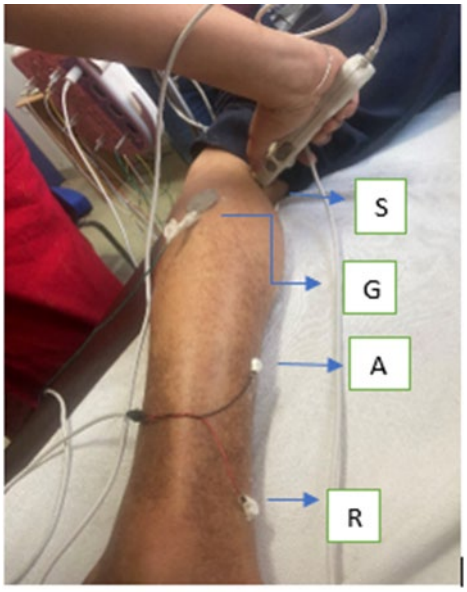


Figure 1 showing electrode placement in semi prone position Active electrode(A) in soleus muscle stimulating tibial nerve(S),Ground electrode(G) and reference electrode(R)

Figure 2: Correlation between Limb Length (cm) and H-Latency (ms) (Left) (n = 119)

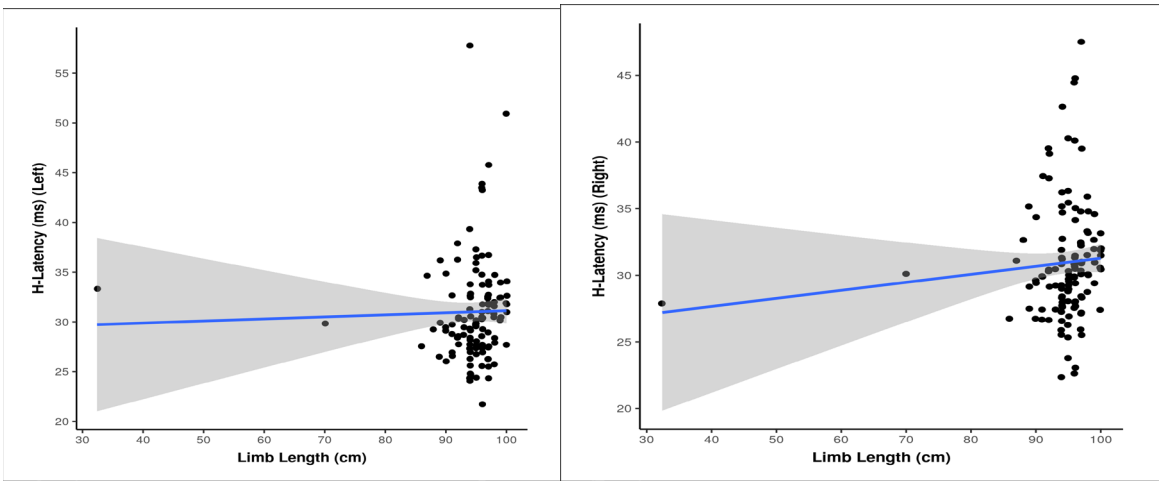


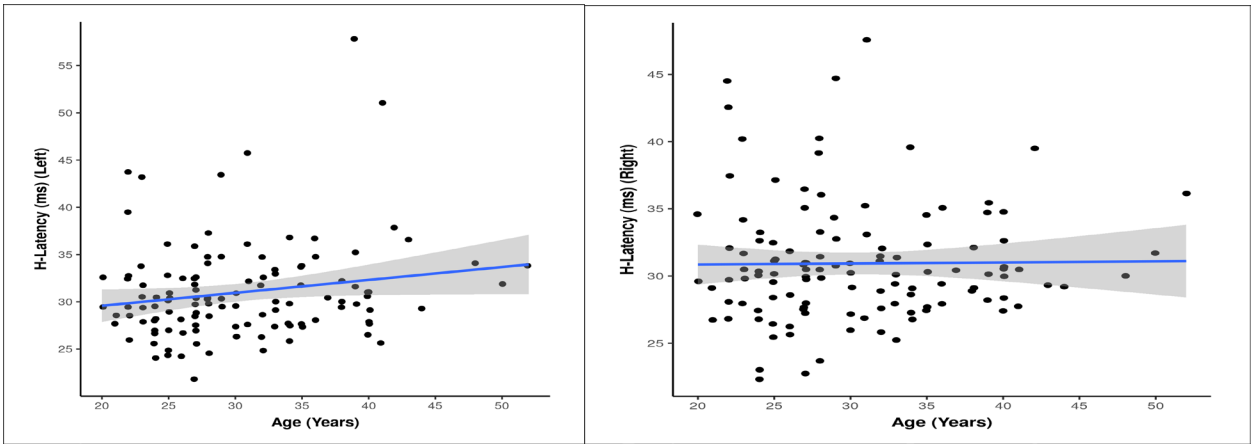
Table 1: Summary of Basic details of subject in term of mean, median ,standard deviations and frequency

Basic Details	**Mean ± SD || Median (IQR) || Min-Max || Frequency (%)**
Age (Years)	30.40 ± 6.78 || 29.00 (25.00-35.00) || 20.00 - 52.00
Age Group	
≤40 Years	111 (93.3%)
>40 Years	8 (6.7%)
Height (cm)	173.11 ± 4.98 || 173.00 (170.00-177.00) || 158.00 - 184.00
Weight (Kg)	70.42 ± 10.48 || 69.00 (63.50-76.50) || 43.00 - 102.00
BMI (Kg/m2)	23.51 ± 3.43 || 23.18 (21.38-25.23) || 14.37 - 34.60
Temperature (Left) °C	31.52 ± 1.27 || 31.60 (31.00-32.35) || 26.10 - 34.00
Temperature (Right) °C	31.61 ± 1.23 || 31.60 (31.00-32.40) || 27.70 - 34.20
Limb Length (cm)	94.28 ± 6.81 || 95.00 (94.00-97.00) || 32.40 - 100.00

Table 2: Summary of H-Reflex

Parameter	Side	Mean ± SD	Median (IQR)	Min - Max
H-Latency (ms)	R	30.93 ± 4.42	30.10 (28.00-32.60)	22.4 - 47.6
	L	31.01 ± 5.21	30.10 (27.75-32.70)	21.8 - 57.8
M-Latency(ms)	R	5.83 ± 1.56	5.50 (4.80-6.30)	3.3 - 12.2
	L	5.80 ± 1.51	5.50 (4.80-6.45)	3.5 - 10.0
M-Amplitude (mV)	R	5.42 ± 3.48	4.90 (2.25-8.05)	0.1 - 12.7
	L	5.06 ± 3.33	4.90 (1.90-7.80)	0.1 - 13.7
H-Amplitude (mV)	R	2.59 ± 2.12	2.30 (1.05-3.65)	0.1 - 15.2
	L	2.37 ± 2.05	2.00 (0.90-3.30)	0.2 - 16.2
H-M Ratio	R	0.47 ± 0.16		
	L	0.46 ± 0.15		

Table 3: Correlation between Age (Years) and H-Latency (ms) (n = 119)



Correlation	Spearman Correlation Coefficient	P Value
Age (Years) vs H-Latency (ms) (Left)	0.2	0.082
Age (Years) vs H-Latency (ms) (Right)	0.1	0.749

Schieppati M Kimura J Braddom and Johnson Fisher M Jankus WR A. 1.Schieppati M. (1987). The Hoffmann reflex: a means of assessing spinal reflex excitability and its descending control in man. Progress in neurobiology, 28(4), 345–376. https://doi.org/10.1016/0301-0082(87)90007-4 2.Kimura, J., Daube, J., Burke, D., Hallett, M., Cruccu, G., Ongerboer de Visser, B. W., Yanagisawa, N., Shimamura, M., & Rothwell, J. (1994). Human reflexes and late responses. Report of an IFCN committee. Electroencephalography and clinical neurophysiology, 90(6), 393–403. https://doi.org/10.1016/0013-4694(94)90131-7 3.Braddom, R. I., & Johnson, E. W. (1974). Standardization of H reflex and diagnostic use in Sl radiculopathy. Archives of physical medicine and rehabilitation, 55(4), 161–166. 4.Fisher M. A. (1992). AAEM Minimonograph #13: H reflexes and F waves: physiology and clinical indications. Muscle & nerve, 15(11), 1223–1233. https://doi.org/10.1002/mus.880151102 5.Jankus, W. R., Robinson, L. R., & Little, J. W. (1994). Normal limits of side-to-side H-reflex amplitude variability. Archives of physical medicine and rehabilitation, 75(1), 3–7.

C21

Exploring expertise: Comparing muscle engagement in yoga poses in expert and novice practitioners using surface electromyography

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Allie Williams, Hristo Dimitrov, Tamar Makin

Skill learning is the improvement in motor, cognitive or perceptual performance following practice. Yoga asana, or the physical practice of yoga, involves performing a range of postures. Correct execution of poses requires specific and precise muscular engagement and coordination across the entire body, making yoga a rich model for understanding expert learning in motor control. While yoga instructors have a general understanding of how poses should be executed, little study has been undertaken in measuring muscle engagement in yoga poses. Further, how patterns of muscle engagement set experts apart from novices remains an open question. To understand variation in expert and novice learning in yoga, we compared how muscle activation patterns differed between novices and experts across 8 muscle groups.

Our analysis is focused on poses "signature" using surface Electromyography. However,While skill expertise is generally associated with reduced variability, we will explore the hypothesis that because there are multiple solutions to achieving a pose, experts will demonstrate more variability than novices both in executing and in maintaining poses due to their superior coordination, flexibility and strength. This will provide us the opportunity to explore whether complex motor skill learning in an ecological setting follows the same fundamental principles for skill learning identified in lab settings.

By delving into complex negotiation of muscle engagement across the entire body, our findings could aid our understanding of how the brain finds a solution for a specific complex problem. Our findings will also provide greater insight into the specific muscle engagement required to correctly execute yoga poses, which lacks concrete scientific measures. Developing tools and techniques to determine and measure muscle engagement in specific poses in an ecological setting will contribute to the development of additional resources to aid in safe yoga training for practitioners at every level. Tools for measuring specific muscle engagement will allow for further development of specific strength or rehabilitation programs using yoga.

C22

A nine-year Longitudinal Study of Neuromuscular Function in Older Adult Cyclists

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Introduction

How ageing, exercise and disease effect neuromuscular function in adults is complex. The aim of this study was to gain greater insight into this relationship by undertaking a nine-year longitudinal study in a cohort of physiologically defined, highly-active, older cyclists.

Methods

Eighty-two older road cyclists now aged 72.4±5.9 years, were re-tested after nine years[1]. On their return, we observed that not all met the original health criteria. Based on their deviation from the original health criteria we re-categorised cyclists in to three groups; i) no declared health issues (Group 1, n=23 males, n= 12 females), ii) exhibiting new but well-controlled health condition(s) unlikely to affect exercise (Group 2, n=14 males, n=10 females and iii) having any poorly controlled underlying condition(s) that had the potential to compromise exercise capacity (Group 3, n=16 males, n= 7 females). We assessed maximum isometric strength of knee extensors (MVT), peak power during explosive cycling (PP), grip strength, and measured time up and go (TUG). DXA scanning determined lower limb fat free mass (LLFFM). In addition, we measured voluntary activation (neural drive) during MVT (MVTVA) through the twitch interpolation method, peroneal nerve conduction velocity (NCV), motoneuron excitability (H-reflex; ratio of H-max to M-max), as well as one-leg balance using the preferred leg in eyes open (B_{EO}) and eyes closed (B_{EC}) conditions. Statistical analysis: i) paired t-test to assess overall change with time and ii) multiple regression analysis for between-group interaction over time. Data are presented as mean±SD.

Results

All n=82 participants were still cycling now aged 72.4±5.9 years, height (m; 1.7±0.1), and body mass (kg; 68.7±10.7). Data from pre and post nine years showed a decline in self-reported cycling volume (km month^{-1}; 667.7±312.5 vs. 456.2±301.8; $p<0.001$). MVT (N.m; 160.2±43.4 vs. 149.4±38.8; $p = 0.006$), and PP (W; 964.4±180.5 vs. 909.3±203.5; $p < 0.001$) both declined with time. LLFFM (kg) declined from 17.6±3.3 to 15.8±3.4. When MVT was normalised to LLFM

there was no age effect (N.m.kg.FFM^{-1}; 9.1±1.9 vs. 9.6±2.3; p = 0.07), but a decline remained in PP (W.kg.FFM^{-1}; 55.0±5.8 vs. 58.2±10.4; p = 0.002). Grip strength declined significantly over time (N; 408.5±97.3 vs. 373.3±103.9; p < 0.001), while TUG (s; 5.6±0.8 vs. 5.2±0.9; p < 0.001) improved. With respect to neural function, MVTVA (%; 93.3±6.2 vs. 89.2±6.3; p < 0.001), the H-reflex (%; 0.35±0.24 vs. 0.26±0.20; p < 0.001), NCV (ms^{-1}; 43.9±5.3 vs. 40.2±9.4; p = 0.001) and BEC (s; 6.4±2.9 vs. 5.1±2.7) all declined significantly over time. There was no change in B_{EO} sway over time in either the anteroposterior (mm; 6.4±2.0 vs. 6.2±1.9; p = 0.52) or mediolateral (mm; 5.6±1.3 vs. 5.7±1.5; p = 0.15) directions. Importantly, the multiple regression analysis revealed no effect of change in health status (i.e. between the three groups) in any of the indices measured after nine years.

Conclusions:

Whilst neuromuscular function declined after nine years of active ageing, we were unable to differentiate between the three different health groups defined above. This suggests that exercise has a positive effect in maintaining neuromuscular function across a wide variety of ageing phenotypes.

(1) Pollock RD, et al. An investigation into the relationship between age and physiological function in highly active older adults. J Physiol. 2015;593(3):657-680

C23

Investigation of the effects of tilt table angle on trunk muscle activity during self-initiated postural perturbations.

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Background: Intensive-Care-Unit Acquired Weakness (ICUAW) is a consequence of prolonged immobilisation in the ICU. Patients report perceived weakness, despite no demonstrable weakness in limb muscles. Research has focused on improving the strength of limb muscles through physical therapy. Patients with ICUAW are at high risk of falls and have poor balance, however the impact of ICUAW on the function of trunk muscles, which have a prominent role in the control of posture, has not been investigated. The tilt table is a medical device used in ICU rehabilitation to put patients into different angles of tilt, therefore reintroducing vertical position. Use of the tilt table has been used to improve upright stability, respiration, strength of limb muscles, and minimise the adverse effects of prolonged immobilisation. The extent to which combining post-ICU rehabilitation tasks with tilt table therapy might improve postural control remains unclear and is the basis for this healthy participant study.

Objectives: To assess the onsets and levels of activity in trunk muscles during a modified version of standard post-ICU rehabilitation task, rapid shoulder flexion, at different angles of tilt (0, 30, 60 and 90 degrees).

Methods: Electromyographic activity of trunk muscles (erector spinae, external obliques, rectus abdominis) was recorded bilaterally from 18 healthy volunteers (8 female, 10 male; mean±SD age 20.8±2.1 years). Participants undertook rapid shoulder flexion (5 times) in response to an auditory cue whilst secured on a tilt table, which was set at 4 different angles of tilt (0, 30, 60 and 90 degrees, with 90 degrees being vertical). Onsets of EMG activity (with respect to the prime mover muscle, anterior deltoid), mean EMG in the 100ms following onset and pre-stimulus (-100ms to 0ms) EMG were determined following averaging across the 5 trials and compared for differences across angles.

Results: There were no significant differences between dominant and nondominant sides, data were therefore collapsed across sides. There was a statistically significant effect of angle of tilt on the onset time of the erector spinae during the task. Post-hoc tests revealed differences between tilt angles 0° and 60° ($p=0.03$), and 0° and 90° ($p=0.048$). The mean (±SD) onset time at 0° was 3 (±31) ms, at 30° was 0 (±28) ms, at 60° was -21 (±35) ms and at 90° was -22 (±19) ms.

Discussion: Delayed onsets of trunk muscle activity associated with limb movements are observed in elderly people and in those with chronic low back pain and spinal cord injury. Exercise which advances delayed postural trunk muscle activity has been shown to improve functional trunk activity. We have shown that the angle of tilt influences the onset of trunk muscle activity during exercises that can be employed during rehabilitation. This suggests that combining rehabilitation tasks with tilt table therapy could be used to improve postural control in patients. This may have use in improving symptoms in patients such as those with ICUAW.

C24

Wearable tracking of motor fluctuations in Parkinson's disease

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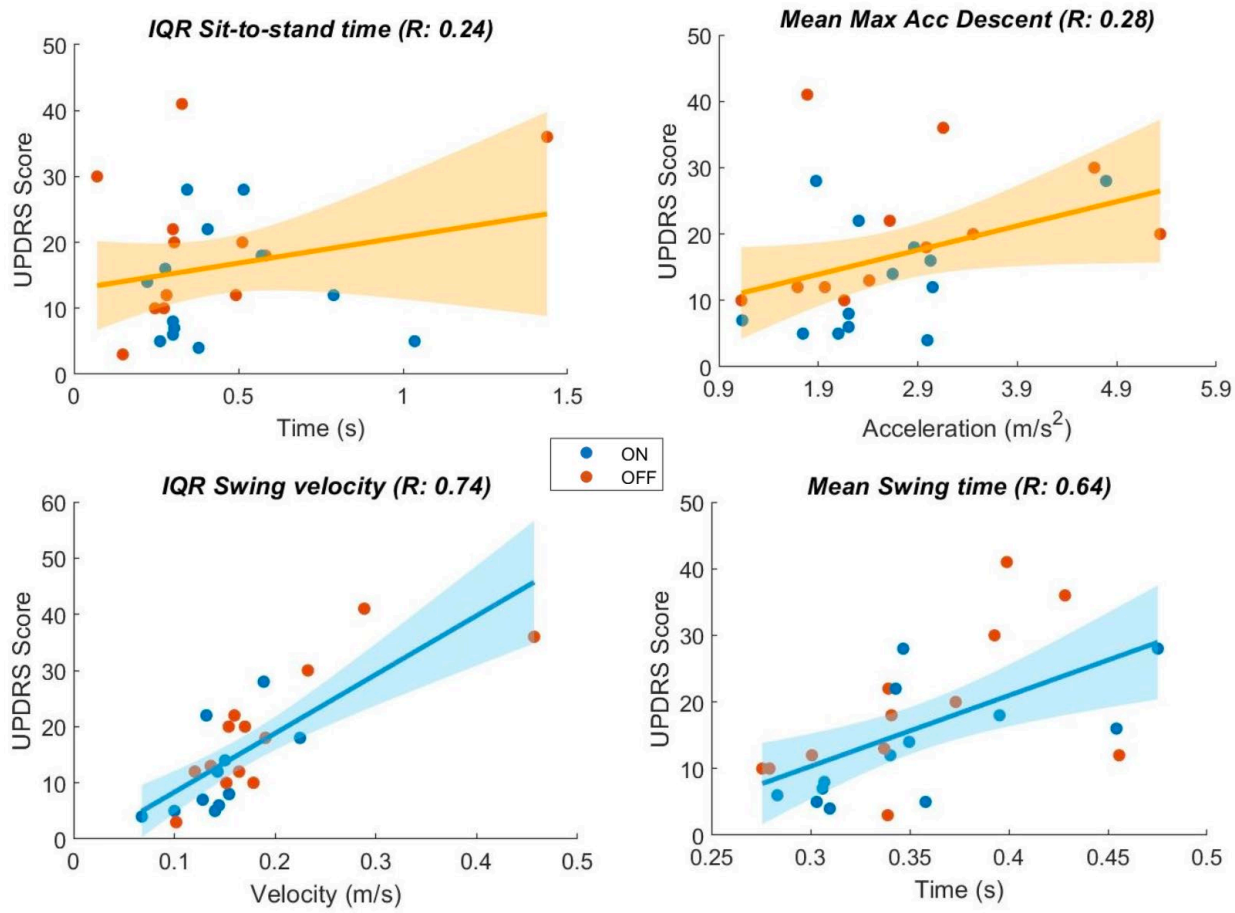
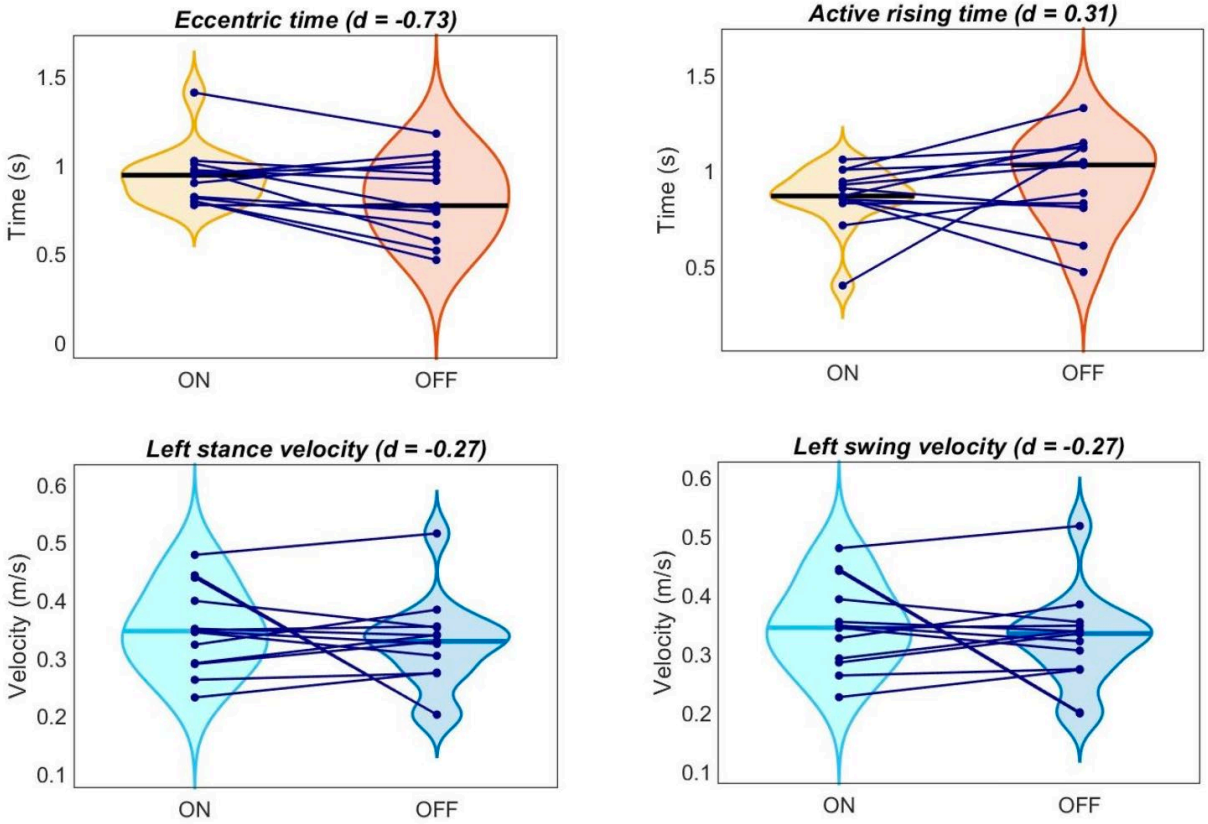
Parkinson's disease (PD) motor symptoms severity is traditionally assessed in a clinical setting using The Unified Parkinson's Disease Rating Scale (UPDRS) which provides snapshots of PD signs and can miss the continuous trajectory of the disease. Longitudinal measurements from wearable devices can provide robust tracking and account for symptom fluctuations [1, 2]. In this study, bilateral wrist-worn wearable inertial sensor devices were utilised to extract digital biomarkers for PD from movement during physical performance tests and real-world tasks. The research zeroed in on measures during gait and sit-to-stand tasks, evaluating the potential of digitally extracted motor features to discern ON/OFF times and assess levels of disease severity.

