Proceedings

18. Tagung der Sektion Sportmotorik der Deutschen Vereinigung für Sportwissenschaften

Dimensions of Motor Control

Sport, Health, Development, Robotics

Munich 19th to 21st March 2025
TUM Campus im Olympiapark

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DOI: ***only final version***

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Disclaimer: *As we did not receive abstracts for all talks and as some authors wished to not publish their abstracts due to concurrent publication processes, some content will not appear in these proceedings.*

Forewords

Foreword of Joachim Hermsdörfer & David W. Franklin

Dear colleagues,

It is our great pleasure to welcome you to Munich for the 18th conference of the *Human Movement Science* section of the *German Society of Sport Science*. At the Technical University of Munich, we are pleased to host the *Dimensions of Motor Control* conference with a focus on sport, health, development, and robotics.

Motor control is a central aspect of human development - from childhood to senescence, plays a central role in health, and is often driven towards perfection in sports. Given the increasing importance of human-machine interaction, the control of 'intelligent' machines and robots is becoming more relevant. The *Dimensions of Motor Control* conference will highlight all these aspects of motor control and present insights from internationally renowned experts. We are delighted to welcome eight experts from around the world, covering each of these four major themes of the conference.

It is more important than ever to bring together expertise from a range of topics to try to expand our understanding of motor control and disseminate our knowledge and expertise to inspire and drive new insights in related fields. We hope that this conference will connect experts from a variety of backgrounds to benefit from each other, to build bridges, and to foster our understanding of motor control. Presentations, posters, product demonstrations, and a panel discussion will cover basic research and new applications and open new perspectives on this exciting field.

We are pleased to have delegates attending from more than a dozen countries and over seventy different universities. It is wonderful to see such a broad interest in the important topic of motor control. Thanks to all the participants, we have a superb collection of keynotes, talks, posters, and panel discussions. We are grateful to all the colleagues who served as reviewers and helped ensure the high quality of abstracts. Finally, we thank our sponsors for their support, without it would not have been possible to shape this conference into what it is now. We welcome everyone to the *Dimensions of Motor Control* conference at our new TUM Campus in the Olympic Park.

Joachim and David

Prof. Dr. Joachim Hermsdörfer, Chair of Human Movement Science, Department Health & Sport Sciences, TUM School of Medicine & Health, Technical University of Munich

Prof. Dr. David W. Franklin, Chiar of Neuromuscular Diagnostics, Department Health & Sport Sciences, TUM School of Medicine & Health, Technical University of Munich

Grußwort des Präsidenten der Deutschen Vereinigung für Sportwissenschaft

Liebe Teilnehmer*innen der 18. Jahrestagung der dvs-Sektion Sportmotorik,
Liebe Sportwissenschaftler*innen,

Ich freue mich, Sie auf dem Campus im Olympiapark der Technischen Universität München willkommen zu heißen. Das Organisationsteam um die Tagungspräsidenten Prof. Joachim Hermsdörfer und Prof. David W. Franklin haben in den vergangenen Wochen und Monaten großartige Arbeit geleistet und für uns alle ein abwechslungsreiches Programm zusammengestellt.

Die Jahrestagung steht unter dem Motto *Dimensions of Motor Control – Sports, Health, Development, Robotics*. Damit bietet die Veranstaltung ein breites Spektrum von aktuellen sport- und gesundheitswissenschaftlichen Themen an, zu der wir zahlreiche Experten aus der gesamten Wissenschafts-Szene erwarten. Die Tagung soll leistungs- sowie alltagsorientierte Aspekte von Sport und Gesundheit vereinen und in ihren spezifischen Entwicklungsfeldern beschreiben. In vielen Beiträgen der 8 Keynote-Vorträgen, 34 Postern und 21 Free Sessions & Symposien werden die Themen aufgegriffen und ich freue mich auf die hoffentlich vielfältigen Diskussionen dazu.

Mit München verbindet die dvs auch eine besondere Nähe zu den Olympischen Spielen von 1972; und vielleicht kann die Tagung ja auch einen Beitrag zu einer weiteren deutschen Bewerbung für Olympische Spiele in 20240 leisten, bei der gezeigt werden kann, wie vielfältig sportwissenschaftliche Forschung ist und welchen Alltagsbeitrag diese dann für die Gesellschaft bieten kann.

Eine Jahrestagung einer dvs-Sektion (die Sektion Sportmotorik gibt es bereits seit 1991) bietet immer eine Gelegenheit für alle Beteiligten zum wissenschaftlichen und kulturellen Austausch zwischen den verschiedenen Kommissionen und Sektionen der dvs, zwischen Jung und Alt, zwischen Nachwuchs und Etablierten. Ich lade Sie dazu ein, gemeinsam eine großartige dvs-Sektionstagung zur Sportmotorik mitzugestalten und mit positiven Eindrücken sowie Erfahrungen nach Hause zu reisen.

Ich bedanke mich schon jetzt bei allen Organisator*innen und Helfer*innen der Technischen Universität München und wünsche allen gute Gespräche, neue Kontakte und eine schöne Zeit in München.

Ich wünsche uns allen eine schöne Veranstaltung und freue mich, hoffentlich viele von Ihnen, vom 18.-20. September 2025 zum 27. Sportwissenschaftlichen Hochschultag der dvs in Münster zum Thema *Sportwissenschaft: Vielfalt und Nachhaltigkeit!?* wieder begrüßen zu dürfen.

Prof. Dr. Ansgar Schwirtz

Präsident der Deutschen Vereinigung für Sportwissenschaft (dvs)

Foreword of Matthias Weigelt,

Spokesperson of the dvs Human Movement Science section

Dear participants and guests,

It is my pleasure to deliver warm greetings to the 18th biennial conference of the *Human Movement Science* section of the *German Association of Sport Science*, hosted by Professor Joachim Hermsdörfer, Professor David W. Franklin, and their teams at the new *TUM Campus in the Olympic Park* of the Technical University of Munich.

The human movement science conference returns to Munich after its last appearance in 2015. Since then, the research field has moved on in many ways. First, this can be inferred from the conference's title *Dimensions of Motor Control – Sports, Health, Development, Robotics*, expanding the more traditional areas of human movement science research, which are motor control, motor learning, and motor development, to health science and robotics. This has attracted a number of researchers from related fields to participate and present their work at the many different working sessions and symposia. Second, it is reflected in the international orientation of the conference. For the first time, the conference homepage, the conference program, and the scientific talks are (mainly) presented in Englisch, and we are welcoming not only our national participants but also a number of great scientists from different countries of the world. Therefore, the conference will provide both young researchers and more experienced scientists with the opportunity to network (literally) across fields and across borders.

For the next three days, we can expect to experience several scientific highlights. Besides the many scientific talks and the poster session, there will be an exceptional series of keynote lectures, the presentation of the *Qualification Award 2025*, and a panel session on the future of the field. These highlights will be accompanied by a guided tour of different laboratories and the presentation of scientific equipment from sponsors.

The new venue in the Olympic Park will also provide a nice environment for a more informal social gathering at the welcome reception and the dinner party, as well as during the coffee and lunch breaks during the conference. All of this has proven to be an important part of scientific exchange and career development at previous conferences and is part of the DNA of the *Human Movement Science* section. For this reason, I would like to encourage everyone to not only participate in the scientific program but also in the different social events.

To conclude, I am looking forward to the scientific debate among colleagues, collaborators, and friends in Munich, and I am very thankful to Professor Joachim Hermsdörfer, Professor David W. Franklin, and their teams to have organized this event!

With warm regards,

Prof. Dr. Matthias Weigelt
Spokesperson of the section of *Human Movement Science*

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Inhalt

Keynote lectures

Keynote: Sport

From elite athletes and musicians to patients – the importance of the cortical inhibitory system

Wolfgang Taube, University of Fribourg

For decades, maximizing neural drive and motor unit firing rates has been a focal point in enhancing motor performance for athletes and patients. However, this talk will shift the focus away from facilitation of neural activity and instead explore the critical role of inhibition in motor control. Specifically, the importance of the inhibitory system and its relevance for motor control, motor learning and motor memory consolidation will be highlighted.

This presentation will demonstrate that GABAergic activity at the cortical level is essential for shaping neural drive, facilitating efficient and economical motor output, and improving overall motor performance. Notably, it is not merely the quantity of inhibition that matters but also the ability to modulate it effectively. For instance, one immediate way to adjust the level of inhibition is by altering the focus of attention: an external focus of attention has been shown to strengthen intracortical inhibition.

To achieve long-term changes in inhibitory mechanisms, coordinative exercises like balance training have proven to enhance both inhibitory capacity and the ability to modulate inhibition. Finally, the talk will address the relationship between GABAergic cortical inhibition and brain health, proposing that targeted sports activities could be valuable interventions for patients with reduced inhibitory capacities.

Keynote: Sport

Optimizing sports performance through motivation and attention

Gabriele Wulf, University of Nevada

Athletes perform some of the most complex motor skills, often under pressure to perform well. What factors influence the quality of their performance, and what practice conditions are necessary to optimize learning? The OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) theory (Wulf & Lewthwaite, 2016) is based on numerous studies that have demonstrated the importance of motivational and attentional factors for effective skill learning and performance. Key factors include: (a) *enhanced expectancies* for future performance, (b) support for performer *autonomy*, and (c) an external focus of attention. These factors align thoughts, attention, motivation, and neuromuscular activity to the performer's goals. Evidence from various lines of research indicates that enhancing performance expectancies facilitates learning. Furthermore, providing learners with some measure of control, or supporting their need for autonomy, has consistently been found to enhance both performance and learning. The sense that one is in a situation in which one has control over one's actions reduces the need to resist, and enhances expectations for future success. Finally, directing attention to the intended movement effects (external focus), rather than the coordination of body movements (internal focus), results in more effective performance and learning. Thus, pairing motor practice with conditions that boost confidence and outcome expectations, support performers' autonomy, and focus their attention on external movement effects facilitates learning. These conditions lead to efficient goal-action coupling. I will give an overview of OPTIMAL theory and important research underpinnings that establish behavioral impacts of subtle motivational and attentional inputs and instructions.

Keynote: Health

Motor control and learning in older adults and clinical samples

Claudia Voelcker-Rehage, University of Münster

Motor control, learning and cognitive performance typically decline with age, affecting daily life. It is well known that there is a high degree of motor and cognitive plasticity into old age and that targeted interventions can effectively delay or reduce this decline. This talk will explore the progression of motor decline associated with ageing and age-related diseases, and how sustained practice and motor expertise can mitigate such decline. It will also examine the complex relationship between motor performance, physical activity and cognitive function, and how these factors can predict and influence the course of motor and cognitive decline. Various interventions will also be presented, including tailored exercise programs designed to improve motor and cognitive performance in activities of daily living. Finally, the practical applications of this research will be explored, illustrating how these findings can be integrated into everyday contexts to improve the quality of life of older adults, thereby promoting greater autonomy and well-being. Overall, the lecture aims to highlight the importance of continued engagement in motor and cognitive activities as powerful tools to counteract the adverse effects of ageing and age-related diseases.

Keynote: Health

Neural substrates of motor skill learning in health and disease

Leonardo G. Cohen, National Institutes of Health

Keynote: Development

How our hands shape our minds

Gustaf Gredebäck, University of Uppsala

In this presentation I will explore how manual actions, that is, actions performed with hands and arms, such as reaching, grasping, and manipulating objects, shape the mind. Based on recent empirical research, I will highlight four embodied developmental pathways that solve unique challenges infants and children face during development: I) Co-opted motor simulation allows action anticipation. II) Interactive specialisation allows executive control to emerge from reaching and grasping. III) Active exploration and IV) error-based learning facilitate cognition and perception. These pathways exemplify how infants use manual actions and the underlying neural processes controlling actions to structure the world, develop cognitive capacities, and to learn from interactions with the physical and social world.

Keynote: Development

Motor-cognitive performance in typically and atypically developing individuals - a lifespan perspective

Nadja Schott, University of Stuttgart

The development of complex motor skills is a multifaceted process that involves the integration of neuromotor, psychological, social, and cognitive processes (including executive functions). A comprehensive understanding of how these processes are embedded and manifest themselves across the various stages of development throughout life is imperative. In particular, the dynamic systems view (Thelen & Smith, 2007), the developmental motor neuroscience approach (Whitall et al., 2020), and the developmental embodied cognition approach (Lux et al., 2021) emphasize that motor-cognitive development is experience-dependent and characterized by a constant interplay between the developing individual, their structural and functional limitations, and their social and physical environment.

For a considerable period, the prevailing perspective was that motor development precedes cognitive development. However, mounting evidence suggests that motor and cognitive development are not distinct, independent phenomena that occur in a predetermined sequence. Instead, both motor and cognitive development commence early in life, persist into adolescence—in the sense of gains—and are intricately intertwined. As these developments progress into adulthood—in the sense of maintenance or decline—the role of physical and sporting activities (or sedentariness) on cognitive performance becomes a pivotal concern. A comprehensive understanding of the developmental trajectory is paramount for interpreting and potentially intervening in cases where observed behaviors and the acquisition of motor skills deviate from expectations (atypical (neuro)motor development).

This presentation will critically examine some conceptualizations of motor development as well as the extant knowledge regarding typical and atypical development across the lifespan. It will consider neural and motor development as the basis for interaction with genetic setup, environmental stressors, or disease.

Keynote: Robotics

Motor learning: context dependency, meta-learning, and redundancy

Daichi Nozaki, The University of Tokyo

The motor system has a remarkable ability to achieve both consistency and flexibility of movement. When an error occurs during movement execution, the motor system updates motor commands to reduce the movement error for the subsequent movement. In this talk, I will discuss the following three topics related to this motor learning process. First, the process of updating motor commands or motor memory depends strongly on the context of what kind of movement is being planned. I will show that the state of the motor system plays an important role for the useful contexts and such context dependency enables us to perform flexible movement control such as bimanual movements (Yokoi et al., J Neurosci 2011; Nozaki et al., eLife 2016). Second, I will show evidence that the motor learning system performs meta-learning: it allows us to learn not only how to move, but also how to correct the movement (Hayashi et al., bioRxiv). As these two examples show, the knowledge gained from a planar reaching movement is useful, but due to the lack of redundancy of the task, conventional experiments are not helpful in addressing the problem of how the motor learning system reduces errors by coordinating to change the redundant body. Finally, I will introduce a novel bimanual stick manipulation task to systematically investigate the problem posed by the inherent redundancy of our body (Kobayashi and Nozaki, eLife 2024).

Keynote: Robotics

Sensorimotor interaction in humans and with robots

Etienne Burdet, Imperial College London

From a parent helping guide their child's first steps, to a therapist supporting a patient, physical assistance transmitted through haptic interaction is fundamental modus for improving motor performance. By observing mechanically connected individuals carrying out a similar task, we found that they conspicuously exchange haptic information to increase own performance. Moreover, connected partners improve their haptic communication by modulating the limb viscoelasticity through muscle cocontraction. We then modelled the underlying computational mechanism and embodied it as a robot partner, which induces similar motor performance improvement as a human partner. This promises sensory augmentation through which contact robots can better assist their user through haptic communication and body adaptation.

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Symposia

Symposium:

Mechanisms of imagery and imagery training

Cornelia Frank[a] & Andrea Polzien[b]

a: Universität Bremen, Bremen, b: Universität Osnabrück, Osnabrück

While it is well-accepted that imagery training can enhance motor learning and performance, the mechanisms of imagery and imagery training are still under debate (Frank et al., 2024). Currently, theories undergo specifications alongside different motor control and learning perspectives coming from sports science, psychology and neuroscience. The aim of the symposium is to discuss the latest research from the area of imagery and imagery training from an interdisciplinary perspective with a focus on the underlying mechanisms. In the symposium, we will particularly consider (1) work that investigates whether prior imagined movements have the same effect as prior overt movements on motor adaptation, thereby drawing on simulation theory (e.g., Jeannerod, 2001) and the postulated functional equivalence between execution and imagery, (2) Evidence for the motor-cognitive model (e.g., Glover et al., 2020) and the central role of executive functions in consciously monitoring imagery of grasping, (3) Findings about how prior experience of a specific complex task, namely javelin throw, moderates imagery training effectiveness in the same task together with (4) Insights into how previous task experience influences the effectiveness of imagery training in a similar task, both which can be explained by way of the ideomotor perceptual-cognitive scaffolding idea (e.g., Frank et al., 2024). The symposium will end with a discussion on the extent to which the different approaches can be integrated to explain the effects of imagery

Motor imagery enhances performance of linked segments in a motor sequence

Magdalena Gippert [a], Pei-Cheng Shih [b], Tobias Heed [c], Ian S. Howard[d], Mina Jamshidi Idaji [e], Arno Villringer [a], Bernhard Sehm [a], Vadim V. Nikulin [a]

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Keywords

Motor learning, Motor control, Neural correlates, Motor adaptation

Highlights

- New evidence for the functional equivalence between imagined and overt movements

Introduction

Motor imagery and overt movement have been hypothesized to be functionally equivalent [1]. At the same time there is evidence that hints at distinct mechanisms of both processes [2]. To explore this disparity, we investigated whether prior imagined movements had the same effect as prior overt movements on motor adaptation performance during a subsequent reach. Additionally, we aimed to identify neuronal correlates of motor imagery predicting such motor adaptation.

Methods

Movement kinematics (exoskeleton robot, Kinarm Lab) and multi-channel EEG of 60 healthy participants (18-35 years old) were recorded to investigate direction-specific adaptation during a reach of the right arm in an interference force-field paradigm. We compared performance of three experimental groups: 1) control (no prior movement) 2) active (overt) prior movement, and 3) motor imagery of a prior movement (Figure 1). Performance of the reach to the final target was quantified by the maximal perpendicular error (MPE), which is the maximal deviation from a straight line between middle and final target.

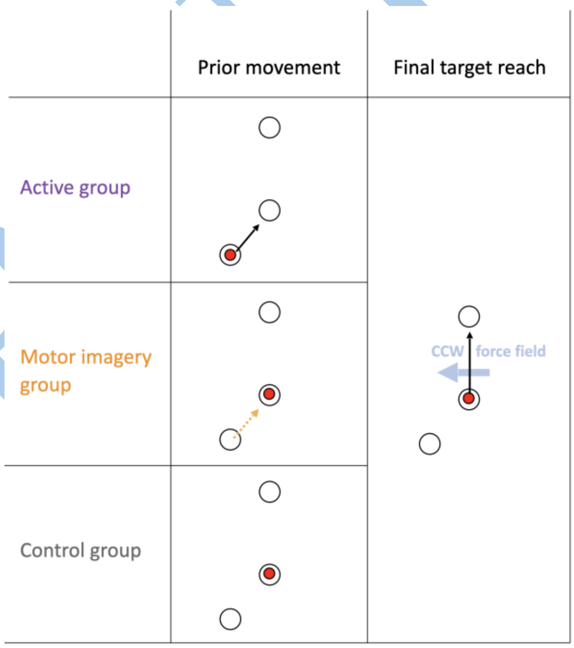

***Figure 1:** Experimental groups with exemplary trial sequence. Red dot – hand position; black arrows – active overt reaches; orange, dotted arrow – imagined reach; CCW – counterclockwise.*

Results

In line with previous research [3, 4], we found that participants in the active group adapted to opposing force-fields, while the control group did not. Participants in the motor imagery group adapted, albeit to a smaller extent (see Figure 2).

We quantified this by calculating the change in MPE between two time points: when force fields were first introduced and before they were removed towards the end of the experiment. T-tests

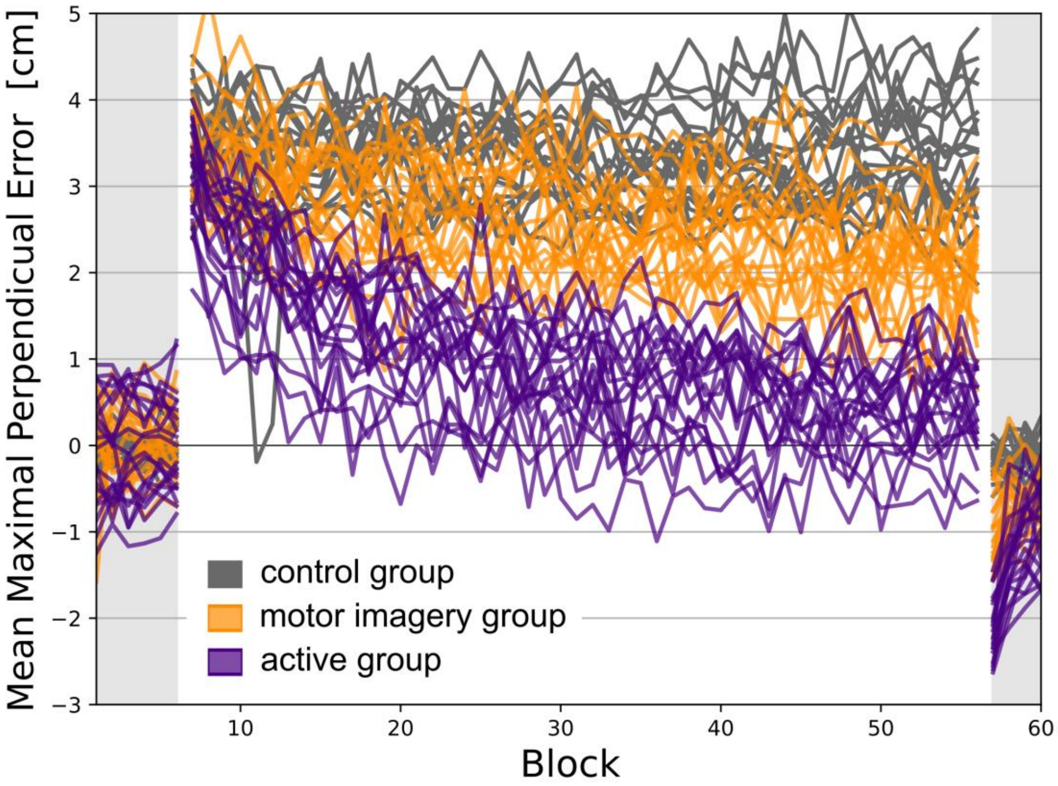

Figure 2: *MPE during final target reach averaged over trials within one block. Each line depicts one participant. Force fields were present from blocks 7-56 (white background). Positive MPE values reflect a trajectory deviation in the direction of the force field.*

within groups against 0 were significant in the active (t(19) = 22.87, p = 1.3e-14) and motor imagery (t(19) = 8.01, p = 6.5e-07) but not in the control group (t(19) = 0.54, p = 0.59). T-tests between groups revealed significant differences for all three pair-wise comparisons (all p < 1.3e-0.6).

In addition, we demonstrated that oscillatory neural responses in the contralateral hemisphere in sensorimotor areas during a simple motor imagery task were correlated with motor adaptation performance.

Discussion

Taken together, our results indicate that motor imagery and overt movements share similar neuronal processes, suggesting that motor imagery can be leveraged to improve the performance of

linked overt movements. People with stronger neural modulation during motor imagery seem to have better imagery proficiency and might be able to benefit from linked imagined movements to a greater extent.

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Motor imagery is immune to variables that impact online control: A further test of the Motor-Cognitive Model

Marie Martel [a,b], Scott Glover [b]

a: School of Psychology, University of Surrey, Guildford, b: Department of Psychology, Royal Holloway University of London, Egham

Keywords

Motor control, Motor cognition, Upper limbs, Motor Imagery, Reaching and grasping

Highlights

- Motor imagery is unaffected by variables that impact the online control of physical action.
- The results further support the MCM.

Introduction

According to the Motor-Cognitive model (MCM) [1-3], motor imagery differs from overt action primarily through its use of executive resources to consciously monitor the unfolding motor image, in place of the automatic online control processes used by overt action. This often results in timing discrepancies between real and imagined actions [1-3]. E.g., performing a demanding mental operation, such as counting backwards by threes or generating words from a single letter, greatly slows the execution of motor imagery while only marginally affecting the timing of its physical counterpart [1-3].

A critical prediction of the MCM is that motor imagery should be most dissimilar to physical action under conditions in which online control is emphasized. When the *quality* of information available to online control is reduced, for instance when performing a movement without vision; or if there is increased reliance on online control, for instance when using the non-dominant hand, there will be increased movement times and an increased number of in-flight adjustments [4]. However, the MCM predicts that variables affecting online control should impact only physical actions, leaving motor imagery unaffected, which would be highlighted by the presence of an interaction between the different levels of online control.

Methods

The general setup is shown in Figure 1 [1-3]. Participants sat at a table, beginning each trial with their right hand in a relaxed position. After a tone, participants either physically reached for the disc to place it in the cylinder or imagined doing so. Both groups marked the start and end of their movements by pressing a key. We extracted movement time (MT) from the keypress data for both physical action and motor imagery and compared them in a 2×2 design fitting nested linear mixed models using adj. likelihood ratios.

In all three experiments participants either executed or imagined performing the task. In Experiment 1, 32 participants carried out the task with their eyes either open (*Full Vision*) or closed (*No Vision*). In Experiment 2, 60 participants performed while either being allowed to move their eyes freely to foveate the target and hand (*Foveal*), or required to maintain fixation (Peripheral). In Experiment 3, 84 participants performed the task either with their dominant (*Right Hand*) or non-dominant (*Left Hand*) effector.

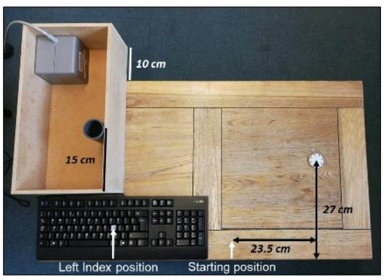

Figure 1: *Experimental Setup for Experiment 1, 2 and for the Right Hand condition of Experiment 3.*

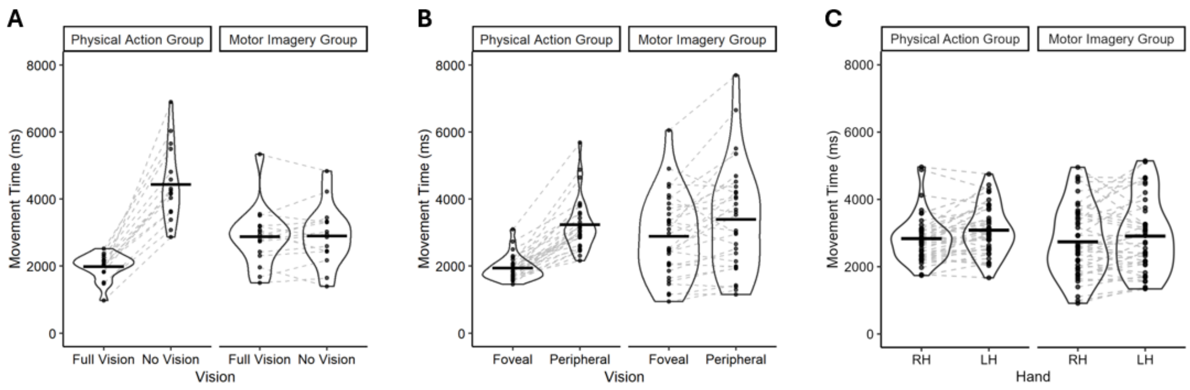

Figure 2: *Effects of varying Vision (Experiment 1 and 2) or Hand (Experiment 3) on movement times in the physical action and motor imagery groups. Each point marks the average score of an individual participant. Dashed grey lines connect paired averages from the same participants, while horizontal lines indicate the group averages.*

Results

Figure 2 shows the mean keypress movement times as a function of *Vision* and *Action* conditions (Experiments 1 and 2) or *Hand* and *Action* (Experiment 3).