In the Living Lab study [3], we enlisted a group of 13 individuals with PD. The Living Lab emulates a residential setting while preserving the experimental rigor of a traditional laboratory, facilitating the replication of daily household activities under controlled conditions. Specifically, we extracted digital biomarkers of mobility from the 5-times Chair Stand Test (5x STS) and the 4-meter Gait Speed Test (4 GST) from the Short Physical Performance Battery (SPPB). Triaxial IMU sensors were affixed in the anteroposterior position on both wrists, collecting data in both the ON state and a practically defined OFF state just before medication intake. Analytical validation was achieved by correlating these findings with total scores from Part 3 of the UPDRS. A Support Vector Machine (SVM) was used to discern between ON/OFF times and subscores from Part 3.26 (Arising from Chair) and 3.27 (Gait) of the UPDRS. Cohen's d effect sizes were computed to gauge the extent of change in features across various levels of severity and medication conditions.

Among all the features examined through Spearman correlation analysis with Part 3 of the UPDRS, those related to gait, particularly the interquartile range (IQR) of swing velocity on the most affected side ($R = 0.74$), exhibited significant associations ($p\text{-value} < 0.05$). Notably, IQR features displayed stronger correlations than mean features. Sit-to-stand features, while showing weaker links to total UPDRS scores, excelled in classifying task-specific severity (AUC = 1) for Part 3.26 and distinguishing ON/OFF times (AUC = 0.88). According to Shapley analysis, key features contributing to ON/OFF states classification included mean active rising time ($d = 0.31$) and mean eccentric time ($d = -0.73$) for sit-to-stand, and mean stance and swing velocity ($d = -0.27$) for gait.

This study underscores the promise and effectiveness of accelerometer-based digital measures for discerning between ON and OFF medication states in PD and evaluating overall and task-specific symptom severity. The potential integration of sock-embedded IMU sensors emerges as a prospective avenue for validating these digital measures. The Living Lab setting facilitates the analysis of everyday activities in controlled conditions, shedding light on the practical implications of our findings in real-world contexts. Furthermore, a longitudinal analysis holds potential for gaining deeper insights into long-term progression patterns in PD.


IQR Sit-to-stand time (R: 0.24)
UPDRS Score
Time (s)
Mean Max Acc Descent (R: 0.28)
Acceleration (m/s²)
ON
OFF
IQR Swing velocity (R: 0.74)
Velocity (m/s)
Mean Swing time (R: 0.64)
Time (s)



1. Rovini E, Maremmani C, Cavallo F. How Wearable Sensors Can Support Parkinson's Disease Diagnosis and Treatment: A Systematic Review. Front Neurosci. 2017 Oct 6;11. 2. Vanmechelen I, Haberfehlner H, De Vleeschhauwer J, Van Wonterghem E, Feys H, Desloovere K, et al. Assessment of movement disorders using wearable sensors during upper limb tasks: A scoping review. Front Robot AI. 2023 Jan 9;9. 3. Crook-Rumsey M, Daniels SJC, Abulikemu S, Lai H, Rapeaux A, Hadjipanayi C, et al. Multicohort cross-sectional study of cognitive and behavioural digital biomarkers in neurodegeneration: the Living Lab Study protocol. BMJ Open. 2023 Aug 3;13(8):e072094.

C25

Exploring motor learning of an extra robotic thumb through longitudinal behavioural training

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Successful integration of augmentative technology in everyday life relies, amongst other things, on individuals' capacity to learn to successfully operate an extra limb. In a previous study (Kieliba, 2021), participants were able to use an extra robotic thumb - the Third Thumb (TT, Dani Clode Design) – and make significant progress over the course of 5 days of in lab training on various motor tasks. Our current aim is to expand on Kieliba's findings and explore the motor learning curves over a longer period of time. We'll include a wider variety of tasks in order to target an array of motor skills. We'll also investigate if participants are able to meaningfully make progress on their training with a majority of unsupervised training.

We aim to recruit 30 participants (currently n=22) to learn to use the TT and train for 7 consecutive days. Days 1 and 7 of training occur in lab, supervised by an experimenter, whilst Days 2 to 6 take place remotely with some limited supervision via Zoom (version 5.15.7). Training lasts between 2 to 3h a day, with the possibility of doing extra hours. Participants enter their own scores via interactive videos hosted on a learning platform. The at-home training was designed to explore several facets of motor learning with augmentation devices and the majority of tasks can be broadly divided in 4 categories: collaboration, shared supervision, expansion, and individuation. Participant are tested on their skills in-lab before and after training, in a pre- and post-behavioural session.

Participants' scores improved for all tasks between Day 1 and Day 7, including every day in between while training was unsupervised. This suggests they were able to successfully improve their motor skill using the Third Thumb in various types of scenarios. A plateau effect can be observed in some tasks towards Days 6 and 7. Score improvement between first and last day of training is positively correlated to in-lab pre and post behavioural measures improvement. Additionally, in-lab pre and post behavioural measures were also positively correlated with extra hours of unsupervised training. This seems to show that training with no direct supervision translates into their performance in-lab, proportionally with the number of hours spent training.

So far, this study demonstrates participants' performance on manual tasks using an extra robotic thumb show progress with only 7 days of training, and little supervision. This is an important insight for the field of augmentative technologies, as it shows that learning to operate an extra limb is within reach of most individuals with regular training. Future studies should

investigate how extra robotic body parts are incorporated into the motor synergies and their impact on individuals’ bodies’ sensory model after repeated use. Indeed, it is essential to explore the ways in which augmentative technologies can interact with individuals’ already established motor resources in order to develop products that can be implemented in harmony with them.

Paulina Kieliba et al. ,Robotic hand augmentation drives changes in neural body representation. Sci. Robot. 6, eabd7935 (2021). DOI:10.1126/scirobotics.abd7935

C26

Coordination of vastus medialis and lateralis activation during localized muscle soreness

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Introduction: Vastus medialis (VM) and lateralis (VL) act as synergists during knee extension. During low-effort isometric contractions, common neural drive [1] and differences in firing rate between VM and VL [2] are thought to represent an attempt to balance mediolateral forces acting on the patellofemoral joint. In rats, the central nervous system is able to alter these motor strategies when the relative force contribution of VM and VL is altered experimentally [3]. It is unclear whether a decreased VM force production capability due to localized muscle soreness results in similar motor adaptations in humans.

Objectives: To investigate: 1) whether electrical stimulation can be used to induce muscle soreness in a specific muscle region; and 2) whether localized distal VM soreness alters single motor unit firing properties of VM and VL.

Methods: After approval of the University Ethics committee, 23 participants (24±5 years old, 10 females) performed knee extension contractions at 20% of their maximal effort, before and 2 days after a stimulation protocol designed to induce localised muscle soreness. The protocol consisted of 100, 5s-long electrical stimulations of the distal VM at intensities as high as tolerable. Pain pressure thresholds were collected to assess muscle soreness. Motor unit firing rates were extracted from high-density surface EMG collected using 64-channel grids. In participants where at least 3 VM and 3 VL motor units could be decomposed, the between-muscle coherence was calculated between the two cumulative spike trains. Low-frequency (1-5 Hz) coherence was extracted and compared between sessions. Wilcoxon tests were used to compare pain pressure thresholds, motor unit firing rate and between-muscle coherence between sessions or muscles.

Results: Participants reported localized pain over the distal VM (intensity: 2.6±1.6 out of 10) when climbing down the stairs. Pain pressure thresholds decreased over the stimulated VM region (-40 [-51, -20]%, N=23, $p<0.001$), but not over VL (-2 [-24, 11]% N=23, $p=0.566$). During submaximal contractions at a similar effort between sessions, motor unit firing rates did not differ between sessions (VM: N=172, $p=0.875$; VL: N=210, $p=0.125$). Motor unit firing rate was larger in VM than VL at baseline (8.9 [7.8, 10.5] vs 8.6 [7.4, 9.7] Hz; N=194, $p=0.017$), but this difference was not observed during muscle soreness (9.0 [7.7, 10.4] vs 9.0 [7.8, 10.1] Hz, N=188, $p=0.502$). Between-muscle motor unit coherence was lower during muscle soreness compared to baseline (-3.3 [-0.6, -4.6] Hz; N=12, $p=0.015$).

Conclusions: Localized electrical stimulation successfully induced localized muscle soreness. Similar to what has been observed in individuals with patellofemoral pain [2], localized muscle soreness resulted in a loss of muscle-specific patterns of activation, possibly by means of a reduced low-frequency neural drive between the VM and VL. Although the motor adaptation observed is small, these results support the notion that the central nervous system can alter the

activation strategy between synergists in the presence of muscle soreness, possibly to compensate for differences in force production between synergists.

1. Laine CM, Martinez-Valdes E, Falla D, Mayer F, Farina D. Motor Neuron Pools of Synergistic Thigh Muscles Share Most of Their Synaptic Input. Journal of Neuroscience. 2015;35: 12207–12216. doi:10.1523/jneurosci.0240-15.2015 2. Gallina A, Hunt MA, Hodges PW, Garland SJ. Vastus Lateralis Motor Unit Firing Rate Is Higher in Women With Patellofemoral Pain. Arch Phys Med Rehabil. 2018;99: 907–913. doi:10.1016/j.apmr.2018.01.019 3. Barroso FO, Alessandro C, Tresch MC. Adaptation of muscle activation after patellar loading demonstrates neural control of joint variables. Sci Rep. 2019;9: 1–12. doi:10.1038/s41598-019-56888-9

C27

Beta transcranial alternating current stimulation during a bimanual coordination task modulates activity in motor areas

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Introduction: Everyday activities, such as typing or knitting, strongly depend on the interplay of both hands. This process of bimanual coordination has been related to interhemispheric connectivity between several motor areas within the beta band (15-30 Hz) (Serrien & Brown, 2002). Current research (Weinrich et al., 2017) showed that non-invasive brain stimulation, such as unifocal transcranial alternating current stimulation (tACS) in the beta band (i.e., at 20 Hz) over the primary motor cortex (M1), can induce changes in resting-state connectivity of the sensorimotor cortex as observed with functional magnetic resonance imaging (fMRI). However, the effects of bifocal beta-tACS in the context of bimanual coordination still need to be explored.

Objectives: In the current study, we investigated whether bifocal beta-tACS over both M1s during task performance can modulate behavioural and neural markers of bimanual coordination.

Methods: 18 healthy right-handed volunteers (18-35 years) participated in the study. All experimental procedures were approved by the local Ethics Committee and were conducted in accordance with the Declaration of Helsinki (2013).

Using fMRI (3T Siemens Prisma MR scanner) we recorded participants' brain activity during a bimanual coordination task: using force grippers they had to execute well-coordinated alternating movements at two different speeds (slow and fast) following auditory cues, in a block design. While performing the task, participants could receive either in-phase, jittered-phase or sham beta (20 Hz) tACS over both M1 in a within-subject, repeated measures design. Active stimulation was applied at 4 mA (peak to peak) during each task run, which lasted 13.15 min. The order of stimulation conditions was counterbalanced across participants.

Coordination (Pearson's correlation between forces produced by both hands), separated per stimulation and speed condition, was analysed in a linear mixed model in R, including

stimulation and speed as fixed and participants as random factors. fMRI data were analysed with FSL. Task's speeds in all three stimulation conditions were first modeled at the individual level using a general linear model. With a permissive threshold for preliminary analyses (Z>2) within the regions activated by the bimanual coordination task (see Figure 1), we then investigated whether we had group-level differences in brain activity due to speed and/or stimulation condition.

Results: At the behavioural level, our preliminary analyses showed no effect of tACS' protocol on coordination (p>0.05), given the absence of a stimulation by speed condition interaction (p>0.05). However, volunteers showed higher performance levels during slow as compared to fast asymmetrical movements (p=0.04), highlighting a well-known effect of task speed on bimanual coordination.

At the brain activity level, we observed that motor areas, such as sensorimotor cortex, supplementary motor area and the striatum, were activated less by in-phase bifocal 20 Hz tACS over both M1, as compared to sham stimulation (Z>2) and jittered-phase stimulation (Z>2). This result was irrespective to the task's speed (see Figure 2).

Conclusions: Our preliminary results suggest that in-phase bifocal beta-tACS over both primary motor cortices decreased activity in several motor areas in the absence of behavioural changes in coordination.

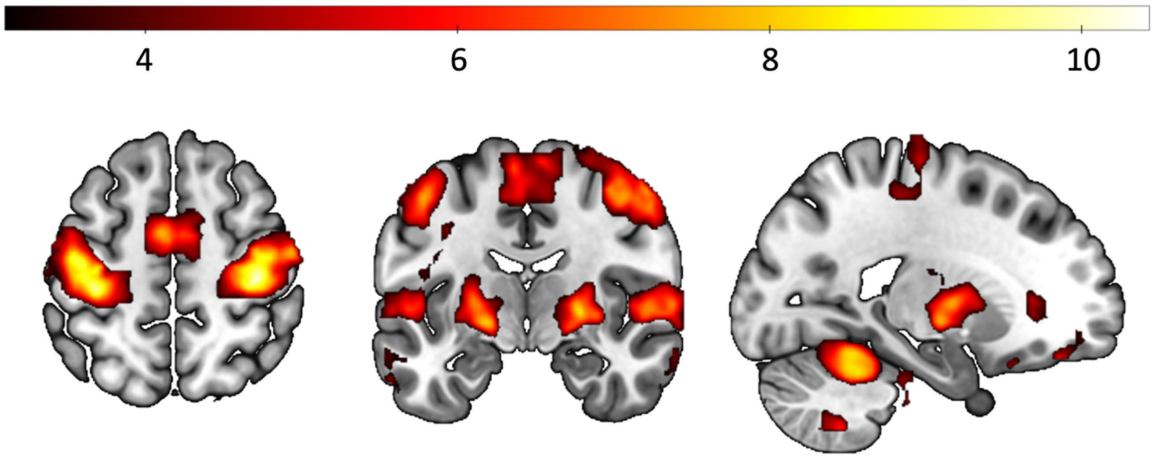

Figure 1: Brain regions activated while performing the bimanual coordination task at either slow or fast speed, as compared to rest, independent of the stimulation condition. The activation map is displayed on a T1-weighted template image (MNI: x=-21, y=-10, z=56) at a cluster threshold of Z>3.1 and a cluster significance threshold of p=0.05. The colour bar represents Z values.

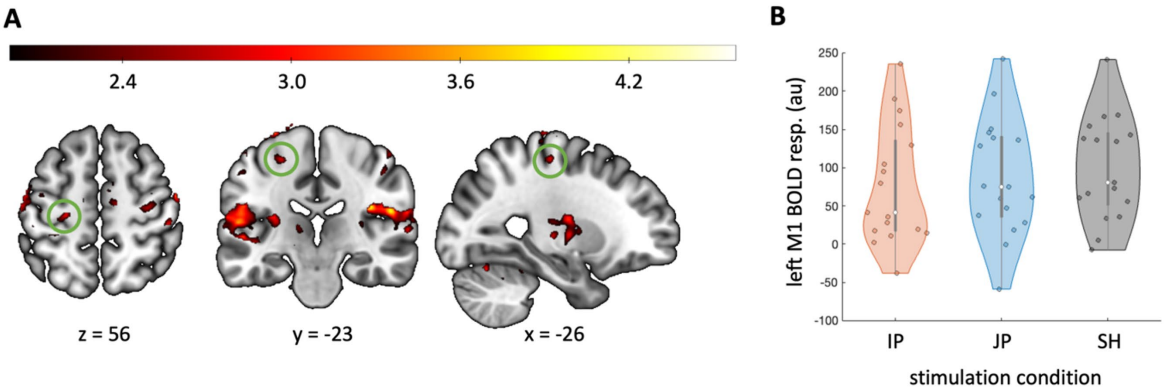

Figure 2: **A**: Brain regions activated less during in-phase (IP) as compared to sham (SH) stimulation, at both task's speed (n=17). The activation map is displayed on a T1-weighted template image (MNI: x=-26, y=-23, z=56) at a threshold of Z>2. The colour bar represents Z values. **B**: Decreased activation (BOLD response/beta values in arbitrary units (au)) was observed during in-phase (IP, orange) as compared to jittered-phase (JP, blue) and sham (SH, black) stimulation in the left primary motor cortex (M1, cluster highlighted with a green circle in A).

Serrien, D. J., & Brown, P. The functional role of interhemispheric synchronization in the control of bimanual timing tasks. Experimental brain research, 147(2):268–272, 2002. Weinrich, C. A., Brittain, J. S., Nowak, M., Salimi-Khorshidi, R., Brown, P., & Stagg, C. J. Modulation of long-range connectivity patterns via frequencys pecific stimulation of human cortex. Current Biology, 27(19):3061–3068, 2017.

C28

Tracking beta bursts at the cortical and peripheral levels for Parkinson's disease

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Research in Parkinson's disease (PD) has centred around the exploration of beta activity (12-30 Hz) and beta bursts as potential markers for evaluating therapeutic effectiveness, and in the context of closed-loop deep brain stimulation (DBS). Although current clinical trials of closed-loop DBS employ beta power as a physiomarker to adjust the stimulation, uncertainties remain regarding how the beta power and characteristics of beta bursts respond to stimulation and different symptomatic scenarios. High-density surface electromyography (HDsEMG) offers a promising non-invasive neural signal to explore the underlying mechanisms of beta activity and bursts along the corticospinal tract. This technique records muscle activity with high spatial and temporal resolution, allowing for a comprehensive assessment of electrophysiological activity. Recent research findings have demonstrated that beta activity occurs in bursting patterns at both cortical and motor unit levels during isometric contractions of the tibialis anterior muscle [1]. This indicates that peripherally measured beta bursts are a consequence of cortical projections. Expanding on this work, our study replicates these findings using smaller muscles of the upper limb, and in a case-study demonstrated its sensitivity to DBS.

We recorded from the forearm muscles to track beta burst characteristics (e.g. duration, amplitude, rate) at the peripheral levels. Motor cortex activity was recorded using a 19-electrode electroencephalography (EEG) headset, while forearm muscle activity was monitored using HDsEMG with 256 electrodes, targeting the flexor carpi radialis (FCR) and ulnaris (FCU), and the extensor carpi radialis (ECR) and ulnaris (ECU). We incorporated torque measurements during a trapezoidal force tracking task at varying tasks (isometric wrist flexion and extension), and varying percentages (5%, 10%, 20%, and 30%) of maximum voluntary contraction (MVC). This involved both non-PD (n=6) and PD (n=1) participants, with a particular emphasis on a case study featuring a PD-DBS patient (n=1). In this case study, the participant manipulated their DBS settings using a remote control (decreasing left electrode amplitude by 1.5mA), allowing us to examine the sensitivity of HDsEMG signals in detecting changes induced by alterations in DBS parameters.

Our analysis involved the decomposition of a substantial number of motor units for each muscle (up to 27 for the ECU), revealing greater decomposition in wrist extension than flexion ($p=0.004$, Mann-Whitney U test). Furthermore, our exploration into variations in beta burst features showed correlations between HDsEMG and EEG beta bursts (Pearson correlation coefficients 0.54, 0.56 and 0.78 respectively for rate, duration, and amplitude), suggesting a degree of coherence between the beta bursts occurring within the motor cortex and those in the peripheral regions. We validated the multimodal setup's ability to track beta bursts across the corticospinal tract and showed its generalisability and sensitivity to PD and PD-DBS patients. This integrated approach holds the potential to understand the dynamic changes the brain undergoes during neuromodulation interventions and fluctuations in symptoms.

[1] Braecklein M et al. (2022) Journal of Neuroscience 42, 3611–3621

C29

Coexistence of broad motor system suppression and antagonist muscle activity implicates a sub-cortical mechanism in movement cancellation

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Background

The ability to cancel or stop planned movements is a key aspect of self-control. The process is thought to involve a prefrontal-basal ganglia-thalamocortical network, which exerts a broad suppression over primary motor cortex (M1) to prevent planned movements from being expressed[1]. For example, when stopping a hand movement, suppression is observed in unrelated motor cortical representations, such as leg motor areas[2]. However, this broad suppression could be counterproductive when attempting to stop an ongoing movement. In such cases, stopping requires the activation of antagonist muscles to actively 'brake' the motion[3].

Aims
In this study, we set out to examine the hypothesis that the activation of antagonist muscles recruited to stop an ongoing movement is independent of the M1 and, consequently, remains unaffected by cortical suppression.

Methods

In two ongoing experiments, participants engaged in a stop signal task using a computer mouse. They responded to 'go' cues by performing reaching movements to maneuver the cursor towards targets on a screen. In ~25% of trials, they received a stop signal instructing them to halt their planned movement. The timing of the stop signal was adjusted so that participants were able to successfully prevent their response in 50% of the trials. In the other 50%, they initiated a movement but then interrupted it before reaching the target. We recorded electromyogram (EMG) activity during the movements from the right anterior and posterior deltoid muscles (AD, PD), which serve as agonists and antagonists during reaching. Transcranial magnetic stimulation (TMS) was applied to M1 to elicit motor evoked potentials (MEPs) in the task-irrelevant FDI of the left hand (Exp.1) and task-relevant AD and PD (Exp.2) at 50 ms intervals following the presentation of the stop signal.

Results

Preliminary results from Exp.1 (n=7, age 24±7 years, 3 males) indicated an expected suppression[3,4] of MEPs in the task-irrelevant FDI, which emerged 150 ms after the stop signal and continued for ≥100 ms. It was observed both when movement was entirely prevented and when it was initiated but then halted by the activation of the antagonist muscle, whose activity started during the suppression phase, ~200 ms after the stop signal. Initial results from Exp.2 (n=8, age 24±7 years, 4 males) focused on examining the temporal relationship between changes in muscle activity and MEP amplitudes in agonist and antagonist muscles. If M1 is responsible for driving EMG activity, we would expect an increase in MEP amplitudes to

precede the rise in EMG activity, with a time delay equivalent to the cortico-muscular conduction time[5]. This pattern held true for the agonist muscles when initiating movements (time delay ~9 ms), but not when the antagonist was recruited to stop an ongoing movement.

Conclusions

The present data offer preliminary evidence of substantial antagonist "braking" activity when stopping an ongoing movement, even in the context of extensive motor system suppression, and without a preceding increase in M1 excitability. This suggests that the initiation of antagonist activity may be governed by a distinct, potentially subcortical, mechanism[5].

References [1] Hannah & Aron (2021) Nature Reviews Neuroscience 22:538–552 [2] Badry et al. (2009) Clinical Neurophysiology, 120(9):1717-1723 [3] Atsma et al. (2018) Journal of Neuroscience, 38(18):4367-4382 [4] Jana, Hannah et al. (2020) eLife, https://doi.org/10.7554/eLife.50371 [5] MacKinnon & Rothwell (2000) Journal of Physiology, 528(3):633-645

C30

Threshold detected noise vestibular stimulation effects on standing balance.