Experiment 1 (Figure 2A): The best-fitting model included both *Vision* ($\lambda_{adj} > 1000$), and *Action* × *Vision* ($\lambda_{adj} > 1000$), reflecting increased movement times in the *No Vision* condition but only for the physical action group.

Experiment 2 (Figure 2B): The best-fitting model included *Action* ($\lambda_{adj} = 803$), *Vision* ($\lambda_{adj} > 1000$), and *Action* × *Vision* ($\lambda_{adj} = 716$): movement times were longer in the *Peripheral* vs. *Foveal* condition, in the MI *vs.* OA groups, and the effect of *Vision* was greater in the physical action group than in the MI group.

Experiment 3 (Figure 2C): A stastistical model including only an effect of *Hand* fit the model best ($\lambda_{adj} = 129$), with longer movement times in the *Left Hand* condition. Contrary to the prediction of the MCM, adding the interaction *Action* × *Hand* did not improve the fit ($\lambda_{adj} = .21$).

Discussion

The presence of the predicted interaction in Experiments 1 and 2 showed that the lower quality of information available to online control resulted in much longer movement times for overt actions but barely affected motor imagery. This shows that motor imagery is mostly unaffected by online control, consistent with the prediction of the MCM. However, the results of Experiment 3 were inconclusive, possibly due to the effects on the physical movement being too small to drive the interaction between *Action* and *Hand*. We indeed did not observe that much of an increased movement time in the physical movement itself.

Overall, these findings generally support the idea that motor imagery uses executive functions as a substitute for online control and nicely complement previous work showing the opposite pattern of effects: disrupting executive functions, either through an interference task, or via TMS over the Dorso-Lateral Prefrontal Cortex, slowed motor imagery but left physical actions relatively unaffected [3].

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Skill level influences imagery practice effects in complex motor action: Evidence for perceptual-cognitive scaffolding

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Keywords

Motor learning, motor cognition, motor skills and abilities, imagery, ideomotor theory

Highlights

- Prior experience changes imagery effect
- More learning in better throwers
- Support for scaffolding through imagery

Introduction

The idea of perceptual-cognitive scaffolding posits that learning via imagery is driven by scaffolding of (quasi) action effects during action planning [1]. One specific assumption of this ideomotor approach to learning by way of imagery relates to the influence of the skill level the imager has and the prior experience he/ she has with the motor task to be imagined: Individuals with task experience draw on existing action-effect-links. During imagery, changes in perceptual-cognitive scaffolding should thus, due to existing links, directly result in changes in motor performance. Instead, in individuals without task experience perceptual-cognitive scaffolding during imagery practice takes place, despite missing links between the action and respective effects. The resulting scaffold is not necessarily linked to their motor repertoire yet and thus does not necessarily lead to improvements in overt action, while those changes might come into effect after some task execution. Meta-analyses to date indicate that the effectiveness of imagery practice depends on skill level [2,3]. Driskell and colleagues [2] found moderate effects for both novice and experienced individuals, with the comparison between skill levels being not significant. However, the effect of experience depended on type of task. Effects were stronger for cognitive tasks in novices, while there was no difference between cognitive and motor tasks in experienced individuals. Similarly, Toth et al. [3] found effects for both novices and advanced individuals, while the difference was not significant. Imagery practice of motor tasks thus seems to particularly be effective in individuals with prior task experience. While syntheses of existing research [2,3] suggest that imagery effects depend on whether and how much prior experience the imager has with the motor task to be learnt, this has yet to be directly tested. The aim of the present study was therefore to test whether the impact of imagery practice of a complex motor action is influenced by prior task experience. Drawing on the idea of perceptual-cognitive scaffolding [1], we hypothesized that individuals with more prior experience with the task would show stronger improvements in overt performance over time compared to individuals with less prior experience with the task.

Methods

To test this hypothesis, we examined the influence of imagery practice on participants' javelin performance, thereby considering their prior skill level. Specifically, we assigned 30 beginners with varying prior experience and resulting skill level to either an imagery practice group or a no imagery practice control group. For this purpose, we proceeded as follows: First, we ranked participants based on their pre-test performance and assigned every second participant to one of the two groups. This procedure allowed us to consider their skill level while ensuring a similar mean baseline performance per group. Second, we split each group into half, with the better performers representing the group with higher skill level and the worse half of performers being grouped as low in their skill level. We tested their javelin performance by measuring throwing distance prior to and after an intervention of six weeks as well after a retention-interval of two weeks. During the intervention, participants practiced javelin by way of execution as part of their regular physical education class over the course of four weeks. The imagery practice group imagined throwing the javelin in each session, while the control group did not use imagery. To answer the questions (1) whether imagery practice improved performance and led to learning in the present study and (2) whether this depended on participants' skill level, we conducted rm ANOVAs on throwing distance.

Results

Specifically, we conducted two 2 x 2 x 2 rm ANOVAs on throwing distance with *test phase* (pre vs. post / pre vs. retention) as within-subjects factor and *imagery practice* (yes vs. no) as well as *skill level* (low vs. high) as between-subjects factor. For performance improvements from pre- to post-test, analysis of variance revealed a main effect of *test phase*, confirming that both groups have improved throwing performance over time (p=.001). While the interaction effect *imagery practice* x *test phase* was not significant (p=.154), the interaction effect *imagery practice* x *test phase* x *skill level* was (p=.016), indicating that the impact of imagery practice related to performance changes was moderated by skill level. Further analysis of this interaction by way of a 2 (*imagery practice*: yes vs. no) x 2 (*skill level*: low vs. high) rm ANOVA on performance changes from pre- to post-test revealed a significant interaction. This interaction confirmed that improvements were moderated by prior experience, with more skilled participants showing greater improvements (M_{diff}=+306cm; SD=±231cm) from pre- to post-test compared to less skilled ones (M_{diff}=+110cm; SD=± 152cm) in the imagery group (p=.043). For learning from pre- to retention-test, analysis of variance revealed a main effect of *test phase*, confirming that both groups have learnt (p=.019). Both the interaction effect *imagery practice* x *test phase* (p=.065) and the interaction effect *imagery practice* x *test phase* x *skill level* (p=.965) did not reach significance (more skilled: M_{diff}=+430cm; SD=±403cm; less skilled: M_{diff}=+158cm; SD=±136cm). This indicates that learning (as opposed to performance improvements) was not moderated by skill level in the present study.

Discussion

The purpose of the present study was to answer the question if skill level influences the impact of imagery practice on the learning of a complex motor action. To this end, an imagery group and a no imagery group, each split into half (low/ high skill level) performed a four-week javelin practice as part of their regular physical education class, with or without imagery practice. The results partly confirmed our hypothesis that individuals with task experience and a higher skill level should benefit more from imagery practice: More skilled participants showed greater improvements after imagery practice from pre- to post-test, but not from pre- to retention-test. Thus, participants holding a higher skill level profit more from imagery practice compared to their low skill level counterparts in terms of immediate performance changes over time. This is in line with our hypothesis that experienced individuals profit more from imagery practice since skilled performers can draw on existing links between the action and its effects, allowing for changes in perceptual-cognitive scaffolding to directly transfer into changes in overt action. However, this advantage seems to diminish after a two-week interval without any task practice.

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Experience in a task influences effectiveness of imagery training in a similar task

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Keywords

Sport, Motor learning, Motor skills and abilities, Motor transfer, Imagery training

Introduction

Numerous meta-analyses have shown that imagery training is effective in promoting motor learning [1–3]. To explain the mechanisms underlying imagery training, Frank et al. [4] put forward the theory of perceptual-cognitive scaffolding. According to this theory, learning by imagery leads to scaffolding of action effects. Whether or not this scaffolding directly leads to improvements in overt performance, depends on prior task experience. If individuals have physical experience in a task, and can draw on action effect links, performance improvements should occur. In contrast, if no link between an action and its effects exists, no direct improvement of the movement should be observed [4].

Along these lines, the theory of perceptual-cognitive scaffolding also predicts that prior task experience should have an impact on the effectiveness of imagery training in a similar task. The influence of a similar task on learning a new task is classically known from motor transfer. In studies on transfer of learning, the impact of prior physical experience in one task on learning a similar (transfer) task is examined [5]. In a typical study on motor transfer, O'Keeffe et al. [6], for example, found positive transfer from the fundamental overarm throw to the badminton overhead clear and the javelin throw. While motor task transfer has been thoroughly examined in the context of motor learning, studies addressing motor task transfer through learning by way of imagery are still lacking. Accordingly, the present study aimed to answer the question if expertise in one task affects learning of a similar task by imagery. To this end, groups with different expertise in the fundamental overarm throw engaged in imagery training of the badminton overhead clear. Based on the theory of perceptual-cognitive scaffolding, and since existing action-effect links of a well-known task should facilitate scaffolding for a similar task, we hypothesized that experience in the fundamental overarm throw would benefit learning of the badminton overhead clear by way of imagery.

Methods

Thirty novices in badminton (M_{age} = 23.2 years, SD = 3,2 years) took part in the study, which included a pre-test, an imagery intervention and a post-test. In the pre-test, each participant performed the fundamental overarm throw and the badminton overhead clear for ten times. We recorded their performance from both a frontal and a side perspective. Following the pre-test, participants' performance in both techniques was rated on scales ranging from 0% (not met at all) to 100% (perfectly met) according to five previously defined criteria, which relate to the preparatory movement, trunk action, humerus action, underarm action and follow-through. The mean for the overall performance in both techniques was calculated from the values for the individual criteria. Based on the performance in the fundamental overarm throw in the pre-test, we assigned each participant to one of the three groups: 1) experienced throwers, who took part in the mental practice (MP_EXP; n = 10), 2) less experienced throwers, who also took part in the mental practice (MP_INEXP; n = 9) and 3) experienced throwers, who served as a control group (C; n = 11). Following this, both MP groups engaged in an imagery training intervention consisting of six sessions for learning the overhead clear. In each training session, we asked the participants to imagine performing the clear from an internal perspective in 3 blocks of 20 trials. Before each block, the participants were read instructions regarding the imagery content. The third group (C) did not undergo any training. Afterwards, all participants took part in the post-test and performed the badminton overhead clear ten times. Participants' performance was again rated and analyzed based on the predefined criteria.

Results

To investigate if experience in the fundamental overarm throw influences learning the badminton overhead clear through imagery, a mixed ANOVA with the within-subject factor *test time* (pre-test vs. post-test) and between-subject factor *group* (MP_EXP vs. MP_INEXP vs. Control) was conducted for the performance in the badminton overhead clear. In line with our expectations, results showed a significant main effect for test time (p = .003, η_p^2 = .28), indicating better performance at the post-test compared to the pre-test. Moreover, a significant main effect for group was found (p = .03, η_p^2 = .23), which was driven by the significantly greater performance of the control group (who were better throwers) compared to the MP_INEXP group. These main effects were qualified by a significant interaction between both factors (p = .009, η_p^2 = .3). To analyze this interaction, post-hoc *t*-tests were used to compare the change in performance (i.e., difference between post-test and pre-test) between groups. The MP_EXP group showed significantly greater improvement (3.4%) compared to the MP_INEXP group (0.9%; p = .036) and the control group (-0.1%; p = .009). No significant differences were found between the MP_INEXP (0.9%) and the control group (p = .103).

Discussion

The present study aimed to answer the question of whether experience in one task benefits learning a similar task via imagery training. To this end, one group of experienced throwers and one group of unexperienced throwers engaged in a six-session imagery training of the badminton overhead clear. A group of experienced throwers served as a no-training control group. Results showed significant differences in performance improvement from pre-test to post-test between groups. As expected, the experienced throwers, who carried out the imagery training showed the largest improvement, and differed significantly compared to both, the inexperienced throwers, who engaged in the imagery training, and the experienced control group. The latter two groups did not differ significantly from each other. The results are consistent with the theory of perceptual-cognitive scaffolding, which assumes that imagery relies on pre-existing action-effect links, suggesting that the efficacy of imagery training is enhanced not only by motor experience specific to the same task but also by prior experience with similar tasks [4].

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Symposium:

Interventionseffekte bei älteren Erwachsenen

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Der wachsende Anteil der älter werdenden Bevölkerung insbesondere in den Industrienationen bedeutet Herausforderungen für das Gesundheitssystem. Deshalb sollte es eine gesamtgesellschaftliche Aufgabe sein, Präventionen anzubieten, die die Wahrscheinlichkeit möglicher Erkrankungen im fortgeschrittenen Alter reduzieren. Ein Aspekt ist dabei, die Motorik zu verbessern bzw. zumindest zu erhalten. Das Ziel des Symposiums ist es, aus unterschiedlichen Perspektiven Interventionen zur Gesundheitserhaltung und insbesondere zum Erhalt und zur Verbesserung motorischer Fähigkeiten und Fertigkeiten von älteren Erwachsenen vorzustellen. Dabei werden sowohl gesunde Menschen im fortgeschrittenen Alter als auch Menschen mit kognitiven Einschränkungen betrachtet.

So geht es im Vortrag von Frau Schumacher et al. um ein sechsmonatiges multidimensionales Bewegungsprogramm, das auf gesunde, aber bisher sportlich inaktive Personen ausgerichtet ist. Es wird gezeigt, dass sich bereits in diesem kurzen Zeitraum motorische Fähigkeiten verbesserten und es gelang, die Teilnehmer*innen bleibend für den Sport zu begeistern.

Im Beitrag von Herrn Thiel wird der Tanz als spezielle Intervention in den Fokus gerückt. Es konnte gezeigt werden, dass sich durch diese Tanzintervention körperliche Fitness und das Gleichgewicht zumindest stabilisieren, wenn nicht auch einen positiven Trend aufweisen.

Herr Prinz et al. stellen speziell für Menschen mit einer Demenzerkrankung entwickelte Serious Games „KoKoFIT“ vor, die insbesondere das Ziel haben, die Gleichgewichtsfähigkeit spielerisch zu verbessern. Es konnten Verbesserungen in der dynamischen Gleichgewichtsfähigkeit belegt werden.

Title only:

Age-related hearing-impairment and cognitive-motor dual-task performance - impacts for training APP development

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Einfluss eines multidimensionalen Bewegungsprogramms auf ausgewählte motorische Fähigkeiten bei gesunden, sportlich inaktiven Senioren (w/m) 60+

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Keywords

Sport, motorisches Lernen, Motorische Fähigkeiten und Fertigkeiten, multidimensionales Bewegungsprogramm, Breitensport

Highlights

Bewegungsprogramme mit Breitensport:

- verbessern motorische Fähigkeiten und
- erreichen viele Männer ab 60 Jahren

Einleitung

Regelmäßige körperliche Aktivität und Sport tragen zum Erhalt der Gesundheit sowie der Selbstständigkeit im Alltag älterer Erwachsener bei [1]. Laut einer Studie der WHO erfüllen dennoch nur rund 40% der über 65-Jährigen in Deutschland die WHO-Bewegungsempfehlungen (mind. 150 Min./Woche moderate oder 75 Min./Woche intensive aerobe körperliche Aktivität sowie 2-3 Einheiten muskelkräftigende körperliche Aktivitäten und Gleichgewichtsübungen) [2]. Breitensportarten wie Tanzen, Tai-Chi oder Nordic Walking haben sich dabei als besonders effektive Bewegungsangebote zur Förderung der motorischen Fähigkeiten erwiesen [1]. Bisherige Studien fokussieren sich meist auf Interventionsmaßnahmen für chronisch kranke ältere Erwachsene oder bereits sportlich Aktive. In der vorliegenden Arbeit werden Trainingseffekte eines multidimensionalen Bewegungsprogramms mit Integration von Breitensportarten anhand geschlechts- und altersspezifischer Faktoren von sportlich inaktiven aber gesunden Seniorinnen und Senioren im Alter 60+ untersucht.

Methoden

Insgesamt nahmen 152 gesunde, aber sportlich inaktive Seniorinnen und Senioren (Alter 68,31 ± 4,38 Jahre; m = 51, w = 101) mit einer regelmäßigen Beteiligung von ≥ 75% an dem 24-wöchigem Bewegungsprogramm teil. Senioren mit bestehender sportlicher Aktivität sowie Personen mit gesundheitlichen Einschränkungen, wie sehr starken Funktionsstörungen, akutem Schlaganfall oder Herzinfarkt, wurden von der Studie ausgeschlossen. Das Bewegungskonzept für Neu- bzw. Wiedereinsteiger in den Sport mit zwei Sporteinheiten à 90 Minuten pro Woche unterteilte sich in eine Fitnesseinheit sowie eine „Schnupperstunde“, in der Breitensportangebote wie z.B. Kegeln, Karate oder Ballsportarten von lokalen (Sport-)Vereinen altersgerecht umgesetzt wurden. Zur Messung der motorischen Fähigkeiten Kraft, Beweglichkeit und Koordination (Reaktion sowie Gleichgewicht) kamen standardisierte Testverfahren an drei Messzeitpunkten (t0 = vor Intervention; t1 = nach 12 Wochen Intervention; t2 = nach 24 Wochen Intervention) zum Einsatz: Handdynamometer (HDM), 30-Seconds-Chair-Stand-Test (30CST), Sit-and-reach-Test (SRT), Fallstabtest und Gleichgewichtstest (GGT). Die Daten wurden anhand einer mehrfaktoriellen ANOVA mit Messwiederholung unter Berücksichtigung der Zwischensubjektfaktoren Geschlecht und Alter analysiert. Die Stichprobe wurde in die Altersgruppen AG1 (60-64 Jahre; n = 28), AG2 (65-69 Jahre; n = 67), AG3 (70-74 Jahre; n = 42) und AG4 (75-79 Jahre; n = 15) unterteilt.

Ergebnisse

Das vielfältige Bewegungsprogramm konnte bei den Teilnehmern eine signifikante Leistungssteigerung bei der Kraftfähigkeit der unteren Extremitäten (*30CST:* $F(2, 288) = 43{,}094$; $p < {,}001$; $\eta^2 = {,}230$), der Beweglichkeit (*SRT:* $F(2, 288) = 17{,}47$; $p < {,}001$; $\eta^2 = {,}108$) und dem Gleichgewicht (GGT: $F(2, 288) = 39{,}461$; $p < {,}001$; $\eta^2 =$

Tab. 1. Veränderungen der motorischen Fähigkeiten durch das Bewegungsprogramm zu Messzeitpunkten t0-t2

Messzeitpunkt / **Testverfahren**	**t0** M ± SD	**t1** (nach 12 Wochen) M ± SD	**t2** (nach 24 Wochen) M ± SD
HDM [kg] ↑	29,81 ± 8,64	29,71 ± 8,58	28,63 ± 8,29
30CST [n] ↑	16,84 ± 4,32	18,57 ± 5,1	19,53 ± 4,87
SRT [cm] ↑	-4,67 ± 11,33	-2,6 ± 10,79	-2,3 ± 10,1
Fallstabtest [cm] ↓	18,78 ± 7,7	17,92 ± 7,13	17,14 ± 6,67
GGT [Punkte] ↑	6,13 ± 3,06	7,8 ± 3,3	8,31 ± 3,36

M Mittelwert, **SD** Standardabweichung, **n** Anzahl an Wiederholungen, ↑ und ↓ zeigen an, ob ein hoher oder niedriger Wert optimal ist, max. Punkte des GGT = 14

,215) erzielen. Die motorische Reaktionsfähigkeit hat sich zwar verbessert, konnte aber nicht signifikant nachgewiesen werden (*Fallstab*: F (2, 288) = ,926; p =,397; η^2 = ,006). Lediglich die maximale Greifkraft der Hände konnte sich nicht verbessern und hat sich signifikant leicht verschlechtert (HDM: F (1,503, 216,438) = 5,762, p =,008; η^2 = ,038) (s. Tab. 1).

Signifikante Verbesserungen zeigten sich bereits nach 12 Wochen Intervention zum Zeitpunkt t1, die zum Zeitpunkt t2 teilweise noch weiterhin gesteigert werden konnten (30CST: t0-t1 p <,001; t1-t2 p = ,011 / SRT: t0-t1 p <,001; t1-t2 p = ,256 / GGT: t0-t1 p <,001; t1-t2 p = ,096).

Bei genauerer Betrachtung der Ergebnisse ließen sich faktorabhängige Unterschiede nachweisen: Ein Nachlassen der maximalen Handkraft über die Zeit war nur bei den Männern signifikant nachzuweisen (p<,001). Bei den Frauen blieben die Leistungen über sechs Monate konstant. Die Bonferroni-Korrektur wies allerdings eine signifikant höhere Maximalkraft der Hände (p <,001) der Männer gegenüber den Frauen auf ($\boldsymbol{M_{Diff}}$ = 13,58; 95%-CI [11.78, 15.37]).

Auch bei der Beweglichkeit des unteren Rumpfes zeigten sich Unterschiede zwischen den Geschlechtern. Die Frauen sind insgesamt beweglicher als die Männer ($\boldsymbol{M_{Diff}}$ = 9,99; p < ,001; 95%-CI [6.52, 13.27]). Dabei wirkte sich das Training vor allem positiv auf die Flexibilität der Teilnehmer aus den höheren Altersgruppen AG3 (Männer t0-t2: $\boldsymbol{M_{Diff}}$ = -5,933; p < ,002; 95%-CI [-9.97, -1,89]) und AG4 (Frauen t0-t2: $\boldsymbol{M_{Diff}}$ = -7,143; p < ,012; 95%-CI [-13.062, -1.224]) aus.

Bezüglich der Beinkraft ergab sich ein Innersubjekteffekt der Altersgruppe*Messzeitpunkt F (6, 288) = 3,78, p =,003; η^2 = ,073, da sich die AG4 im Gegensatz zu den anderen Altersgruppen hinsichtlich ihrer Kraft nicht über die Zeit verbessern konnte. Beim GGT zeigten sich zwar keine Innersubjekteffekte (p>,05), allerdings ein Zwischensubjekteffekt des Faktors Altersgruppe, da sich die AG1 mit ihrer stärkeren Leistung von den anderen Altersgruppen unterschied.

Diskussion

Das multidimensionale Bewegungsprogramm wirkte sich zwar grundlegend positiv auf die motorischen Fähigkeiten der gesunden und sportlich inaktiven Seniorinnen und Senioren aus, dennoch könnten physiologische Unterschiede zwischen den Geschlechtern sowie der unterschiedlich schnelle Abbau der motorischen Fähigkeiten im Zuge des Alterungsprozesses die ungleichmäßigen Veränderungen des Trainings erklären [3].

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Auswirkungen einer Tanzintervention auf körperliche Fitness und Balance bei älteren Erwachsenen mit leichter kognitiver Störung

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Keywords

Sport, Health, Geriatrics, Physical fitness, Gait and postural control

Highlight

- Die sechs-monatige Tanzintervention führte zu einem signifikanten Anstieg der VO_{2max} bei älteren Erwachsenen

Einleitung

Die Erhaltung der körperlichen und kognitiven Fitness ist ein essenzieller Bestandteil erfolgreichen Alterns [1]. Physisch inaktive, ältere Erwachsene sind gebrechlicher und tragen ein erhöhtes Risiko für kardiovaskuläre Erkrankungen, kognitive Einschränkungen oder auch Stürze [2, 3], welche oft mit Hospitalisierung einhergehen und dadurch Gesundheitssysteme weltweit belasten. Verschiedene Bewegungsinterventionen können diesen Problemen entgegenwirken [4]. Aktuelle Forschungsergebnisse weisen vermehrt auf positive Effekte von Tanzinterventionen hin [5, 6]. Ältere Erwachsene mit einer leichten kognitiven Störung (engl.: MCI [mild cognitive impairment], die als Vorstufe zu Demenz erachtet wird [7], sind typischerweise von reduzierter körperlicher Leistungsfähigkeit sowie verringerter Balance betroffen [8]. Bisher wurden nur wenige Studien veröffentlicht, welche die Effekte von Tanztraining bei älteren Erwachsenen mit MCI untersucht haben. Ziel dieser Studie ist es, die Effektivität einer sechs-monatigen Tanzintervention für diese Zielgruppe zu evaluieren: es wird davon ausgegangen, dass die Tanzintervention einen positiven Einfluss auf die körperliche Leistungsfähigkeit und Balance bei älteren Erwachsenen mit MCI haben wird.

Methodik

Insgesamt 55 Teilnehmer*innen wurden randomisiert und entweder einer Interventionsgruppe, die zweimal wöchentlich 90 Minuten Tanztraining absolvierte, oder einer Kontrollgruppe zugeordnet. Der Fokus des Tanztrainings lag auf dem kontinuierlichen Lernen neuer Bewegungsmuster mit einer durchschnittlichen Belastungsintensität von 64.32% der maximalen Herzfrequenz. Vor und nach der sechs-monatigen Tanzintervention wurden folgende Messungen zur Überprüfung der körperlichen Fitness durchgeführt: Spiroergometrie, Messung der Handgriffkraft, Sit-to-Stand Test (5x) sowie Messungen der Herzfrequenzvariabilität. Mithilfe des Neurocom Smart Balance Master® wurde die dynamische Balance (Limits of Stability) und die statische Balance (Sensory Organization Test) gemessen. Im Rahmen der statistischen Auswertung wurde eine gemischte Varianzanalyse (Zeit x Gruppe) mit einem Signifikanzlevel von α = 5% durchgeführt.

Ergebnisse

Die gemischte Varianzanalyse zeigte nach der Intervention eine signifikante Verbesserung der kardiorespiratorischen Fitness (VO_{2max}) in der Interventionsgruppe im Vergleich zur Kontrollgruppe ($p = .045$) (Tabelle 1). Außerdem konnte bei der Leistung während des Sit-to-Stand Tests ein positiver Trend beobachtet werden ($p = 0.88$). Weitere Parameter der körperlichen Fitness sowie der Balancefähigkeit wiesen nach der Intervention jedoch keine signifikanten Veränderungen ($p > .05$) oder positiven Trends ($p > .100$) auf.

Tabelle 1: *Mittelwerte, Standardabweichungen und Ergebnisse der ANOVA für die VO_{2max} in beiden Gruppen. * kennzeichnet Signifikanz*

	KG	IG
VO_{2max} Prä (ml/min/kg)	26.47±6.51	25.45±5.99
VO_{2max} Post (ml/min/kg)	24.40±5.97	26.00±6.98
F	4.326	
p	**.045***	
η^2_p	.110	

Diskussion

Die Ergebnisse dieser Studie können den positiven Einfluss des Tanztrainings bei älteren Erwachsenen mit MCI, den die Literatur aufzeigt [5, 6], teilweise unterstützen. Die Verbesserung der VO_{2max} sowie der positive Trend zur Verbesserung beim Sit-to-Stand Test stehen im Einklang mit der Literatur und können durch eine adäquate Belastungsintensität zur Verbesserung der Lungenkapazität und der funktionalen Fitness der unteren Extremitäten begründet werden [9, 10]. Während nur bei der VO_{2max} ein statistisch signifikanter Effekt der Intervention nachgewiesen werden konnte, zeigten andere Parameter positive Trends oder Leistungsstabilisierungen, was in Hinblick auf erfolgreiches Altern dennoch als wichtig erachtet wird, da somit altersbedingten Rückgängen der körperlichen Leistungsfähigkeit entgegengewirkt werden kann [11]. Mögliche Ursachen für die geringen Effekte, zum Beispiel in Bezug auf die Balancefähigkeit, könnten in der fehlenden Spezifität des Tanztrainings liegen. Ein weiteres Problem stellte die fehlende Kontrolle über die Kontrollgruppe dar. Diese führte zwar kein Tanztraining durch, wurde aber angewiesen, ihren üblichen sportlichen Aktivitäten nachzugehen. In zukünftigen Arbeiten sollte der Einfluss des Tanztrainings auf die Kognition bewertet und mögliche Zusammenhänge zwischen körperlicher Fitness und kognitiver Leistung untersucht werden. Dadurch könnte ein gesamtheitlicheres Bild über den Nutzen von Tanztraining für ältere Erwachsene mit MCI entstehen. Letztendlich könnte dies zu einer erhöhten Akzeptanz von tänzerischen Sportangeboten bei älteren Erwachsenen mit MCI führen und Krankenversicherungen könnten angehalten werden, mehr finanzielle Mittel für Sportangebote zur Demenzprävention bereitzustellen.

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Feasibility and effectiveness of serious games in motor training for people with dementia

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Keywords

Health, Motor skills and abilities, Clinical research, Dementia, Serious Games

Highlights

- Serious games can be used for different degrees of dementia & enable individualization
- Potential improvement of motor skills

Introduction

The global prevalence of dementia is increasing rapidly, posing significant challenges to healthcare systems. While traditional pharmacological approaches to treating dementia alleviate symptoms, they often cause side effects and do not provide a cure [1]. Non-pharmacological therapies, particularly physical activity and cognitive interventions, have the potential to improve motor and cognitive functions as well as the quality of life for individuals with dementia [1]. However, these programs frequently require substantial resources and are difficult to implement in practice. Technology-based approaches, such as "serious games," offer a promising alternative [2, 3]. These games, also known as "exergames," combine physical activity with cognitive challenges and allow for individualized training. However, previous studies have shown considerable variability in their methodologies, sample sizes, and outcomes, and there is a lack of standardized protocols for the design and application of these games [4]. The aim of this study was, therefore, to investigate the feasibility of specially developed serious games for people with mild to moderate dementia and to assess their impact on motor skills, with a particular focus on balance, mobility and risk of falling.

Methods

In the ten-week pilot study, specifically designed serious games under the name “KoKoFIT" were used to train the motor skills of individuals with dementia. A total of 21 participants with dementia (83.95 ± 4.6 years) took part in the study. KoKoFIT comprises five games that are played on a force measurement platform, with control achieved through shifts in the center of gravity (COG). This enables players to improve their balance while simultaneously training their cognitive abilities. The following games were utilized:

1. **Music-Game (MG)**: Players must uncover hidden images by shifting their COG in various directions. The goal is to recognize the image as quickly as possible while music plays to encourage movement.
2. **Balance-Ball (BB)**: A coordination game in which players tilt a virtual table to move a metal ball and collect various objects. The game has three levels and challenges players to maintain their balance to achieve the goal.
3. **Forest-Walk (FW)**: In this game, players control a human figure walking through a virtual forest while collecting objects, such as pictures of family members. The game includes realistic background sounds, such as birdsong, to create a more immersive experience.

4. **PickIT (PIT)**: A cognitive game in which players must match either a picture or a word. They select the correct picture or word by shifting their COG accordingly.
5. **Surflex (SU)**: A coordination game where players collect beach balls and earn points. Colliding with obstacles results in point deductions. In addition to coordination, cognitive skills are tested through a quiz in which players must recall words or numbers that briefly appear during the game.

All games were played three times a week for approximately 20 minutes in seven nursing homes (total: 600 min). To evaluate the effectiveness of the interventions, motor assessments were conducted. Various stances (a two-leg stance with eyes open (TLEO)/closed (TLEC), semi-tandem stance left (STL)/right (STR), and the Functional Reach Test (FRT)) were performed on a PLUX force plate, along with the Timed Up and Go Test (TUG) and the Falls Efficacy Scale (FES-I). Feasibility and acceptability were assessed through participation rates and participant feedback (Feedback form and Observation protocol). For the statistical analysis of the intervention's effects, the Wilcoxon test was applied. Additionally, to enhance individualization, the Spearman correlation was used to examine which games were best suited for different levels of dementia. This was done by calculating the correlation between the playtime of each game and the Mini-Mental State Examination (MMSE) score.

Results

The results of the study demonstrated a significant improvement in dynamic balance (FRT) ($p < .001$), while no significant changes were observed in the other tests (*TUG* $p=.498$; *FES-I* $p=.218$; *TLEO* $p=.259$; *TLEC* $p=.370$; *STL* $p=.748$; *STR* $p=.627$). Descriptive improvements were noted in the Timed-Up-and-Go test and in fear of falling (FES-I), although these were not statistically significant. The feasibility and acceptability of these games were supported by the high participation rate (85%) and positive feedback from the participants. In terms of playing time, the BB game was played the longest (approx. 157 min), followed by MG (approx. 143 min), PIT (approx. 117 min) and SU (approx. 101 min). FW was played the least (approx. 82 min). Additionally, it was found that individuals with mild dementia tended to play more complex games (e.g., BB ($r=0.88$; $p<0.001$) and SU ($r=0.479$; $p=.023$)), while individuals with moderate dementia preferred simpler games (MG ($r=-0.344$; $p=.143$), PickIT ($r=-0.549$; $p=.08$) and FW ($r=-0.569$; $p=.042$)).

Discussion

The study confirms the feasibility and acceptability of specially designed serious games for individuals with dementia. Participants demonstrated a high willingness to engage and enjoyed playing, with preferences for different games varying according to the severity of dementia. Additionally, a significant improvement in dynamic balance was observed, along with descriptive improvements in the TUG and FES-I. The results suggest that serious games can be valuable to dementia care. Future studies should consider longer intervention periods and personalized game development based on the insights from this study to achieve greater motor benefits [4].

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Symposium:

Virtual Reality in Action: Advancements in Motor Control, Learning, and Training

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Despite its long-standing history, virtual reality (VR) has emerged as a rapidly growing field in both research and applied sports and health settings. In the domain of human movement science, VR not only allows for the recreation of real experiences in a virtual environment but also enables the creation of new scenarios for both basic and applied research. This ranges from highly controlled experimental setups to virtual assessment tools and enhancements in the learning and coaching of motor actions. The aim of the symposium is to discuss how VR influences research in motor control, motor learning and training by highlighting the latest VR research in these areas. Specifically, we will address (1) the potential of VR to initiate and enhance motor learning, drawing on a systematic review conducted on motor learning in the context of VR; (2) the use of VR for assessing motor behavior, introducing a newly developed battery for motor testing in VR; (3)/(4) VR as a tool for experimentally investigating aspects of motor control and training, such as neurophysiological changes during dual-task walking and full-body hysteresis as a motor planning principle, and finally (5) a discussion of several studies on perception and action that highlight potential pitfalls when using immersive VR. The symposium will conclude with a discussion on the advantages and disadvantages, as well as the potentials and challenges of VR in the study of human movement.

The impact of Virtual Reality on motor skill learning in sports: A systematic review

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Keywords

Motor learning, Virtual Reality, Extended Reality, Motor skills, Skill Acquisition, Immersive Training

Highlights

- VR can improve motor outcomes
- VR is effective across skill levels
- VR enables innovative motor learning

Introduction

Recent advancements in immersive virtual reality (VR) have introduced innovative methods for enhancing motor skill acquisition [1,2], yet the extent to which VR supports motor learning in sports contexts effectively has yet to be fully established. This seems particularly important as studies to date yield different results regarding the impact that VR may or may not have on motor learning. While existing studies have explored this topic, their results vary widely [3,4], leaving it uncertain whether VR is beneficial for motor learning and if so, what specific factors may influence its effectiveness.

Objective

To bridge this gap, the present study aimed to systematically review the existing literature on VR interventions in sports, specifically focusing on the effects of VR on motor learning outcomes. In particular, it seeks to answer which specific technological, methodological, and participant-related factors benefit or limit motor learning in VR across sports.

Methods

A systematic review was conducted following the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) guidelines (Page et al., 2021). An electronic search was performed in January and February 2024 using IEEE, Psychinfo, PubMed, and Web of Science databases, combining keywords related to virtual reality, motor learning, and sports as well as their relations. We coded specific aspects relating to the categories of participant demographics, methods and procedures, outcome measures, control variables, and statistical results.

Results

The initial search yielded 1509 articles, from which 33 studies met the inclusion criteria for this systematic review. Studies included were published between 2011 and 2023. Most studies demonstrated that VR training could effectively enhance motor learning in sports, with consistent improvements noted from pre- to post-test across motor skills. The review shows that VR technology can significantly enhance motor learning across a wide range of sports, especially in tasks requiring precision and controlled movements such as golf or dart-throwing. When compared to no training, VR consistently demonstrated substantial benefits, with long-term retention in several studies. In comparison to traditional training, VR showed potential for improving certain motor skills, though it did not always outperform conventional methods, especially in precision sports. VR was effective across all skill levels, supporting learning in beginners and refining techniques in more advanced athletes. Limited evidence exists on how prior VR familiarity influences training effectiveness. While most studies used head-mounted displays and interactive

VR environments, often supplemented with motion capture, subjective immersion remains underexplored to date. Furthermore, the review revealed that VR enables innovative learning paradigms, allowing precise feedback, focused attention or safe simulation of dangerous contexts that traditional settings may not easily provide.

Conclusions

The findings of this systematic review indicate that immersive VR can support motor learning in sports, particularly by enhancing specific technical skills. However, VR is currently less suitable for dynamic and complex game situations and should primarily be used as a supplement to traditional training methods. Future VR training programs should more fully consider long-term effects and the specific requirements of different sports and experience levels.

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Reliability of a Sport-Motor Test Battery in Virtual Reality

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Keywords

Virtual / Augmented Reality, Motor skills and abilities, Sensorimotor performance, Reaction times, Jumping ability

Highlights

- VR extends existing test procedures in sports performances
- VR serves as a reliable method for testing reaction times and jump heights

Introduction

Athletic performance depends on core motor skills and abilities, such as reaction time, coordination and explosive strengths. Traditional sport-motor assessments aim to evaluate these abilities, yet isolating any single skill remains challenging because athletic movements typically involve complex, multi-joint, and multi-muscle actions. Moreover, these conventional tests often require significant resources, including manual input, and frequently lack automation, making widespread application difficult. Virtual Reality (VR) offers a compelling alternative by enabling the simulation of sport-specific scenarios while automating evaluations and data collection. However, most existing VR tools primarily focus on recovery and skill acquisition [1], with limited emphasis on comprehensive motor skill assessment. This study aims to address this gap by introducing a VR-based test battery specifically designed to measure key performance metrics such as reaction time and jump height. A preliminary step is to validate the reliability and accuracy of data collected through VR assessments, ensuring it is consistent and comparable to data obtained from traditional testing methods.

Methods

A total of 32 participants (mean age 24.2 ± 4.3 years) completed two tests: the drop-bar test (DT), which measures reaction time, and the jump and reach test (JT), which evaluates jumping ability. Each test was conducted twice (pre- and posttest) as illustrated in Fig. 1.

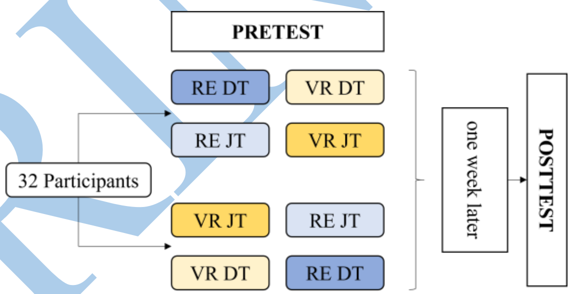

Figure 1: *Overview of the study design: RE refers to the real environment, while VR denotes virtual reality. DT represents the drop-bar test, and JT stands for the Jump and Reach test.*

Both tests were recreated in VR using Unity, with custom functionalities implemented via self-written C# scripts. Participants wore the HTC VIVE Pro Eye headset to visually perceive the virtual environment. The DT was slightly improved by adding outcome parameters such as reaction time, movement time and the resulting response time (see Fig. 2), whereas in real environments (RE), only response time could be measured. For the JT, minimal visual stimuli were added in VR, while task instructions remained consistent with the official test protocol. Participants' absolute jump height was calculated by subtracting the baseline captured by the controller from the maximum jump height (see Fig. 2). Significant outliers were carefully examined by using the robust median-absolute deviation score, and the prerequisites for the statistical test procedures were verified.

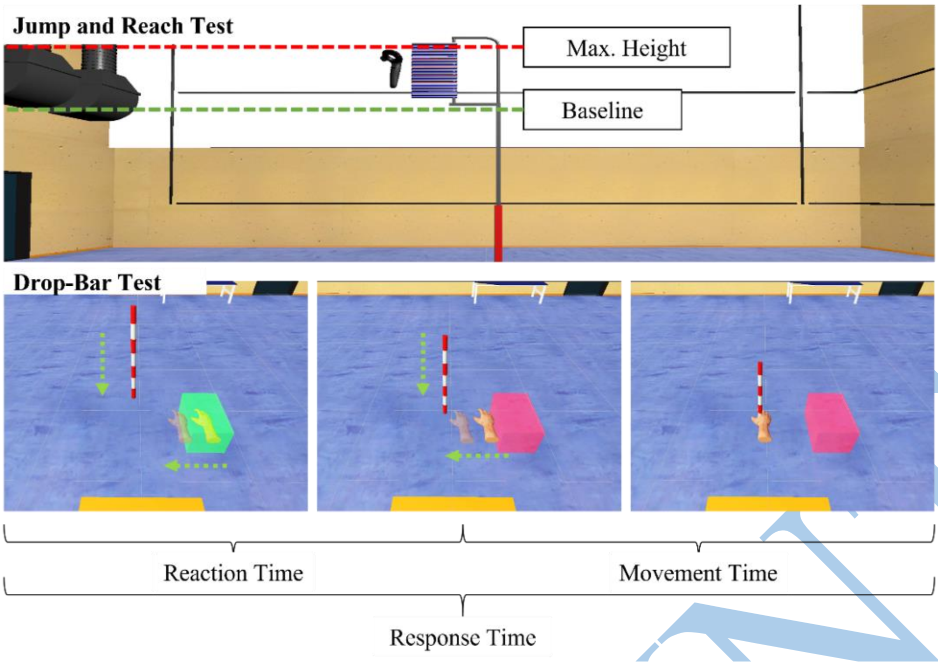

***Figure 2:** Overview of the parameters' determined of the Drop-Bar and Jump and Reach test. The controller was used to measure each participant's reach height and maximum jump height. The lower row shows the timing, capturing the interval from the moment the hand left the starting position until it made contact with the bar.*

Before starting the comparisons between RE and VR, each test was assessed for reliability between the pre- and post-test to identify any potential learning effects inherent to the test. Therefore, the intraclass correction coefficient (ICC) was used to determine the test-retest reliability. Correlations of DT performances between RE and VR assess if faster response time in RE correspond to similar behavior in VR. In JT, a 2x2 ANOVA with repeated measurements evaluates significant differences over time and condition.

Results

Strong ICCs were observed for response times in RE (0.858) during the DT, while the VR condition demonstrated excellent reliability (0.946). In the JT, an excellent ICC was identified for the absolute heights in RE (0.944), along with a high ICC for the VR condition (0.886). Overall, both tests exhibited good to excellent ICCs [2], highlighting their reliability across conditions. Moderate significant correlations were found between response time in DT for RE and VR (r = 0.431). In JT, no significant difference were observed between the conditions ($F(1, 24) = 0.615$, $p = .440$, partial $\eta^2 = .025$, Wilks-Lambda: .975).

Discussion

In this study, multiple tests were rebuilt in VR, based on existing real-world tests and enhanced to address their limitations. The ICCs indicate promising results regarding test reliability for both tests, and the correlations between the response time in RE and VR, as well as the analysis of differences, revealed high valid data. However, factors such as the practicality and accessibility of the VR device (which could potentially be replaced by other alternatives like stand-alone devices) should also be evaluated to draw further conclusions about the usability of this VR-based sports-motor test battery. Expanding the test battery to encompass more complex abilities, such as parkour running with virtual opponents, could further highlight VR's potential in this field, including its capacity for robust data curation.

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Training-induced changes in brain activation during dual-task walking in virtual reality in healthy older adults

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Keywords

Motor cognition, Virtual / Augmented Reality, Gait and postural control, Activities of daily living, Neuroplasticity

Highlights

- Training induced reduction in brain activation during dual-task walking
- Cognitive training seems most effective

Introduction

Walking is a fundamental daily activity that is controlled by various brain regions, including frontal and parietal areas. Neural efficiency of gait control decreases with age, and in particular for dual-task (DT) walking, e.g., when talking or typing while walking [1]. Cognitive (COG), motor (MOT), and combined cognitive-motor (CMT, multitasking) training have been shown to counteract neural decline in older adults, improving neural processing for various motor and cognitive functions [2]. COG enhances brain function mainly in frontal regions, while MOT can restore movement automaticity, typically affecting both frontal and parietal areas differentially. CMT combines both COG and MOT and is discussed to provide cumulative neural benefits and improve task coordination during DT.

Each training type, COG, MOT, and CMT, may offer distinct advantages for DT walking by supporting specific neural aspects of cognition and motor functions involved in gait control. However, previous studies on DT walking focused on (pre-)frontal areas mainly, potentially missing key neural mechanisms in other brain regions, such as the parietal cortex [3].

This study investigates the differential effects of COG, MOT, and CMT on brain activation in both frontal and parietal regions during single- (ST) and DT walking in virtual reality in older adults (VR) (see Figure 1).

Figure 1: *Virtual dual-task walking scenario*

Methods

A total of 106 healthy older adults participated in this study and performed three different tasks (treadmill walking at 1 m/s (W), Stroop task (STR), and Serial 3's task (S3)) under ST and DT (i.e., Walking + Stroop and Walking + Serial 3's) conditions and a baseline standing task. Functional near-infrared spectroscopy (fNIRS) was used to measure brain activity (HbO_2) over the prefrontal cortex (PFC) and parietal cortex (PC) during task performance. After pre-test, participants were assigned randomly to either COG, MOT or CMT. Each group trained for 12 weeks, 2 x 45-minutes per week.

Linear mixed models were utilized to analyze the effects of Time (pre, post) x Group (COG, MOT, CMT) x Condition (ST_STR/S3, ST_W, DT_STR/S3) on HbO_2 in PFC and PC (controlled for Age and Sex). Planned post-hoc contrasts evaluated task-specific changes per group.

Results

For the Stroop task, there was no main effect of Time and no interaction of Time x Group, neither for PFC nor PC. However, a significant interaction of Time x Group x Condition was observed. COG demonstrated reduced activation at post-test in both the PFC and PC for DT (Figure 2), but not for the two STs. CMT exhibited decreased activation at post-test during DT but only in the PFC, with likewise no changes during STs. MOT showed no task-specific changes in activation from pre- to post-intervention, neither in PFC nor PC. For the Serial 3's task, no significant changes in activation from pre- to post-test were found in the PFC or PC across intervention groups, neither for ST nor DT.

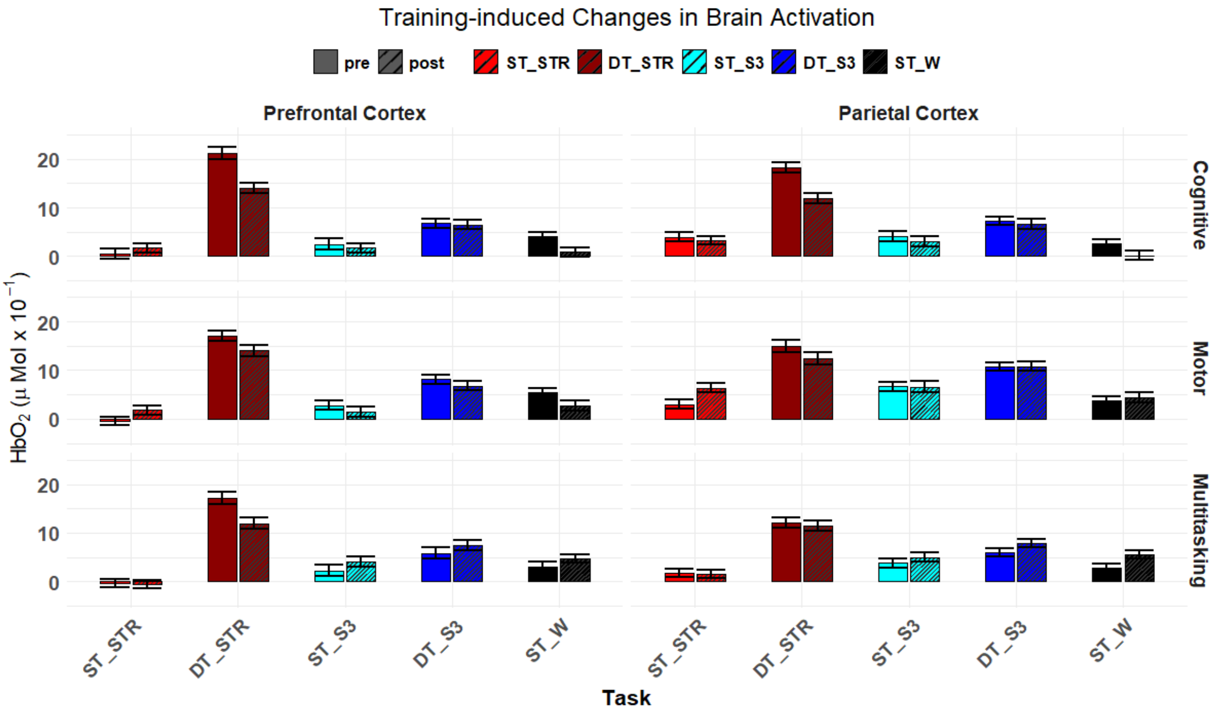

Figure 2: Brain activation during pre- and posttest for training groups and tasks.

Discussion

Our findings revealed intervention group-specific changes in PFC and PC during DT walking (Stroop only) in older adults. Reduced brain activation during DT in both the PFC and PC in COG may suggest a more widespread improvement in neural efficiency spanning frontal and parietal brain regions. In contrast, decreased activation in the PFC but not in the PC for CMT could indicate specific improvements in neural efficiency of task coordination during DT walking, which is associated mainly with frontal areas. MOT demonstrated the least impact with no changes in brain activation from pre- to post-test, which may be a result of limited effects on brain areas associated with higher order cognitive processing involved in DT walking. In summary, training interventions may be most effective for enhancing neural efficiency during DT walking when integrating cognitive exercises. Particular benefits for the Stroop task may further suggest improved visuomotor processing, a key component of both COG/CMT training and the demands of the Stroop task.

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Full body hysteresis in a virtual reality environment

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Keywords

Motor control, Virtual Reality, Gait and postural control, Motor hysteresis, Working Memory

Highlights

- First investigation of full body hysteresis
- Use of virtual reality to test if event segmentation theory applies to motor plans

Introduction

In a repetitive posture selection task like opening a column of drawers in an ordered sequence, people persist in their former arm postures. Rosenbaum & Jorgensen [1] state that this hysteresis effect results from the storage, modification, and reuse of a former motor plan. So far, posture hysteresis has only been demonstrated in arm movements. In the current study, we wanted to test if hysteresis is a general planning principle that also applies to full body movements.

Our second research question addressed how motor plans are stored in working memory (WM). Event segmentation theory [2] states that all sensory information is stored in WM as part of an event model (EV), which degrades after a model update. The model update can be induced by a location shift (i.e., moving from one room to another). If former motor plans for hysteresis are also stored as part of the EV, they should degrade as well, thus reducing the hysteresis effect.

To test both questions, participants performed a sequential full body hysteresis task in a virtual reality (VR) environment. As this was the first time that such a task was measured in VR, we also tested whether posture selection was similar to when performing the same task in a real environment.

Methods

Participants executed a sequential full body hysteresis task in a virtual environment. On each trial, they walked 6m from a starting position to a target position. At the halfway point, a horizontal bar was placed as an obstacle at different heights (see Figure 1A). The dimensions of the obstacle and bar heights were identical to those used in a reference task in the real environment.

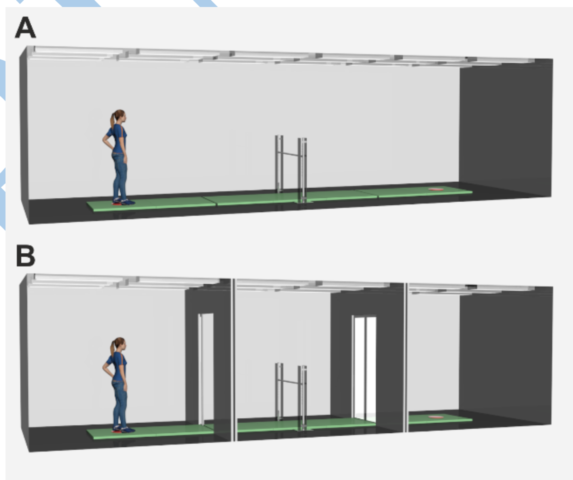

*Figure 1: Schematic of the experimental setup in **A** the single room condition **B** the three room condition*

Participants had to decide whether to step over or to duck under the bar. Bar height was varied in ordered (ascending or descending) sequences to induce hysteresis. Participants' decisions were recorded as the dependent variable. In condition A, participants executed the task in a single room of 9×3m. In condition B, space was subdivided into three 3×3m rooms which were separated by sliding doors (see Figure 1B). Participants started and ended their movement in a side room and crossed the obstacle in the central room.