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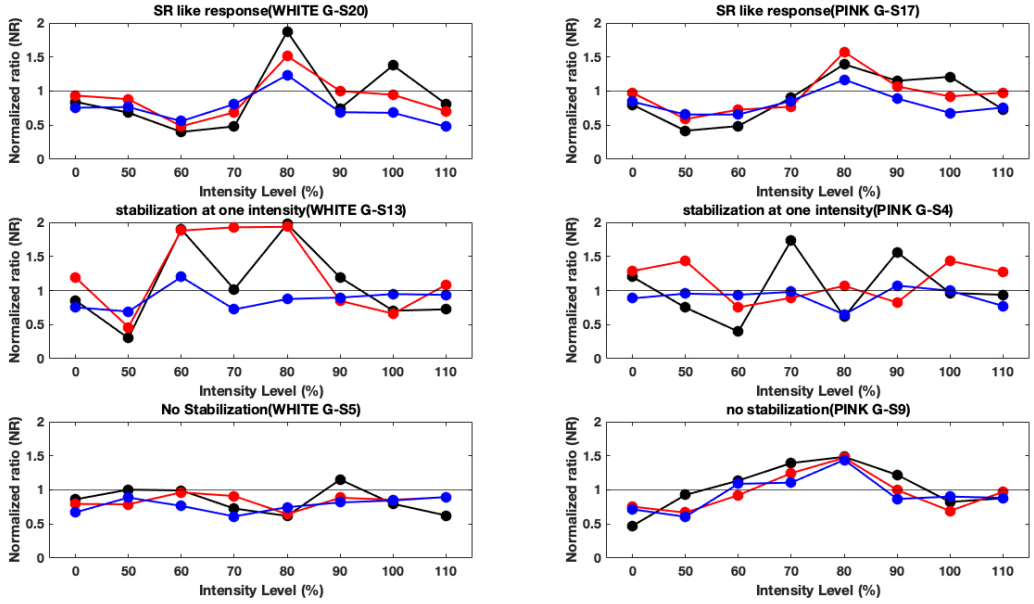
Low (sub-threshold) levels of noisy vestibular stimulation (nVS) improve stability in healthy adults[1]. This has been explained by the stochastic resonance[2] (SR) phenomenon according to which adding random noise to a non-linear system can enhance the detection and transmission of weak signals. However, for a system to exhibit SR behavior, stimulus-response data should follow a pseudorandom bell-shaped curve peaking at optimal levels for signal transmission[3]. The **objectives** of the present study were a) employ an individual-based threshold detection approach to identify optimal stimulus intensity, b) examine if noise-induced reductions in postural sway align with Stochastic Resonance (SR) phenomenon, c) compare white and pink noise vestibular stimulation in inducing SR-like postural sway reductions.

Method: Forty-two (42) healthy young volunteers (15 males, 27 females, age 30.0 ± 9.0 years), were randomly divided into a group that received WHITE noise VS (n=22) and a group receiving PINK noise stimulation (n=20). Participants were fitted with a set of bipolar electrodes, with the cathode electrode always attached on the left mastoid. Stimuli were generated in LABView, sent to an analog output device (NI PCI-6221) and delivered to the participant after passing through an constant current isolator (A-M Systems). For the thresholding task, participants received, while seated, 10s bouts of nVS (zero-mean, Gaussian, 0-30 Hz) of increasing intensity in steps on 0.05 mA until they felt and verbally declared the stimulus onset and offset times for three successive stimuli bouts. This was defined as the individual perceptual threshold (PT) intensity. For the standing task, participants stood for 60 s on a force platform (Bertec Balance Plate, 100 Hz) with feet together and eyes closed. nVS was applied during the 2nd half of the trial (30 to 60s) at 7 intensities around the individual perceptual threshold (50%, 60%, 70%, 80%, 90%, 100% and 110% of threshold). A trial with sham stimulation was performed at the beginning of testing. Standing balance was quantified in the area, the root mean square (RMS) displacement and the mean velocity of the Centre of Pressure (CoP). A normalized ratio (NR) of the stimulus vs. the no stimulus period was calculated for each balance measure and this ratio was then subject to statistical analysis.

Results and conclusion: PT intensity was not different between the WHITE and PINK noise groups ($p>.05$). In standing, the NR did not change across stimulus intensities ($p>.05$) and was not different between groups except for the NR of CoP velocity that increased at 90% ($p=.032$) and 100% ($p=.006$) of PT for the PINK group. Most participants (95% of the WHITE and 75% of the PINK group) showed stabilization (NR<95% of CI) for 2/3 measures at one intensity at least[1] (Figure 1). Nevertheless, only a minority of them (42% and 35% for the WHITE and PINK group respectively) exhibited an SR-like pseudo bell shaped response[3]. These results do not confirm a stabilizing effect of nVS but contribute to the ongoing discussion on optimal protocols for

delivering nVS and further our understanding of the vestibular system's involvement in balance control.



[1] Iwasaki, S., Yamamoto, Y., Togo, F., Kinoshita, M., Yoshifuji, Y., Fujimoto, C., & Yamasoba, T. (2014). Neurology, 82(11), 969-975 [2] Moss, F., Ward, L. M., & Sannita, W. G. (2004). Clinical neurophysiology, 115(2), 267-281. [3] Assländer,L., Giboin, L. S., Gruber, M. ,Schniepp R. & Wuehr, M.(2021) Scientific Reports | (2021) 11:12327

C31

Neurophysiology vs Neuroanatomy of Deep Brain Stimulation in Parkinson's Disease

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Deep brain stimulation (DBS) is a common therapy for Parkinson's disease. To determine clinically effective DBS parameters, clinicians complete extensive open-loop programming sessions which are prone to unreliability in accuracy. To guide parameter selection, neuroanatomical and neurophysiological biomarkers are being developed. At a neuroanatomical level, an increase in overlap between the volume of tissue activated (VTA) by the stimulation and target nuclei can be used to predict clinical outcomes [1]. Similar findings have been observed when using cortical recordings to guide DBS parameter selection [2]. Whilst both types of biomarkers can, to a degree, optimize DBS, they are not being used in conjunction as the relationships between them have not been fully explored.

This study aimed to determine the role of active electrode location, and corresponding overlap of the volume of tissue activated with the target nuclei, on cortical oscillatory activity during changes in DBS settings in Parkinson's disease patients [3].

Using a 7-channel wireless EEG headset, cortical recordings were obtained during routine DBS parameter adjustment visits in the clinic (n=21). Arm tasks were used by the clinician to determine the efficacy of the DBS settings. From these task periods, relative power and bursting activity (burst amplitude, duration, and rate) were extracted for low (12-20Hz) and high (21-35Hz) beta power. To obtain the volume of overlap corresponding to the DBS settings, leads were localized by merging pre-operative MRI and post-operative CT scans in LEAD-DBS [4]. The location of the active electrodes was identified and overlap was calculated with the corresponding nucleus. If electrodes were in the subthalamic nucleus (STN) and an adjacent nucleus, overlap was calculated only with the STN. Following the extraction of these biomarkers, the delta between them for each pair of DBS settings was calculated.

Active contacts were found in the motor area of the STN (motor-STN; n=23), in the STN and adjacent nucleus (STN+; n=43), and in the substantia nigra pars reticulata (SNr; n=12). When stimulating multiple nuclei (STN+), change in low beta burst durations was reduced (p>0.01) compared to motor-STN stimulation. The low beta burst rate decreased when there was an increase in overlap with the motor-STN (p>0.01). High beta burst durations were greater when SNr was stimulated rather than motor-STN (p=0.03). High beta burst rates were significantly greater when active contacts were in the SNr than the motor-STN (p>0.01) or STN+ (p=0.02).

Neurophysiological biomarkers change depending on the location of the active electrode and which nucleus is being primarily stimulated. Low beta burst rate appeared most sensitive towards changes in overlap with the motor-STN but further investigation is required into other neurophysiological biomarkers.

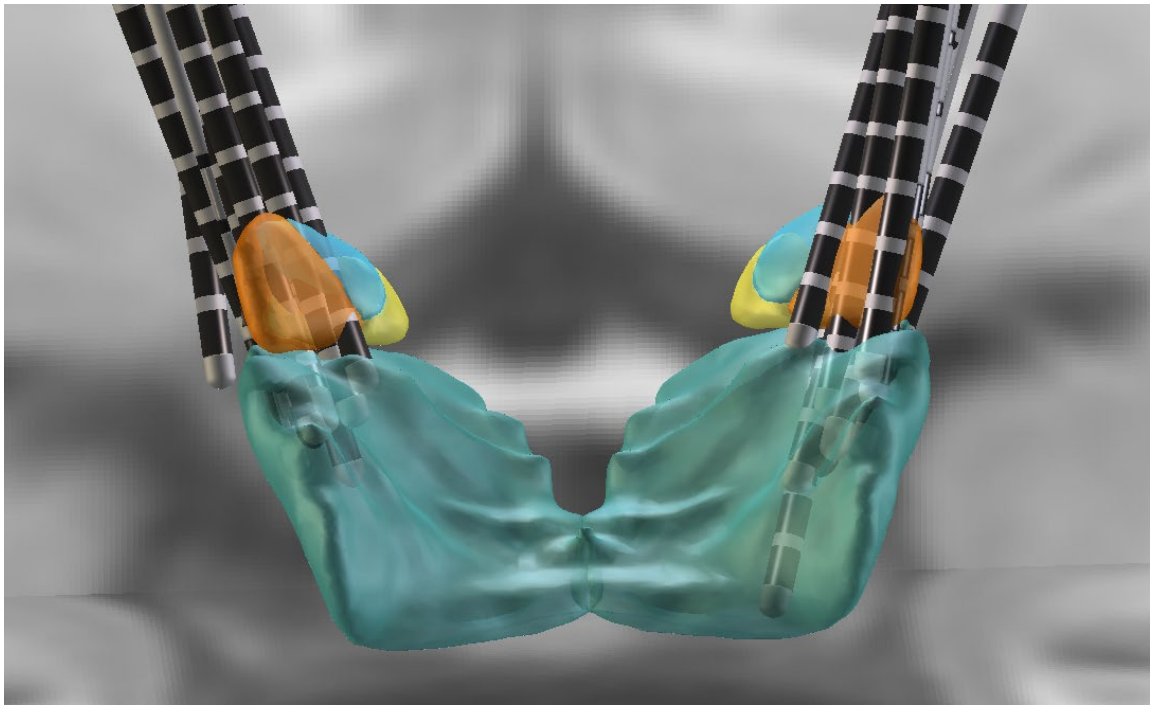

Figure 1. Location of leads for patients displayed in the MNI template space. Top nucleus: sensorimotor-STN denoted in orange, associative-STN in blue, and limbic-STN in yellow. Bottom nucleus: substantia nigra pars reticulata.

[1] Dembek TA, et al. Ann Neurol. 2019; 86(4):527–38 [2] Liu C, et al. Cogn Neurodyn. 2021; 15(6):1157-1167 [3] Kutuzova A, et al. Mov Disord. 2023; 38(suppl 1) [4] Horn A, Kühn AA. NeuroImage. 2015; 107:127–35

C32

Effect of Sinapic Acid on Scopolamine-Induced Learning and Memory Impairment in SD Rats

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In modern times, the seriousness of diseases caused by aging is drawing attention. Among them, Alzheimer's disease, a chronic neurodegenerative disease, accounts for 80% of senile dementia. Continuous research is being conducted on the cause of Alzheimer's disease, and it is believed that complex factors such as genetic factors, accumulation of amyloid beta plaque, tangle of tau protein, oxidative stress, cholinergic dysfunction, neuroinflammation, and cell death are involved. Sinapic acid is one of the hydroxycinnamic acids found in the plant family, such as orange, grapefruit, cranberry, mustard seeds, and rape seeds. It shows various biological activities such as anti-inflammatory, antioxidant, anticancer, and antidepressant. In other words, Sinapic acid is considered to be an acetylcholine esterase inhibitor that can be applied to the treatment of Alzheimer's disease, senile dementia, motor dysfunction, severe work history, and Parkinson's disease. However, studies from the electrophysiological perspective on the effects of Sinapic acid on memory and learning still need to be made clear. Therefore, it was confirmed that the administration of Sinapic acid was effective in long-term potentiation (LTP) using organotypic hippocampus segment tissue. In addition, the effect on Scopolamine-induced learning and memory impairment was measured by oral administration of Sinapic acid 10 mg/kg/day for 14 days by conducting behavioral experiments related to short-term and long-term spatial memory and avoidance memory. Administration of Sinapic acid increased the activity of field excitatory postsynaptic potential (fEPSP) dose-dependent after TBS and restored fEPSP activity in the CA1 region suppressed by scopolamine. The scopolamine-induced learning and memory impairment group showed lower results than the control group in Y-maze, Passive avoidance, and Morris water maze experiments. Sinapic acid improved avoidance memory, short-term and long-term spatial recognition learning, and memory. In addition, Sinapic acid weakened inhibition of brain-derived neurotrophic factor (BDNF), tropomyosin receptor kinase B (TrkB) and activation of prostaglandin-endoperoxide synthase 2 (COX-2), interleukin 1 beta (IL-1β) induced by scopolamine in hippocampus tissue. These results showed that Sinapic acid is effective in restoring LTP and cognitive impairment induced by cholinergic receptor blockade. In addition, it showed the effect of alleviating the reduction of scopolamine-induced BDNF and TrkB, and alleviating neuroinflammatory effects due to inhibition of the increase of COX-2 and IL-1β. Therefore, we show that Sinapic acid has the potential as a treatment for neurodegenerative cognitive impairment.

C33

Lack of somatotopy in the macaque lateral corticospinal tract: implications for understanding of human incomplete spinal injury

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In some cases of incomplete cervical spinal cord injury (iSCI) there is marked paresis and dysfunction of upper extremity movement, but not of the lower extremity. A persistent explanation of such symptoms is a somatotopic organization of corticospinal tract (CST) fibres passing through the decussation of the pyramidal tract (PT) at the craniovertebral junction (CVJ) and lateral corticospinal tract (LCST). In Central Cord Syndrome, it has been repeatedly suggested that traumatic injury to the core of the cervical spinal cord may include selective damage to medially-located arm/hand LCST fibres, without compromising laterally-located leg fibres.

To investigate whether somatotopic organization exists in the primate PT, CVJ or LCST, and with

approval of the USD IACUC, we made a systematic investigation using localised injection of high-resolution anterograde tracers into physiologically-characterised cortical representations of 17 anaesthetised macaque monkeys. We thereby defined the course of the corticospinal projection (CSP) through the PT, CVJ and LCST from sensorimotor areas of the frontal and parietal lobe contributing to the corticospinal tract, including the arm/hand, shoulder and leg areas of primary motor cortex (M1), dorsal and ventral premotor cortex, SMA, rostral and caudal cingulate motor areas, S1 arm and leg areas, and parietal area PE. The approach used labels CST fibres of all sizes, large and small. We found no evidence for somatotopic organization of CST fibres passing through the CVJ or contralateral LCST. Fibre labelling from each cortical representation was widespread throughout the PT, CVJ and LCST, and overlapped extensively with fibres from other representations. Fibres from some of the parietal areas tended to cluster in one particular region of the PT, but again overlapped with fibres from other areas. Area S1 leg and arm projections were completely overlapping.

Stereological analysis of tissue from PT and two different spinal levels (C5, C8) from 8 cases revealed no significant difference in the number of labelled M1 arm/hand fibres in different medio-lateral sectors across PT and LCST. This was assessed from the slope of the line regressing labelled fibre numbers in medial, ventral and lateral sectors of PT/LCST (p range 0.16 - 0.80). A similar result was found for fibres labelled from the M1 leg area (0.6-0.22) and shoulder (0.08-0.60) area.

Our investigation firmly rejects the concept of somatotopy amongst CST fibres passing through the PT, CVJ and LCST. All CST fibres in the LCST, regardless of their cortical origin, would thus appear to be equally susceptible to focal or diffuse injury. The disproportionate impairment of arm/hand movement after iSCI must therefore be due to other factors. One is the greater

dependence of hand/arm movements on the integrity of the CST, when compared with lower limb function, and particularly on the fast-conducting cortico-motoneuronal input to hand and digit muscles. The dispersed and commixed nature of frontal and parietal CST fibres is clearly a fundamental principle of corticospinal organization and may be important in motor recovery after cervical iSCI in humans. Textbooks and teaching explaining the effects of iSCI should be revised in the light of these new findings.

Morecraft RF et al (2021) Lack of somatotopy among corticospinal tract fibers passing through the primate craniovertebral junction and cervical spinal cord: pathoanatomical substrate of central cord syndrome and cruciate paralysis. J. Neurosurg 136, 1395-1409. Lemon RN & Morecraft RF (2023) The evidence against somatotopic organisation of function in the primate corticospinal tract. Brain 146, 1791-1803.

C34

Bifunctionality: variability in peronei muscles function during abduction of the foot and plantar flexion of the ankle

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Introduction: Peroneal muscles, main ankle evertors, are commonly affected and overstretched by sudden inversion of the ankle, the most frequent injury in sports, leading to impaired function and frailty. Their role includes mediolateral stability of the ankle and prevention of sudden and involuntary ankle inversion (Konradsen et al. 1998). However, they are considered as bifunctional muscles (abductors of the foot and plantar flexors of the ankle) (Pérot & Goubel, 1982) as the direction of their torque vector is not aligned with a single plane of action. By studying the discharge times of multiple concurrently active Motor Units (MUs) into these muscles, with high-density electromyography (HD-EMG) (Farina & Enoka, 2023), and by comparing estimates of the variance in the common modulation of MUs activity, a more detailed information for neural drive can be acquired during two tasks: abduction of the foot and plantar flexion of the ankle.

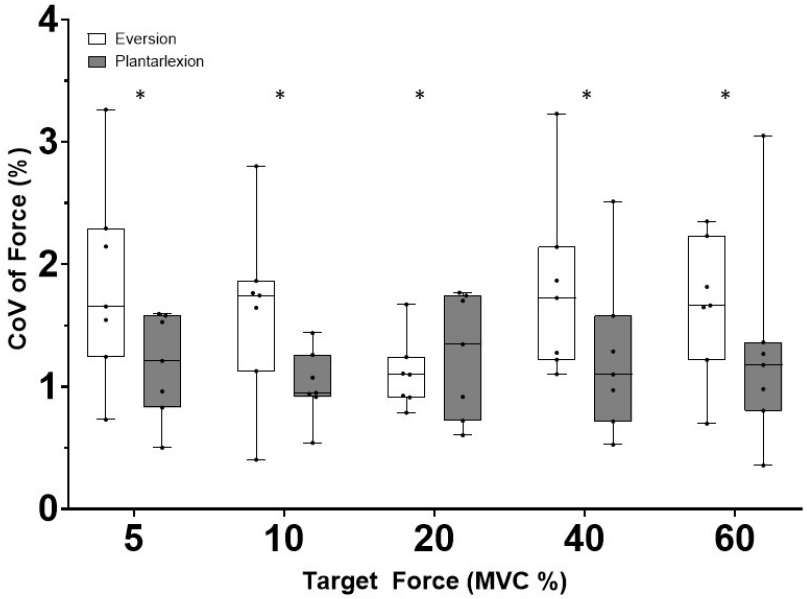
Aim/Objective:Thus, this study aims to compare neural drive variability of peroneal muscles during these two tasks.

Method:Seven active men participated in the experimental procedure. Prior to experiment, ultrasound recordings were acquired to ensure the proper array placement over the muscle belly for peroneus longus (PL) and peroneus brevis (PB). The experimental procedure comprised of trapezoidal isometric contractions of abduction of the foot and plantar flexion of the ankle at five target forces (5, 10, 20, 40 and 60% of MVC) with HD-EMG recordings using a 400-channel EMG amplifier (Quattrocento, OT-Bioelettronica, IT, 2048 Hz) from PL and PB. Force steadiness was quantified as Coefficient of Variation for force (CoV for force) and MUs discharge characteristics of PL and PB were analyzed as Mean Discharge Rate (MDR), Coefficient of Variation of InterSpike Interval (CoV ISI) and Standard Deviation of filtered Cumulative Spike Train (SD fCST). Linear mixed effects models were used to compare the two muscles (PL and PB), two tasks (abduction and plantarflexion) and five target forces (5, 10, 20, 40, and 60%). In all models, muscles, tasks, and force level were specified as fixed factors with participant as a random factor.

Results:The MVC force was significantly ($p=0.004$) greater during plantar flexion of the ankle compared to abduction of the foot. The CoV for force was greater during abduction of the foot compared to plantar flexion of the ankle ($p=0.022$). The MDR were similar between PL and PB and increased linearly with force. The CoV ISI was similar between muscles ($p=0.895$) and actions ($p=0.257$), but increased gradually with force ($p=0.001$). Additionally, the SD fCST was similar between the two muscles and actions ($p=0.414$).

Conclusions: Despite the differences on force output, the MU's discharge characteristics of PL and PB were similar between the two tasks. The results might be attributed to the reduced variability of neural drive, due to improved capability of the motor unit pool to discharge action potentials during plantar flexion, as a result of daily activity. Collectively, these findings should be considered in order to design more efficient clinical interventions.

Figure 1: Indicates CoV force between to tasks for all target forces. (*=p<0.05)



Perot C. & Goubel F. (1982). Eur J of Appl Physiol 48, 59-65 Farina D. & Enoka R. M. (2023). J Electromyogr Kinesiol 71, 102796 Konradsen et al. (1998). Am J Sports Med 26, 72-77

C35

Evaluating the characteristics of evoked spinal cord high-frequency wave potentials using posterior and anterior surface electrodes: A preliminary study

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Background: The characterization of neurological and neurodegenerative conditions, such as Amyotrophic lateral sclerosis (ALS), relies on biomarkers that can quantify sensorimotor dysfunction. Potential candidate biomarkers associated with spinal cord dysfunction have received little attention so far, especially very high frequency oscillation which may be generated (in part) by long sensory tracts. Previous studies[1,2] have measured low-amplitude high-frequency wave evoked potentials (LHWs) recorded invasively at cervical spinal levels. Invasive neuroelectric recordings from the posterior location of the spinal cord have reported changes in the characteristics of LHW responses in the patients with neuropathic pain. In this study, we explore the possibility of using non-invasive recording techniques to evaluate Spinal-LHWs using both the anterior and posterior electrode locations at the cervical spinal cord level.

Objective: To investigate the characteristics of evoked LHW components recorded (anteriorly and posteriorly) at C6 cervical spinal level using the surface ring electrode placement system[3] in response to median nerve stimulation.

Methodology: Data from 10 young healthy participants were collected. Non-invasive surface electrodes were placed on the neck in accordance with the ring electrode placement system at C6 vertebral level (Cv6) to record the neuro-electrophysiological signals (sampling rate of 8kHz). A total of 1400 evoked responses (trials) were recorded in response to the median nerve (MN) stimulation at wrist (1.5 X Motor Threshold, 2Hz). The recorded signals were pre-processed to remove artifacts, bandpass filtered between 350-2000Hz, and spatially filtered to increase the signal-to-noise ratio. The high-frequency evoked potentials (LHW) were obtained by averaging the resulting signals across all trials.

Results: The LHW responses were observed in response to the MN stimulation at anterior cervical (AC) and posterior cervical (PC) electrode locations. The recorded peak amplitude (mean ± SD) was Cv6-PC: 0.081 ± 0.029 (μV), Cv6-AC: 0.26 ± 0.11 (μV). The peak amplitude recorded at AC was greater than the amplitude measured at PC ($p = 0.0011$, paired t-test).

The observed peak (mean ± SD) and onset latencies (mean ± SD) were Cv6PC: 11.5 ± 2.4 (ms), Cv6-AC: 10.5 ± 0.97 (ms) and Cv6PC: 6.1 ± 0.81 (ms), Cv6-AC: 6.2 ± 0.58 (ms)

respectively. The duration of the evoked responses was Cv6-PC: 9.0 ± 1.9 (ms), Cv6-AC: 7.9 ± 2.0 (ms).

Discussion: The preliminary results on young healthy participants indicate that LHW responses can be recorded with non-invasive techniques at cervical levels. Furthermore, the response measured at anterior location had higher amplitude than the response measured at posterior location. This could indicate that long-sensory tracts (eg. spinothalamic tract) located anteriorly might be responsible for LHW response, supporting Prestor[1] et. al. The non-invasive LHW assessment could uncover potential biomarkers associated with sensorimotor dysfunction in the spinal cord.