The virtual environment was created in Unity, a Valve Index headset was used for the visualization. The presentation of trials and the recording of the results was controlled by the UXF toolbox

[3]. Binomial decision data was analyzed with a generalized linear mixed-effects model (GLMM) with a logit link function, with 'bar height', 'condition', and 'order' as fixed effects and 'participant ID' as a random effect.

Results

Preliminary data is presented from the reference experiment conducted with 14 participants in the real environment (data collection ongoing). The main effect of 'bar height' was significant, $z = +8.928$, $p < .001$, odds ratio (OR) = $2.378*10^7$, indicating that participants stepped over the bar for lower bar heights and ducked under the bar for higher bar heights (see Figure 2). More importantly, the main effect of 'order' was significant as well, $z = -2.732$, $p = .006$, OR = .251, indicating that the point-of-change between stepping over or ducking under the bar differed in the ascending (bar height 6.8) and the descending (bar height 7.0) sequence of heights.

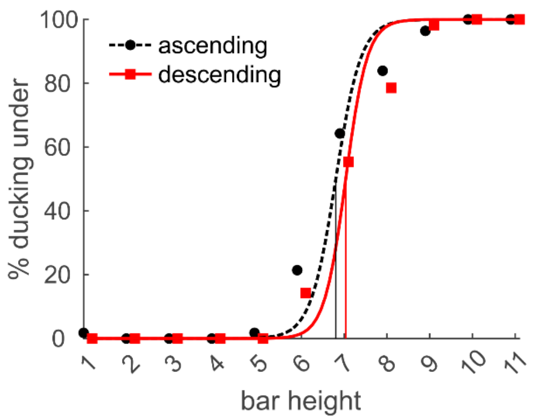

Figure 1: *Probability for ducking under the bar, plotted against bar height (11 height levels). Each data point corresponds to the average across all participants.*

Discussion

While preliminary data suggest a main effect of 'order' in the real environment, the question of whether full body hysteresis is present in a virtual environment and whether it degrades after a location shift cannot be answered until data collection in the virtual environment is completed. At the conference, the results of the VR experiment will be presented and compared to those of the real environment.

To compare the behavior in the real environment with that of the virtual one, a GLMM with fixed effects for 'bar height', 'condition' (virtual vs. real environment), and 'order' will be calculated on the decision data. If the real behavior is replicated in VR, we expect no effects of 'condition'. Since participants are unable to knock down the bar in VR, thus lacking an error feedback, one might expect a shift of the point-of-change to a higher value, which would result in a significant main effect of 'condition'.

To test if motor plans for hysteresis are stored as part of an EV and, thus, degrade after a location shift, a second GLMM with fixed effects for 'bar height', 'condition' (one room vs. three rooms), and 'order' will be calculated on the data from the VR experiment. If motor plans degrade, hysteresis should be reduced in the three-room condition, which would result in a significant interaction of 'condition' × 'order'.

If hysteresis effects were present in the real environment, this would prove that hysteresis also applies to full body posture selection, highlighting its importance as a planning principle. If findings were replicated in the virtual environment, it would demonstrate the feasibility of conducting hysteresis studies in VR and, thus, open up new lines of research that would be difficult to realize in a real environment. If hysteresis effects were reduced in the location switch condition, it would support the notion that not only sensory information, but also former motor plans are stored in WM as part of an EV. This would further support the hypothesis that hysteresis effects result from the reuse of a stored motor plan.

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Using Immersive Virtual Reality to Remotely Assess Upper Limb Motor Control

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Keywords

Health, Motor control, Virtual / Augmented Reality, Motor skills and abilities, Upper limbs

Highlights

- VR-based assessments offer a low-cost alternative for upper-limb function measurement.
- This study compares hand performance differences with VR.
- Findings support VR as a feasible, scalable tool for remote motor function assessments.

Introduction

Upper limb dysfunction, common post-stroke, impairs daily activities. Current functional outcome measures, while reliable, lack granularity and often fail to capture subtle motor control differences. Recent studies have had some success using kinematics for detailed movement data, yet conventional setups are costly and impractical in healthcare settings. Immersive virtual reality (VR), particularly using portable head-mounted displays like Meta Quest, offers a scalable, low-cost solution with integrated motion capture for accessible kinematic-based assessment of upper-limb function. This study validates a VR-based circle tracing task for remote data collection by comparing the kinematics of dominant and non-dominant hand movements in healthy individuals. This study lays the groundwork for clinical applications across a range of special populations with upper-limb dysfunction.

Methods

Due to the challenges of physical data collection during COVID-19, a VR-based circle tracing app, *Circle Tracer*, was developed to operate independently on the Meta Quest headset for remote data collection. This immersive virtual reality environment provided instructions, obtained consent, and captured hand movement data for assessing upper limb function. 47 participants, recruited globally, installed the Circle Tracer app on their Meta Quest headset, and used handheld controllers in the app to trace 16 circles with their dominant and non-dominant hand which were presented in a randomized order. Data which were returned through a remote server (37 complete datasets, recorded at ~70hz) were processed to yield kinematic measures of movement speed and circularity using standard filters and custom scripts.

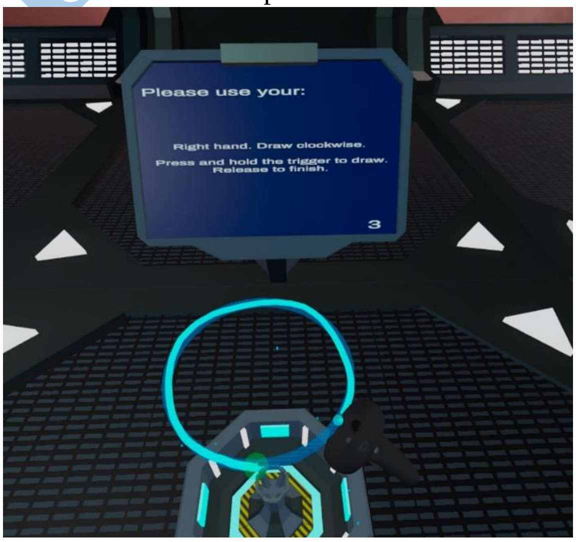

Figure 1: *The 'Circle Tracer' app, as viewed from the participant's perspective during one of the 32 trials. A video showing an example of a trial, can be found at* [*https://osf.io/zn3my/*](https://osf.io/zn3my/)

Results

The study's VR-based assessment tool successfully identified several kinematic differences between dominant and non-dominant hand movements in our pre-specified metrics in our pre-registered analyses (https://osf.io/zn3my/). While there was no significant difference in the size or roundness of circles drawn by each hand (Figure 2A), there were distinct temporal and spatial variations.

The dominant hand demonstrated more rapid performance, completing the tracing task in less time compared to the non-dominant hand ($T = 132.5$, $z = -3.30$, $p < 0.001$, $r = -0.53$) and with a higher mean velocity ($T = 536$, $z = 2.78$, $p = 0.005$, $r = 0.45$) than the non-dominant hand. Path length, however, showed only a marginal difference between hands, indicating that both hands followed a similar trajectory around the circle, although at different speeds.

The data showed no indication of differences in smoothness (jerk) between hands, nor did it find a significant variance in circle area size or roundness across hands. The dominant hand's faster movement time and higher mean velocity align with expectations of dominant limb efficiency but indicate that under self-paced conditions without strict timing constraints, the task may not be sensitive to all aspects of motor asymmetry.

Additional exploratory analysis examined movement stability along the vertical (Y) axis, where unsupported hand movements against gravity were analyzed. Here, the dominant hand displayed greater stability, moving a shorter distance in the Y-axis, which suggests better control. However, there were no differences in vertical speed and speed variability between hands, nor were there significant differences in mean jerk or acceleration.

All data and analysis scripts are available on the Open Science Framework (https://osf.io/zn3my/), and the data presented here have been published [1].

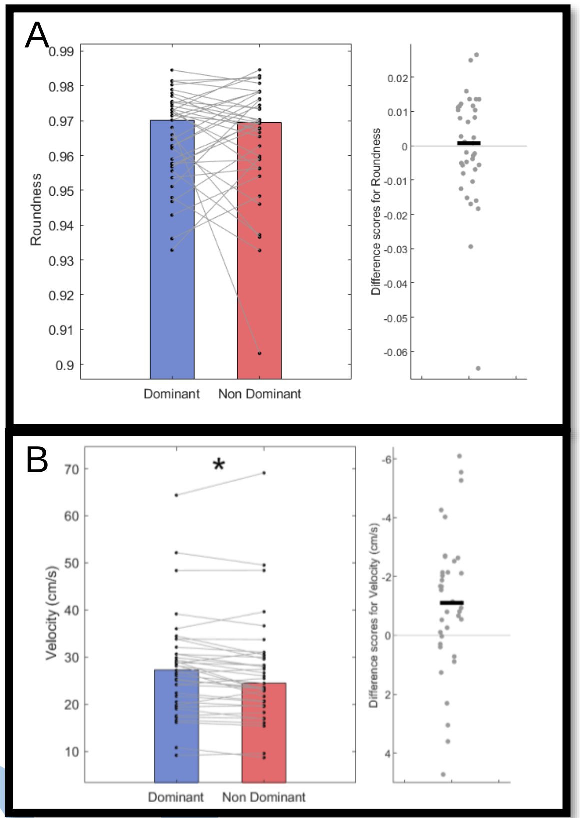

Figure 2. *When comparing drawing kinematics, both hands drew equally-round circles (A), but the dominant hand was faster than the non-dominant hand (B)*

Discussion

This study shows that VR-based remote assessments can detect small performance differences in upper limb function. These findings underscore the potential for VR tools to capture subtle motor performance metrics that may be missed by conventional assessments, supporting their future use in clinical applications to track motor recovery or diagnose impairments in adults and children [2]. Future work should quantify tracking accuracy relative marker-based motion tracking in a laboratory, and test-retest reliability of the application.

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Symposium:

Balance training in healthy older individuals: effects on brain and behavior

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Healthy and pathological aging is associated with a decline in postural control, and postural instability is closely linked to increased mortality and cognitive decline. At the same time, postural control training puts a lot of strain on the neuromuscular and central nervous system. The relationships found suggest that improved postural control might play an important role in healthy cognitive aging and brain aging. However, there is little evidence from intervention studies of a relationship between training-induced improvements in balance, cognition and the brain in older people. In this symposium we will present longitudinal results of balance training interventions with healthy older individuals (also in comparison to healthy younger individuals). We will focus on the effects of balance training over short (days to weeks for Nisha Prabhu et al.) and longer (several months for Sven Egger et al., Yves-Alain Kuhn et al., Lehmann et al.) time scales and the effects on brain structure and function as well as motor and cognitive performance. We will highlight associations between training-induced behavioral improvements and neural plasticity. Our goal is to raise awareness of the positive effects of balance training and possible effects on healthy cognitive aging and brain aging.

Response-optimized balance training in healthy older individuals: task-, transfer- and neural effects

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Keywords

Motor learning, Motor cognition, Neural correlates, Neuroplasticity, Aging

Highlights

- Optimized training interventions enable higher learning gains as well as create potential for motor transfer.

Introduction

Positive effects of exercise on overall wellbeing are evident across the lifespan. Unfortunately, in cases of older adults approaching varied degrees of physical and cognitive decline, devising effective interventions that extend uniform benefits remains a concern [1]. Here optimization of exercise induced benefits by means of matching the level of task difficulty to the individual's abilities is necessary [2]. Hence, we hypothesized that optimized training would induce higher learning gains and enhance transfer effects onto untrained motor and cognitive tasks. In addition, neural changes pertaining to these gains are hypothesized to simultaneously ensue.

Methods

We conducted a randomized, single-blinded, 5-week dynamic balance training (DBT) [3] intervention optimized to the participants individual balance performance [2] (n=60, age: 60-75 yrs). Balance performance was assessed using 6-different levels of task difficulty ranging from level 0 (highest) to level 5 (lowest) on a stabilometer. Based on their performance on these difficulty levels, training was formulated to emulate either optimal load condition (intervention, n=40) or suboptimal load condition (underload, based on pilot data) (control, n=20). The larger intervention sample was chosen to provide enough cases for within-group correlations with person characteristics (not included). Training intensity was maintained at the optimal/sub-optimal level by increasing or decreasing the intensity within training session (TD) based on participants' balance performance. Cognitive (d2-test of attention, Trail making test and Memory image completion test) and motor transfer (untrained variations of DBT and Wii balance) were investigated half-way through the training duration (mid) and after training (post). Near motor transfer tests included DBT at the highest untrained task difficulty, i.e., (i) while wearing a weight vest (10% body weight); (ii) increased distance between the rotating axis and the board. MRI scans of the entire brain (diffusion MRI) preceded every TD (one TD per week) and preliminary analyses involved time-point-specific comparisons.

Results

Over 5-weeks of training, on average both groups improved balance performance on the stabilometer. Repeated measures ANOVA revealed a main effect of time, $F(2, 16.9) = 133.1$, $p < .001$, $d > 1$; without an effect of group, $F(1, 20.78) = 1.62$, $p = .22$. However, the intervention group exhibited higher improvements as compared to the control group, time x group interaction, $F(2, 16.9) = 5.42$, $p = .02$, $d = 0.65$. On closer inspection it was observed that the intervention group had significantly higher gains at the highest difficulty level (time x group, $F(2, 19.25) = 5.015$, $p = .02$, $d = 0.62$) and the lowest difficulty level (time x group, $F(2, 18.1) = 4.47$, $p = .03$, $d = 0.59$).

Near motor transfer test results revealed higher performance gains for the intervention group at post-test, i.e., board position condition: intervention (85.4%) vs control (45.9%), $t(35.43) = 2.16$, $p = .03$, *Cliff's* $\delta = 0.33$ (medium) & weight vest condition: intervention (89.4%) vs control (32.4%), $t(40.11) = 2.97$, $p = .005$, *Cliff's* $\delta = 0.42$ (medium) (Brunner-Munzel tests). These between group differences were already seen after 3 training sessions (weight vest condition: intervention (62.5%) vs control (6.9%): $t\,(49.92) = 4.1$, $p < .001$, *Cliff's* $\delta = 0.53$ (large)). However, only a trend towards significance was observed for the board position condition at this point, intervention (54.3%) vs control (28.5%): $t\,(34.1) = 1.75$, $p = .08$, *Cliff's* $\delta = 0.27$ (small)). Similarly, there was a trend towards significance in the far transfer task (Wii balance) at the mid testing session, intervention (21.6%) vs control (5.6%): $t\,(44.87) = 1.88$, $p = .06$, *Cliff's* $\delta = 0.3$ (medium). This between group difference disappeared at post-test (intervention (35.5%) vs control (25.7%): $t\,(30.38) = 0.91$, $p = .37$, *Cliff's* $\delta = 0.15$ (small)). No significant between-group differences were observed in any of the cognitive transfer tasks.

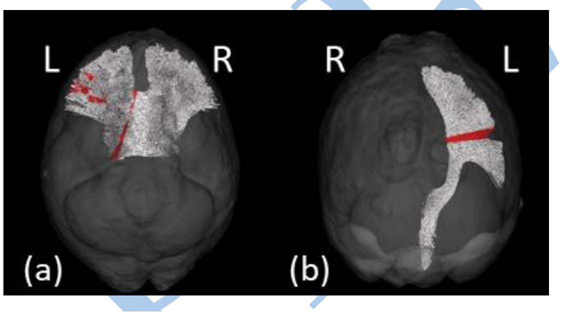

Figure 1: *Exemplary results from tract-based analyses of white matter showing NDI changes (pFWE < 0.05) in the (a) corpus callosum (genu) and (b) left corticospinal tract (CST) measured after one training session (significant segments marked in red).*

Preliminary diffusion MRI analyses (advanced biophysical model fitted to diffusion data [4]) revealed higher neurite density index (NDI) in the intervention group, reflecting an increased packing density of axons in the white matter (WM), compared to the control group. Some of these changes occurred as early as after just one training session (Figure 1). NDI changes were specific to motor learning-relevant tracts like the left corticospinal tract (post-test $pFWE < .05$), genu of the corpus callosum (fibers interconnecting left and right prefrontal cortices, TD4 $pFWE < .05$) and left superior longitudinal fasciculus (SLF-I, III TD2 and post-test $pFWE < .05$) [3, 5].

Discussion

Our results demonstrate higher task-related improvements and benefits on motor transfer through response-optimized balance training compared to suboptimal training. In addition, preliminary analyses of white matter changes suggest neurite-specific plasticity in tracts coinciding with cortical regions previously implicated in balance training. Results from this study display benefits of incorporating response-optimized training in the elderly not just in the trained balance task but also extending to untrained motor tasks.

Further analyses will be aimed at establishing a brain-behavior relationship based on the WM changes and improvements in DBT performance by means of statistical mediation analyses.

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Improved postural control in the elderly after long-term balance training is related to modulation in intracortical inhibition

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Keywords

Motor learning, Motor control, Neural correlates, intracortical inhibition, primary motor cortex

Highlights

- After 6 months of balance learning, intracortical inhibition can be upregulated in elderly subjects

Introduction

Aging is linked to a decline in GA-BAergic intracortical inhibition [1], which affects well-being, cognition, pain management, and motor control. Recent research indicates that impaired postural control is associated with age-related functional changes in the brain, such as a reduction in motor intracortical inhibition [2]. However, little is known about whether targeted interventions can reverse this decline in the primary motor cortex (M1). The present study [3] aimed to investigate whether balance learning (BL) can reverse age-related cortical disinhibition and if there is a connection between behavioral and brain adaptations.

Methods

Over 6 months, 17 healthy older adults (66–81 years) participated in a balance training program (BL group), performing 1-hour sessions twice weekly, while 13 participants served as a control group (CON group; see Figure 1). All participants were assessed at four time points over one year: baseline, 2 months, 6 months, and 12 months (follow-up). At each time point, balance performance was evaluated by measuring the center of pressure (CoP) during two 30-second trials on an unstable device (wobble board, see Figure 1). To assess the activity of inhibitory circuits within the primary motor cortex (M1), short-interval intracortical inhibition (SICI) was measured in the tibialis anterior muscle using transcranial magnetic stimulation (TMS). Forty stimulations were delivered, with conditioning stimulation at 70% of active motor threshold (aMT) and test stimulation at 120% of aMT, while participants balanced on the unstable device.

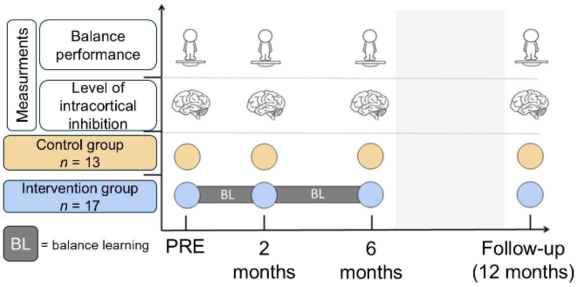

***Figure 1:** Shown is the experimental design. The participants were aged between 66 – 81 years. Seventeen of them (eight females) followed 1h of balance learning (BL) twice a week for 6 months (intervention group, represented by the blue dots) and thirteen of them (6 females) served as a control group (orange dots).*

Results

Behavioral analysis using a mixed-design two-way ANOVA revealed a significant interaction effect of group x time on balance performance (CoP while standing on the device) ($F_{3, 84}$ = 11.74, $p < 0.001$, $\eta^2 = 0.06$). Post hoc comparisons showed that the BL group significantly improved balance after 2 and 6 months, outperforming the CON group at all time points except baseline (all $p \leq 0.01$; see Figure 2A).

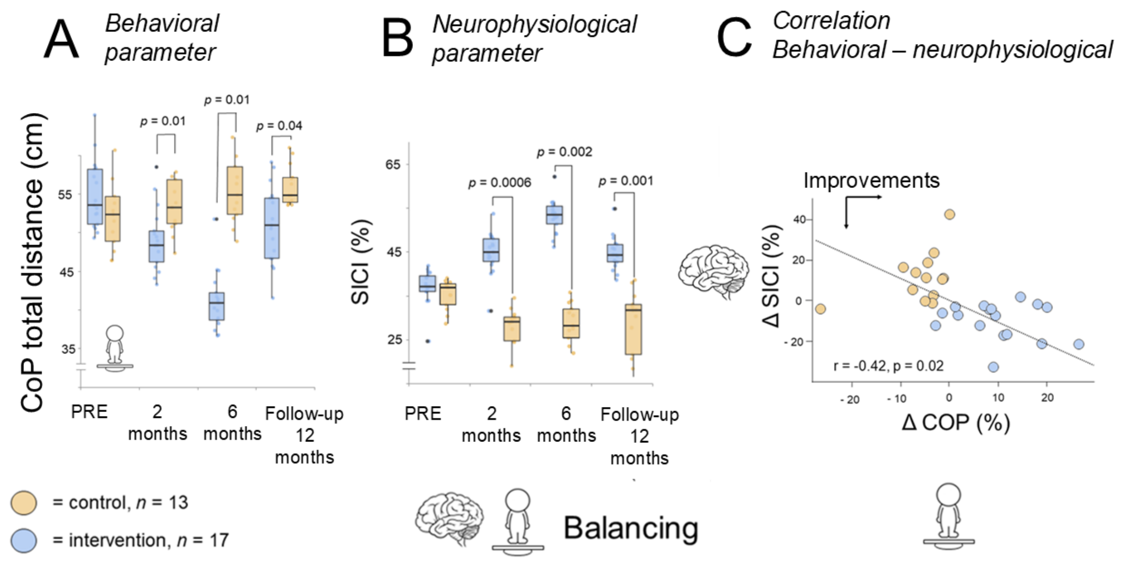

Figure 2: *Boxplots display individual values for control (blue, n=13) and intervention (orange, n=17) groups across four time points: PRE, 2 months, 6 months, and a 12-month follow-up. (A) Total COP displacement: Balance performance significantly improved in the intervention group after 2 and 6 months of training and remained enhanced after 6 months of de-training. No baseline differences were found. (B) SICI (%): The intervention group showed significantly greater intracortical inhibition than the control group at all time points, except baseline. (C) Correlation: A negative correlation (r = -0.42, p = 0.02) was observed between balance improvements and intracortical inhibition adaptations, indicating greater inhibition was associated with larger balance gains.*

Regarding intracortical inhibition, the mixed-design two-way ANOVA also revealed a significant interaction effect of group x time ($F_{2.16, 60.84} = 13.74$, $p < 0.001$, $\eta^2 = 0.13$). Post hoc comparisons showed that the BL group exhibited significantly enhanced inhibition after 2 and 6 months of training, with inhibition levels remaining elevated after 6 months of detraining (follow-up), compared to the CON group (all $p < 0.01$; see Figure 2B).

No significant changes over time were observed in the CON group for either behavioral or neurophysiological measures. A significant negative correlation between changes in balance performance and SICI modulation was found ($r = -0.42$, $p = 0.02$; see Figure 2C).

Discussion

This study shows that long-term balance training (BL) can upregulate intracortical inhibition in older adults, potentially reversing age-related declines in inhibitory neural function and restoring the balance between inhibitory and excitatory neurotransmitters. These changes are critical, as reduced inhibition is linked to impaired motor control and increased fall risk. The correlation between improved balance performance and increased short-interval intracortical inhibition (SICI) underscores the role of neural adaptations in enhancing postural control. This finding highlights the aging brain's plasticity and supports the use of targeted training to mitigate balance deficits. Future research should investigate the longevity of these effects and the mechanisms linking intracortical inhibition to balance improvements to optimize interventions for age-related motor decline.

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Brain microstructural changes after balance training in older adults: Novel insights based on quantitative MRI analysis

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Keywords

Aging, Motor learning, Gait and postural control, Methods, Neuroplasticity

Highlights

- We demonstrate behaviorally relevant structural neuroplasticity after 6 months of balance training in older adults.

Introduction

Given the high prevalence of fall accidents in older adults (OA), effective treatments to delay physical frailty and care dependency are urgently needed. While we have already learned much about the neural mechanisms involved in the aging process of the postural control system [1], the question of whether and to what extent these processes can be targeted by balance training (BAL) is less clear. One facet of aging is the atrophy of the brain, which is usually measured using magnetic resonance imaging (MRI). The majority of MRI studies investigating age-related changes in balance performance (including falls) and BAL-induced neuroplasticity focused on meso- and macroscopic brain shape (morphometry) [1,2]. Recent developments in the field of quantitative MRI (qMRI) allow a higher sensitivity and specificity compared to conventional morphometry and thus promise a better understanding of the changes induced by balance training in the distributed cortical and subcortical areas and their connecting fiber tracts [3,4]. We hypothesize that subjects receiving BAL show a different pattern of microstructural plasticity in balance-related brain areas than controls, which in turn correlates with improved balance performance.

Methods

A randomized controlled trial with healthy OA (n = 32, 50% ♀, 65-80y) was conducted to compare the effects of a 6-month individually tailored BAL intervention (n = 18; 1h of BAL twice weekly) against a non-BAL control group (CON, n = 14). Measurements of balance performance and qMRI were carried out at the beginning of the study, 2 months after baseline, 6 months after baseline (≙ end of training), and 12 months after baseline (≙ follow-up). The qMRI protocol consisted of a set of contrasts weighted towards diffusion, relaxation times, proton density, and magnetization transfer. Parameter maps sensitive to features such as tissue organization and density, myelin, and others [3,5] were derived from these data. We employed a region-of-interest (ROI) approach, which means that qMRI metrics were averaged within preselected subcortical and cortical brain areas (e.g., primary motor cortex [M1], premotor cortex [PMC], cerebellum, basal ganglia, thalamus, and others) and within segments of interconnecting fiber tracts. Linear mixed models (LMM) with random intercept were used to analyze longitudinal brain changes. Correlated change between brain microstructure and behavior (i.e., two trained and two untrained balance tests) was assessed by Pearson correlations. The resulting correlation coefficients were pooled based on the method proposed by Olkin and Pratt, and an aggregated p-value was calculated [6].

Results

The BAL group reduced the sway in both trained and untrained balance tasks significantly more than controls (group-by-time interaction $p < .05$),

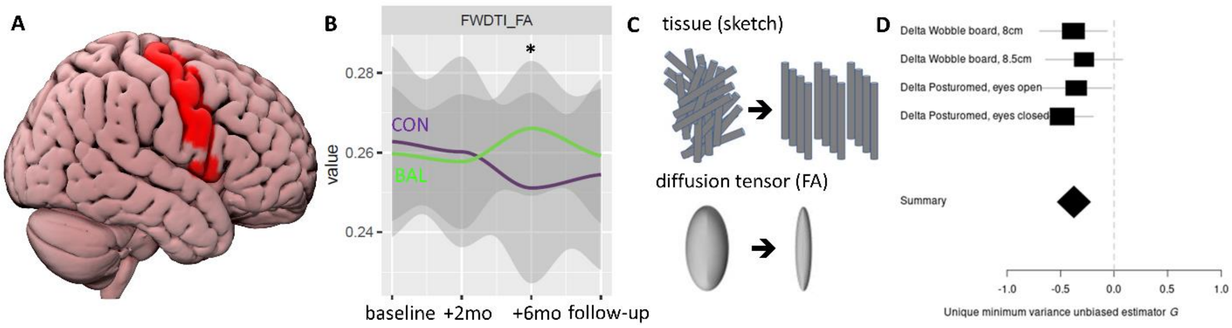

Figure 1: *Evidence of balance training-induced microstructural plasticity in the PMC in OA. A, Lateral view of the right PMC. B, Mean trajectories of fractional anisotropy (FA) as derived from the diffusion tensor (corrected for the effects of extracellular free water, [5]) of the CON and BAL groups, respectively. After training (+6mo), the time-by-group interaction assessed with an LMM was significant, B = 0.41, p = .04 (FDR-corr.). C, On a biological level, an increase in FA can be interpreted to mean that the underlying brain tissue (e.g., neurites) has become more organized after training. D, Consistent correlations were found between changes in FA from baseline to +6mo and concurrent changes in two trained (wobble boards) and untrained (Posturomed) balance tasks. Negative correlations indicate that the higher the increase in FA, the more postural sway reduced. The aggregated effect across the four correlations revealed a medium effect size, G = -0.38, 95% CI [-0.22, -0.53], p < .001.*

an effect that was largely retained throughout the follow-up period. Due to the abundance of material, only one exemplary microstructural finding will be explained in more detail in the following. Studies in young adults have shown that the PMC undergoes morphometric [6], functional [7], and microstructural changes [4] after BAL. ROI analysis in the present study suggests that similar changes are also occurring in OA, as evidenced by an increase in fractional anisotropy (FA) after 6 months of BAL as compared to controls (Figure 1B). These changes in FA were correlated with concurrent changes in both trained and untrained balance tasks (Figure 1D).

Discussion

Preliminary results from the present study support the idea that BAL may induce microstructural plasticity in balance-relevant brain areas in OA. It is noteworthy that the higher degree of local tissue organization in the PMC after 6 months of training was correlated with concurrent changes in both trained and untrained balance tasks, suggesting that the effect of training was generalizable, at least to some extent. The present study is not without limitations: the sample size was relatively small and the study lacked an active control group. However, the use of qMRI offers the possibility to characterize key neuroplastic processes and their dynamics in unprecedented specificity [3,4], thus promising a better understanding of the mechanisms underlying BAL in physiological and pathological aging or movement disorders. In perspective, we anticipate that novel multicontrast estimates of brain anatomy *("in-vivo histology")* will be increasingly used in the field of movement neuroscience, with potential applications in early diagnosis, guiding treatment, and assessing individual response to training and therapy.

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Improved sleep quality after three months of balance learning in older adults

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Keywords

Health, Motor control, Gait and postural control, Sleep, Aging

Highlights

- Balance training improves sleep quality in older adults, possibly through increased cortical GABA levels.

Introduction

Approximately half of adults over the age of 60 experience sleep problems [1]. The most commonly used treatments, namely pharmacotherapy and cognitive behavioral therapy, have been linked to either increased mortality and fall rates or are difficult to access [2]. Consequently, there is a need for the development of new effective and affordable treatments with reduced side effects. GABAergic inhibition plays a pivotal role in the initiation and maintenance of sleep [3, 4]. However, GABAergic inhibition and GABA concentrations decrease throughout the lifespan [5]. This decline may contribute to the observed worsening of sleep quality in older adults.

It has been demonstrated that balance training increased GABAergic inhibition in both younger and older adults [6, 7]. Therefore, we hypothesized that balance training in older adults would improve subjective sleep quality through an increase in GABA levels and GABAergic inhibition.

Methods

Forty volunteers, aged between 64 and 81 years, were randomly assigned to either participate in a three-month balance training intervention comprising a minimum of 30 sessions (2-3 times per week for 45 minutes) or to continue with their habitual activities. The primary objective of the balance group was to maintain stable posture under progressively more challenging conditions during supervised group training. Eighteen participants in each group completed both pre- and post-measurements and were included in the analysis (20 females / 16 males, age: 70.2 ± 4.4 years). The pre- and post-measurements consisted of the following assessments:
The Pittsburgh Sleep Quality Inventory (PSQI) was employed to evaluate the participant's perception of their sleep quality during the four weeks preceding the intervention and the last four weeks of the intervention. Balance performance was assessed through determination of the sway area in cm^2 during a twenty-second balance task on a challenging wobble board. Short-interval intracortical inhibition (SICI) is a measure of the activity of GABAergic inhibitory interneurons in the motor cortex. SICI of the tibialis anterior muscle was assessed using transcranial magnetic stimulations while the participant was balancing on the same wobble board as during the balance performance assessment. GABA levels in the left ventral motor cortex were determined with magnetic resonance spectroscopy.

PSQI scores were not normally distributed, and therefore square root-transformed prior to statistical analysis. Descriptive statistics are presented with mean ± standard deviation or median (IQR) for PSQI scores. Two-way repeated measures analysis of variance (ANOVA) was conducted to identify differences in changes over time between the two groups. Bonferroni-corrected paired t-tests were calculated to determine the direction of change within the groups.

Results

The statistical data can be found in Table 1. ANOVA demonstrated a statistically significant difference in the change over time in subjective sleep quality and in balance performance between the two groups. The t-tests revealed significant improvements in both parameters after balance training.

The change in GABA levels significantly differed between the two groups. As hypothesized, the balance group showed significantly higher levels after the training. The balance group also demonstrated an increase in SICI, but this change was not significantly different from the control group.

Table 1: *Descriptive statistics in mean ± sd or in median (IQR) and p-values of ANOVA and t-test calculations.*

		Balance Group	**Control Group**	**ANOVA** Time x Group
PSQI [0-21]	PRE	5.5 (4 - 8)	5.5 (4 - 8.5)	.038
	POST	4 (2 - 7)	5 (3.25 - 7)	
t-test		.020	> .999	
Sway area $[cm^2]$	PRE	129.54 ± 71.34	127.90 ± 89.61	.049
	POST	86.78 ± 40.40	121.96 ± 90.63	
t-test		.004	.782	
GABA [mmol/L]	PRE	2.24 ± 0.49	2.40 ± 0.49	.017
	POST	2.71 ± 0.27	2.50 ± 0.46	
t-test		.007	.968	
SICI [%]	PRE	11.86 ± 16.70	8.96 ± 14.55	.163
	POST	17.12 ± 16.36	7.55 ± 9.94	
t-test		.080	> .999	

Discussion

The older adults who participated in the balance training demonstrated an improvement in their subjective sleep quality with the median score decreasing from the category of poor sleepers (5 - 10) to healthy sleepers (< 5). They also showed increased GABA levels. The observed increase in GABAergic inhibition was not significant after correction for multiple comparisons, which may be attributed to the relatively short training period [7].

These findings suggest that balance training has the potential to improve sleep quality in a population with a high prevalence of sleep dissatisfaction, possibly by increasing GABA concentration to counteract hyperarousal.

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Symposium:

Sensorimotor predictions

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Successful sensorimotor behavior fundamentally relies on predictions about unfolding events and sensory consequences of one's own actions (e.g., Wolpert et al., 1995) – may it be when performing in a throwing game, when sliding an object over a table or when returning tennis serves on the court. In this symposium, current research on distinct functionalities of sensorimotor predictions is presented and discussed.

In presentation 1, Brand et al. (Justus Liebig University Giessen) will present the latest findings on the functional role of predictive saccades to optimize information uptake in a complex throwing task. In presentation 2, Tatai et al. (TU Darmstadt) will show how combining virtual reality with advanced computational modelling techniques provides insights into how humans intuitively take physical properties into account, such as friction, when interacting with objects under risk. Presentations 3 and 4 focus on the functional role of predictions to reduce uncertainty in state estimation. Beck et al. (University of Bern) examine how prior and sensory information continuously shape tennis players' anticipatory decision-making in unfolding situations, while Zahno et al. (University of Bern) investigate whether humans learn and use bimodal priors in sensorimotor behavior.

Together, the symposium presents recent experimental studies, using a wide range of methodologies (eye tracking, VR, full body kinematics, computational modelling), on the functional role of predictions in complex sensorimotor behavior.

References

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(Predicted) task success mediates eye movements toward targets with high informational or motivational value

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*: Contributed equally as last authors

Keywords

Action monitoring, Predictive eye movements, Motor control, Motor skills and abilities, Sensorimotor performance

Highlights

We elucidate potential benefits of internally generated action effect predictions with respect to the optimization of information uptake.

Introduction

Previous research revealed that action effects of self-generated movements can internally be predicted before outcome feedback becomes available [1]. These predictions have been shown to be used to guide gaze toward locations in the environment that provide informational value for feedback processing [2]. In goal-directed actions, like targeted throws, a difference in the informational value of outcome feedback can be assumed dependent on the (predicted) outcome of the action (hit vs. miss). While it is particularly important to process feedback on erroneous trials to derive suitable adjustments (in order to succeed in the long term), it may be less crucial to guide gaze towards learning relevant information if one is sure that a trial is going to be a hit. Videos of popular basketball players show that when they expect to make the shot, they sometimes turn around directly after ball release and do not (need to) perceive the outcome feedback; since to hit a second time, the same motor command can be used. Thus, it is plausible to assume that sensorimotor predictions are not only used to find (precise) locations with high informational value for feedback processing [3], but to furthermore attribute those locations a specific value depending on the predicted action outcome. To test this, we assessed systematic differences between eye movements toward targets with high informational value (showing movement outcome information) and targets with high motivational value (showing the monetary reward in a current trial) as a function of (predicted) task success in a semi-virtual goal-directed throwing task.

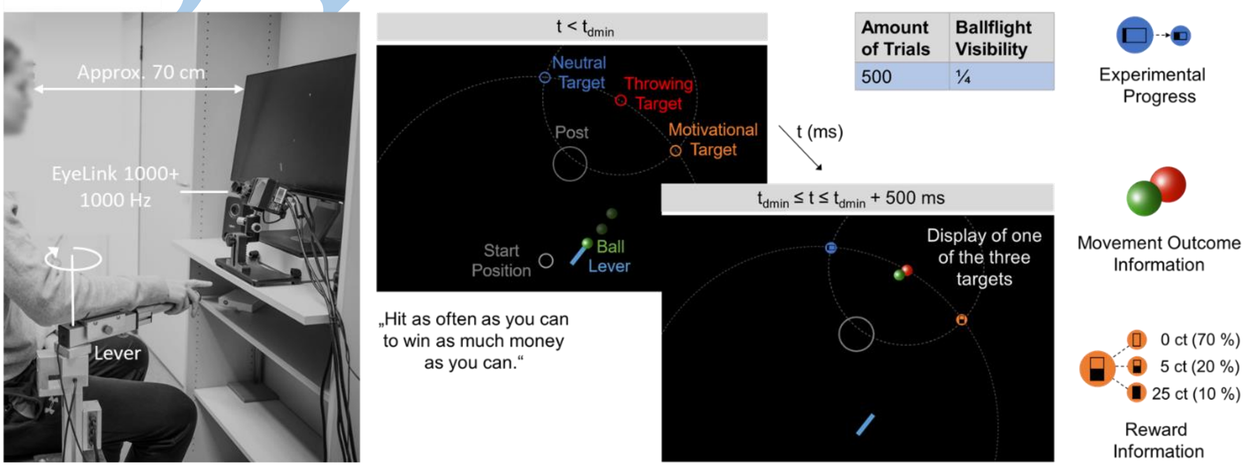

***Figure 1:** Setup of the semi-virtual throwing task.*

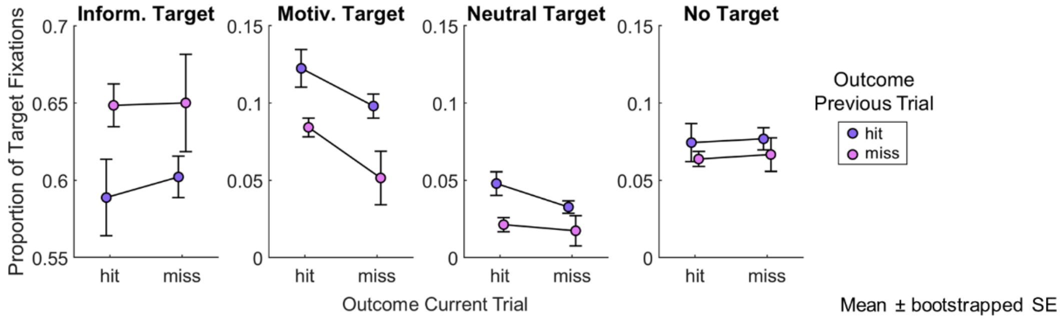

***Figure 2:** Proportions of target fixations as a function of (predicted) task success.*

Methods

Participants (n = 22, 10 females, age: 21.95 ± 2.15 years) threw a virtual ball around a center post in order to hit a target on the opposing side. To throw and release the ball, they used a metal lever device and executed an outward-rotational movement (Fig. 1). The task was practiced over 500 trials in a first session, in which the ball flight information was successively faded out as to only show static outcome feedback at the time of minimum distance between the ball and the target (t_{dmin}). In session two, also 500 trials were executed and only the first quarter of the ball flight was visible. Furthermore, two additional visual targets were displayed (Fig. 1), between which participants chose to look at. That is, depending on the participants' gaze position at t_{dmin}, feedback at only one of the target locations could be perceived for 500 ms. The (i) neutral target indicated the experimental progress, (ii) the throwing or informational target provided movement outcome information and (iii) the motivational target provided reward information. The reward for each trial was pseudorandom and could either be 0, 5 or 25 cents for a hit. The instruction was to hit as often as possible to win as much money as possible.

Results

In most of the trials, participants made a saccade to one of the targets shortly (about 250 ms) after ball release. Four generalized linear mixed models were run, considering the random effects of subjects (heterogeneity between subjects), to analyze the effects of throwing results in the current and previous trial (hit vs. miss) on the proportion ($n_{occurences}$ out of n_{trials}) the different targets (either (i) the neutral, (ii) the informational, (iii) the motivational, or (iv) no target) were fixated. We observed a larger proportion of fixations at the informational target in case the previous trial was a miss compared to a hit (Wald z = 2.67, $p < .01$) and the opposite for fixations at the motivational (Wald z = -2.84, $p < .01$) and neutral (Wald z = -3.59, $p < .001$) targets (Fig. 2, main effect "outcome previous trial"). Additionally, effect predictions in a current trial led to a larger proportion of fixations at the motivational target in hits compared to misses (Wald z = -3.68, $p < .001$; Fig. 2, main effect "outcome current trial").

Discussion

Overall, we observed large individual differences in the proportions with which each target was fixated. However, individual baseline proportions were systematically modulated by the throwing outcome of previous trials (e.g., larger proportion of informational target fixations in trials that followed a miss) and the predicted outcome of a current trial (larger proportion of motivational target fixations in predicted hits compared to misses). Thus, we conclude that humans combine previous experiences with sensorimotor predictions to attribute value to different parts of the visible space and to guide gaze at highly valued positions.

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Ballistic sensorimotor actions under risk take Newtonian physics into account

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Keywords

Motor control, Virtual Reality, Motor skills and abilities, Intuitive Physics, Economic Decision-Making

Highlights

People can take into account how their sensorimotor variability interacts with object kinematics in order to maximize economic outcomes.

Introduction

The success of our interactions with objects in natural tasks involves generating motor actions, which are subject to sensorimotor variability, the objects' physical properties, which are governed by physics, and the costs and benefits associated with the actions' outcomes. Therefore, such interactions jointly involve sensorimotor control, intuitive physics, and decision-making under risk. While in explicit economic decision-making, often studied with forced choice between lotteries, people have been shown to decide sub optimally [1], they are able to maximize the outcomes of their motor actions [2]. Missing in these studies is that everyday sensorimotor interactions are governed by the laws of physics. We have found that in such settings people can correctly reason about physical object properties [3]. Still, it remains open whether this integrates with economic decision-making. Here, we devised a mixed reality puck sliding experiment, which allows investigating human behavior involving the interaction of all these three cognitive faculties. We hypothesize that people can account for how Newtonian physics impacts object sliding, to plan their actions accordingly with the goal of maximizing economic action outcomes.

Methods

Subjects slid real standard hockey pucks across a table with the aim of scoring points by ending up within the bounds of a green target area and avoiding a red penalized area behind it (see Figure 1a). They were tasked to maximize their score, proportionally paid out as a monetary incentive at the end of the experiment. 20 subjects completed 12 experimental conditions (3 target distances, 4 penalties, see Figure 1b) in blocks of 30 trials. In our experimental setup subjects can naturalistically slide a real puck on the table's surface, while viewing the puck, table and target virtually through a head mounted display. Our past work shows that this leads to an intuitive embodied understanding of the task [4]. After subjects released the puck, its initial velocity v_0 was taken to simulate the puck's displacement x via motion with constant deceleration.

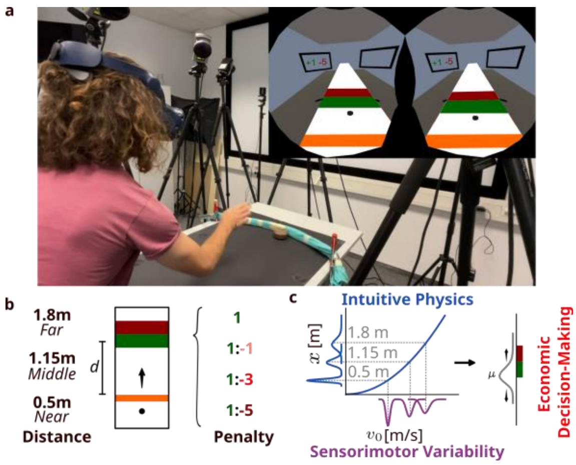

***Figure 1: a)** Experimental setup. **b)** Experimental conditions: target (green) vs. penalty (red) at different distances and penalties. **c)** Subjects controlled the puck's initial velocity v_0, the table's friction determined the final position x, subjects aimed to maximize payoff*

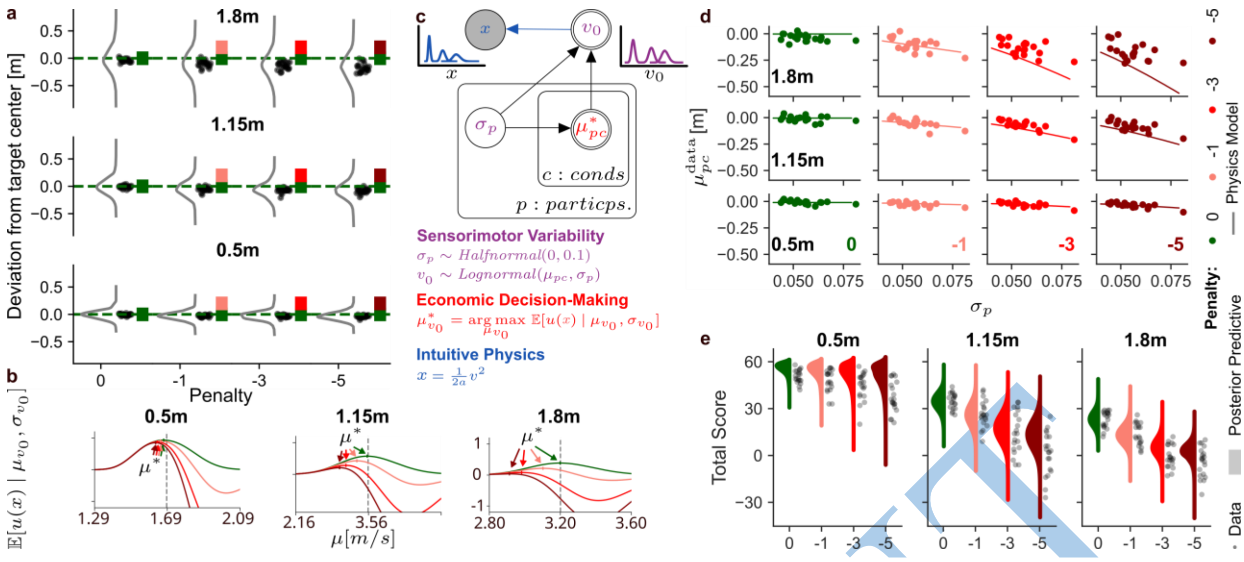

***Figure 2: a)** End point deviation from green target center (lines: all slides, dots: subjects' medians). **b)** A generative model of subjects' sliding behavior based on statistical decision theory normatively prescribing where subjects should aim given their individual motor variability interacting with friction. **c)** Expected utility of aim points and the optimal aim points μ^* in each condition given an example subject's motor variability. **d)** Subjects' motor variability σ_p fit by the model and their empirical aim points μ_{pc}^{data} compared to the model predictions. **e)** Subjects' scores (dots) compared to the posterior predictive (densities) corresponding to 10000 simulations of the experiment.*

Sensorimotor actions are subject to signal-dependent variability and are additionally transformed by the puck's kinematics, determining where subjects should aim (see Figure 1c).

Results

We find that subjects undershoot more the higher the penalty and the larger the distance, but also that those two factors interact (see Figure 2a). This is what statistical decision theory predicts from the interaction of sensorimotor variability with the physics of friction (see Figure 2b). We incorporated this within a generative model (see Figure 2c), where each subject has their own variability σ_p determining their optimal aim point μ_{pc}^* for condition c by maximizing expected utility. We find that subjects' aim points are well described by this model and that individuals with higher variability undershoot the target more, again just as predicted (see Figure 2d). Many subjects perform on par with the rational actor, or only slightly worse (see Figure 2e).

Discussion

We confirm our hypothesis that subjects can account for the influence of friction on their sensorimotor actions while maximizing the prospective outcomes of their actions. Our results even show that subjects are sensitive to their individual motor variability. This extends the results from [2] to more complex object interaction tasks. The integration of uncertainty with physics and outcomes suggests that the outcomes of sensorimotor actions might be represented in a probabilistic fashion in the brain [5]. Our results also highlight mixed reality experimental designs, with immersive experience for the subjects, while maintaining experimental control.

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Humans can learn bimodal priors in complex sensorimotor behavior

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Keywords

Bayesian Integration, Sport, Sensorimotor Performance, Motor Control, Virtual Reality

Introduction

Two decades of research suggest that humans integrate current sensory information and prior expectations in a Bayesian way to guide behavior [1]. However, while Bayesian integration provides a powerful framework for perception, cognition, and motor control, evidence is largely limited to simple lab tasks [2]. In recent years, testing major theories in naturalistic situations has been increasingly emphasized as a key challenge in the field [3].

Here, we test Bayesian integration in a complex sensorimotor task: returning tennis serves. We developed an immersive virtual reality (VR) environment, allowing us to study realistic, unconstrained movements while keeping full experimental control. Further, the tennis task provides a natural example of where players are confronted with bimodal distributions: Typically, your opponent's serves are not distributed around one location but rather contain two peaks of highly probable ball locations. Even though Bayesian theory makes clear predictions on how bimodal priors should be integrated, the extent to which humans can learn and exploit bimodal priors has been addressed only in a few studies so far and remains a subject of debate [4].

In this study, we thus examined whether humans could learn a bimodal prior through playing tennis and use it in a Bayesian manner.

Methods

Participants ($N = 24$) returned tennis serves in an immersive VR environment (Figure 1; video on GitHub).

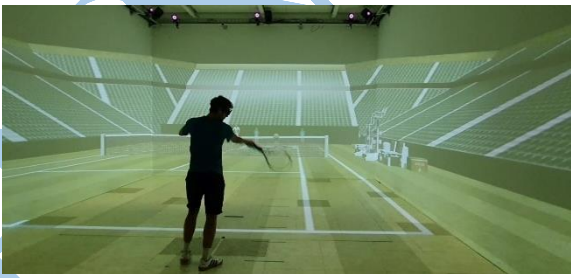

Figure 1: *Virtual reality tennis setup.*

On three days, participants returned 1'440 serves that followed a bimodal distribution (Figure 2). We manipulated visual uncertainty by introducing three levels of ball speeds: slow (i.e., ball trajectories being easily observable), moderate, and fast (i.e., ball trajectories being increasingly hard to perceive). As a measure of the participants' estimation error, we computed the horizontal deviation between the ball and the racket's sweet spot at the time of contact (Figure 2).

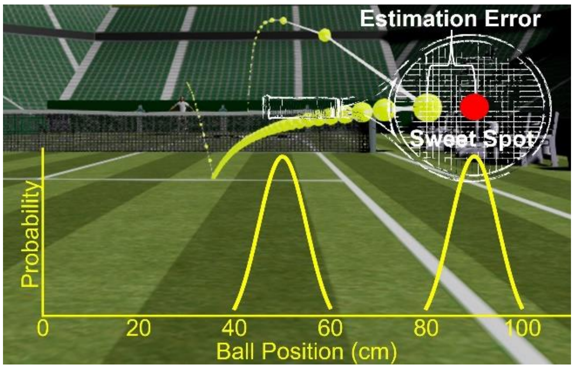

Figure 2: *Measure of estimation error (top) and distributions of the opponent's serve locations (bottom).*

Bayesian theory predicts that participants use sensory and prior information to estimate the ball's position in action, relying more on the prior as visual uncertainty increases. To test Bayesian predictions, we analyzed the estimation error as a function of true ball position [1]. The Bayesian model with a bimodal prior predicts a nonlinear relationship between the estimation error and the true ball location. This nonlinear relationship can be quantified with a "jump" between the left and right side of the distribution, which we termed "bimodal prior effect". The Bayesian model predicts that the magnitude of the bimodal prior effect increases with increasing uncertainty (i.e., ball speeds).