1. Prestor et al., 1997, 104(6), pp.470-479 2. Insola et al., 2008, Clin. Neurophysiology 119.1: 237-245. 3. Chander et al., 2022, NeuroImage, 253, 119050

C36

Non-invasive decoding of the neural drive in the upper-limb during individual finger movements thorugh automatic motor unit decomposition

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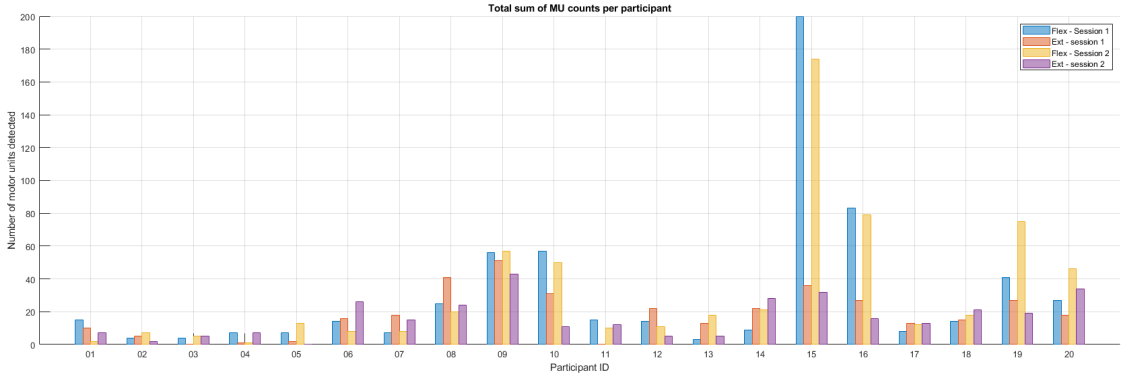
Advancements in recording methods for neurophysiological signals, in particular, the use of high-density surface electromyography (HD-sEMG) results in increased spatial resolution but also opens the possibility to decode the neural drive to muscles. The higher number of electrode channels allows the detection of individual motoneuron action potentials and spike trains through the technique known as motor unit (MU) decomposition. Current studies on decomposition for decoding the neural drive to muscles focus on lower limb muscles, where the number of decoded MUs can be much higher compared to upper limb muscles [1]. This is mainly due to anatomical differences affecting signal propagation. Regardless, MU decomposition in the upper limb opens the exciting possibility to non-invasively decode the neural drive during manipulation tasks that involve a richer motor repertoire. Hence, in this study, neural drive decoded through motor unit decomposition from forearm muscles during finger movement is analysed. We decided to analyse the neural drive during individual finger movement as a starting point before moving to multi-finger gestures.

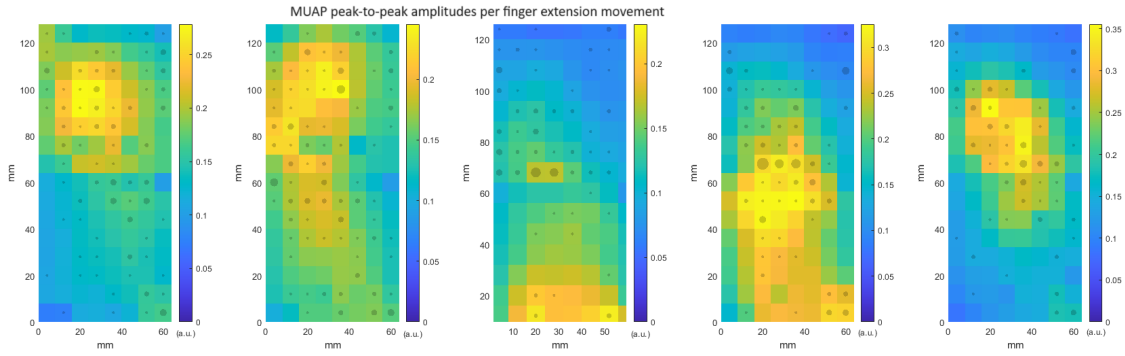
For this study, a publicly available dataset (the Hyser MVC dataset [2]) of HD-sEMG over forearm muscles during individual finger flexion and extension were analysed. The dataset comprises 256 EMG channels over the forearm flexor and extensor muscles (128 on each side of the forearm) during individual finger isometric contractions. Automatic motor unit decomposition was applied to this dataset using the method by Negro et al. [3]. The decomposition hyperparameters were chosen after empirical testing in sub-samples of the dataset to ensure reliable identification of MUs. We extracted the number of decomposed MU, their locations, and their waveforms' amplitudes over the electrode grid.

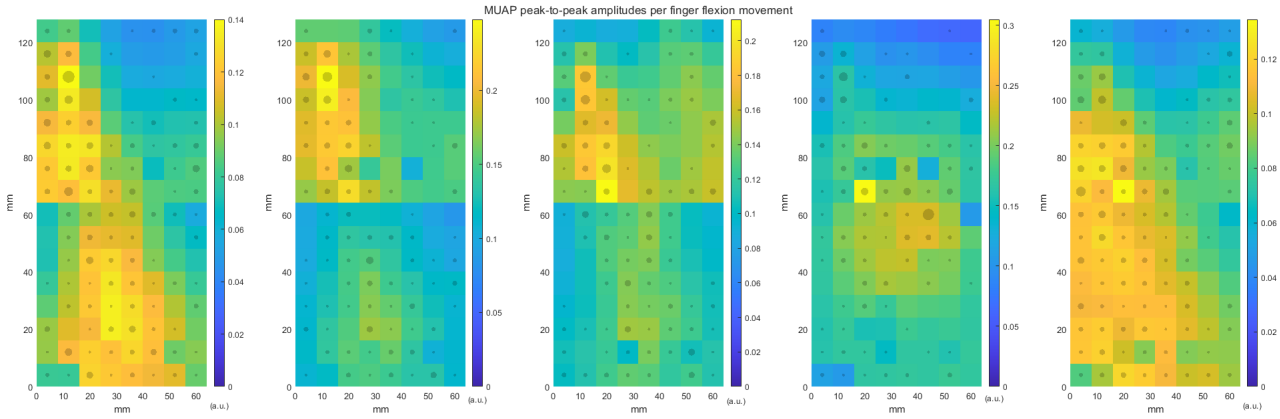
On average, 6.22 ± 9.47 (n=20) MUs were decomposed from anterior forearm muscles during finger flexions and 3.46 ± 3.54 (n=20) from the posterior forearm during finger extensions, with 128 channels on each side. There was a very high inter-subject variability on the number of decoded MUs (see Fig. 1). Despite this, there were clear areas where the MU activations where clustered depending on which finger was flexing or extending (see Fig. 2 and Fig. 3, respectively). To verify this, the mean cosine similarities of the activation maps across participants and for each finger were computed, resulting in a grand average of 0.91 ± 0.03.

From these results, we can infer that, although the number of MUs decoded in forearm muscles is lower than what can be expected from lower limb muscles, more MUs could be decoded from specific subjects, which might be related to variable signal recording quality across sessions. Nonetheless, MU activity was clustered over specific finger-dependent areas, and this was consistent across subjects. Therefore, for isometric contractions, it is possible to consistently decode neural drives with similar spatial distributions for each individual finger movement with low inter-subject variability. This is crucial for non-invasive interfaces decoding neural drive that require increased selectivity. Additionally, knowledge of this activation areas could be used to

apply moderate ablations by removing the less active electrodes depending on the movement studied, thus improving computation times.







[1] A. S. Hassan et al., "Properties of Motor Units of Elbow and Ankle Muscles Decomposed Using High-Density Surface EMG," 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Berlin, Germany, 2019, pp. 3874-3878. [2] Jiang, X., Dai, C., Liu, x., & Fan, J. (2021). Open Access Dataset and Toolbox of High-Density Surface Electromyogram Recordings (version 1.0.0). PhysioNet. https://doi.org/10.13026/ym7v-bh53. [3] F. Negro, S. Muceli, A. M. Castronovo, A. Holobar and D. Farina, "Multi-channel intramuscular and surface EMG decomposition by convolutive blind source separation", J Neural Eng, vol. 13, pp. 026027, 2016.

Neurophysiological Bases of Human Movement
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C37

Cognitive and motor aspects of using an upper limb soft exosuit

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C38

Effectiveness of Electrical Stimulation on Upper Limb Function Rehabilitation in Young Adults and Children with Hemiplegic Cerebral Palsy: A Systematic Review

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Abstract

Background

In children with hemiplegic cerebral palsy, upper limb motor deficits often impede functions like reaching and grasping. Electrical neuromodulation targets these deficits using electrical stimulation (ES) to modulate neuromuscular activity, changing muscle recruitment patterns, which can lead to improved motor outcomes.

Objective

This review seeks to evaluate the effectiveness of ES in improving upper limb function in children with hemiplegic cerebral palsy.

Methods

A systematic literature search from inception until May 2023 was conducted in the following databases: CINAHL, Cochrane, EMBASE, PEDro, PsycINFO, PubMed, Scopus, Ovid Medline, and Web of Sciences. Due to the amount of heterogeneity between the studies, a narrative synthesis was used to review the included studies. A range of study designs (e.g., randomised control trial, ABA design and pretest-posttest design) comparing the effect of various ES techniques (e.g., functional electrical stimulation; FES, transcutaneous electrical nerve stimulation; TENS, neuromuscular electrical stimulation; NMES, and transcranial direct-current stimulation; TDCS) on upper limb function in children (from infancy up to 21 years old) with hemiplegic cerebral palsy were included. A modified version of the Cochrane Risk of Bias tool 2 was used to assess the methodological quality of the studies.

Results

A total of 11 studies were selected for review and quality assessment. Seven studies were randomised controlled clinical trials (RCT), two were ABA design, and two were pre-test/post-test design studies. The systematic review included a total of 298 participants, with participant sample sizes ranging from 8 to 68 across included studies. A total of 13 outcome measures were used across all 11 studies to examine the effects of ES on upper limb function in patients with hemiplegic cerebral palsy. Three studies showed a low risk of bias, four studies raised some concerns, and another four studies demonstrated a high risk of bias. Four studies utilized TDCS, three employed TENS, and two studies each implemented FES and NMES. This review indicated that ES is an effective adjunct therapy for upper limb rehabilitation in children with hemiplegic cerebral palsy. Studies showed that multiple TDCS enhanced upper limb function. Both NMES and FES present the potential for upper limb improvement, though the quality of the four studies indicates the need for more robust research designs. Moreover, TENS interventions consistently resulted in significant enhancements in at least one upper limb outcome but were always paired with intensive physiotherapy.

Conclusions

ES, including TDCS, FES, NMES, and TENS, show promise as adjunct therapies for upper limb rehabilitation, especially when combined with intensive physiotherapy. Future high-quality research should evaluate the effects of NMES and FES, validate specific TDCS parameters, and isolate the impact of TENS when used either alone or in combination with other therapies.

C39

Cortical beta oscillations as neural marker for learning mechanisms in Embodied Virtual Reality

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Motor learning is driven by error and reward feedback which are considered to support two different mechanisms: *error-based* and *reward-based* learning. While in the real-world we normally experience them together, in lab-based tasks we typically isolate them to study the different learning mechanisms. Yet, dissociating between them in the real-world is not trivial.

In previous studies, we established a paradigm to study real-world motor learning using the game of pool billiards, capturing full-body movement using motion tracking (Haar, van Assel, & Faisal, 2020) and brain activity through wireless electroencephalography (EEG) system (Haar & Faisal, 2020). In this paradigm, we showed the use of varying contributions of error-based and reward-based learning mechanisms in different individuals during real-world learning in the pool task (Haar & Faisal, 2020). We then incorporated it in an embodied Virtual Reality (EVR) environment (Haar, Sundar, & Faisal, 2021) to allow perturbations and visual manipulations to be applied. In the EVR setup, while the participants perform the shot in the real world on a physical pool table, we provide visual feedback through the VR system, which allows us to introduce feedback manipulations (isolating error and reward feedback) and visuomotor perturbations.

In this study, we used the EVR setup to study the effects of the forced use of a single learning mechanism on learning and related brain activity. Each of the 32 participants attended the lab for two sessions to learn visuomotor rotation (clockwise or counterclockwise) with each feedback (error or reward) separately, counterbalancing among participants by the order of the feedback and rotation directions. The error feedback provided in the EVR showed the cue ball trajectory only up to the point of ball collision, whereas the reward feedback consisted of the ball pocketing with a fixed trajectory for all rewarded trials while for all unrewarded trials, the ball disappeared after the shot. Rewarded trials were defined based on a reward zone based on improvement from previous trials, following previous works in lab-based tasks (Therrien, Wolpert, & Bastian, 2016).

Our behavioural results showed significant differences between the learning with the different feedback, but in both cases the participants learned to correct for the rotation, at least partially.

In their brain activity, we were looking at the post-movement beta rebound (PMBR) response, which was linked to motor learning performance in many previous studies. Specifically, previous studies showed different trends of PMBR over reward-based and error-based learning.

Our results show the presence of different trends over reward and error-based learning, in line with the suggested role of the PMBR as a neural marker for learning mechanisms. Specifically, in the reward condition, participants' PMBR displayed a steadily decreasing behaviour, in line with the initial hypothesis in the pool study held in the real-world. However, unlike previous results in multiple studies, in the error feedback, participants' PMBR displayed no significant trend.

Our study provides preliminary evidence for the potential to manipulate brain activity through the manipulation of visual feedback in a real-world motor learning task.

Haar, S., & Faisal, A. A. (2020). Brain activity reveals multiple motor-learning mechanisms in a real-world task. Frontiers in Human Neuroscience, 14, 354. Haar, S., van Assel, C. M., & Faisal, A. A. (2020). Motor learning in real-world pool billiards. Scientific reports, 10(1), 20046. Haar, S., Sundar, G., & Faisal, A. A. (2021). Embodied virtual reality for the study of real-world motor learning. Plos one, 16(1), e0245717. Therrien, A. S., Wolpert, D. M., & Bastian, A. J. (2016). Effective reinforcement learning following cerebellar damage requires a balance between exploration and motor noise. Brain, 139(1), 101-114.

C40

Superior Neuromuscular Function in Older Cyclists Compared to Non-exercisers.

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Introduction

Advancing age is typically associated with a decline in muscle strength and power (1). However, for many individuals getting older this is also accompanied by insufficient levels of physical activity which can also contribute to a decline in function. The present study thus compared a number of measures of muscle function in older males and females who were either i) regular exercisers (recreational road cyclists) or ii) healthy non-exercisers.

Methods

A total of 120 healthy, older individuals aged 64-86 years were recruited. Seventy of those were amateur road cyclists (44M: M-C; 72±6 years; height 1.74±0.06m; weight 74.2±9.6kg, 26F: F-C 71±6 years; height 1.62±0.05m; weight 58.8±6.1kg). Fifty healthy, but non-exercising participants were also studied (22M: M-ONE (71±5 years; height 1.75±0.07m; weight 80.6±8.5kg, 28F: F-ONE 71±6 years; height 1.60±0.06m).Each participant underwent testing of i) maximum voluntary isometric knee extensor strength (MVIKES) with twitch interpolation to determine levels of voluntary activation; ii) maximal explosive cycle power and iii) handgrip strength. DXA scanning determined lower limb fat free mass (LLFFM) and an incremental exercise test was used to determine aerobic power (VO_{2peak}). The data (mean±SD) were analysed using a two-factor ANOVA.

Results

The difference in exercise status between the cyclists and non-exercisers was confirmed by the lower VO_{2peak} in the non-exercisers (35.7±7.5 vs 22.5±6.0 $ml.kg^{-1}.min^{-1}$; $p<0.001$). MVIKES showed a significant effect of exercise (cyclists stronger; $p<0.001$) and sex (males stronger, $p<0.001$) (M-C 164.8±36.0; M-ONE 146.5±39.2; F-C 114.3±19.0 and F-ONE 101.2±26.3 Nm). When normalised to LLFFM there was no difference between males and females, but the cyclists were still stronger ($p<0.05$) compared to the non-exercisers (M-C 8.9±2.2; M-ONE 8.3±2.1; F-C 10.0±4.6; F-ONE 7.4±2.0 $Nm.kg.LLFFM^{-1}$). This may partly be explained by higher levels of voluntary activation ($p<0.001$) in the cyclists and in this measure the females exhibited higher levels ($p<0.05$) than the males (M-C 88.3±6.1; M-ONE 79.6±14.1; F-C 89.5±6.4; F-ONE 85.8±12.1 %). Explosive power during sprint cycling was greater in cyclists compared to non-exercisers and in males compared to females (M-C 1004.1±176.8; M-ONE 874.5±241.7; F-C 740.6±114.1 and F-ONE 617.0±133.5 W). The difference in power between the sexes was removed when normalised to LLFFM but the cyclists could generate more normalised peak power ($p<0.001$) compared to the non-exercisers (M-C 56.0±9.0; M-ONE 49.5±12.2; F-C 63.3±21.6 and F-ONE 52.2±11.7 $W.kg.FFM^{-1}$). Handgrip strength was greater in the cyclists

($p<0.001$) compared to non-exercisers and the males stronger ($p<0.001$) than females (M-C 415.9±85.6; M-ONE 371.3±72.7; F-C 276.7±93.2 and F-ONE 198.9±49.1 N). These differences remained when data were normalised to total FFM (M-C 7.7±1.6; M-ONE 6.8±1.2; F-C 7.1±2.5 and F-ONE 5.2±1.2 $N.kg^{-1}$).

Conclusion

The results show superior levels of neuromuscular function in older cyclists compared to non-exercisers and older males compared to females. The differences between males and females in lower limb strength and power could be accounted for by a smaller LLFFM mass in females. However, normalisation to LLFFM did not reduce the differences between cyclists and non-exercisers. This suggests that exercise during old age results in more optimal neuromuscular function compared with not undertaking exercise.

1. Power, G. A., Dalton, B. H., & Rice, C. L. (2013). Human neuromuscular structure and function in old age: A brief review. Journal of Sport and Health Science, 2(4), 215–226. https://doi.org/10.1016/j.jshs.2013.07.

C41

Hierarchical and functionally diverse muscle interactions underlie human motor behaviour

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Introduction

Hierarchical modularity is a ubiquitous characteristic of complex systems (e.g. human motor system), describing how constituent parts interact in a goal-directed manner, forming functional modules. The '*muscle synergy'* concept is employed by the motor control research field to investigate the modular structure of neural circuitry coordinating movement [1]. Recent influential works however highlight limitations among current analytical approaches [2–4]. In particular, recent theoretical innovations suggest that muscles not only work together towards functionally similar task-goals, but also functionally complementary and independent task objectives [5]. Moreover, functional modularity is proposed to not only operate between muscles but also within muscles, enabling the concomitant compliance of muscles towards various task constraints. However, current approaches cannot facilitate the quantification of these muscle interactions across scales. Thus, the aim of our study was to probe the functional architecture of the human motor system in a novel way by developing a principled methodology that aligns with the best current knowledge on human movement modularity.

Methodology

Here we extended traditional approaches and built on our previous developments in directly characterising the functional roles of muscle interactions with respect to task performance. Specifically, we implemented the Partial information decomposition (PID) framework to quantify functionally diverse (i.e. functionally similar, complementary, and independent) inter- and intra-muscular interactions [6]. By incorporating the PID approach into an established pipeline [7,8] (Fig.2), these interactions can be simultaneously quantified as redundant (R) (pink intersection), synergistic (S) (orange shading) and unique (U) (magenta and cyan intersections) information respectively (Fig.1). In doing so, we pose the degrees-of-freedom problem of motor control as the problem of information sharing across complex muscle networks.

Results

Through the application of this framework to three benchmark datasets, we firstly demonstrated how the decomposition of task-relevant muscle combinations reveals a complex functional architecture underlying everyday human movements. This functional architecture displayed a nested network structure of functionally similar and complementary muscle couplings along with unique contributions by individual muscles to task performance. We found that the extracted representations were consistently generalizable beyond any data subset and across disparate motor tasks (i.e. whole-body reaching and balancing tasks). We then further investigated the contribution of individual muscles to task performance by applying the proposed framework to

pairs of frequency-specific intramuscular rhythms, revealing that functional modularity is a scale-invariant characteristic fundamental to movement construction. Finally, we showed that these inter- and intra-muscular representations were differentially predictive of salient motor features including motor adaptation and age group, suggesting they offer complementary windows into movement control.

Conclusions

We have developed and successfully applied a novel computational framework for the extraction of functionally diverse muscular interactions across multiple scales. We were able to comprehensively characterize the functional underpinnings of several distinct motor tasks while ensuring physiological relevance and generalizability. Our method further widens the scope of the muscle synergy concept, showing how muscles can work together redundantly, synergistically, and independently towards task performance. We thus align current analytical approaches with the forefront of theoretical understanding in the field and open up novel opportunities for future research through novel perspectives on modular movement control.