Results

Bimodal prior effect

Consistent with Bayesian predictions, after extensive exposure to the opponent's serves, nonlinear effects were found (Figure 3). Significant bimodal prior effects were found for fast (red) and moderate serve speeds (blue). No significant bimodal prior effect was observed in the slow condition (green). This pattern of results aligns with the core predictions of the Bayesian model.

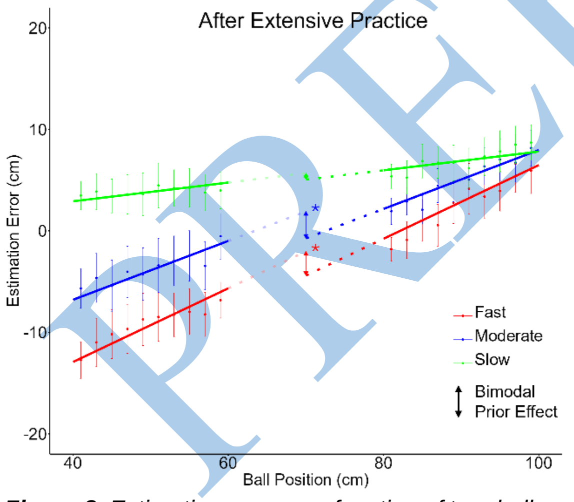

***Figure 3**: Estimation error as a function of true ball position and uncertainty condition (slow, moderate, fast).*

Biomechanical effect

In addition to the bimodal prior effect, data shows a general positive linear trend between the estimation error and ball position, which can be attributed to biomechanical constraints and associated motor costs: When the ball is played close to the participants' body, they are likely to hit too far to the right, leading to negative errors, especially when balls are fast.

Participants' prior knowledge is implicit

After the experiment, we asked the participants if they had been able to detect a pattern in the opponent's serve distribution. Remarkably, despite being exposed to the opponent's serves over 1'440 trials and incorporating this information into their behavior, participants were unable to report above chance level whether the opponent's serves followed a bimodal distribution when asked explicitly. This result suggests that participants integrated implicit "knowledge" of the bimodal distribution into their tennis returns without explicit awareness of the pattern.

Discussion

The results show that Bayesian principles generalize to more complex situations, including naturalistic movements and bimodal distributions [4]. Our data indicate that in this complex task, participants' movements were not only biased by prior expectations but also by biomechanical constraints and associated motor costs. Together, participants' behavior is well explained by a combined effect of the acquired bimodal prior and motor costs.

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Evidence for Bayesian exploitation of prior knowledge and continuous decision-making under uncertainty in tennis

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Keywords

Bayesian inference, Decision-making, Sport, Motor control, Sensorimotor performance

Introduction

Returning a fast tennis serve is a spatiotemporal task that pushes the human sensorimotor system to its limits. High-speed serves are particularly successful as they force the returning player to act under extremely high sensory uncertainty arising (among others) from noise and delays in incoming sensory signals. Leading theories of sensorimotor control propose that humans cope with uncertainty by integrating prior and sensory information in a Bayesian manner and continuously make predictions to evaluate action options in online decision-making [1]. However, most empirical evidence in favor of those theories is based on simple lab tasks, and it remains unclear how humans use prior information in online decision-making in naturalistic behavior [2]. Returning fast tennis serves is a particularly informative task to gain insights into the dynamics of unfolding decisions in action due to a peculiarity of the return movement: the split step – a preparatory movement with a small jump to increase initial speed into the desired direction. In this study, we investigated whether participants exploit accumulated prior knowledge of the opponent's preferred serve direction – a T-serve vs. a wide-serve – to improve performance under representative conditions. Further, we aim to gain insights into the online use of prior and sensory information in the dynamics of decision-making by analyzing the temporal evolution of the weight shift over the split step.

Methods

Fourteen experienced tennis players returned serves in an immersive virtual reality setup with unconstrained movements and task demands matching real tennis (Figure 1; video on SwitchTube (https://tube.switch.ch/videos/2otCdMkJpF). After a neutral condition, we manipulated the distributions of the opponent's preferred serve locations (biased condition: 80% to the right vs. 20% to the left of the service box and vice versa in a second session). We measured the weight shift over the split step, defined as the difference in the relative distances between the center of mass and the left and right foot, respectively.

Figure 1: *Setup of the virtual tennis experiment: 3D glasses, six marker clusters, a real tennis racket (with integrated Wii controller for haptic feedback), and the two possible ball trajectories (T-serve vs. wide-serve).*

Results

Figure 2 shows that, in the biased condition (80:20), a significant overall weight shift towards the more probable side can already be measured before the serve (B = 2.49 cm, CI = [0.37, 4.61], $t(1037) = 2.30$, $p = .011$). This weight shift increases over the split step and predicts the direction of the later initiated lateral movement. Inferentially, this can already be proven for the starting position at rest before the serve since the odds ratio for initiating a movement in the same direction as the direction of the weight shift turns out to be significantly higher than one (OR = 1.02, CI = [1.01, 1.03], $z(1067) = 4.97$, $p < .001$). This Bayesian optimization process ultimately leads to hit rates increasing from 35.5% in the neutral condition to 67.7% in congruent trials and decreasing to 33.1% in incongruent trials. Thus, by integrating prior knowledge in early weight shift, participants accept errors in the rare, incongruent cases (20%) to gain an advantage in frequent, congruent cases (80%) – a functional strategy to increase overall performance. Further, in contrast to decision-making at a certain instant in time, three indications for a continuous anticipatory decision-making process can be observed (Figure 2). First, weight shifts of the congruent/correct and incongruent/incorrect responses develop similarly over the early phase of the split step until the players, based on incoming sensory evidence, seem to realize in the incongruent/incorrect cases that they are wrong. Second, in incongruent/correct and congruent/incorrect trials, the weight shift – even before the split step – does not tend to the more likely side but remains close to zero. Since the weight shifts are distributed around a mean value in early phases, players sometimes start with a less pronounced weight shift to the congruent side, which in turn increases the attractiveness of the incongruent side. This random deviation is then reflected in a higher probability of initiating a movement in the correct direction in incongruent trials, but also of moving incorrectly in response to congruent serves. Third, the weight shifts in congruent/correct and neutral/correct trials develop almost in parallel over the split step, which again implies that if one is already inclined towards a particular option, this option becomes even more attractive as, due to biomechanical motor costs, alternatives become increasingly difficult to achieve. Together, prior information pays off over the whole course of the split step.

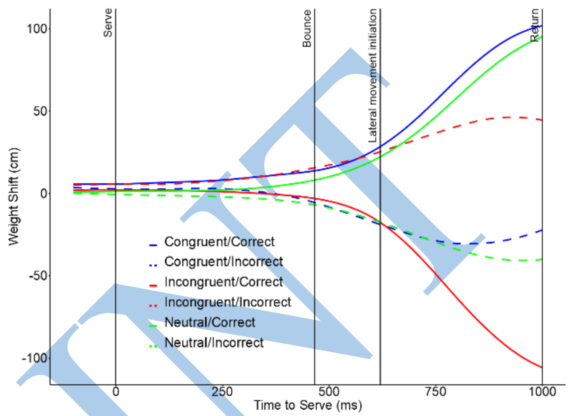

Figure 2: *Weight shift over the split step in congruent vs. incongruent trials with correct vs. incorrect responses in the final blocks of the biased condition (80:20), plotted relative to the prior, in comparison to the weight-shift dynamics for the neutral condition (50:50), plotted relative to the correct direction.*

Discussion

We showed that over the split step, participants continuously adjusted their weight shift with incoming sensory information, while a bias toward the expected side was observed throughout and already before the serve. Our results thus provide evidence that humans use prior and sensory information to probabilistically optimize online decision-making in complex behavior.

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Symposium:

How Exercise and Sleep Shape Learning and Performance in Human Movement

Simon Steib[a], Nicole Frisch[b]

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How do exercise and sleep shape the way we learn and perform? This symposium delves into the critical links between exercise, sleep and memory, emphasizing their importance in human movement science. We will examine the multifaceted roles of exercise and sleep in modifying different memory systems, offering a deeper understanding of how these factors interact to enhance learning and performance across various contexts.

The first talk will discuss the effects of an acute bout of intense cardiovascular exercise on subsequent sleep and motor learning, highlighting how physical activity influences sleep architecture and, in turn, may modify motor memory consolidation. The second presentation will discuss how varying exercise intensities impact sleep quality, and how this will affect post-sleep episodic memory encoding. The third talk will present findings from an ongoing cohort study examining how mental rehearsal paired with sleep affects motor skill learning across the lifespan. Lastly, the final presentation will address the effects of psychological or physical stress on extinction learning, focusing on how these factors contribute to the ability to unlearn maladaptive behavior.

Taken together, these presentations provide a comprehensive view of the dynamic interaction between sleep and exercise in influencing memory processes. This symposium will provide valuable insights for researchers in the field of human movement sciences, deepening our understanding of how these factors interact to optimize learning and performance.

Title only:

The effects of physical exercise on extinction memories and their contextualization

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The Effects of High-Intensity Interval Training on Sleep and Sleep-related Motor Memory Consolidation

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Keywords

Motor learning, Neuroplasticity, Neuropsychology, Sleep, Exercise

Highlights

- gold-standard PSG and psychophysiological measures for in-depth analyses to link exercise, sleep and memory

Introduction

Both exercise and sleep have been shown to benefit motor memory formation [1,2]. Acute exercise seems to alter subsequent sleep architecture [3], potentially affecting memory consolidation. However, few studies have investigated whether exercise-induced changes in sleep architecture benefit motor memory consolidation. Intensive exercise is likely to cause multiple psychophysiological responses, including elevated cortisol and body temperature, which may affect subsequent sleep and thereby also sleep-related memory consolidation [4]. Recently, we reported data indicating that exercise-induced increases in N2 sleep were positively correlated with improved motor memory retention [5]. However, further investigation is required to confirm and extend these findings, given the limited statistical power and the methodological limitations of the study, including the absence of a wake control group. Building on these preliminary findings, this pre-registered study investigates the effects of exercise-induced changes in sleep architecture on motor memory consolidation, examining both macro- and microstructure of sleep, and explores the underlying psychophysiological mechanisms.

Methods

In this ongoing study with a mixed within-between-subject design, we test 80 healthy young men, who are randomly allocated to either a WAKE or a SLEEP group. To date, N = 56 participants (M = 23.7 ±3.5 years) have been successfully enrolled in this study (26 WAKE/30 SLEEP). Within each group, participants perform two conditions with either (i) a bout of exercise (HIIT at 90%/25% W_{max}; EXE) or (ii) rest (watching a documentary; REST) immediately after encoding a novel motor sequence (finger tapping task; FTT). Participants in the SLEEP group practice the five-item sequence in the evening and are retested 12 hours later, following a night of sleep. In contrast, participants in the WAKE group perform the task in the morning and are retested 12 hours later that same evening. In the SLEEP group, nocturnal sleep is recorded via polysomnography to assess sleep architecture. Meanwhile, in the WAKE group, activity during the retention interval is monitored using actigraphy. Motor memory consolidation is measured by calculating the percentage change in task performance from end of encoding to the retention test (offline change). Additional data is collected to control for psychophysiological confounders, including nocturnal body temperature, cortisol levels, subjective ratings of daytime sleepiness, self-reported pleasure and arousal levels, as well as physical activity and sleep diaries maintained throughout the intervention period.

Results

The preliminary analyses of the subset (N = 56) reveal an average offline change in the FTT of 17.7 ±18.7 % in the SLEEP compared to 8.8 ±18.0 % in the WAKE group ($F(1,50) = 4.820$, $p < .05$, $\eta^2 = .056$). No major within-group differences were found between EXE and REST in either the SLEEP group (EXE: 16.7 ±19.8 % vs. REST: 18.7 ±17.9 %) or the WAKE group (EXE: 7.2 ±16.7 % vs. REST: 10.3 ±19.5 %) (Figure 1). There was no significant effect of condition ($F(1,50) = 0.657$, $p = .421$, $\eta^2 = .005$) and no interaction between group and condition ($F(1,50) = 0.030$, $p = .863$, $\eta^2 < .001$).

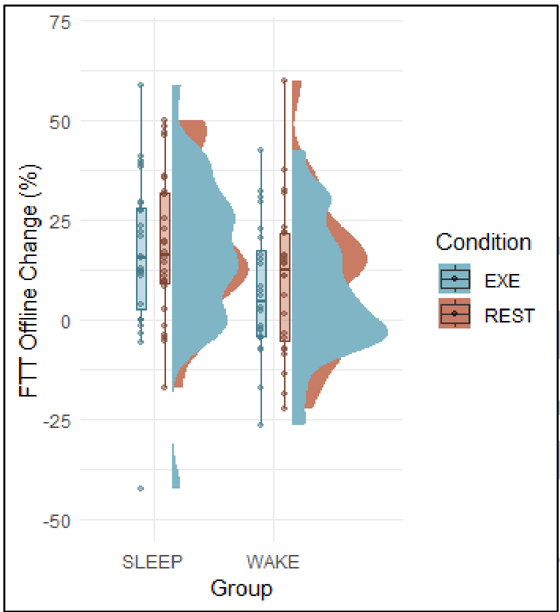

Figure 1: *Motor memory consolidation separated by group (SLEEP, WAKE) and condition (EXE, REST).*

Preliminary analyses of sleep data indicate that HIIT did not affect the proportion spent in sleep stages, except for a trend towards a reduction in REM sleep following EXE (Table 2). However, in-depth analyses of sleep microstructure, which are still pending, may reveal memory-related changes in sleep that are not captured by stage-based analyses.

In the talk, we plan to present the following data:

(i) Analysis of variance for between- and within-group differences and interactions

(ii) Correlation analysis of exercise-induced sleep changes and memory consolidation

(iii) Initial analyses of sleep microstructure (sleep spindles, slow wave activity) and psychophysiological responses (cortisol, body temperature)

Table 2: *Polysomnographic sleep data (mean percentage of sleep stage ± SD).*

Sleep stage	EXE	REST	Cohen's *d* (p-value)
N1	2.6 (1.1)	2.4 (1.1)	0.16 (.445)
N2	41.6 (5.3)	41.6 (7.4)	0.01 (.997)
N3	23.2 (6.0)	21.9 (5.8)	0.29 (.156)
REM	16.6 (3.1)	18.2 (3.8)	0.36 (.083)

Discussion

The descriptive analysis indicates that the FTT was consolidated more efficiently in the SLEEP group, thereby confirming the expected sleep-dependent effects observed in previous research [1]. The sleep analysis suggests a slight decrease in REM sleep following exercise, aligning partially with existing evidence on exercise's effects on sleep architecture [3]. Based on the preliminary analysis, no other differences were noted between the conditions. However, the results must be considered with caution, given that these preliminary findings are based on partial data and the final data collection (June 2025) will allow for a more comprehensive and in-depth analysis.

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Training the Sleeping Brain: Effects of Acute Exercise on Sleep and Memory

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Keywords

Sportpsychology, Neuroplasticity, Neuropsychology, Sleep, Memory

Introduction

Sleep plays a crucial role in efficient memory processing (1). According to the synaptic homeostasis theory, sleep helps restore the brain's encoding capacity (2). A key goal of sleep and memory research is to identify non-invasive interventions that can manipulate underlying neuronal processes, allowing cost-effective, low-tech methods to enhance cognition and health. Behavioral interventions, such as acute exercise (a single bout of physical activity), have shown moderate to large effects on episodic and motor memory when performed close to the time of encoding (3,4). Additionally, although the evidence is less consistent, some research suggests that exercise can influence sleep. Meta-analyses indicate that acute exercise affects objective sleep quality, architecture, and neurophysiological sleep features (5). This study examines the impact of two different evening exercise protocols on nocturnal sleep and memory encoding the following morning.

Methods

Forty participants (19 female, 21 male) completed three sessions (control, high-intensity interval training [HIIT], and moderate-intensity continuous training [MICT]) in a counterbalanced, within-subject design. Each participant visited the lab four times (see Fig. 1). In each condition, participants arrived at the lab four hours before their usual bedtime. They completed the assigned control/exercise protocol for one hour, then took a five-minute shower, put on a wrist-worn actigraphy device, and went home to sleep. The next morning, participants woke up, ate a provided granola bar, and approximately 30 minutes later completed the memory and vigilance tasks online. On the second morning, they repeated the vigilance task and the retrieval component of the memory task.

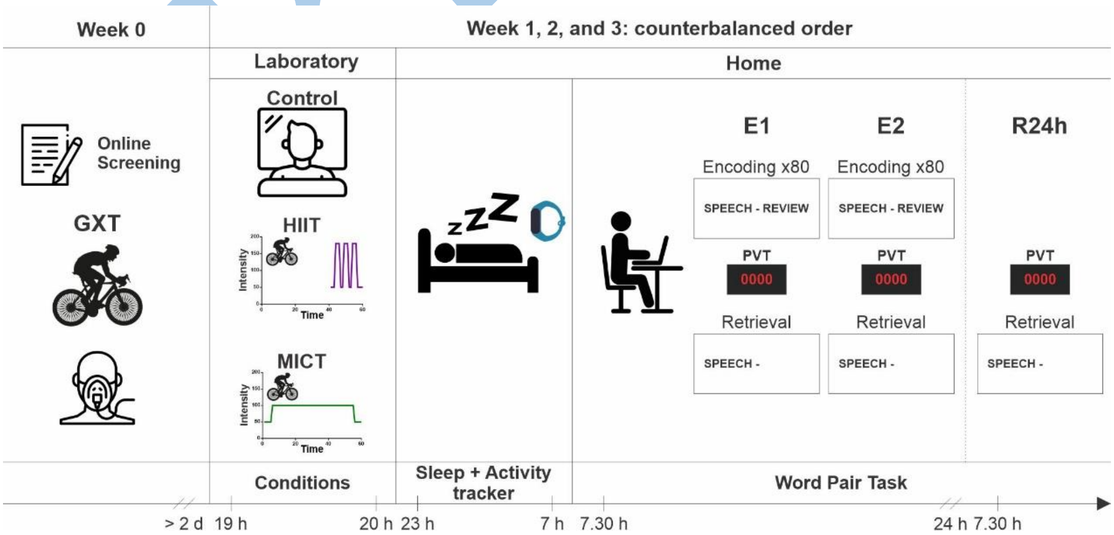

Figure 1: *Experimental protocol.*

Results

We conducted a generalized linear mixed model that included binary data for each item during all measurement points (E1, E2, R24h). Overall, HIIT had a positive effect on memory performance compared to the control (*β = 0.27, SE = 0.13, z = 2.02, p = 0.043*; see Fig. 2). In contrast, the MICT condition did not significantly differ from the control condition (*p = 0.647*). Exploratory analyses showed that participants in the HIIT condition encoded early items in the word pair task better than in the control condition (*β = 0.46, SE = 0.14, z = 3.35, p < 0.001*), with this effect persisting for 24 hours. Furthermore, low-performing participants (low- and high-performing groups were divided based on a post hoc median split of their performance in the control condition during E1) showed greater memory encoding in the HIIT condition compared to the control condition (*β = 0.52, SE = 0.16, z = 3.15, p = 0.002*), while no significant differences emerged between the control and MICT conditions (*p* = 0.249). We did not observe changes in sleep parameters measured with actigraphy (all *p* > 0.05).

Discussion

In this study, we investigated the effects of two evening exercise interventions on post-sleep memory encoding, probing their utility for basic systems-level research on synaptic homeostasis and for potential future applications. By using a combination of online and laboratory-based methods, we achieved a larger sample size than is typical used in exercise and sleep research. Our results show that a single session of HIIT three hours before bedtime significantly improves memory performance the following morning, a benefit not observed with MICT. These findings highlight the promise of brief, intense exercise as an effective way to enhance memory encoding.

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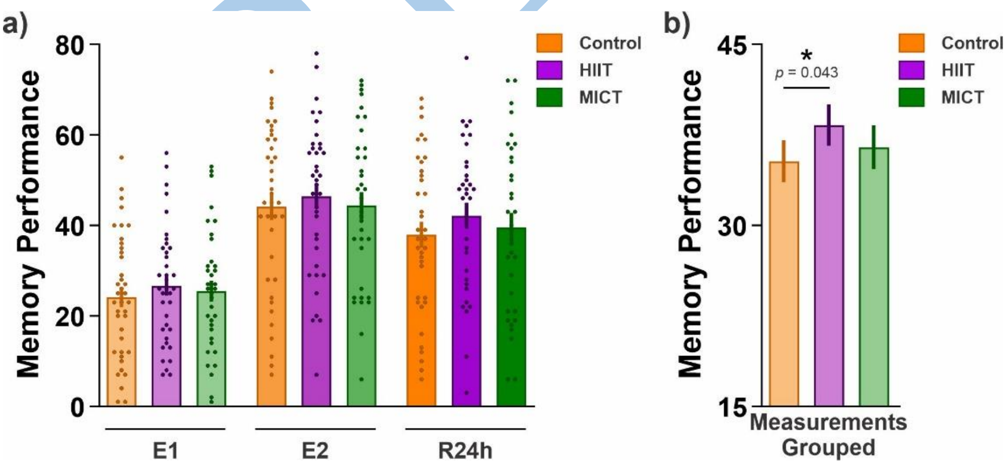

Figure 2: Positive effect of HIIT on memory performance. a) *Memory performance is shown as the mean ± SEM for each condition.* ***b)*** *The measurements across testing time points were averaged. The generalized linear mixed model revealed a significant difference between the control and HIIT conditions,*, p = 0.043.*

The Effects of Sleep on Gross Motor Sequence Learning by Motor Imagery – Preliminary Results

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Keywords

Motor learning, Motor skills and abilities, Neural correlates, Motor imagery (MI), Sleep-dependent memory consolidation (SDMC)

Highlights

- Overnight performance gain correlates with N3 sleep duration in first quarter of the night
- MI in the evening is most effective

Introduction

Motor imagery (MI) involves mentally simulating a specific motor action without producing physical movement and can improve motor performance [1]. While sleep has been demonstrated to enhance the consolidation of fine and gross motor skills [2,3], the specific role of sleep for motor sequence learning (MSL) through MI is less understood. Some research has found that fine motor skills improve after a night of sleep following MI [4], though only two recent studies have replicated this effect for gross motor movements [5, 6]. Our study aims to investigate whether a period of sleep, as compared to wakefulness, enhances MSL after MI, using a sequential whole-body task, while assessing the neuronal correlates during MI and sleep by employing EEG and polysomnography (PSG).

Methods

The study has been preregistered on OSF: osf.io/nr529. 77 healthy subjects (M_{age} = 22.1 years, 37 males) participated in a seven-day experimental schedule, including two nights of ambulatory PSG recordings. Participants visited the laboratory three times, starting either in the morning (AM group) or evening (PM group) with an 11-12-hrs retention period between the visits. After learning an eight-step foot sequence on a square mat with nine fields [5], they subsequently either had to mentally rehearse the sequence for 12 blocks of 45 seconds (MI intervention) or they had to listen to an audio book (control intervention). We assessed performance of the sequence before (pre-test) and after (post-test 1) the intervention, as well as after retention period 1 (post-test 2) and 2 (post-test 3). Performance change was measured as the percentage change in the number of correct steps during the three post-tests (1-3) relative to the pre-test. Sleep was scored automatically and visually cross-validated by an expert. We applied a non-parametric linear mixed model using the ARTool package in R with random intercept across subjects, including intervention time, intervention condition, and testing time point as fixed effects.

Results

Regardless of intervention condition, only the PM group showed higher performance gains at post-test 2 (post-sleep) than at post-test 1 (pre-sleep; $p < .001$, Figure 1). At post-test 3, the MI group by trend exhibited greater performance gains compared to the control group ($p = .076$). This effect was primarily driven by the PM group, as the evening MI group demonstrated a greater increase in performance than the evening control group ($p = .034$) and the morning MI group ($p = .041$). To assess sleep-dependent memory consolidation (SDMC) we examined changes directly from pre- to post-retention periods. Irrespective of the intervention condition, the PM group tended to show greater performance gains across both retention periods compared to the AM group (p = .088). This trend was mainly attributed to higher performance gains in the PM compared to the AM group during the first retention period (p = .043).

Considering objective sleep parameters, we observed a trend showing an association between overnight performance gain after the MI intervention in the evening and the duration spent in N3 sleep during the first quarter of the post-intervention night (r = .38; p = .096; Figure 2). No such associations were found in the AM group.

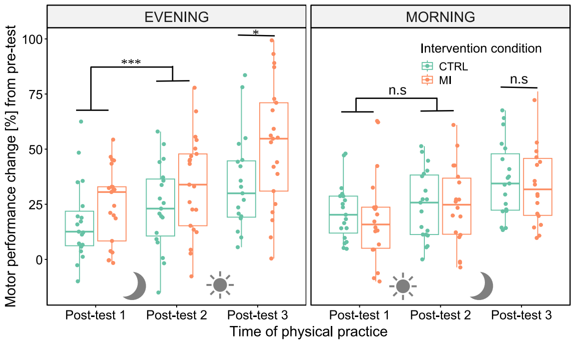

Figure 1: *Performance gain relative to the pre-test, separately for each intervention time and condition.*

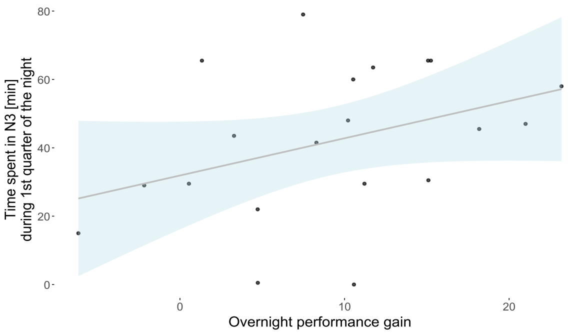

Figure 2: *Association between time spent in N3 during first quarter of the night and overnight performance gain in the evening MI group.*

Discussion

Consistent with previous research [2], our results indicate SDMC after gross MSL. As SDMC was observed for both the evening MI and the control group, we cannot fully confirm earlier findings [5,6], showing SDMC of gross motor memory for the MI group only. However, we found that participants who practiced MI in the evening tended to have better motor skills at the end (post-test 3) than those who listened to an audio book. This effect was absent in the morning intervention group, suggesting that sleep after encoding and MI initiates a process of long-term motor memory consolidation that continues over time. Taken together, these results indicate that MI improves gross MSL only when practiced in the evening. This finding may have implications for the application of MI in real-life settings. The observed trend-level association between the duration of N3 sleep in the first quarter of the night and overnight performance gain suggests a potential role of early slow wave sleep in motor memory consolidation after MI [7]. Upcoming analyses of more specific sleep parameters at the microscopic level (i.e. sleep spindles, slow oscillations) will provide deeper insights into the effects of sleep on MSL.