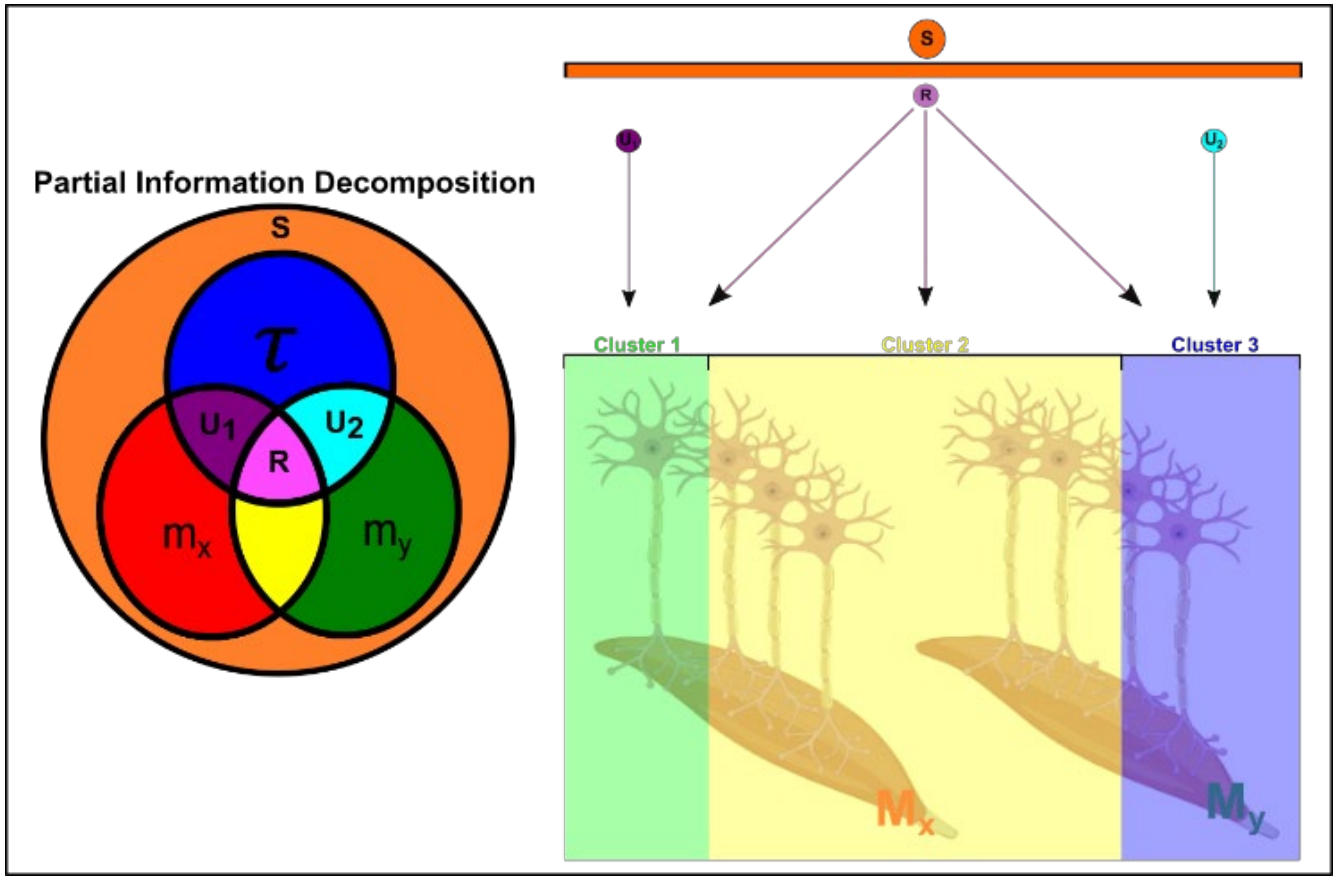


Fig.1: *Our study integrates recent theoretical innovations into a computational framework for extracting muscle synergies.*

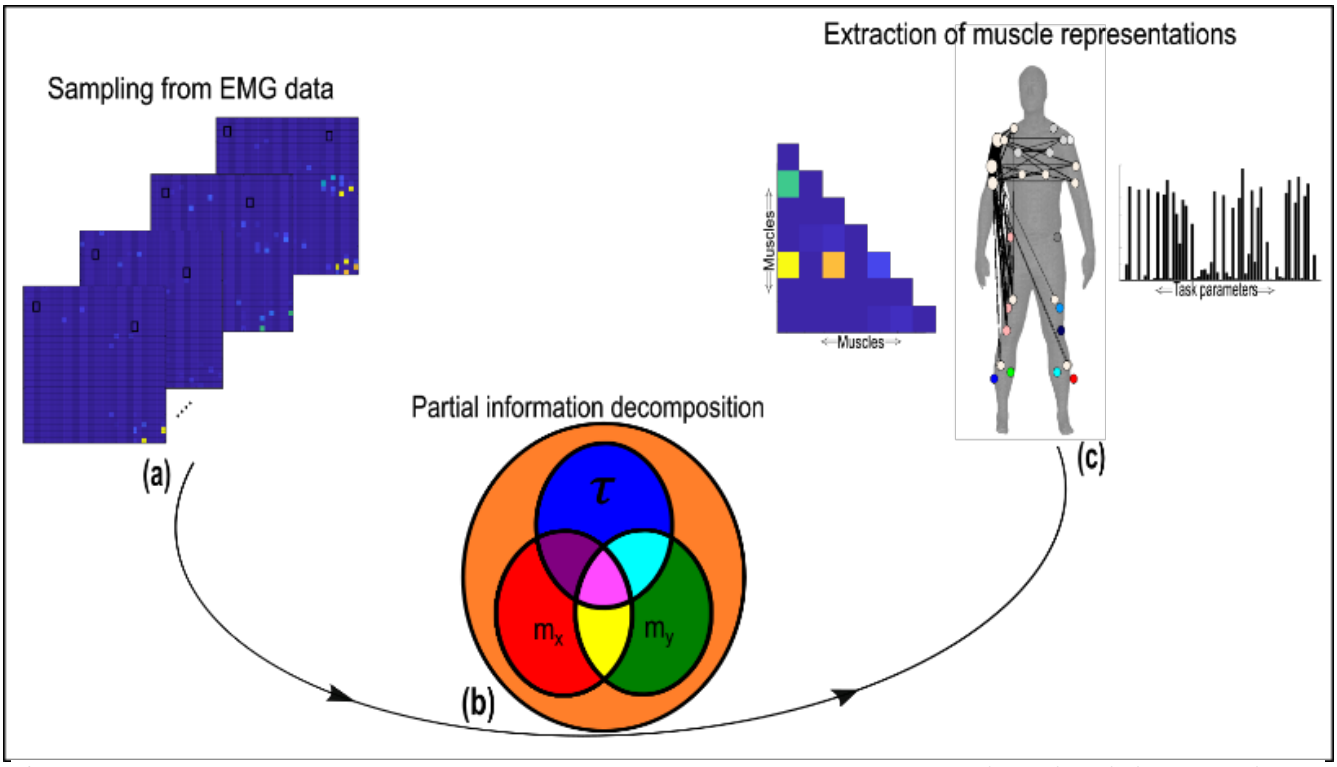
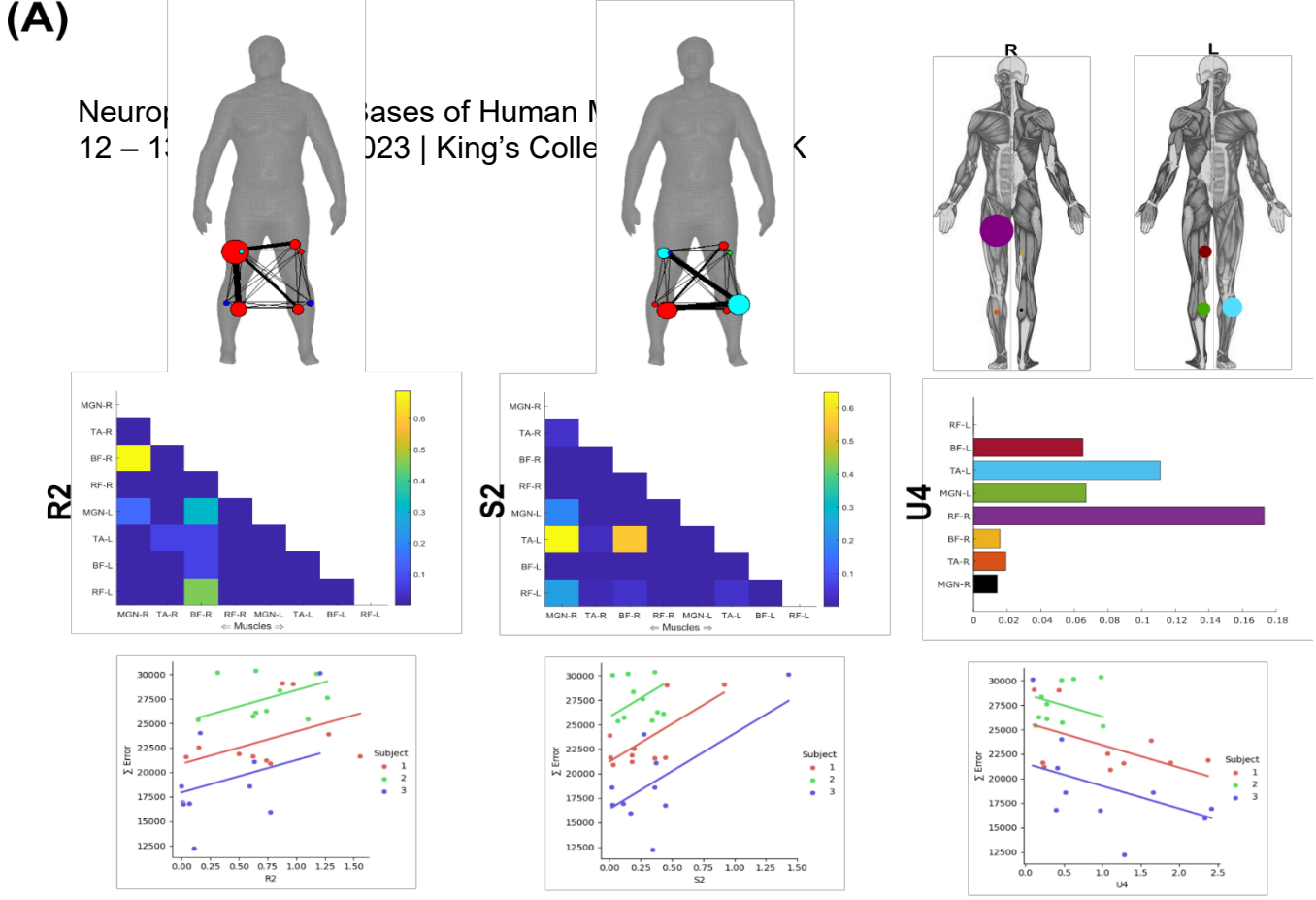


Fig.2: *The proposed framework. () EMG and task space data are collected. () The PID approach is applied within an established pipeline. () Functionally diverse muscle representations are principally extracted.*



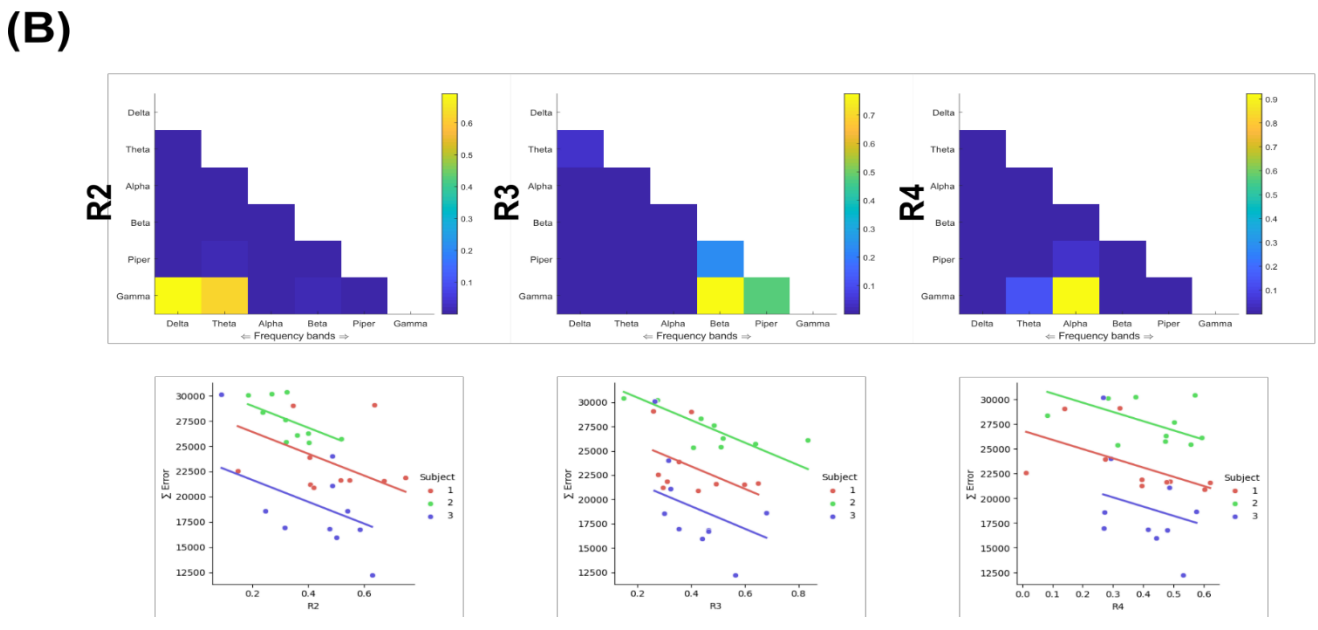


***Fig.3**: A sample of the results produced. **(A)** Inter- and **(B)** Intra-muscular representation significantly correlated with task performance in different ways. Modular control (R2 and S2) was shown to be deleterious in early motor adaption while independent control (U4) improved performance. Increased redundancy intramuscularly however was indicative of superior balance performance.*

[1] Bizzi E, Cheung VC. The neural origin of muscle synergies. Frontiers in computational neuroscience. 2013 Apr 29;7:51. [2] Alessandro C, Barroso FO, Prashara A, Tentler DP, Yeh HY, Tresch MC. Coordination amongst quadriceps muscles suggests neural regulation of internal joint stresses, not simplification of task performance. Proceedings of the National Academy of Sciences. 2020 Apr 7;117(14):8135-42. [3] Del Vecchio A, Germer C, Kinfe TM, Nuccio S, Hug F, Eskofier B, Farina D, Enoka RM. Common synaptic inputs are not distributed homogeneously among the motor neurons that innervate synergistic muscles. BioRxiv. 2022 Jan 23:2022-01. [4] Hug F, Del Vecchio A, Avrillon S, Farina D, Tucker K. Muscles from the same muscle group do not necessarily share common drive: evidence from the human triceps surae. Journal of applied physiology. 2021 Feb 1;130(2):342-54. [5] Hug F, Avrillon S, Ibáñez J, Farina D. Common synaptic input, synergies and size principle: Control of spinal motor neurons for movement generation. The Journal of Physiology. 2023 Jan;601(1):11-20. [6] Ince RA. Measuring multivariate redundant information with pointwise common change in surprisal. Entropy. 2017 Jun 29;19(7):318. [7] Ó'Reilly D, Delis I. A network information theoretic framework to characterise muscle synergies in space and time. Journal of Neural Engineering. 2022 Feb 18;19(1):016031. [8] Reilly David Ó', Delis Ioannis (2023) Dissecting muscle synergies in the task space eLife 12:RP87651.

C42

Neuromuscular control across the menopausal transition

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Introduction. Females typically live longer than males but spend a greater proportion of their life in poor health. In addition, females have a higher frailty index score with an increasing effect size into older age. The neuromuscular system experiences age-associated declines contributing to the disparity between the biological sexes. The menopause indicates the end of a female fertile window and the dramatic reduction in the sex hormones may contribute to the exacerbated decline in neuromuscular functions in females. A reduction in firing rate of motor units from middle to older age within females is not observed in males and has the ability to influence force steadiness, a measure that can be used to identify the ability to control a force at any given level and plays an important role in stability.

Aim. The aim of this study was to compare the force steadiness of submaximal contractions with the tibialis anterior in females across the lifespan, taking into consideration the transition through the menopause.

Methods. There were 4 groups: pre-menopause (PRE) (n= 5, age 23.2 ± 3.2 years), peri-menopause (PER) (n= 6 , age 49 ± 3.4 years), post-menopause (PO) (n= 5 , age 61.75 ± 9.5 years) and post-menopause + HRT (POH) (n = 3, age 56 ± 5.3 years) who performed maximum voluntary contraction (MVC), and then a series of contractions at intensities of 10%, 25% and 40% of their MVC, respectively, using visual and verbal feedback. Intramuscular electromyography was used to record motor unit potentials within the tibialis anterior. A univariate ANOVA was used to compare the groups for their MVC and force steadiness (expressed as coefficient of variation (CoV)).

Results. There were no significant differences between the 4 groups for their respective MVC and CoV at all contraction intensities (10% MVC p =.083, 25% MVC p =.342, 40% MVC p =.105), but the postmenopausal group had the lowest MVC (103.67 ± 18.04 N).

Conclusion. Whilst there are no initial significant findings within the data herein, this data forms part of a larger study and it is intended that over the forthcoming months further data will be collected to enhance our n number and ensure our sample size is large enough to draw firm conclusions. Nevertheless the data described will contribute knowledge to an area that has been lacking in regards to female physiology and in particular the menopause. Further investigations are required to explore the central and peripheral aspects of neuromuscular control and the contribution of the menopausal transition to the reduction in neuromuscular function for females in later life.

C43

Unravelling the role of late I-wave pathways in sensorimotor processing during skilled grasp using a directional TMS protocol

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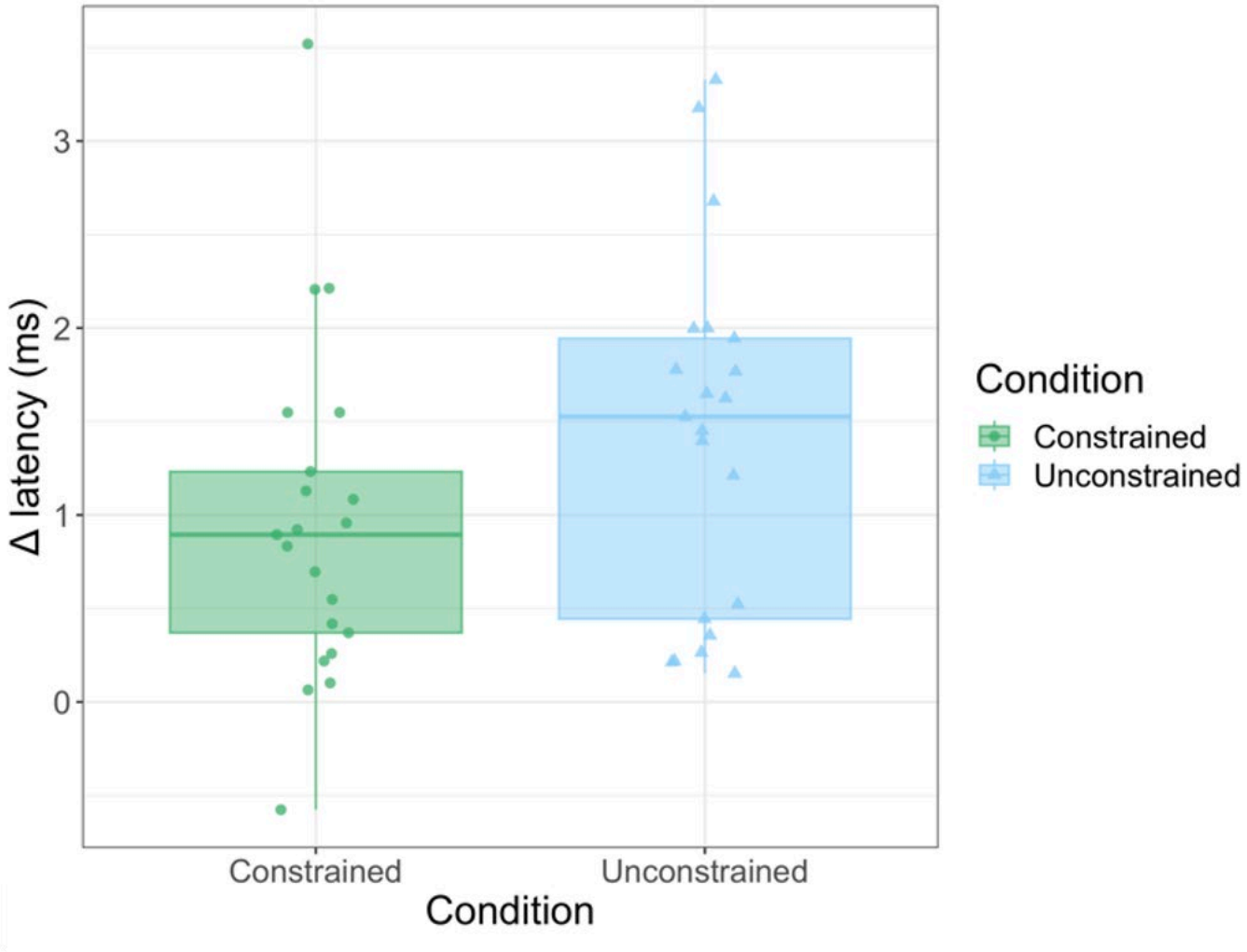
Grasping and lifting objects necessitate anticipatory planning of fingertip forces. However, when objects have a complex geometry, for example an asymmetric centre of mass, fingertip forces are further scaled based on the fingertip positioning relative to the object centre of mass, a process only taking place after object contact. Thus, skilled grasp control arises from a sophisticated interplay between anticipatory and feedback control mechanisms. The relative weighting between anticipatory and feedback mechanisms depends on the degree to which one can predict fingertip positioning before object contact, for example through prior experience with the object. In the present experiment, we varied the predictability of fingertip positioning, hypothesising that this would modify the reliance on anticipatory vs. feedback mechanisms in high vs. low predicable fingertip positioning conditions, respectively.

We then probed the effect of a shift from anticipatory to feedback control mechanisms on corticospinal excitability (CSE) using a directional transcranial magnetic stimulation (TMS) protocol, by applying postero-anterior (PA) or antero-posterior (AP) induced currents.

We asked participants (n=21) to grasp and lift an object with an asymmetrical centre of mass while minimizing tilting. Fingertip positioning could be either visually cued (i.e., constrained) or freely chosen (i.e., unconstrained), thus altering the reliance on anticipatory vs. feedback control mechanisms, respectively (as in Davare et al. 2019). Single pulse TMS was delivered just after object contact in a PA or AP configuration. While PA TMS led to short latency motor evoked potentials (MEPs), AP TMS delayed MEP onset by 1.2 ms on average, likely as AP currents preferentially activate late I-wave inputs to corticospinal neurons. We found that the increased weighting of sensorimotor feedback processing in the unconstrained vs. constrained condition had no differential effects on the MEP amplitude in either PA or AP TMS conditions. Interestingly, we found changes in MEP latencies depending on the grasp context: the differential MEP latency between AP and PA TMS conditions was larger in the unconstrained (t_{20}=2.75; p=0.012) compared to the constrained grasp.

These findings suggest that an increased reliance on feedback control mechanisms is driven by late I-wave pathways, likely mediating cortico-cortical inputs to the primary motor cortex. We ultimately suggest that MEP latency, as assessed by directional TMS protocols, can be a neurophysiological biomarker for probing the integrity of sensorimotor processing during skilled hand movements.


Δ latency (ms)
3
2
1
0
Constrained
Unconstrained
Condition
Condition
Constrained
Unconstrained

C44

Muscle synergies between hamstrings: teammates or competitors?

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Introduction: The hamstring muscles are a complex group with distinct architectural characteristics (Kellis, 2018). Surface electromyographic (EMG) signal amplitude is typically used to compare the neural drive to hamstrings muscles but previous studies have documented conflicting results regarding their activation during knee flexion across different knee joint angles (Kellis & Blazevich, 2022).

Aims: The purpose of the present study was to examine the differences between the Biceps femoris (BF) and Semitendinosus (ST) contribution at two different knee joint angles (0° = full extension, and 90°).

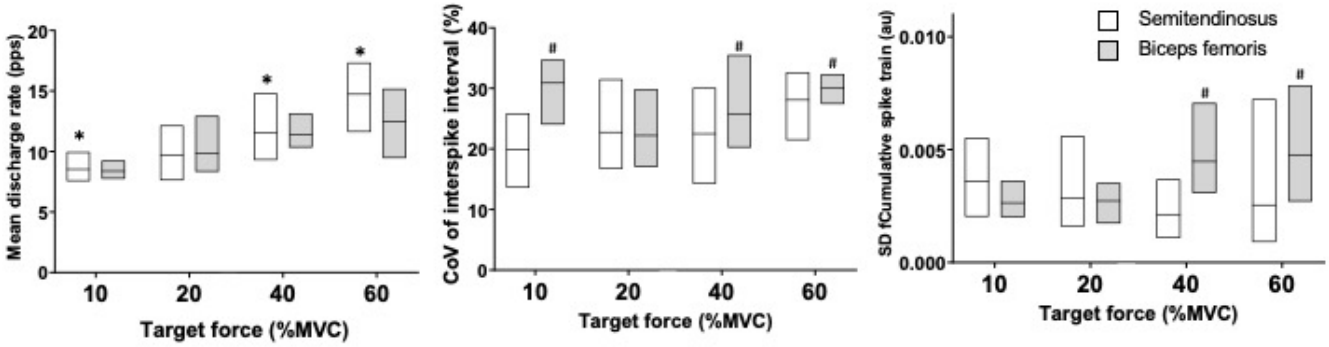
Method: Fifteen healthy active participants performed isometric knee flexions at four target forces [10%, 20%, 40%, and 60% of Maximum Voluntary Contraction (MVC)] at two knee joint angles. High-density EMG was used to examine the motor unit (MU) discharge characteristics (mean discharge rate, coefficient of variation of interspike interval and standard deviation of filtered cumulative spike train) from the BF and ST. Linear mixed effects models were applied to compare the MU discharge characteristics between the two muscles (BF and ST), knee angles (0° and 90°) and target forces (10%, 20%, 40%, and 60%). In all models, muscles, knee angle and force level were specified as fixed factors with participant as a random factor.

Results: The MVC force was greater at the 0° knee angle (long length) compared to 90° ($p = 0.002$). Additionally, the coefficient variation of force was greater at 90° knee angle compared to 0° ($p = 0.032$). The mean discharge rate was greater for the ST compared to the BF ($p = 0.022$). However, the variability in discharge times (coefficient of variation for interspike interval) ($p = 0.039$) and variability in neural drive (standard deviation of filtered cumulative spike train) ($p = 0.047$) was greater for the BF compared to the ST (Figure 1).

Conclusions: It seems that the fluctuations in force are caused by varying combinations of independent and shared synaptic inputs to the motor neuron pool and the ensuing modulation of MU discharge times in synergist muscles (Trypidakis et al., 2022). These results could be explained by the different morphological characteristics that have been observed among these muscles. These differences between synergist muscles should be considered for the design of targeted interventions for this muscle group to improve the clinical outcomes.

Figure Legend

Figure 1: A: Mean discharge rate, B: coefficient of variation of inter spike interval and C: standard deviation of filtered cumulative spike train of motor units in Semitendinosus (open) and Biceps femoris (filled) during submaximal isometric knee flexions at the four submaximal target forces (10, 20, 40, and 60 % MVC force) for 0° knee angle. * = greater compared to biceps femoris ($p < 0.05$), # = greater compared to semitendinosus ($p < 0.05$)



Kellis E (2018). Sport Med 48, 2271–2283. Kellis E & Blazevich AJ (2022). BMC Sports Sci Med Rehabil 14, 166. Trypidakis et al. (2022). Int J Sports Med 43, 131-137

C45

Different activation of nociceptive muscular afferents may promote a bilateral flexion reflex pattern in the feline spinal cord with different duration

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The classical spinal flexor reflex pattern of ipsilateral flexion and contralateral extension is not a rigidly fixed spinal reflex pattern, but can be modulated from supraspinal structures or by changing peripheral conditions. Here we show how acute muscle pain promotes a transient bilateral flexion reflex response to group III/IV muscle afferents in the feline spinal cord.

Selective activation of group III/IV afferents of the gastrocnemius-soleus (GS) muscle by local intra-arterial injections of KCl has been used to study bilateral reflex transmission under four different conditions of the left GS muscle: (a) controls without any inflammatory conditions (n=6); (b) with strong eccentric stretch of the muscle (n=4); (c) "acute" myositis induced by carrageenan (1-2% in Ringer's solution, 5 ml i.m., n=6); (d), sub-acute ("chronic") myositis induced by i.m. infiltration of GS with complete Freund's Adjuvant (CFA) 9-12 days before terminal experiments (under full anaesthesia, see below, n=4). All terminal experiments cats were done under initial halothane-nitrous oxide anaesthesia (O_2/N_2O, 1:2; halothane first at 2.5%) followed by ether, then anaemically decapitated as described by Kniffki et al. (1981, technique repeatedly approved by ethic commissions of the Medical Faculty of the University of Göttingen and of the District Council Brunswick), artificially ventilated, spinalised at C1 and paralysed with pancuronium. Reflex transmission was investigated by bilateral monosynaptic reflex testing of the posterior biceps-semitendinosus (PBST) and the GS muscles. Although Group III/IV stimulation evoked the flexion reflex ipsilaterally under all conditions, the contralateral responses did not follow a general extension reflex pattern. In control experiments only 9% of tests revealed a contralateral inhibition of PBSt flexor motoneurones and fewer than half induced a small contralateral facilitation of the extensor GS. Following eccentric GS contraction for up to about 1hour or following acute carrageenan "myositis" up to about 2 hours an unidirectional facilitation of PBST reflex effects from the pre- to the un-treated contralateral side occurred. In 'chronic' myositis about 90% of tests revealed a bidirectional i.e. from the pre-treated to the un-treated side and, less distinct vice versa, predominance of crossed facilitation of PBSt but no crossed facilitation of GS, instead, in about 50% of tests crossed inhibition of GS was observed. Thus, in "chronic" muscle pain the crossed extension reflex functioning as a bilateral reflex adjustment to stabilise posture is replaced by a bilateral flexion reflex pattern possibly as an adaptive postural mechanism for minimising pain and perhaps to promote healing.

References

Kniffki KD et al. (1981). J Physiol 319,543-554.

C46

Cortical high gamma power during movement relates to movement speed and stroke pathology

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[1]Department of Neurology, University Medical Center Hamburg-Eppendorf, Hamburg, Germany, [2]Department of Neurophysiology and Pathophysiology, University Medical Center Hamburg-Eppendorf, Hamburg, Germany, [3]Department of Neurophysiology and Pathophysiology, University Medical Center Hamburg-Eppendorf, Hamburg, Germany, [4]Wellcome Centre for Integrative Neuroimaging, FMRIB, Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford, United Kingdom, [5]Research Council Brain Network Dynamics Unit, Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford, United Kingdom, [6]Biomedical Signals and Systems, Technical Medical Centre, University of Twente, Enschede, Netherlands

High gamma oscillations (60-90 Hz) in the human primary motor cortex (M1) are elevated at the onset of active movements (movement-related gamma synchronization, MRGS) [1,2]. While subcortical MRGS has been shown to be related to movement velocity, effort, or force level [3-5], the relationship between MRGS in M1 and motor performance measures remains less clear.

We recorded magnetoencephalography data from 29 healthy young participants, 14 well-recovered chronic stroke patients and 15 age-matched control participants during a movement speed task. All participants were right-handed. The task consisted of alternately pressing two buttons four times with the thumb of the performing hand (the left hand in the young group, the affected hand in stroke patients, the hand matched to the stroke group in the control group), as quickly as possible. *Movement speed* was defined as the inverse of the duration between the first and fourth button press. Each participant performed 6 blocks of 40 trials each. Participants received feedback regarding their task performance and their improvement relative to previous trials.

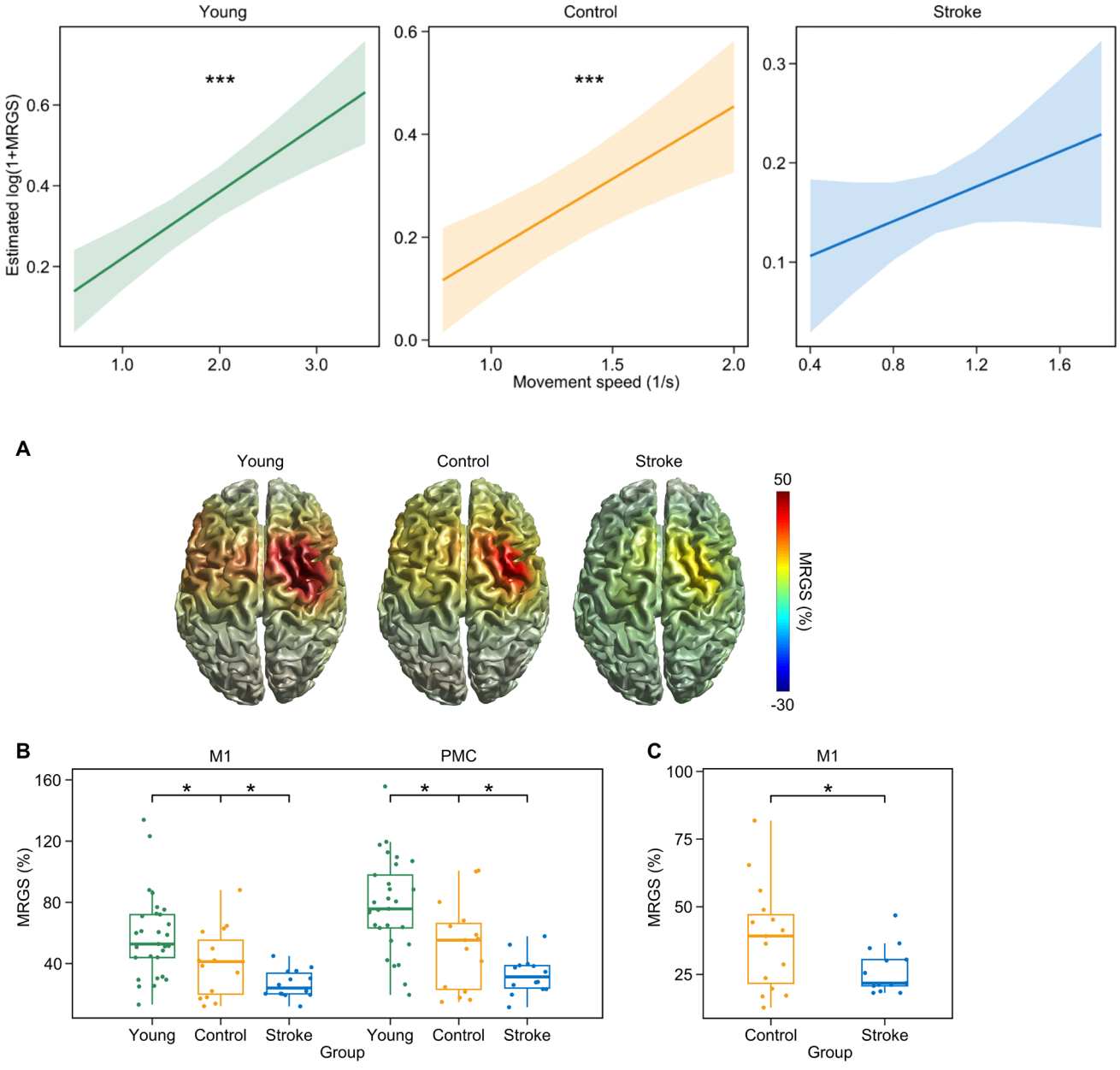
Movement speed served as a significant predictor of MRGS in the young and control participant groups, as trials with higher *movement speed* were associated with greater MRGS in M1 and premotor cortex (PMC) (Fig. 1, young participants: M1: $\chi^2(1) = 24.6$, $p_{cor} < 0.001$, PMC: $\chi^2(1) = 39.5$, $p_{cor} < 0.001$; control participants: M1: $\chi^2(1) = 15.3$, $p_{cor} < 0.001$, PMC: $\chi^2(1) = 10$, $p_{cor} = 0.003$). In stroke patients, the association of *movement speed* and MRGS did not reach significance (M1: $p_{cor} = 0.14$, PMC: $p_{cor} = 0.14$). Stroke patients had significantly lower MRGS than control participants (Fig. 2, M1: $p_{cor} = 0.04$, PMC: $p_{cor} = 0.04$), and control participants had significantly lower MRGS than young participants (M1: $p_{cor} = 0.04$, PMC: $p_{cor} = 0.03$). When matching *movement speed* and handedness in stroke patients and age-matched controls, stroke patients still had a significantly lower MRGS than control participants (Figure 2C, M1: $p_{cor} = 0.04$, PMC: $p_{cor} = 0.04$).

Our findings suggest a strong link between movement speed and MRGS in the human M1 and PMC. In addition, we find that MRGS is decreased in stroke patients compared to age-matched control participants, even if corrected for movement speed. We propose the exploration of non-

invasive brain stimulation in the high gamma range as a strategy to improve the rehabilitation of stroke patients.

*Figure 1: Effect plots of the effect of the predictor movement speed in trial-level linear mixed-effects models that model the relationship between MRGS and movement speed. Movement speed was a significant predictor of MRGS in young and control participant groups in both M1 and PMC. ***p < 0.001*

*Figure 2: A: Group-averaged MRGS topography (flipped to the right hemisphere). B: Distribution of participant averages of MRGS in virtual sensors in M1 and PMC. C: Group difference in MRGS when matched for movement speed. Boxplots show the distribution of mean MRGS for each participant of 1000 repetitions of the matching process. *p < 0.05*



[1] Crone, N. E., Miglioretti, D. L., Gordon, B., & Lesser, R. P. (1998). Functional mapping of human sensorimotor cortex with electrocorticographic spectral analysis. II. Event-related synchronization in the gamma band. Brain: a journal of neurology, 121(12), 2301-2315. [2] Nowak, M., Zich, C., & Stagg, C. J. (2018). Motor cortical gamma oscillations: what have we learnt and where are we headed?. Current behavioral neuroscience reports, 5, 136-142. [3] Anzak, A., Tan, H., Pogosyan, A., Foltynie, T., Limousin, P., Zrinzo, L., ... & Brown, P. (2012). Subthalamic nucleus activity optimizes maximal effort motor responses in Parkinson’s disease. Brain, 135(9), 2766-2778. [4] Brücke, C., Huebl, J., Schönecker, T., Neumann, W. J., Yarrow, K., Kupsch, A., ... & Kühn, A. A. (2012). Scaling of movement is related to pallidal γ oscillations in patients with dystonia. Journal of Neuroscience, 32(3), 1008-1019. [5] Joundi, R. A., Brittain, J. S., Green, A. L., Aziz, T. Z., Brown, P., & Jenkinson, N. (2012). Oscillatory activity in the subthalamic nucleus during arm reaching in Parkinson's disease. Experimental neurology, 236(2), 319-326.

C47

Comparing functional mobility and neural function in aged matched older exercisers and non-exercisers

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Introduction

Impairments in balance and functional mobility, as well as reduced nerve conduction velocity and motor neurone excitability have been reported in older people (1). However, the extent to which ageing and physical inactivity interact to determine these remains unclear. To address this, the current study utilised a number of neuromuscular indices in two groups of older individuals i)

older exercisers (cyclists) and ii) non-exercising older males and females.

Methods

A total of 120 healthy, older males and females aged 64-86 years were recruited. Forty-four male amateur road cyclists (M-C,72±6 years; Height 1.74±0.06m; weight 74.2±9.6kg) and 26 female cyclists (F-C, 71±6 years; height 1.62±0.05m; weight 58.8±6.1kg). In addition, 22 male older non-exercisers (M-ONE, 71±5 years; height 1.75±0.07m; weight 80.6±8.5kg) and 28 female (F: F-ONE; 71±6 years; height 1.60±0.06m) were tested. Single leg balance testing with eyes open (with measurement of anterior-posterior and medio-lateral sway) and with eyes closed (with measurement of time) was undertaken using a balance platform. Peroneal nerve conduction velocity and motor neurone excitability (H-reflex; ratio of H-max to M-max) were both measured, as was TUG. An incremental exercise test was used to determine aerobic power (VO_{2peak}). The data (mean±SD) were analysed using a two-factor ANOVA.

Results

The cyclists had a significantly higher VO_{2peak} compared to the non-exercisers (35.7±7.5 versus 22.5±6.0 $ml.kg^{-1}min^{-1}$, $p<0.001$,). There were no differences between cyclists and non-exercisers in the amount of sway during the eyes open balance test, but females had lower values in both medio-lateral (M-C 6.0 ±1.4; F-C 4.8±0.9; M-ONE 6.9±2.1; F-ONE 5.0±1.7 mm; $p<0.001$) and anterior-posterior directions (M-C 6.5±1.7; F-C 5.3±1.2; M-ONE 6.9±2.9; F-ONE 6.6±2.1mm; $p<0.01$). The balance time during the eyes closed test was not different between cyclists and non-exercisers or between males and females (M-C 5.1±2.6; F-C 5.2±2.8; M-ONE 4.2±2.1; F-ONE 5.1±3.3 s). There was no difference in peroneal nerve conduction velocity between the cyclists and the non-exercisers, but was significantly ($p<0.05$) faster in females

compared to the males (M-C 38.0± 7.9; F-C 44.0± 7.7 M-ONE 37.2±10.0; F-ONE 39.5±8.3 ms^{-1}). In the cyclists, motor neurone excitability was significantly ($p<0.05$) higher compared to the non-exercisers, but there was no difference between males and females (M-C 0.27±0.20; F-C 0.33±0.23; M-ONE 0.24±0.22; F-ONE 0.15±0.15). For the TUG test the cyclists had significantly ($p<0.01$) lower times compared to the non-exercisers, but there was no difference between males and females (M-C 5.2±0.7; F-C 5.2±0.8; M-ONE 5.6±1.3; F-ONE 5.9±1.3 s).

Conclusion

These data suggest that some aspects of functional mobility and neural function can be influenced by physical activity status during ageing. They support the suggestion that ageing results from a mosaic of interacting physiological function and re-emphasise the inadvisability of using physiological indices from inactive participants as epitomising optimal physiological values for ageing.

1. Vandervoort, A.A. (2002), Aging of the Human Neuromuscular System. Muscle Nerve, 25: 17-25. https://doi.org/10.1002/mus.1215.

C48

Changes in motor unit behavior after chronic spinal cord injury

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After a spinal cord injury (SCI), some motor neurons can still be functional below the level of the injury and voluntarily controlled. The changes in motor neuron behavior that allow that are not well understood. In this study, we investigated the residual voluntary activity in chronic complete SCI using high-density surface electromyography (HDsEMG). We recorded HDsEMG signals from two groups, SCI (n=8) with no hand function and control (n=12), non-injured young adults. All the participants signed a written informed consent approved by the ethics committee of the Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany (22-150B and 22-138Bm). All the procedures accorded with the Declaration of Helsinki. We placed grids of electrodes around the forearm and wrist of the participants and recorded HDsEMG signals while they were asked to attempt eight different hand tasks shown by a virtual hand (individual fingers, power grasp, two- and three-finger pinches). By decomposing these EMG signals, we could compare motor units' neural and peripheral characteristics between SCI and control groups. First, we have used a factorization analysis on the smoothed spike trains of motor units to understand if they shared common synaptic input. We have found that the activity of motor units from SCI subjects is controlled by two main neural modules, corresponding to the flexion and extension of the hand digits as in the control group (SCI= 78.3%, control= 73.7% of variance explained with two modules). The comparable number of modules extracted and variance indicate that the synaptic input to the spinal motor neurons might be preserved. Second, we analyzed the behavior of the individual motor units by looking into the phase difference between their smoothed discharge trains and virtual hand kinematics. Through this analysis, we could classify the motor units according to their variance into modulated or non-modulated motor units. We found a significant difference in their variance distribution (generalized linear mixed model: $p = 4.3e-10$, $t(1386)=6.2891$) with a high proportion of non-modulated motor units for the SCI group (variance > 0.7; SCI = 40.8%, control = 16.4%), and low proportion of modulated motor units for this same group (variance < 0.3; SCI = 22.5%, control = 47%). Last, we extracted the area of activity of motor units according to their amplitude spatial map. We found that motor units present a larger area of activity (SCI = 584mm² (320,1032), control = 400mm² (300,600); $p=1.2e-09$, $t(1384) = 6.1236$). Overall, at the neural level, motor neuron changes are characterized by a higher number of non-modulated motor units in SCI in comparison to the control group but with a preservation of common input. At the peripheral level, we found changes in motor unit innervation. These properties are important for the characterization of residual activity and to clarify recovery mechanisms after SCI. Understanding them is crucial to change rehabilitation strategies and exploit this residual activity.

C49

Modulation of Wrist Rigidity Through Mechanical Perturbation

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Parkinson's Disease (PD) is a neurodegenerative disorder primarily impacting motor control. Research into the neurophysiological basis of PD often uses tremor or gait impairment as the motor end-point due to their ease of assessment. However, rigidity is another important symptom to encapsulate the motor presentation of the disease state, which is rarely tracked digitally and typically assessed only by a clinician passively moving the patient's limbs. Additionally, a common limitation of PD research is the inability to modulate symptomatic severity in a controlled manner, instead relying on dramatic contrasts between an individual's medicated and unmedicated states. In this project we present a novel motor control paradigm seeking to address these deficits.

Using a robotic wrist manipulandum participants were subject to a destabilisation phase of short, forceful perturbations from the robot while attempting to stabilise the robot's handle at a centralised position. Participants were then presented with a visual cue to perform voluntary flexion (F) or extension (E) movement of the wrist to a target. Participants were next passively moved through the range of FE movement by the robot to quantify rigidity as a measure of resistance to smooth, external, low-amplitude force. During the protocol, participants' neural activity was recorded through EEG while motor and behavioural data was collected using EMG sensors and integrated force and positional data from the robot.

Testing has focussed on the application of this paradigm to healthy controls (HCs) with the intent to assess which features defining the destabilisation phase were most significant in modulating the participant's rigidity. Frequency, amplitude and temporal uniformity of perturbations were investigated.

Investigation of 14 HCs subject to both high (10) and low (5) perturbation schedules has shown that increased perturbation count results in slower voluntary movement following the destabilisation phase ($p=0.012$, *paired t-test)* while reaction time is not significantly differentiated ($p=0.080$, *paired t-test)*.

Preliminary investigation of the impact of perturbation amplitude contrasting 1Nm and 0.5Nm perturbations on 5 HCs has suggested that higher amplitude of perturbation results in slower voluntary movement but no change in reaction time. Computing co-contraction indices (CCIs) of the antagonist muscle pairing during the robot-led passive movement as a computation of rigidity has so far proven inconclusive.

The preliminary findings confirm the potential to effectively modulate wrist rigidity in HCs using only mechanical perturbations. Future work includes exploration of the neural data as well as application of the finalised paradigm to PD patients is required.

C50

Investigating the Causal Role of Locus Coeruleus Arousal System in the regulation of speed and accuracy during Decision-Making: Insights from Transcutaneous Vagus Nerve Stimulation

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Introduction: Research in the past decades suggests a strong impact of the locus coeruleus norepinephrine (LC-NE) arousal system on human experience: when arousal is increased, individuals are generally more alert to sensory stimulation, more motorically active, and exert more cognitive control (e.g., Pfaff, D.W. 2006). Still, the exact contribution of LC-NE to behavioural control is still unclear. Previous human studies have found that pupil size, used as a non-invasive index of arousal, is larger when decisions are made under strict deadlines compared to situations with more time for accuracy, leading to the proposal that LC-NE may generate urgency, speeding up decisions (Murphy, P.R., et al. 2016). However, this contrasts with the perspective that LC-NE serves to enhance information processing (Aston-Jones, G. and J.D. Cohen. 2005), implying that involvement of LC-NE should primarily improve accuracy. In this study, we used transcutaneous vagus nerve stimulation (tVNS) to causally probe the role of LC-NE in regulating speed and accuracy during decision-making.

Methods: we considered decision-making behaviour (speed and accuracy) in 42 healthy human subjects (28 women, mean age 26 ± 4.0 years old) performing the random dot motion discrimination task, with either an active stimulation of LC-NE by means of tVNS or with an electrical stimulation of the earlobe as a sham condition. Subjects performed a total of 8 blocks of 40 trials in a single session. Trains of stimulation were applied for 4 seconds on each trial, with tVNS or sham in separate blocks (counterbalanced). Half of the subjects (Group 1; n=21, 12 women, mean age 26 ± 4.5 years) received stimulation early in the trial, while the other half (Group 2; n=21, 16 women, mean age 25 ± 3.5 years) received stimulation later on during a period covering the decision phase. Pupillometry was used to monitor changes in arousal during the task, as a function of tVNS or sham stimulation.

Results: In both groups, tVNS led to significantly larger pupil sizes than sham stimulation (both $t > 1.8$, both $p < 0.05$), indicating effective activation of LC-NE during decision-making under tVNS condition. Interestingly, such an increase in arousal was paralleled by a higher decision accuracy with tVNS compared to sham (76 ± 8.3% versus 74 ± 8.5% on average in both groups), though this effect was only significant in Group 1 ($t(20) = 2.68$, $p = 0.01$) but not in Group 2 ($t(20) = 0.43$, $p = 0.67$). Yet, when considering all subjects from both groups together, there was a positive correlation between effects on pupil size and accuracy: the more tVNS increased pupil size during decisions, the more accuracy was enhanced ($r = 0.48$, $p < 0.01$). We did not find any significant effect of tVNS on decision speed.

Conclusion: Our results are inconsistent with the view that LC-NE generates urgency as we did not observe any effect of tVNS on decision speed. Rather, the enhanced accuracy with tVNS

suggests that LC-NE facilitates information processing to optimize the performance of the decision-making process.

1. Pfaff, D. W. (2006). Brain arousal and information theory: neural and genetic mechanisms. Harvard University Press. 2. Murphy, P. R., Boonstra, E., & Nieuwenhuis, S. (2016). Global gain modulation generates time-dependent urgency during perceptual choice in humans. Nature communications, 7(1), 13526. 3. Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine function: adaptive gain and optimal performance. Annu. Rev. Neurosci., 28,403-450.

C51

Sexual dimorphism in tendon reflexes and nerve conduction velocity: a systematic review

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Spinal reflexes are the pillars of the motor system's organization. The assessment of the spinal cord reflexes is an exploratory routine in neurological and clinical practice, providing valuable, real-time information about the state of our nervous system, in health as well as in illness.The influence of sex in some neurological diseases is largely recognized. Nevertheless, we noted a shortage of clinical or research studies recording the differences in spinal cord reflexes. Thus, we reviewed the existing sex-disaggregated data literature on spinal cord reflexes. Based on the studies reporting sex-disaggregated data, we can conclude that there is a sex dimorphism in the knee jerk reflex, since there is a shorter reflex latency in females than in males.