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Symposium:

The Role of Exercise in Enhancing Motor Learning in Aging and Neurorehabilitation: Insights into Mechanisms and Applications

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The ability to acquire and retain motor skills is essential for successful motor rehabilitation. However, research indicates that motor learning tends to decline with increasing age and in neurodegenerative diseases, underscoring the need for strategies to mitigate motor learning deficits (Aslan et al., 2021). Recent evidence suggests that physical exercise may serve as an effective method to improve brain health and motor learning (Boa Sorte Silva et al. 2024). Despite its importance, studies exploring the exercise-induced effects on motor learning in older adults are scarce. In this symposium, we will present recent research that addresses this gap and discuss whether exercise can improve motor learning in older adults with and without movement disorders. As empirical data on age-related motor learning deficits are heterogeneous, the first talk will present an ongoing systematic review with meta-analysis that comprehensively summarizes the current evidence from motor learning studies in older adults. The second talk will examine the effects of a single bout of exercise on motor learning in older adults and discuss potential differences compared to young adults. The last two presentations will focus on the effects of exercise on motor skill learning in people with Parkinson's Disease. The third talk will present the results of a recently completed randomized controlled trial on pairing exercise and motor learning over multiple sessions. The final talk will cover data from an ongoing multi-center randomized control trial exploring how chronic exercise may impact motor learning.

Motor Memory Formation in Old Age – A Systematic Review with Meta-Analysis

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Keywords

Motor learning, Motor skills and abilities, Sensorimotor performance, Aging, Motor memory formation

Introduction

Across the globe, populations are aging, a trend driven by longer life expectancy and lower fertility rates [1]. This demographic shift has several implications, as aging is accompanied by increasing physical limitations [2]. A central concern is the decline in physical performance, which can reduce independence and mobility. Addressing these age-related motor deficits requires targeted practice to enhance and maintain motor skills. Improving and refining these motor skills with practice requires the acquisition of new information and the effective transfer into long-term storage, a process referred to as motor memory formation [3]. Its efficacy is essential for many activities and settings, such as sporting performances, activities of daily living, or rehabilitation. It involves encoding motor information during practice, which subsequently undergoes stabilization and strengthening, i.e., consolidation. Aging, however, impacts not only motor performance but also cognitive functions, including long-term memory formation. This may affect how effectively motor memories are encoded and consolidated. The results across different studies investigating the influence of aging on motor memory formation are ambiguous. Some studies have demonstrated preserved memory encoding in older individuals, such as during motor sequence learning [4]. Conversely, other research indicates deficits in encoding compared to younger individuals [5]. Most evidence on motor memory consolidation suggests a decrease with advancing age [6]; however, there is some ambiguity in the literature. The observed variability may be partially attributed to differences in the motor tasks used, varying amounts of practice, different retention intervals, or participants' characteristics, making it challenging to draw definite conclusions. Therefore, we aim to address how motor memory formation declines in older compared to younger adults. Specifically, we want to answer how old age affects motor memory (i) encoding and (ii) consolidation, respectively, and unravel the role of potential moderators such as task type, participants' characteristics, retention interval, and sleep on age-related changes in motor memory formation.

Methods

We conducted a systematic literature search following the PRISMA guidelines with a predefined list of keywords using the PECO (Population, Exposure, Comparator, Outcome) framework and boolean strategies in relevant databases – MEDLINE (PubMed), Web of Science, SPORT Discuss, and PsycINFO – from database inception until April 2024. We included studies that compared motor memory formation of healthy older (≥50 years) to younger adults without interventions targeting motor learning. Two authors independently screened the retrieved records by examining the titles, abstracts and evaluating the full-texts of those not considered out of scope. Additionally, we reviewed the reference lists of included articles. The same authors extracted data from the included articles to calculate effect sizes and potential moderators. The meta-regression, as well as a quality assessment of included articles, is currently being prepared.

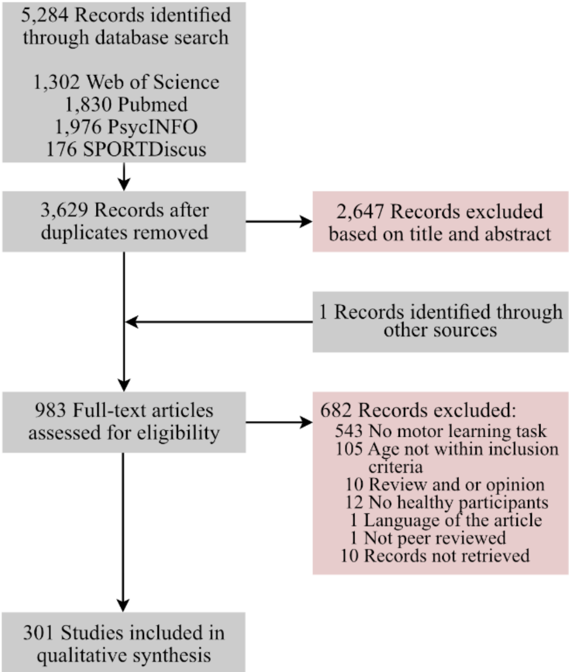

Figure 1: *PRISMA flow chart showing the results of the systematic literature search.*

Results

The comprehensive search across four electronic databases yielded 3629 records after removing duplicates. Screening these records resulted in 301 studies meeting the inclusion criteria (Figure 1). Preliminary qualitative analyses revealed mixed findings across studies (Figure 2), with older less likely to outperform younger adults in encoding or consolidation measures. The overall ambiguity emphasizes the variety in study design. These findings remain preliminary and underscore the need for further analysis. To address this, we plan to conduct meta-regressions, taking task type, age difference, and retention interval into account, among others, and intend to present the results.

Discussion

Given the extent of available literature identified by our search, we aim to address critical questions about how aging influences motor memory encoding and consolidation while also clarifying the variability seen across different study designs, motor learning tasks and their complexity, retention intervals, sleep-dependent compared to sleep-independent consolidation, and age groups. Beyond helping to explain some of the observed variability, our findings may support tailored recommendations for enhancing motor memory formation in various contexts for older adults.

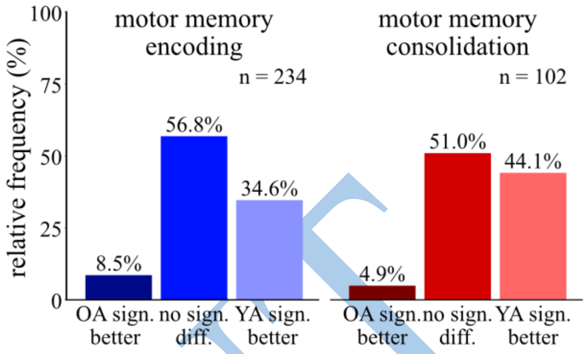

Figure 2: *Relative frequency of studies reporting significant differences between age groups regarding motor memory encoding and consolidation. diff. = difference, n = amount, OA = old adults, sign. = significant, YA = young adults*

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The Effect of Combined Motor Practice and Cardiovascular Exercise on Learning a Balance Skill in Parkinson's Disease

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Keywords

Motor learning, Neuroplasticity, Neurorehabilitation, Clinical research, Aerobic training

Highlights

- Improved motor memory formation with exercise in PD when individual performance is considered

Introduction

Parkinson's Disease (PD) is the second most common neurodegenerative disease, significantly affecting motor function and mobility. Goal-based motor practice is an integral component of non-pharmacological treatment in PD. The efficacy of this approach relies on the capacity to effectively encode and store the acquired motor information in long-term memory. However, motor memory deficits are a common feature of PD, thus significantly reducing the effectiveness of motor rehabilitation. As pharmacological treatment options are limited [1], methods that promote PD-related memory deficits are urgently needed. Petzinger et al. [2] postulated a model in which cardiovascular exercise (CVE) and motor skill practice work synergistically to enhance the formation of new motor memories. Data from our lab support this model by indicating that a single bout of CVE performed in close temporal proximity to motor practice may facilitate motor memory consolidation [3, 4]. Nevertheless, the potential benefits of combining skill practice with CVE over multiple sessions, and thus the potential for neurorehabilitation, have yet to be studied. Thus, the primary aim of this study was to investigate the effects of multiple sessions of combined motor skill practice and CVE in PD. We hypothesized that CVE would improve motor memory, resulting in enhanced learning of a novel balance task over the course of six practice sessions. In a secondary analysis, we examined whether these effects would be explained by improved between-session memory consolidation.

Methods

In this pre-registered randomized controlled trial (RCT, trial registration: NCT04653285), 24 people with mild-to-moderate PD (age: 63.4 ± 6.9 yrs.; age range: 52-77 yrs.; biological sex: 7 females; Hoehn & Yahr: 2.2 ± 0.4 pt.; UPDRS-III: 25.2 ± 9.1 pt.) participated in six practice sessions over the course of six weeks. Each practice session consisted of practicing the motor task, immediately followed by either (i) moderate-intense CVE (60% W_{max}) (EXE), or (ii) seated rest (REST) for 30 min, depending on group allocation. The motor task was a dynamic balancing task (stabilometer) that has been widely used in PD. Participants completed 15 trials per practice session and were instructed to keep the platform as close to the horizontal as possible during a trial. For the primary analysis, we quantified the time in balance (TIB; platform within ± 5° of horizontal) and then calculated the mean TIB (i.e., mean of 15 trials) for each practice session. The effects of CVE were analyzed using an a-priori planned 2 (GROUP: EXE vs. REST) x 6 (TIME: mean TIB session 1-6) ANOVA. Because motor performance data indicated large variability across participants, we conducted a sensitivity analysis using linear mixed models (LMM) with random intercept and slopes to provide a more powerful analysis that accounted for interindividual variance. For the secondary analysis of motor memory consolidation, we calculated the relative change scores from the last

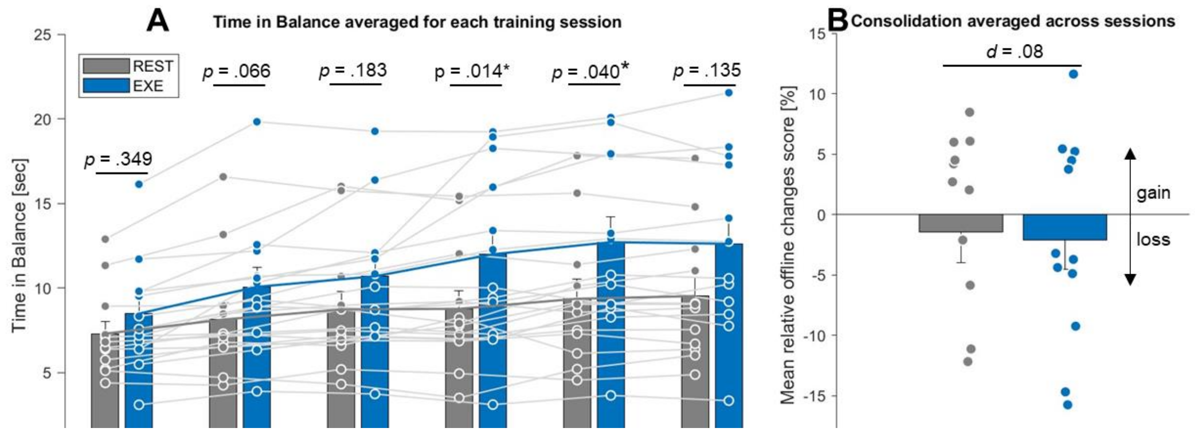

Figure 1: *A) Time in balance averaged across each practice session; B) Between-session offline change averaged across all practice sessions; p-values represent fixed effects of the LMM; * = sig. group difference.*

block of each practice session (X_i) to the first block of the subsequent practice session (X_{i+1}) and analyzed the data using mixed ANOVA.

Results

Both groups significantly improved performance over the six practice sessions (TIME: F(1.69, 37.21) = 19.61, $p < .001$, $\eta^2_G = .075$; Figure 1 A). The average improvement in the EXE group was 86% greater over the course of the six weeks (EXE: 4.1 ± 3.1 sec; REST: 2.2 ± 1.7 sec). However, the GROUP x TIME interaction effect was not statistically significant after Greenhouse-Geisser correction (F(1.69, 37.21) = 2.53, $p = .101$, $\eta^2_G = .010$). Notably, the sensitivity analysis using LMM to account for interindividual baseline differences indicated a significantly better performance of the EXE group in session 4 and 5 (session 4: $t(28.50) = 2.63$, $p = .014$; session 5: $t(24.57) = 2.16$, $p = .040$). The mixed ANOVA on memory consolidation showed no beneficial effect of CVE (GROUP: F(1, 22) = 0.04, $p = .845$, $\eta^2_G < .001$; TIME: F(4, 88) = 0.85, $p = .496$, $\eta^2_G = .030$; GROUP x TIME: F(4, 88) = 0.88, $p = .482$, $\eta^2_G = .031$, Figure 1 B).

Discussion

This is the first study to examine the effects of CVE on motor memory formation over multiple sessions in PD. Our preplanned analyses did not confirm an exercise-induced improvement in motor memory formation over six practice sessions. However, interindividual baseline differences were large, and a more powerful LMM suggested better performance gains in the EXE group in weeks 4 and 5. This preliminary data needs caution but lends some support for the idea that CVE may potentially improve motor memory formation when coupled in close temporal proximity to skill practice, and thus, could have practical implications for neurorehabilitation [1]. This, however, needs further confirmation and extension in better powered studies. Data on between-session offline changes did not confirm the hypothesis that enhanced learning was explained by improved memory consolidation.

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The Influence of Chronic Exercise on Motor Skill Retention in Parkinson's Disease.

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Keywords

Motor skill learning, Consolidation, Parkinson's Disease, Neurorehabilitation, Exercise.

Highlights

- Chronic exercise may improve motor memory consolidation in PD.

Introduction

Parkinson's Disease (PD) is the fastest-growing neurological condition on the planet, for which no available neuroprotective treatments are yet available. The hallmarks of PD are alpha-synuclein accumulation in the nervous system and loss of nigrostriatal dopaminergic neurons, which leads to the clinical motor manifestation of the disease [1]. In addition to cardinal motor signs, PD causes several other motor & non-motor symptoms, including motor learning deficits [2]. Motor learning, the ability to acquire and retain skilled movements, depends on optimal encoding and consolidation processes. Recent studies have shown that consolidation of new motor skills into long-term memory is impaired in PD, and interventions that can restore consolidation deficits are urgently needed [2]. Chronic exercise, which may have disease-modifying effects, can improve skill acquisition in this clinical population [3]. However, whether exercise can restore consolidation deficits is still unclear [2].

Methods

Data from ongoing RCTs, including 49 (F:M=21:28) people with PD tested "On-medications", were analyzed. Skill acquisition and retention were assessed using a tapping task (**Figure 1**) at baseline (T0) and after 12 weeks (T1) of either exercise or a waiting period (control). Participants performed two practice sessions (i.e., acquisition and retention) with their most affected hand at each time point (T0/T1). Two different sequences were implemented and counterbalanced between time points (2,3,1,4,2 & 4,1,3,2,4). Motor skill performance was calculated with a performance index (Pi) by combining speed and accuracy, with a higher Pi reflecting better performance. Skill acquisition was measured as the difference in Pi between the beginning and end of practice, while consolidation was the difference in Pi between the end of practice and retention test (i.e., positive values reflecting better consolidation). Participants also performed comprehensive motor, cognitive and sleep evaluations at both time points (see [4] for methods). Group differences at T0 were assessed using t-tests or Wilcoxon tests for continuous variables and Chi-square tests for categorical variables. Multivariate regression adjusted for key covariates (age, sex, disease duration, and levodopa equivalent daily dose) was used to investigate associations between initial skill performance (first block), skill acquisition and consolidation and clinical outcomes (SCOPA–cognition, Unified PD Rating Scale section III [UPDRS-III], and PD Sleep Scale 2) at T0. Linear-mixed models were used to investigate differences in initial skill performance, skill acquisition and consolidation between groups at the two time points. Statistical analyses were performed with JMP pro, version 17.

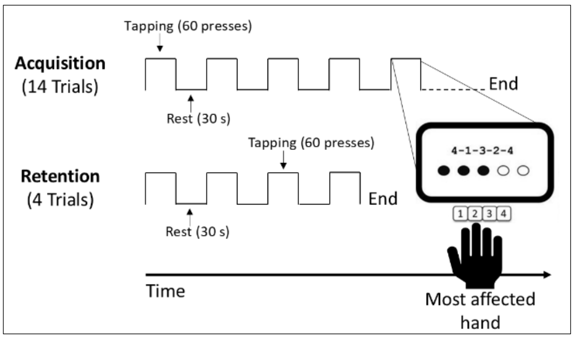

Figure 1: *Tapping task overview.*

Results

Out of 49 participants, eight were removed from the analysis because they were not able to perform the task. No statistical differences in age, years of education, disease duration, levodopa equivalent daily dose, UPDRS-III, SCOPA–cognition and fitness level ($p > 0.05$) were found between groups at T0. The proportion of females was significantly higher in the exercise group ($p = 0.02$). The initial skill performance ($p = 0.0325$) and skill acquisition ($p = 0.0211$), but not consolidation ($p = 0.0730$), were significantly associated with SCOPA-Cognition, indicating that participants with higher cognitive function had better initial Pi and more considerable Pi gains during practice at T0. Associations between tapping task outcomes and UPDRS-III did not survive after controlling for age, sex, disease duration, and levodopa equivalent daily dose, while no associations were found with the PD Sleep Scale 2. Linear mixed models showed no statistically significant differences between groups in initial skill performance at T0 and T1. Similarly, no statistically significant differences between groups were found in skill acquisition at T0 and T1. This result indicates that both groups had a similar ability to acquire a novel motor sequence at both time points. Finally, the model used to assess the effects of exercise on consolidation showed no statistically significant differences for random intercepts for subjects (variance = 0.15, $p = 0.51$), Timepoint (B = -45.03, SE = 40.17, $p = 0.27$) and Group (B = -38.25, SE = 48.47, $p = 0.44$). However, there was a significant Timepoint x Group interaction (B = 82.70, SE = 40.30, $p = 0.049$). Tukey HSD multiple comparisons indicated that only the exercise group significantly improved the ability to consolidate a new fine motor skill ($p=0.01$) at T1 (**Figure 2**), indicating that exercise may ameliorate consolidation processes in this clinical population.

Discussion

Our preliminary results indicate that, while no positive effects on skill acquisition were observed[3], chronic exercise may be a valuable intervention to enhance consolidation in PD. Additionally, our findings suggest that the tapping task may be a sensitive and relatively inexpensive test to assess treatments responses, disease severity and progression in the early disease stages. Future larger studies need to replicate and expand our findings (further considering the early PD phases[5]).

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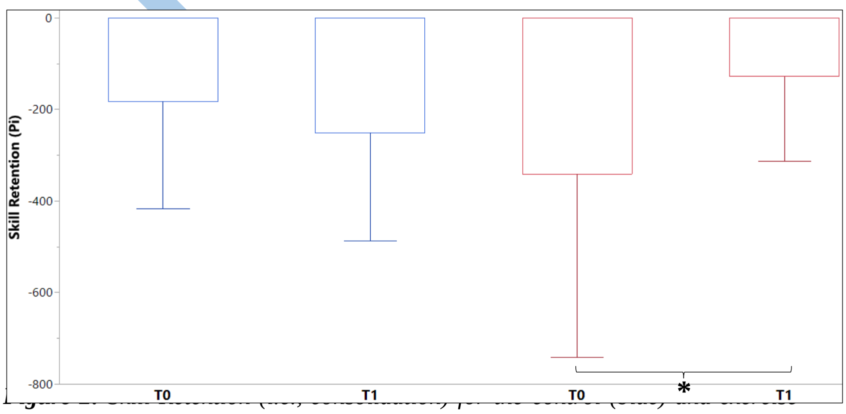

Figure 2: *Skill Retention (i.e., consolidation) for the control (blue) and exercise (red) groups at T0 and T1. Control: T0 = -182.14 ± 234.64, T1 = -251.08 ± 236.31. Exercise: T0 = -340.91 ± 399.90, T1 = -127.87 ± 185.43.*

Symposium:

Manual dexterity technologies – from musical and martial arts expertise to post-stroke rehabilitation

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This symposium will include four talks spanning motor control expertise and post-stroke rehabilitation of manual dexterity. (1) How the human motor system controls the position of a working point (WP) externalized from the body, using a traditional Taichi sword technique, is analyzed and discussed. Kinematic data from codified exercises were recorded to identify the WP based on velocity patterns along the sword's length. The results provide insights into motor control mechanisms for tool manipulation. (2) The theremin, an early electronic instrument, is unique as it is played without touch, sensing changes in the electrical field through antennas. This autoethnographic study examines three years of learning to play accurate and expressive melodies through free-hand gestures It highlights the challenges of mastering fine motor control and the roles of auditory feedback, proprioception, and imagination. (3) This study presents technology for the multi-component characterization of dexterity and effects from a pilot RCT study evaluating its efficacy on dexterity recovery post-stroke. The Dextrain Manipulandum™ tasks will be presented, including visuomotor force-tracking, finger tapping timing, and finger movement individuation. Training with device improved hand function and increased hand use at 3-month follow-up, beyond that achieved with conventional therapy. (4) A tool for the provision of haptic feedback (touch-based feedback) during dexterous tasks will be presented. Preliminary results comparing haptic influence on dexterity in healthy controls and stroke patients will be presented. Finally, the symposium will include an open discussion on the potential and barriers of implementing various technologies into clinical practice.

Control of a working point outside the body. A single case kinematic preliminary investigation of Taichi sword practice.

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Keywords

Motor skills and abilities, Sensorimotor performance, Upper limbs, Tool use, Martial art.

Highlights

- Taichi jian techniques with defense periods are examples of a working point moving outside the body.

Introduction

The question of redundancy is a fundamental basic question in motor control. However, it is often limited to that of interjoint coordination to achieve a goal directed trajectory of the extremity of the limb. Since Bernstein's seminal work on blacksmiths, it has been accepted that what is controlled is the functional extremity of the tool [1][2]. This implies that the technical object is incorporated into the body's schema [3]. The choice of a working point (WP) adds to the complexity of motor control. However, relatively little attention has been paid to the way in which the human motor system directs a working point externalized from the body. In this study, we take advantage of a traditional sword technique (Taichi sword or jian) in which the assumed position of the WP varies along the sword (i.e. in its reference system) depending on the practitioner's intention. Defense techniques require explicit control of the proximal third of the sword for blocking. The practice of codified exercises enables the instruction to be made explicit, with emphasis on mentalization.

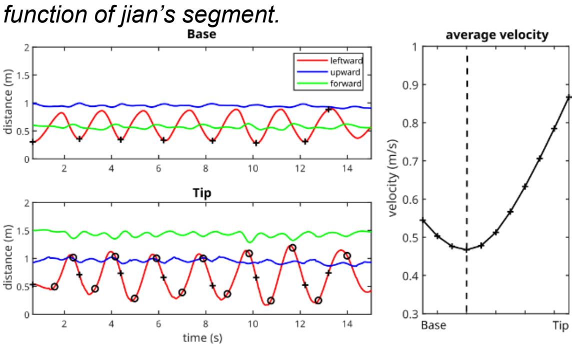
Our aim was to find a kinematic index that would allow us to objectify the position of the WP.

Methods

In this preliminary and exploratory study, we asked a regular Jian practitioner to perform some codified exercises. This abstract focuses on a planar horizontal exercise combining a translation and the explicit instruction to rotate the jian around a vertical axis "at its first third".

The 3D position of the extremities of the jian and its orientation (Euler angles) were recorded at 120 Hz with an Optitrak system (thanks to 4 clusters and geometrical computations) then decimated at 30Hz. Seven cycles were recorded. Our analysis focuses on the trajectory of the base and the tip of the jian (Figure 1, left) and the velocity (norm of the velocity vector) at the level of 11 segments along the jian (average over the whole sample, Figure 1, right).

Figure 1: *Left: 3D position of the base and tip of the jian. Crosses indicate arbitrary cycle start. Circles indicate the times of azimuth minima and maxima. Right: Average velocity for the whole sample as a function of jian's segment.*



Direct kinematic model was performed by 1) generating a minimum jerk trajectory of the displacement of the base 2) computing an azimuth value proportional to this trajectory 3) introducing a phase shift between these values 4) computing the tip position.

Results

The hypothesis was that the WP during the exercises could be characterized by the segment along jian's length with the minimum velocity. This indicates the segment where the component of translation was at a minimum. Velocity was averaged over the whole sample for each segment. Average velocity was effectively at a minimum at the end of the third section of the jian length (Figure 1, right). The minimum azimuth occurred 683.57 ms ± 118.55 after the maximum rightward displacement of the base (magenta dashed rectangle on Figure 2) and 193.29 ± 64.41 ms after the maximum displacement of the tip (blue dashed rectangle). The displacement of the tip was reconstructed with phase shifts of the azimuth signal by reference to the translation signal by 18° steps (~100 ms). Direct kinematic models show that the phase shift strongly influences the trajectory of the jian (Figure 3). The comparison between experimental and model data shows a comparable pattern with similar values when the phase shift is 120° (Figure 3).

Figure 2: Experimental (left) and model data (phase shift 120° and 180°). From top to bottom: azimuth, horizontal displacement and velocity of the base (blue) and tip (red).