Table 1. Summary of the information analyzed in each of the reviewed studies, grouped in descending order of anatomical limb and nerve involved and arranged chronologically

Author/s	Reflex	Nerve	Sex/age range (years)	Technique	Latencies (ms)	MNCV (m/s)	Dimorphism	Statistical significance
Kossioni & Karkazis (1994)[28]	Masseter	Trigeminal	♂♀ 21-26	sEMG	♀ 5.75±1.09 ♂ 6.14±1.28	-	Yes ♀<♂	Yes
Peddireddy et al. (2006)[29]	Masseter	Trigeminal	♂♀ 24-28	sEMG	♀ 8.3±0.7 ♂ 8.4±0.7	-	No	No
Kiziltan et al. (2010)[30]	Masseter inhibitory	Trigeminal	♂♀ 19-65	sEMG	♀ 52.8±9.4 ♂ 52.1±6.6 (1)	-	No	No
Kiziltan & Gündüz (2020)[31]	Trigeminal - cervical	Trigeminal	♂♀ 18-75	sEMG	*	-	No	No
Peddireddy et al. (2006)[29]	Blink	Trigeminal	♂♀ 24-28	sEMG	♀ 39.4±3.5 ♂ 36.4±3.5 (2)	-	No	No
Kiziltan et al. (2010)[30]	Blink	Trigeminal	♂♀ 19-65	sEMG	♀ 31.5±2.5 ♂ 31.2±2.5 (3)	-	No	-
Kofler et al. (2013)[32]	Blink	Trigeminal	♂♀ 27-54	sEMG	♀ 32.3±3.8 ♂ 33.0±3.8 (4)	-	No	No
Kommalage & Gunawardena (2013)[33]		Ulnar	♂♀ 11-96	sEMG	-	♀ 56.1±4.93 ♂ 54.04±5.00	Yes ♀>♂	Yes
Alemdar (2014)[34]		Median-ulnar	♂♀ 16-68	sEMG	-	♀ 58.3±5.8 ♂ 57.7±5.4 (5)	No	No
Singh et al. (2016)[71]		Median-ulnar	♀ Postmenopausic	sEMG	-	*	Yes	Yes
Tan U (1991)[35]	Hoffman	Piramidal tract	♂♀ 18-21	sEMG	♀ 29.9±1.3 ♂ 31.5±1.5	-	Yes ♀<♂	-
Miller et al. (2010)[4]	Paraspinal	Cutaneous (several)	♂♀ 19-35	sEMG	♀ 48.8±3.0 ♂ 60.0±3.2	-	Yes ♀<♂	Yes
Sajadi et al. (2014)[36]		Cutaneous antebrachial posterior	♂♀ 22-75	sEMG	-	♀ 58.64±9.31 ♂ 56.90±5.46	No	No
Alisauskiene et al. (2007)[37]	Knee-jerk	Femoral	♂♀ 18-64	sEMG	♀ 20.9±1.58 ♂ 22.7±1.92	-	Yes ♀<♂	Yes
Vickery & Smith (2012)[13]	Knee-jerk	Femoral	♂♀ 20-22	sEMG	♀ 17±0.23 ♂ 21±0.3	-	Yes ♀<♂	Yes
Tindell & Smith (2017)[6]	Knee-jerk	Femoral	♂♀ 19-21	sEMG	♀ 22.0±0.2 ♂ 24.1±0.22	♀ 52.4±1.5 ♂ 47.6±1.3	Latency Yes ♀<♂ NCV Yes ♀>♂	Yes
Mylius et al. (2005)[14]	Flexor nociceptive	Sural	♂♀ 20-40	sEMG	♀ 96.8±17.6 ♂ 95.2±16.5	-	Yes ♀>♂	
Cinar et al. (2013)[15]		Tibial Median plantar Lateral Calcaneous Sural	♂♀ 20-50	sEMG	*	*	No	No
Singh et al. (2016)[71]		Peroneal	♀ Postmenopausic	sEMG	-	*	Yes	Yes
Fan et al. (2009)[16]	Pupillary	Motor ocular (III) ANS	♂♀ 18-22	Pupilogram	*	-	No	No
De Campos et al. (2014)[22]		Laringeal ANS	♂♀ 70-76	Histological sections	-	-	Yes, g-ratio ♀<♂	Yes

Latency and MNCV data represented as mean ± standard deviation.
- indicates an unmeasured parameter; * indicates those results not reported for a measured parameter.
ANS, autonomic nervous system; sEMG, surface electromyography; (1), latencies of the left SP2 response with electrical stimulation; (2), R2 response initiation latencies; (3), latencies of the R2 response on the left side; (4), latencies of the unconditioned R2 response; (5), MNCV of the median nerve.

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The Effect of Posture on Corticospinal Excitability of the Trunk Muscles during Rhythmic Arm Cycling

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Background: Corticospinal excitability projecting to the trunk muscles increases during tonic muscle contractions of the upper extremities – a phenomenon known as 'cross facilitation'. However, the modulation of rhythmic bilateral dynamic muscle contractions of upper limbs on the corticospinal excitability of the trunk muscles in healthy adults remains unknown.

Objectives: This study aimed to investigate the presence of cross facilitation in the erector spinae (ES) during rhythmic bilateral arm cycling and whether postural position influenced the degree of facilitation.

Methods: Twenty healthy adults underwent the study. Transcranial magnetic stimulation (TMS) over the primary motor cortex (M1) was used to elicit motor evoked potentials (MEP) in the ES during bilateral arm cycling and during static sitting with and without trunk support. Peak-to-peak amplitudes of MEPs in the ES where measures during arm cycling and static sitting to determine the corticospinal excitability of the ES. To examine the cortical and spinal excitability underpinning the modulation of arm cycling on amplitudes of ES MEPs, both short-interval intracortical inhibition (SICI) and cervicomedullary MEPs (CMEPS) were obtained during rhythmic arm cycling and static sitting with trunk support in a subset of ten participants.

Results: MEP amplitudes of the ES were greater during rhythmic arm cycling than during static sitting when the participant was seated with trunk support (174.79±18.01% of static sitting ES MEP) and without trunk support (120.42±10.03% of static sitting ES MEP). SICI was decreased during rhythmic arm cycling (51.42±3.31%) compared to static sitting (44.66±3.90%), whereas the amplitudes of CMEPs were increased during static sitting (0.09±0.05) compared to rhythmic arm cycling (0.07±0.03) in most participants.

Conclusion: Cross facilitation between the arm and trunk muscles was present during rhythmic bilateral arm cycling, shown by an increase in the amplitudes of ES MEPs. This facilitatory effect experienced was similar when the trunk was both supported and unsupported. SICI was reduced during arm cycling, while the amplitudes of CMEPs were increased during static sitting, suggesting differential modulation of cortical and spinal circuits on corticospinal excitability of the ES between the movements, with the facilitatory effect during arm cycling likely mediated by the motor cortical circuits. Our findings suggest that performing bilateral arm cycling in both supported and unsupported seated posture may induce short-term neuroplasticity in the corticospinal pathways projecting to the ES, leading to changes in trunk motor function in the long term. This highlights the potential for the use of simple arm cycling exercise for trunk rehabilitation in individuals with impaired trunk control.

The study protocol was approved by the School of Sport, Exercise, and Rehabilitation Sciences Research Ethics Committee at University of Birmingham (MRC2022-03) and performed in accordance with the Declaration of Helsinki.

C53

The association of beta synchronization and motor skill acquisition in chronic stroke patients and healthy participants

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Understanding the underlying neuronal mechanisms of motor skill acquisition after stroke plays an essential role in designing new therapeutic approaches. Movement event-related synchronization (ERS) in the beta-band (~13-30 Hz) has previously been related to motor learning in healthy participants (Tatti et al., 2021) and has been shown to be reduced in stroke patients (Kulasingham et al., 2021; Parkkonen et al., 2017; Tang et al., 2020). Here, we investigate whether beta ERS is related to motor skill acquisition in chronic stroke patients.

We recorded MEG data from 14 chronic stroke patients and 15 age-matched control participants during a feedback-guided motor skill acquisition task. The task aimed to increase the speed of button presses conducted with the thumb (the affected hand for stroke patients, and the hand corresponding to the stroke group in the control group) (Fig.1A). Movement speed was calculated as the reciprocal of the time taken between the initial and fourth button press. Motor skill acquisition was defined as the relative increase of movement speed from the first to best block. Patients were characterized with standardized clinical tests. MEG data were preprocessed and projected into source space, using individual structural images if available. The ERS was calculated between 0.6-1.4 s after the last button press in the range from 14-28 Hz. We computed differences in beta ERS between stroke patients and control participants in source space using permutation-based cluster statistics. Using linear mixed models, we related residual motor function and well movement speed and motor skill acquisition to the ERS.

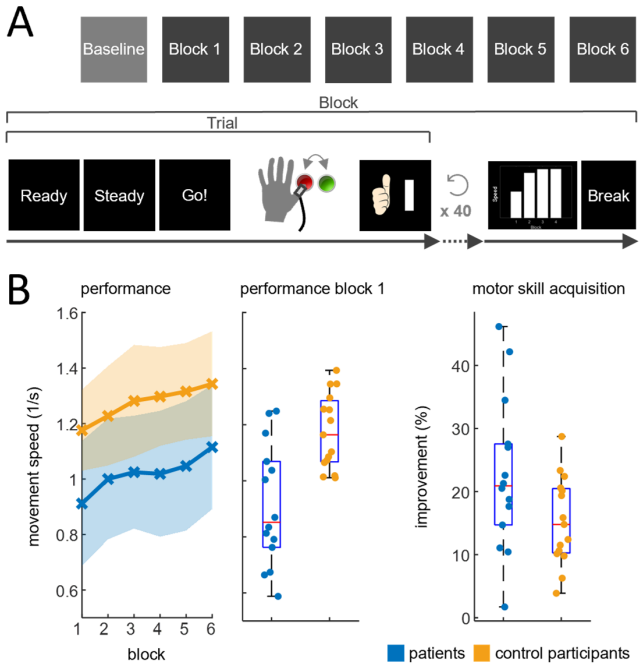
Stroke patients were mildly impaired with a median UEFM of 63.5 [range: 46-66]. Movement speed was significantly lower in stroke patients than in in control participants [$p<0.001$; patients: 1.01 ±0.22 1/s; control participants: 1.27 ±0.17 1/s; mean ± standard deviation] (Fig.1B), however motor skill acquisition did not differ in both groups [$p=0.22$; patients: 22.6 ±12.2%; control participants: 15.3 ±7.0%; mean ± standard deviation]. The beta ERS was significantly lower in stroke patients compared to control participants in a cluster located over the frontal lobe, covering ventral premotor cortex [$p<0.001$] (Fig.2A). In control participants, beta power measured in this cluster was positively related to motor skill acquisition in the task, hence participants with greater improvement over time had a higher ERS (Fig.2B). This relation was inverted in stroke participants. The ERS was not related to residual motor function from standardized clinical tests.

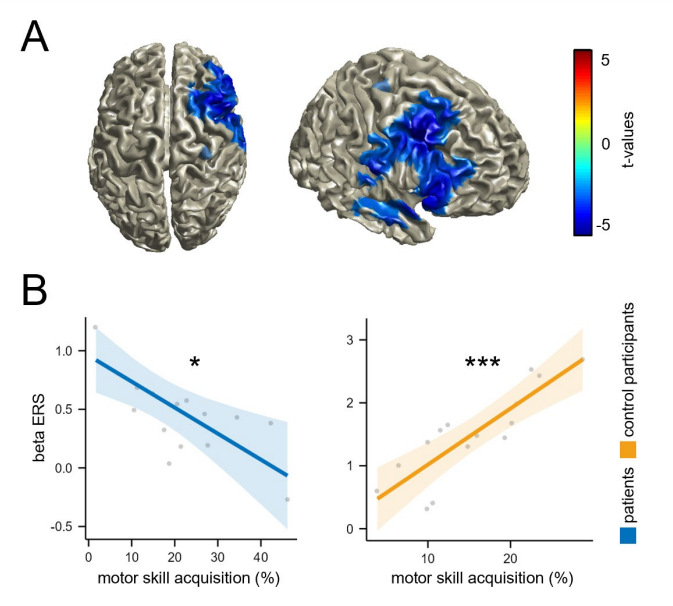
We report an association of beta ERS over secondary motor areas and motor skill acquisition. Even though motor skill acquisition is still evident in stroke patients, the underlying neuronal

mechanisms may be altered in stroke as the relation of motor skill acquisition and ERS shows diverging results in both groups.

Fig.1 A) Overview of Task B) Task performance (movement speed) and motor skill acquisition in patients and control participants

Fig.2 A) Differences in beta ERS between stroke patients and control participants (results of permutation-based cluster statistics) B) The association of motor skill acquisition and ERS in patients and control participants. Improvement predictor effect for each group from linear mixed effect modeling





Kulasingham, J. P., Brodbeck, C., Khan, S., Marsh, E. B., & Simon, J. Z. (2021). Bilaterally Reduced Rolandic Beta Band Activity in Minor Stroke Patients. BioRxiv, 2021.10.15.464457. https://doi.org/10.1101/2021.10.15.464457 Parkkonen, E., Laaksonen, K., Piitulainen, H., Pekkola, J., Parkkonen, L., Tatlisumak, T., & Forss, N. (2017). Strength of ~20-Hz Rebound and Motor Recovery After Stroke. Neurorehabilitation and Neural Repair, 31(5), 475–486. https://doi.org/10.1177/1545968316688795 Tang, C.-W., Hsiao, F.-J., Lee, P.-L., Tsai, Y.-A., Hsu, Y.-F., Chen, W.-T., Lin, Y.-Y., Stagg, C. J., & Lee, I.-H. (2020). β-Oscillations Reflect Recovery of the Paretic Upper Limb in Subacute Stroke. Neurorehabilitation and Neural Repair, 34(5), 450–462. https://doi.org/10.1177/1545968320913502 Tatti, E., Ferraioli, F., Peter, J., Alalade, T., Nelson, A. B., Ricci, S., Quartarone, A., & Ghilardi, M. F. (2021). Frontal increase of beta modulation during the practice of a motor task is enhanced by visuomotor learning. Scientific Reports, 11(1), 17441. https://doi.org/10.1038/s41598-021-97004-0

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ROLE OF CONTRALATERAL PRIMARY MOTOR CORTEX IN INTERLIMB GENERALIZATION OF NEWLY LEARNED MOTOR SKILLS

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INTRODUCTION: Successfully learned motor skills can generalize to untrained contexts. Specifically, some recent work has showed that newly learned motor skills can symmetrically generalize to the untrained arms (from right to left arm and vice versa), both immediately as well as after a period of 24 hours of learning (Yadav & Mutha, 2019;2020). However, the neural substrate underlying this form of generalization after skill memory has stabilized (following 24hrs) is unclear. Contralateral primary motor cortex (M1) is considered a key site for skill learning-related neuroplastic changes and skill memory stabilization (Kantak et al., 2010; Christiansen et al., 2020).

OBJECTIVE: We probed whether skill generalization is causally mediated by contralateral M1. We hypothesized that this key area for skill memory stabilization following learning plays critical role (as compared to ipsilateral M1) for interlimb skill generalization.

METHODS: In an ongoing study (in accordance with University Ethics Committee and principles of the Declaration of Helsinki) spanning over two days, we tested young healthy right-handed participants (currently n=10, target sample size n=30, planned completion Dec-2023) who learned a novel motor skill on Day-1 with right arm. Following learning they received offline 1Hz rTMS (1800 pulses delivered using Neuronavigation) over either contraM1 (left M1, Group1) or ipsiM1 (Right M1, Group2). The skill task involved tracking movements (10 blocks of 16 trials each) from a start circle (green-color, 1cm diameter) to one of the eight target circles (blue-color, 1cm diameter) that appeared on the screen at a distance of 15 cm, connected via a tunnel (white parallel lines, 1cm width). Participants were instructed to make fast and accurate movements to the target while moving within the tunnel. After each movement, participants received performance feedback along with a numeric score (Motor Skill Error). In addition, we measured Motor Evoked Potentials (MEPs) using surface electrodes over first dorsal interosseus muscle (right hand for Group1 and left hand for Group2), pre and post learning, as well as immediately, at 5 min and 10 mins post rTMS to assess change in corticospinal excitability. On Day-2 after 24 hrs, all participants were tested for interlimb skill generalization by performing the task with their untrained (left arm, 10 blocks), as well as the trained arm (right hand, 1 block).

RESULTS: Our preliminary findings indicate that both groups learned the skill task on Day-1 (reduction in Skill Error over 10 Blocks in all current subjects). As expected, 1 Hz rTMS also led to a decrease in contralateral MEPs for both groups (most pronounced at 5min post rTMS). Next, when untrained arm was tested on Day-2, we observed higher skill error on Block1 in Group1 (contra-M1 rTMS) as compared to Group2 (ipsi-M1 rTMS). However, both groups reached similar performance with untrained arm at the end (Block 10) and exhibited comparable performance when the trained arm was tested in a subsequent (and last) Block on Day-2.

CONCLUSION: Hence, our early results suggest that 1Hz rTMS over contra-M1 but not ipsi-M1 can impair skill generalization to untrained arm without affecting its learning ability and follow-up performance of the trained arm.

1.Yadav, G., & Mutha, P. K. (2020). Symmetric interlimb transfer of newly acquired skilled movements. Journal of Neurophysiology, 124(5), 1364-1376. 2.Yadav, G., Mutha, P. K. (2019). Retention and interlimb generalization of motor skill learning have common features. Society for Neuroscience. Program No. 229.11. 2019. 3.Kantak, S. S., Sullivan, K. J., Fisher, B. E., Knowlton, B. J. & Winstein, C. J. Neural substrates of motor memory consolidation depend on practice structure. Nat. Neurosci. 13, 923–925 (2010). 4.Christiansen, L., Larsen, M. N., Madsen, M. J., Grey, M. J., Nielsen, J. B., & Lundbye-Jensen, J. (2020). Long-term motor skill training with individually adjusted progressive difficulty enhances learning and promotes corticospinal plasticity. Scientific reports, 10(1), 15588.

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A Non-invasive, Quantitative Method for the Detection of Muscle Fatigue

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Intro and aim

Muscle fatigue is a common phenomenon with clinical implications. In healthy individuals, it reduces muscle power, causes discomfort and pain, impairs muscle function, and reduces overall performance. In various disorders, including neurological, muscular, and cardiovascular conditions, it worsens, reducing an individual's ability to perform activities of daily living (ADLs). It is widely recognized that most ADLs are dynamic movements involving non-isometric muscle contractions. Current methods to assess fatigue include measuring changes in force production using measures of maximum voluntary contraction (MVC) and power output along with a subjective Borg RPE scale. Moreover, current methods utilise an isometric task and only take measurements at the end of a fatiguing task; both these approaches lack real-time insights during muscle activity, raising questions about the suitability of current methods for tracking muscle fatigue in such contexts. This highlights the need for improved, and clinically useful, methods to detect and quantify fatigue. Assessing muscle fatigue using metabolic biomarkers is more reliable but is currently done invasively, limiting its applicability. However, surface electromyography (sEMG) is widely used in muscle fatigue detection, offering advantages such as non-invasiveness, applicability in situ, real-time muscle monitoring, and the ability to monitor fatigue of specific muscles which can overcome the limitations of current methods. Although sEMG is still used to detect fatigue at the end of isometric tasks, there is growing interest in its potential to detect fatigue during dynamic tasks.

We designed a two features method (TFM) that simultaneously uses both median frequency (MDF) and root mean square (RMS) to detect muscle fatigue during a dynamic task.

Method

We assessed fatigue using TFM, in 14 healthy subjects (5 females) aged 19-39, height 170.25±8.82 cm, weight 68.4±11.63kg in both dynamic and static tasks. Fatigue perception was recorded using the Borg RPE scale. Additionally, 6 participants underwent pre- and post-task MVC measurements by performing an elbow flexion with a 90-degree elbow joint posture. Participants performed tasks without restrictions, with the dynamic task comprising 15 dumbbell curls in 30 seconds, and the static task involving a 30-second duration of holding a dumbbell with the elbow at 90 degrees.

Result

During both static, and dynamic tasks the Borg RPE scale showed a significant increase between set 1 and set 4. A comparison of MVC before and after the fatiguing task showed a

significant decrease after the whole task. When considering data from all subjects, in both the static and dynamic phase, the TFM showed a concurrent decrease in MDF and increase in RMS. The difference between the mean values of both features was most significant in set 4.

Conclusion

Our research introduces an innovative, non-invasive, quantitative method for detecting muscle fatigue, applicable to both static and dynamic movements. This significant step forward in measuring fatigue enables us to not only monitor the occurrence of muscle fatigue but also to observe fatiguability. Critically, TFM identifies fatigue in active muscles prior to an individual's perception of fatigue.

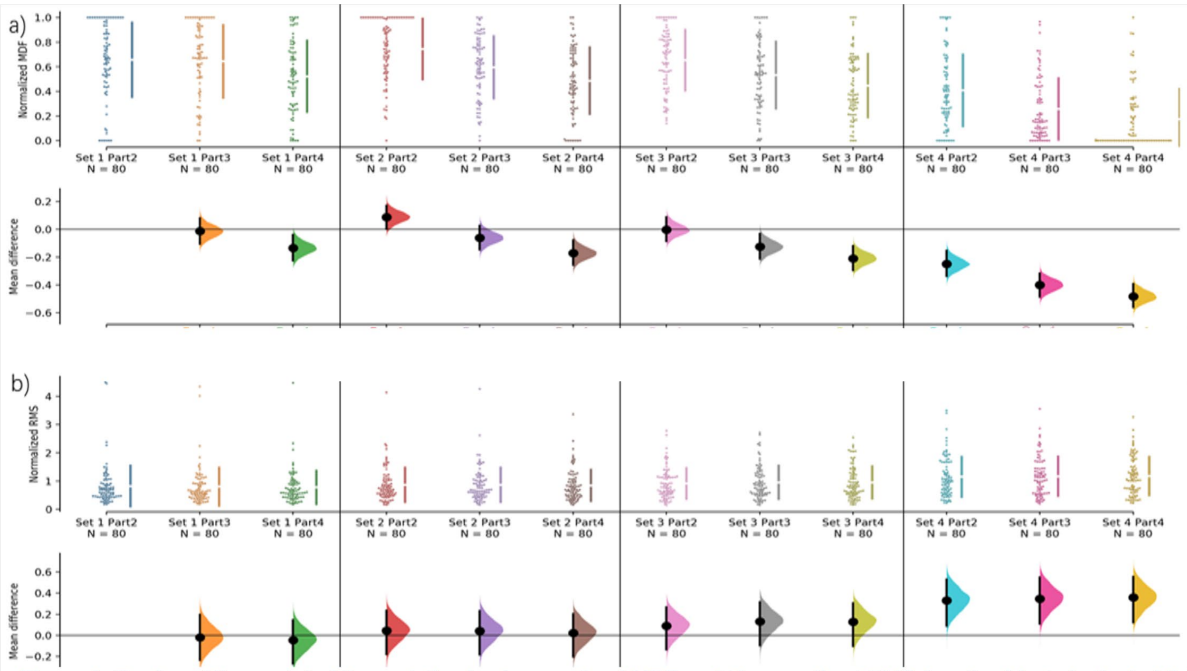

Figure 1. Gardner-Altman plot of the variation in a) normalized MDF and b) normalized RMS for all subjects in the holding phase. MDF and RMS for part2 in set1 were set as the baseline for all subjects. Top: Raw data, distribution of all subject's data. Bottom: Mean differences are plotted as bootstrap sampling distributions. Vertical error bars indicate 95% confidence intervals. The solid black vertical lines in the figure separate each set. The solid black vertical lines in the figure separate each set.

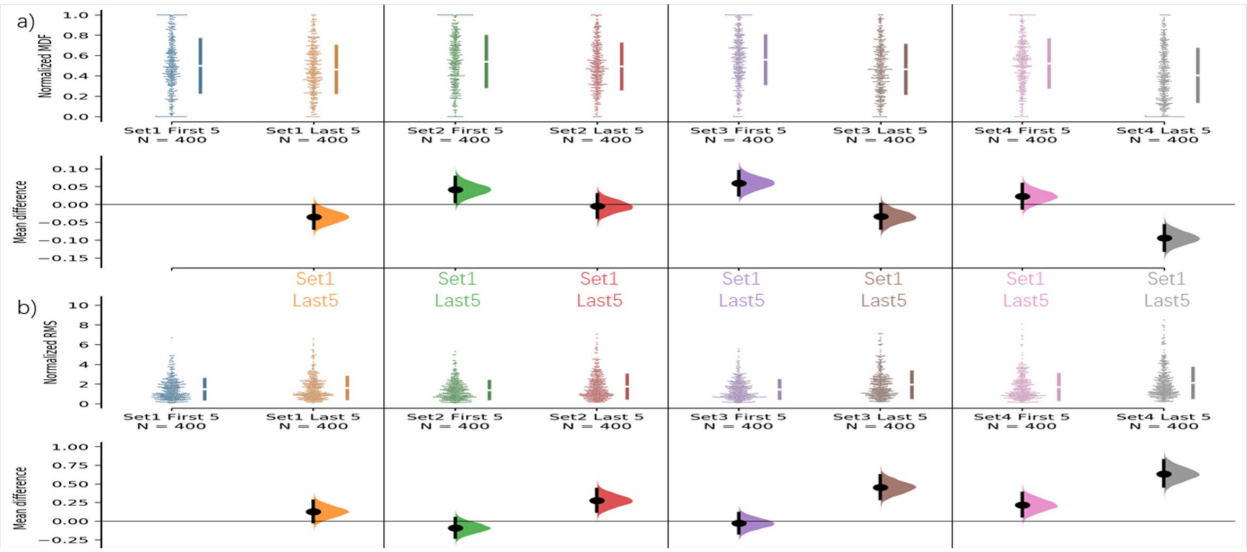

Figure 2. Gardner-Altman plot of the variation in a) normalised MDF and b) normalised RMS for all subjects in the curling phase. MDF and RMS for the first five curls in set1 were set as the baseline for all subjects. Top: Raw data, distribution of all subject's data. Bottom: Mean differences are plotted as bootstrap sampling distributions. Vertical error bars indicate 95% confidence intervals. The solid black vertical lines in the figure separate each set.

Al-Mulla MR et al. (2011). Sensors 11(4), 3545–3594. Finsterer J. (2012). BMC Musculoskeletal Disorders 13, 218P. Whittaker RL et al. (2019). J Electromyography and Kinesiology 47, 88-95 . Gandevia SC. (2001). Physiological Reviews 81, 1725–1789.

C57

Deciphering Motor Control: Unraveling Correlations of Motor Command and Sensory Feedback during Bimanual Movements

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Introduction

Understanding the cortical representation of movement is central to the study of human neurophysiology. While it is recognized that both efferent motor commands and afferent sensory feedback contribute to motor control [1][2], their distinct and combined roles have yet to be fully studied [3]. Our research examines this relationship by analyzing neural signals during hand grip behaviours, employing Electroencephalogram (EEG) and functional near-infrared spectroscopy (fNIRS) for functional brain imaging. Furthermore, we utilized Functional Electrical Stimulation (FES) to stimulate muscle contraction in the absence of voluntary motor commands from the brain, solely incorporating sensory feedback of movement [4]. This study aims to contribute to the broader discussion on the neurophysiological bases of human movement, promoting a deeper understanding of motor control mechanics.

Methods

We designed 4 distinct task conditions to acquire different combinations of sensory feedback and motor commands in hand grip behaviors (as shown in Table 1) and conducted statistical analyses to investigate the interplay between them. We simultaneously recorded the EEG and fNIRS signals of eight right-dominant participants during bimanual hand grip tasks under the 4 conditions. The force was normalized based on each individual's maximum voluntary grip power during Maximum Voluntary Contraction (MVC) of muscles, which was measured prior to the experiments.

The participants were guided via a GUI throughout the tasks as shown in Figure 1. Our unique sensor configuration enabled an efficient fusion of EEG and fNIRS data. Post-data acquisition, Pearson correlation coefficients were computed to ascertain multimodality correlations between EEG, oxygenated hemoglobin (HbO), deoxygenated hemoglobin (HbR), and grip force, and task-specific EEG signal correlations.

Results

The EEG mu-band spectrograms from each session as shown in Figure 2 exhibited power decreases along with the periodic grip or MI, known as mu-band event-related desynchronization, an indication of motor cortex activation. The congruence of EEG signal

changes with hand grip behavior in both time and frequency domains affirms the capture of motor-related brain activity.

The multimodal correlation maps, averaged across subjects, displayed in Figure 3 showed opposite correlations between EEG and force were observed in distinct EEG hemispheres, with strong correlations in ipsilateral EEG and force, for tasks with sensory feedback. A robust anti-correlation existed between HbO and HbR in tasks incorporating sensory feedback, signifying brain activation. Such correlations underscore valid brain activation dynamics which affirmed the data set's integrity.

Regarding EEG task correlations, the Passive-FES-grip task exhibited minimal correlation with the Pure-Motor-imagery task, implying limited overlap between sensory feedback and motor command as shown in Figure 4. While all tasks correlated positively with natural voluntary grip, the pure-MI task displayed a higher correlation than the passive-FES task ($p=0.0222$), suggesting shared brain components but the dominance of motor commands.

Conclusion

Our findings illuminate the distinct representations of motor command and sensory feedback, emphasizing the former's alignment with natural voluntary signals. The use of FES to trigger sensory feedback, independent of brain activity, underlines the potential to enrich sensory feedback understanding. In conclusion, our research challenges existing paradigms and paves the way for a refined understanding of the neurophysiological bases of human movement.

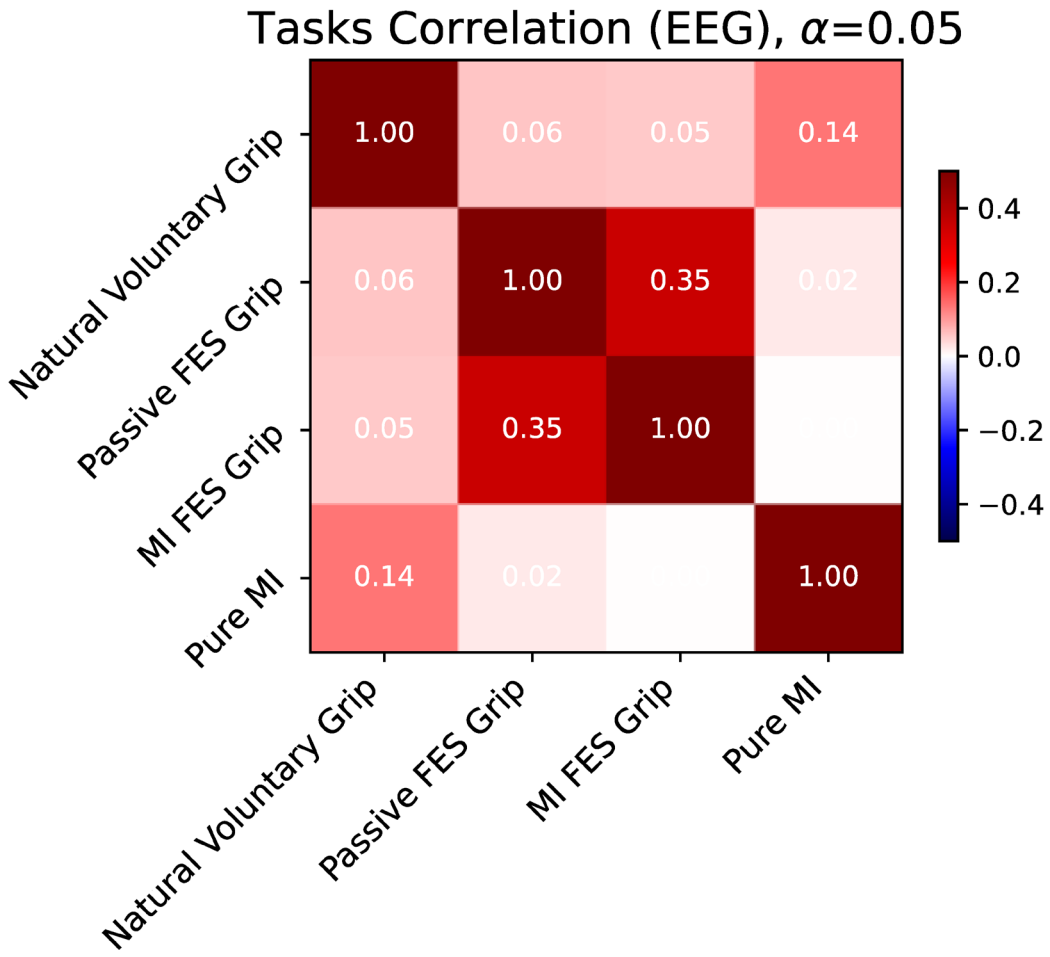

Figure 4. Task correlations matrix based on EEG. Pearson correlation coefficients were calculated between different task sessions (t=[-1s, 9s]). Only significant correlations ($p<0.05$) from each subject were averaged (N=8 in Pure MI tasks, N=11 in other 3 tasks) and showed in the matrix.

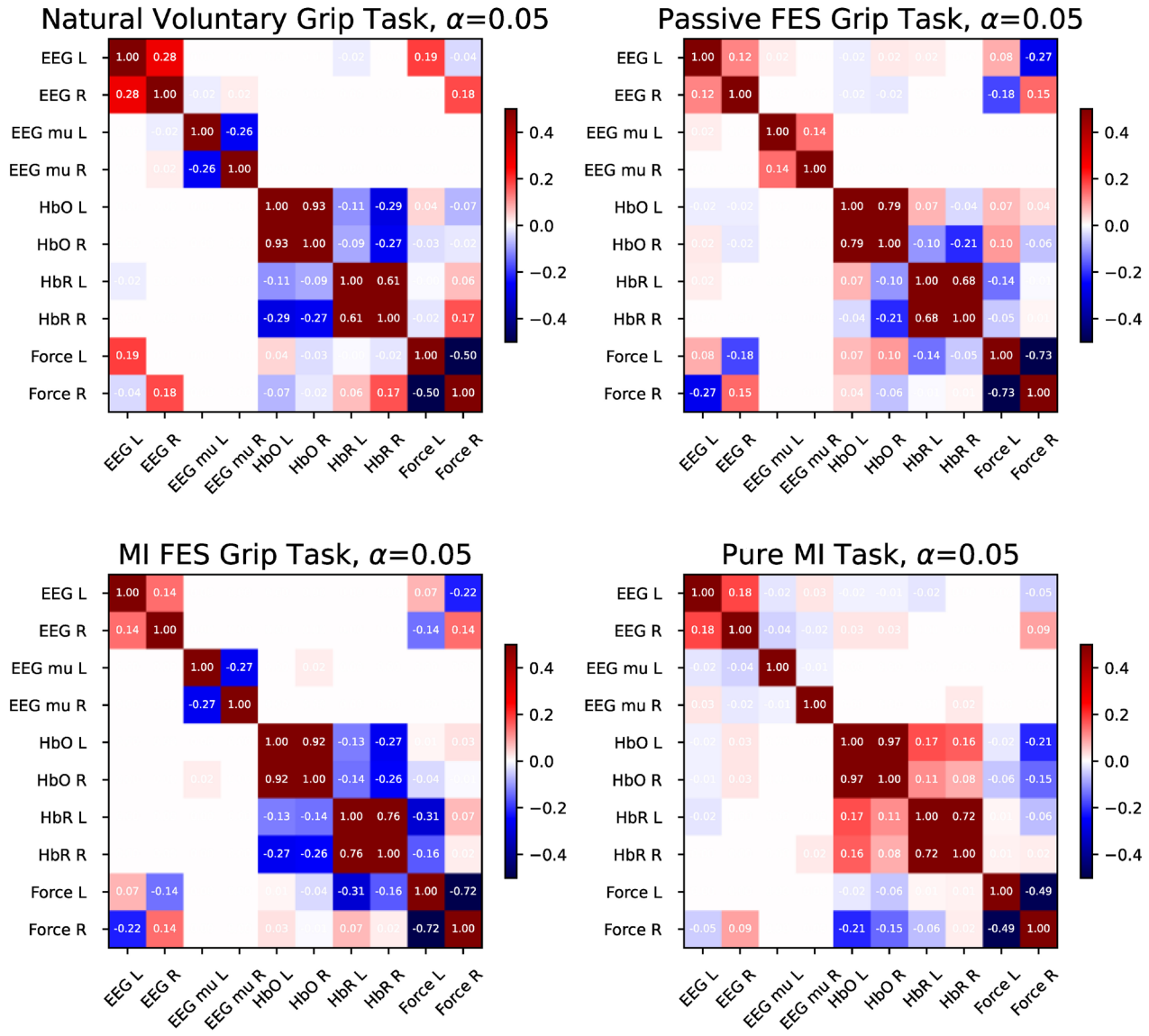

Figure 3. Multimodality correlation matrices in 4 task sessions (t=[-1s, 9s]). Only significant correlations ($p<0.05$) from each subject were averaged (N=8 in the Pure-MI task, N=11 in other 3 tasks) and showed in the matrices. Modalities include: 1. brain signals on left (L) or right (R) hemisphere including: raw EEG, EEG Mu band (8-13 Hz), HbO, HbR; 2. Grip force of left (L) or right (R) hand. The imagined grip force in the Pure-MI task used the same grip force label in the Natural-Voluntary-Grip task.

Task Conditions	FES ON	FES OFF
Voluntary grip ON	/	1. Natural Voluntary Grip: MC+SF
Voluntary grip OFF	2. Passive FES Grip: SF 3. MI FES Grip: MC+SF	4. MI No-Grip: MC (Rest)

Table 1. Task conditions and corresponding brain components combination. (1) Natural Voluntary Grip: Subjects grip naturally by their own intention. Both sensory feedback (SF) and motor command (MC) are present. (2) Passive FES Grip: FES stimulates muscle contraction for passive grip. Subjects perceive only kinaesthetic feedback, denoting pure sensory feedback. (3) Motor Imagery (MI) FES Grip: Subjects only imagine the grip, FES triggers actual muscle contraction. Both externally-caused sensory feedback and motor command are present. (4) Pure MI: Subjects imagine gripping with FES off. Only the motor command component is present.

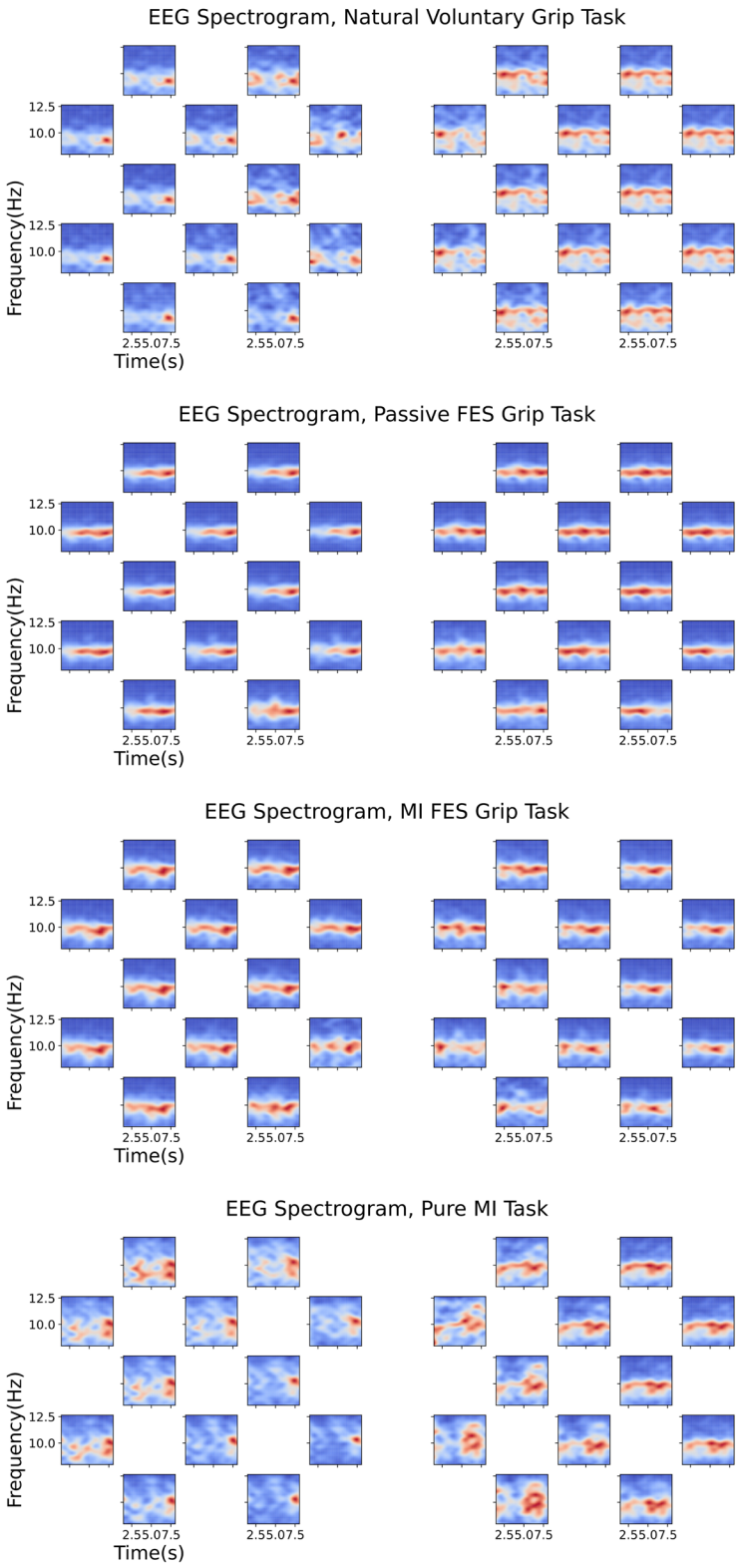

Figure 2. EEG frequency analysis with consecutive Fourier transforms from all tasks. Data example from 1 subject. EEG mu band (8-13 Hz) spectrogram (t=[-1s,9s]) was averaged by all repeated trials per session. Red colour indicates higher power spectral density (V^2/Hz) than blue colour. Topology showed channel layout information in Figure. 1(D).

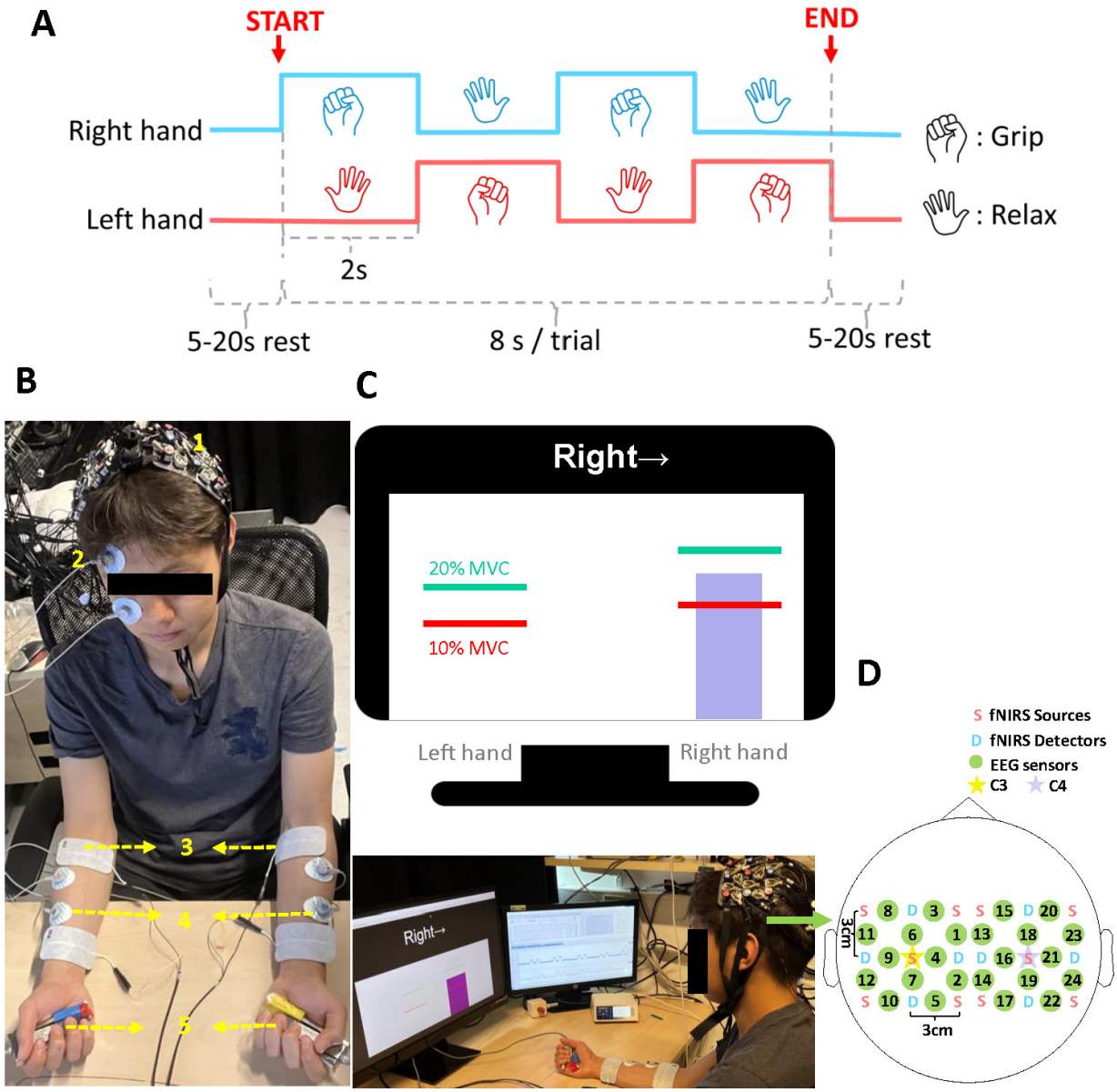

Figure 1. Experiment paradigm (A) Illustration of the continuous bimanual grip task for each trial. (B) Sensors set up: 1. EEG and fNIRS sensors, 2. Electroocoulogram (EOG) sensors. 3. FES patches, 4. Electromyography (EMG) sensors, 5. Grip force transducers. (C) GUI displaying motor task instructions. Dynamic bars represent grip strength while horizontal markers indicate the target force range (10%-20% of an individual's MVC). A more extended bar signifies a firmer grip. (D) Spatial configuration of EEG and fNIRS sensors on the 3D-printed cap.

[1] E. R. Kandel, J. H. Schwartz, T. M. Jessell, S. Siegelbaum, A. J. Hudspeth, S. Mack et al., Principles of neural science. McGraw-hill New York, 2000, vol. 4. [2] J. X. Brooks and K. E. Cullen, "Predictive sensing: the role of motor signals in sensory processing," Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, vol. 4, no. 9, pp. 842–850, 2019. [3] M. Hommelsen, M. Schneiders, C. Schuld, P. Keyl, and R. Rupp, "Sensory feedback interferes with mu rhythm based detection of motor commands from electroencephalographic signals," Frontiers in human neuroscience, vol. 11, p. 523, 2017. [4] D. B. Popovic´, "Advances in functional electrical stimulation (fes)," Journal of Electromyography and Kinesiology, vol. 24, no. 6, pp. 795–802, 2014.