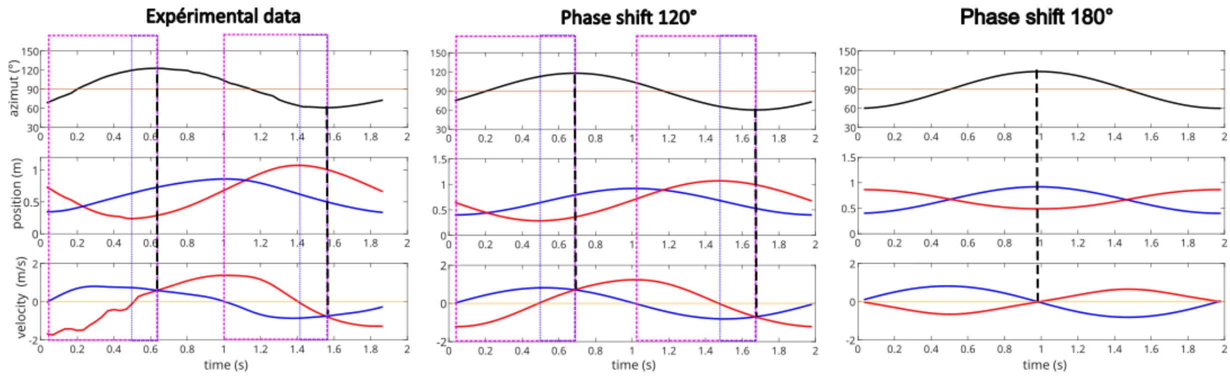
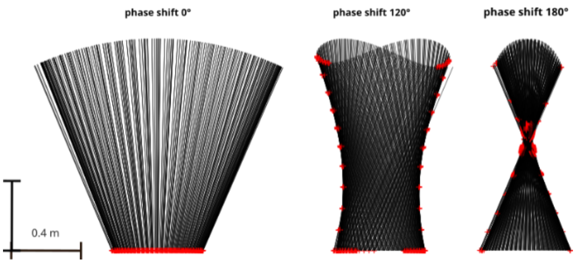


Figure 3: *Modeling jian displacement as a function of the phase shift between base translation and azimuth rotation. The red cross indicates the section with the lowest velocity norm.*



Discussion

This exploratory experiment demonstrates that it is possible to rotate a hand-held tool at the level of an intended position of its length. The position of the minimum velocity at the first third section is consistent with the hypothesis that the WP is situated at this level. This position is suitable for defense (blocking) actions. The direct kinematic models show that a sufficient condition in order to rotate the tool at a given level along its length is to introduce a phase shift between the translation and the rotation of the handle. The change in delay duration might be used to regulate the position of the turning point.

The limitation of this study is that it is based on recordings from a single person. Statistical analysis was not performed. Further studies are needed with expert participants to test the reproducibility of these results. Studies of more complicated 3D gestures are needed to test whether these results can be generalized.

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Measurement and rehabilitation of finger motor control after stroke

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Keywords

Manual dexterity, Interactive technology, Sensorimotor control, Stroke, Neurorehabilitation, Force control, Finger independence

Highlights

- Interactive manual dexterity method permits measurement and rehabilitation of key finger control capacities
- Manual dexterity impairments better explain activity limitations in stroke patients compared to conventional upper limb tests
- Rehabilitation with Dextrain device shows promising results for improving finger motor control and hand use

Introduction

Up to 50% of stroke patients still suffer from upper limb motor impairments in the chronic phase post-stroke, particularly impacting dexterous hand function [1]. Manual dexterity, an evolutionary feature of primates, refers to the fine, skillful use of the hand to grasp, and manipulate objects. It is expressed through coordinated hand and finger movements relying on sensorimotor integration [1, 2]. We developed an interactive kinetic method for measurement and rehabilitation of finger force control, rhythm tapping and independent finger movements [3]. A pilot randomized clinical trial was conducted in chronic stroke patients to study efficacy of targeted dexterity training [3]. From that study we investigated whether impairments in manual dexterity and finger proprioception could explain variance in post-stroke upper limb activity capacity better than conventional clinical sensorimotor assessments (reflecting global upper limb motor impairments) [4]. We also evaluated whether 12 sessions of training with Dextrain could lead to enhanced improvements in dexterity recovery compared to conventional occupational therapy.

Objectives

The aims were (i) to characterize multi-component dexterity recovery and (ii) to test the efficacy of targeted dexterity training post-stroke.

Methods

Participants: Forty-two late subacute (N = 8) and chronic stroke (N = 36) patients were recruited between 2018 and 2021 for this study. Inclusion criteria included presence of a single symptomatic stroke dating back >3 months, age >18 years, Box and Blocks score between 1 and 52 blocks/minute, no cognitive disorder (Mini Mental State Examination).

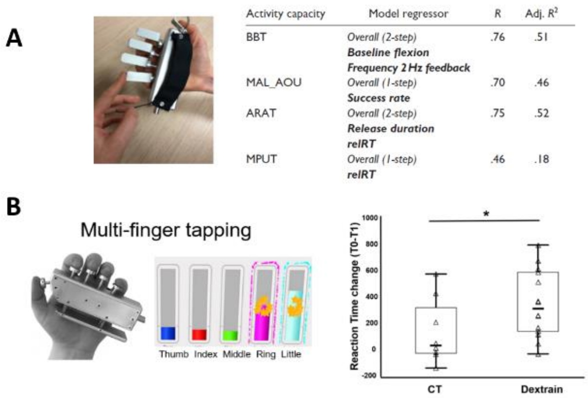
Dexterity impairments: The Dextrain Manipulandum ™ was used to quantify accuracy of visuomotor force-tracking, timing of finger tapping and individuation of finger movements. Finger proprioception was measured using a novel finger proprioception assessment.

Training: Consisted of 12 Dextrain or conventional therapy sessions over four weeks. Dextrain therapy consisted mostly of finger force tracking and multi-finger tapping tasks for 40 min followed by 20 min conventional therapy. The difficulty level of each exercise was adapted across the 12 training sessions, according to the degree of impairment of each patient. Conventional therapy (CT) consisted of 60 min of occupational hand and dexterity training.

Analyses: Stepwise multiple regression including manual dexterity and proprioceptive variables as well as clinical predictors were used to test whether manual dexterity and proprioceptive variables could outperform clinical variables in explaining variance in upper limb activity capacity. The efficacy of training was compared across Dextrain vs CT with primary outcome BBT-change (after–before training). The BBT-change was not normally distributed, so the Mood median test was used to compare treatment effect across groups. Secondary outcomes included changes in motor impairments, activity limitations and dexterity components.

Results

Dexterity and proprioceptive components significantly increased the variance explained in activity capacity (Fig. 1). Box and Block Test was best explained by baseline tonic force during force-tracking and tapping frequency (adjusted R^2 = .51). Motor Activity Log was best explained by success rate in finger individuation (adjusted R^2 = .46). Action Research Arm Test was best explained by release of finger force and proprioceptive measures (adjusted R^2 = .52). Moberg Pick-Up test was best explained by proprioceptive function (adjusted R^2 = .18). Excluding dexterity and proprioception variables explained up to 19% less variance.



Activity capacity	Model regressor	R	Adj. R^2
BBT	*Overall (2-step)*	.76	.51
	Baseline flexion		
	Frequency 2 Hz feedback		
MAL_AOU	*Overall (1-step)*	.70	.46
	Success rate		
ARAT	*Overall (2-step)*	.75	.52
	Release duration		
	relRT		
MPUT	*Overall (1-step)*	.46	.18
	relRT		

Figure 1A: *proprioception task and multiple regression analyses showing that specific finger sensory and motor control impairments explain activity limitations.* ***B:*** *Training results showed enhanced recovery of finger individuation speed in the multi-finger tapping task.*

The training comparison showed a non-significant trend for enhanced BBT-change in the Dextrain group at 3-month follow-up (median [CL95%] = 3[-1 − 7.0], P = 0.06). Reported hand-use (Motor activity log) showed greater change in Dextrain group at 3-months (median/IQR = 0.7/0.2 – 0.8 vs 0.2/0.1 – 0.6, P = 0.05). Finger force control tracking precision showed greater improvement in Dextrain group (mean ± SD = 0.3 ± 0.3N vs - 0.1 ± 0.33N; P < 0.0018) and so did independent finger movements (34.7 ± 25.1 ms vs 7.7 ± 18.5 ms, P = 0.02) and maximal finger tapping speed (8.4 ± 7.1 vs 4.5 ± 4.9, P = 0.045).

Discussion

The multiple regression analyses showed that manual dexterity and finger proprioception explain unique variance in activity capacity not captured by conventional impairment measures and should be considered to delineate underlying mechanisms of post stroke activity capacity limitations. The pilot randomized controlled trial investigating the efficacy of dexterity training showed promising tendency for enhanced gross dexterity recovery (measured with clinical BBT). Dexterity training also enhanced recovery of several dexterity components and reported hand-use. Findings need to be confirmed in a larger trial.

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Haptic stimulation effects on finger tapping, cortical excitability and inhibition in healthy controls and stroke patients

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Keywords

Sensorimotor performance, Upper limbs, Neurorehabilitation, Stroke, Haptic effect

Highlights

- Vibrotactile stimulation might have an impact on manual dexterity performance

Introduction

Stroke is the leading cause of acquired disability in adults worldwide often causing impaired manual dexterity, described as fine motor skills of the hand and fingers. Currently, there is an emerging interest in personalized rehabilitation targeted to the patient's specific impairments across sensory, cognitive and motor domains. These impairments together enhance prediction of upper limb motor recovery [1]. Sensory impairment can explain additional variation in dynamic precision grip force recovery, beyond that explained by degree of stroke injury to the corticospinal tract [2]. Moreover, recent studies show that stroke lesions to frontoparietal circuits, important for sensorimotor integration, also partly explain post-stroke hand motor deficits. In addition, studies show that tactile and proprioceptive feedback is important for planning and execution of hand movements. A haptic deficit, that is the use of tactile feedback for initiation and control of movements, could be a factor impacting dexterity in post-stroke patients. Stimulation of the somatosensory network during rehabilitation could have an impact not only on sensory recovery but also on the recovery of motor functions after stroke [3]. We therefore hypothesize that haptic effect, described as the improvement of fine motor control through tactile sensory feedback, will be impaired in chronic stroke patients compared to healthy controls.

Methods

This multicenter study will include 60 healthy controls and 30 chronic stroke patients (> 6 months post-stroke) with mild to moderate motor impairment at the upper limb and no cognitive deficits.

Manual dexterity is measured with clinical assessments including the Box and Blocks Test (BBT) and the Purdue Pegboard Test (PPT). We also measure bilateral maximal grip force using a Jamar dynamometer.

The haptic effect is measured as the difference between multi-finger tapping task performance with and without vibrotactile stimulation applied to the fingers. Sensory stimulation is provided through a haptic device we developed, and the multi-finger tapping task is assessed using the Dextrain manipulandum ®. The haptic effect is measured as the reaction time (RT) to a finger tapping cue and the subject was asked to press as fast as possible. Three types of cues were compared: (i) Haptic (with a vibratory cue to the finger only), (ii) Visual (with a visual cue only) and (iii) Visual + Haptic with a visual and vibratory cue, given at the same time) (figure 1A).
Motor cortex excitability and inhibition was measured during the task with Transcranial Magnetic Stimulation (Magstim BiStim2 device). Motor Evoked Potentials (MEP) were recorded

from four hand muscles using surface EMG electrodes (first dorsal interosseous, abductor digiti minimi, flexor carpi radialis, and extensor carpi radialis) (fig. 1B). Short-latency intra-cortical inhibition (SICI) was also measured using double-pulse technique with a delay of 2ms.

Planned analyses include inter and intra group analysis of the haptic effect on reaction time during the finger tapping task using repeated measures ANOVA. Pearson correlations will be used to test correlation between haptic effect, reaction time in finger tapping and conventional clinical tests (BBT, PPT, Maximal Grip Force). For TMS data, MEP amplitude will be compared between groups with t tests, regarding cortical excitability and SICI.

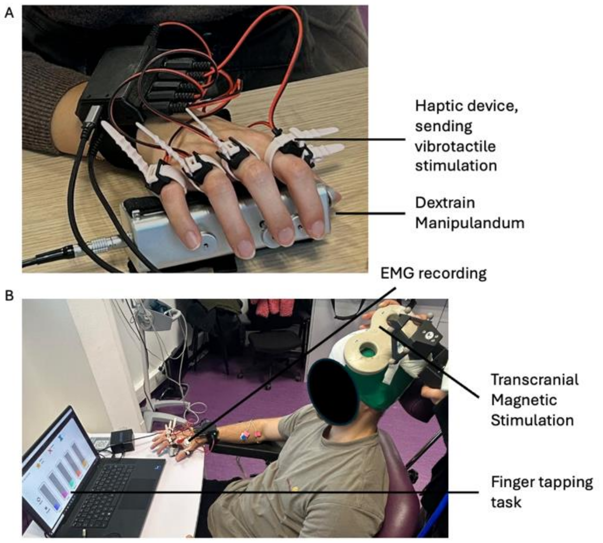

Figure 1: *A: Haptic device showing positioning of finger vibrators on the dorsum of each finger. The finger tips are positioned on the pistons of the Dextrain Manipulandum. B: Transcranial Magnetic Stimulation (TMS) allows measurement of MEPs during a finger tapping task.*

Results

Inclusion started in July 2024. We included 24 healthy controls (mean age 27.6 ± 5.28 years), of which 11 also underwent TMS measurements. Preliminary data are summarized in this paper and full results will be presented (table 1).

Table 1: *demographic data and clinical assessments*

N=24		Mean	Standard deviation
Age (years)		27.6	5.28
Gender (M/F)		13/11	/
Max. Grip Force (kg)	Right	41.29	13.12
	Left	37.66	13.37
BBT (blocs/min)		68 .21	6.52
PPT (nb of pieces)	Dominant	15.75	1.29
	Non dominant	14.71	1.51
	Bimanual	12.29	1.43
	Assembly	37.96	5.49

Preliminary calculation of the RT in the 3 conditions was done on 17 healthy controls. Haptic and Visual had similar RT (mean±SD: Haptic: 0.69s ± 0.22s; Visual: 0.66s ± 0.13s; p=0.478) but in the condition Visual + Haptic, RT was shorter (0.50s ± 0.11s, with Visual RT vs Visual + Haptic RT: p<0.001 and Haptic RT vs Visual + Haptic RT: p<0.001).

The average Haptic Effect on RT during a finger tapping was 0.16s ± 0.07s, showing a motor facilitation induced by haptic stimulation of around 0.16s.

Discussion

These preliminary findings showed that measurement of haptic effect is feasible in young healthy controls during a finger individuation task. Our findings, in line with literature, showed that vibrotactile stimulation might have an impact on manual dexterity performance, reducing RT [4]. More results on haptic effect and TMS measurements will be presented.

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Symposium:

Motor Control and Learning for Rehabilitation

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The symposium “Motor Control and Learning for Rehabilitation” brings together experts in neuroscience, robotics, and clinical neurorehabilitation to explore groundbreaking approaches for restoring motor function in individuals with neurological impairments. Focusing on the integration of advanced motor control theories with robotics and clinical practices, the session will highlight how neurophysiological insights and engineering innovations are reshaping the rehabilitation landscape. Topics will include cutting-edge techniques in electromyography and biomedical signal processing for accurate neural decoding, enabling adaptive human-machine interfaces and neural prosthesis control. Presentations will also cover AI-driven robotic systems designed for physical human-robot interaction, allowing personalized motor learning and real-time adaptation to patient needs. In addition, the symposium will emphasize clinical applications of these technologies in stroke, brain injury rehabilitation and subjects with limb loss to support functional recovery. This interdisciplinary forum will provide attendees an opportunity to discuss recent advancements in robotics-driven neurorehabilitation, highlighting practical applications that connect research with everyday clinical use. Attendees will have the chance to learn from experts about how these developments are changing therapy and making it easier to tailor treatments to individual needs. By focusing on the practical side of these technologies, the symposium aims to encourage new ideas for helping patients recover and improve their mobility and overall quality of life.

Presentations will be given by Prof. Dr. Alessandro del Vecchio (FAU), Prof. Dr. Silvia Muceli (Chalmers University), Dr. Johannes Lachner (MIT), and Dr. Federico Masiero (TUM).

Validation of an implanted remotely actuated magnetic human-machine interface to study kinesthesia in limb amputees

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Keywords

Kinesthesia, Sensorimotor Perception, Human-Machine Interface, Clinical research

Highlights

- We developed a robotic system to induce remote vibrations to magnets implanted in forearm muscles.
- We assessed the system capability in selectively vibrating magnets at the desired frequency for different amplitudes.
- The system will be soon tested in a clinical trial with a trans-radial amputee.

Introduction

Designing functional and intuitive Human-Machine Interfaces (HMIs) to control robotic limbs still represents a significant challenge in prosthetics research. While past studies have largely emphasized restoring touch, there remains a considerable gap in understanding the potential benefits of proprioception for amputees [1]. Kinesthesia is studied by non-invasively applying 70-115 Hz vibrations to muscles or tendons [2], but this method makes it difficult to distinguish muscle proprioception from skin sensations.

We recently demonstrated an HMI based on permanent magnets implanted in residual forearm muscles of a trans-radial amputee to control a robotic hand in real-time [3]. We dubbed this the *myokinetic interface*. Beyond control, this HMI enables kinesthetic sensations by vibrating the implanted magnets using external coils [4]. In this way, muscle proprioceptors can be triggered without simultaneously recruiting the responses of skin mechanoreceptors.

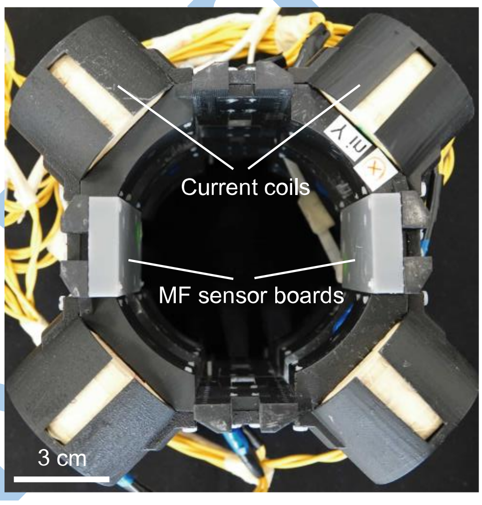

Figure 1: *Bench device to deliver magnetically-controlled vibrations.*

In this work, we present the validation of a clinical platform to deliver kinesthesia by simultaneously tracking and selectively vibrating multiple target magnets implanted in the forearm muscles of an amputee.

Methods

We present the design of a bench device (Fig. 1), fitting the 99th percentile male forearm, to induce selective vibrations into remote moving magnets within a wide frequency range (60-100 Hz) including the one that triggers kinesthesia. Vibrations are produced by controlling an external magnetic field (MF) generated by 12 current

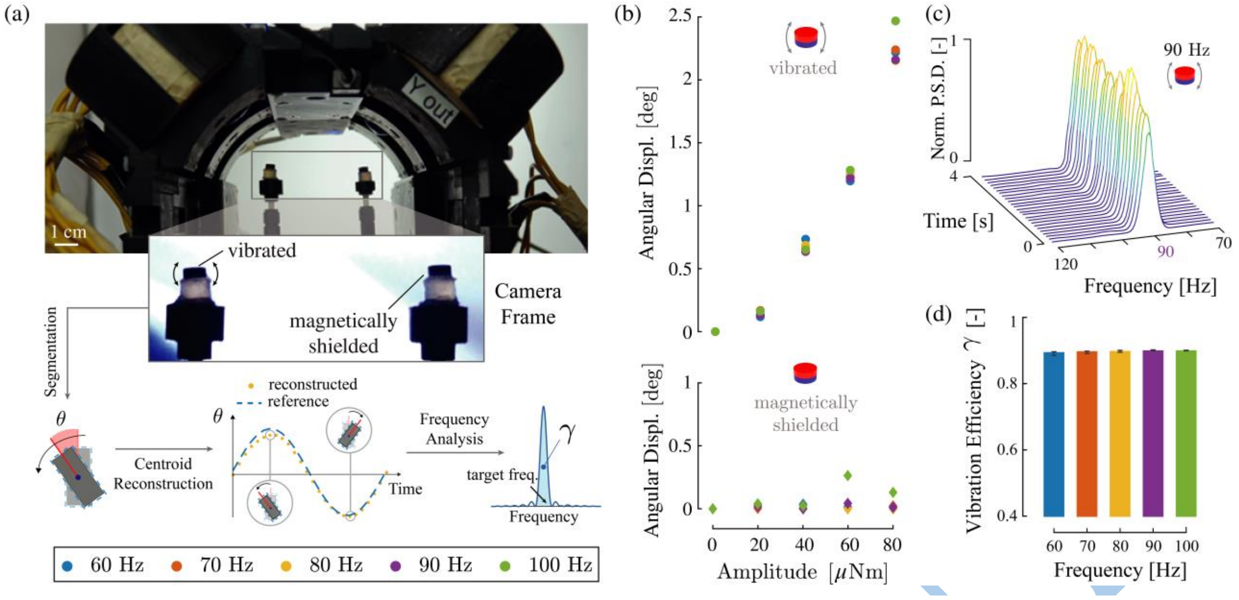

Figure 2: *(a) Experimental setup and video analysis. (b) Angular displacements induced on the magnets while focusing the vibration on one and magnetically shielding the other. (c) Representative example of power spectral density of a recorded 90 Hz vibration. (d) Vibration efficiency across the tested frequencies (60–100 Hz).*

coils, which interacts with the implanted magnets. Simultaneously, the positions of the magnets are tracked using 4 MF sensor boards for real-time adjustments of the induced vibrations.

Two magnets (4 mm far from each other) lying on the plane of the camera were located in three distinct locations inside the system. Camera recordings at 1000 fps were performed while focusing sinusoidal vibrations on a single magnet (torques: 20, 40, 60, 80 µNm, frequencies: 60, 70, …, 100 Hz) and magnetically shielding the other (Fig. 2). Videos were then analyzed to extract magnets motion and compute the system actuation efficiency (as in [4]).

Results

The system successfully focused vibrations on the target magnet while magnetically shielding the other. As a result, vibration amplitudes were detected only in the target magnet, with null or negligible displacements observed in the shielded magnet (Fig. 2b). In addition, the amplitudes of magnets vibration were maintained constant regardless of the imposed frequency (Fig. 2b). Moreover, the induced vibrations were always delivered at the desired frequency (Figure 2c,d), showing high levels of torsional efficiency (around 0.9, meaning that 90% of the vibration spectral power was located at the target frequency) in all tested conditions.

Discussion

This study demonstrates the feasibility of selectively vibrating multiple static remote magnets with precise amplitudes and frequencies. Additional tests will be soon conducted in moving magnets to affirm the functionality of a novel instrument poised to study kinesthesia in amputees with myokinetic implants. This device will soon serve as a tool for evoking proprioceptive sensations in trans-radial amputees, deepening our understanding of kinesthesia and opening new horizons for sensory-motor restoration.

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Symposium:

Sensory feedback in human-machine interaction and prosthetics

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When we hit a tennis ball with a racket, we see the ball hit the racket, we hear the sound the racket's strings produce, and we feel the forces generated during the collision. This single event generates multiple physical signals that are captured by our sensorimotor system through multiple sensory modalities. One advantage of having similar information coming from different sensory modalities is the ability to reduce uncertainty regarding the state of the body or the environment using multisensory combination. In such a case, the estimated state uncertainty using the combined information is lower than the estimated state uncertainty of each single sensory modality. However, there is evidence for cases in which the sensorimotor system chooses to rely on a single sensory modality instead of the combined information. This raises questions of when and why cue combination is beneficial. To answer this, we will present several studies examining these questions while using and interacting with robotic systems. Specifically, we present results about sensory combination in prosthetic devices, robotic surgery training, robotic sensory enhancing devices, and during human-machine collaboration.

Adaptation to Periodic Motion Perturbations in Robot-Assisted Minimally-Invasive Surgery Training

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Keywords

Health, Robotics, Motor learning, Surgical Robotics, Sensorimotor Adaptation.

Highlights

- Training with motion perturbations significantly improved participants' skill learning compared to training without perturbations.

Introduction

In robot-assisted minimally-invasive surgery (RAMIS), surgeons utilize robotic manipulators to control instruments inserted through small incisions in the patient's body. While RAMIS offers many benefits, achieving these benefits requires adequate training. Efforts have been made to optimize the technical skill acquisition of RAMIS surgeons; however, the best training methods are still unknown. Insights from motor learning studies can help address this gap, but most of the studies are based on simple motor tasks, and it is unclear whether their findings can be generalized to the complex movements required in surgery. A significant knowledge gap remains regarding how surgeons cope with time-dependent motion perturbations, such as those caused by heartbeats. While surgeons report that they adapt to these disturbances with experience, motor learning studies indicate that there is no adaptation to time-dependent perturbations [1]. Understanding how surgeons cope with these perturbations is vital for developing effective training programs. Current training methods, including dry and wet lab training, often do not replicate the challenges posed by organ movements. This study aims to investigate the effects of motion periodic perturbations on learning in a dry-lab surgical training task. This abstract summarizes part of the study published in [2].

Methods

In this study, we used the da Vinci Research Kit (dVRK), a development platform for researchers in the field of RAMIS [3] (Fig. 1.a). Participants used the dVRK to operate curved scissors and a large needle driver and were required to cut a 5 cm diameter circle on gauze (Fig. 1.b). In some trials, they were exposed to motion perturbations – movement of the task platform up and down.

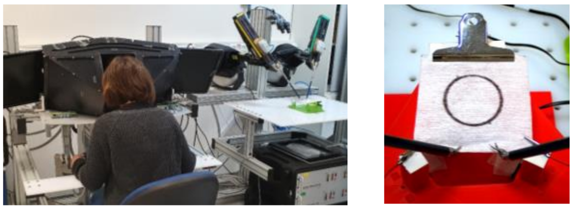

Figure 1: *(a) The da Vinci Research Kit (dVRK). (b) The pattern cutting task.*

Twenty-four volunteers participated in the study, with twelve randomly assigned to the experimental group and twelve to the control group. The experiment consisted of three types of trials: **Baseline (B)**, which included 5 trials without perturbations to assess baseline performance; **Training (T)**, consisting of 10 trials where the control group trained without perturbations and the experimental group trained with 1Hz perturbations; and **Post-training (P)**, comprising 9 trials to evaluate the effects of training on performance. The first three post-training trials (P1) were without perturbations, the next three (P2) included 1Hz perturbations, and the last three (P3) presented unpredictable perturbations, which were a combination of five sine waves, to assess resistance to new perturbations. *Errors* were quantified using a custom MATLAB image processing algorithm that counts pixels in areas where the cutting deviated from the intended line. *Task time* was measured from the first cut to the last. The *combined error-time* (*CET*) metric for each trial was calculated by normalizing the task time and errors against their averages and standard deviations across all trials, and then summing them. Lower *CET* values indicate better performance, with the expectation that participants would improve in speed and accuracy through practice, leading to a decrease in this metric during training. Due to the non-normal distribution of the metric, we employed permutation tests for statistical analysis. For detailed information regarding the tests, please refer to the full paper [1].

Results

During the training phase (T), participants from both the control and experimental groups significantly improved their *CET* scores (p = 0.013 and p = 0.036). After the training (P1), no significant difference was observed between the *CET* scores of the control and experimental groups (p = 1). This result indicates that training with perturbations did not impair performance upon their removal. Individual differences in *CET* scores between trials with 1Hz perturbations (P2) and those without perturbations (P1) showed significant differences between the groups (p=0.011). A significant difference was observed between the groups when comparing individual scores from trials with unpredictable perturbations (P3) to those without perturbations (P1) (p = 0.03).

Discussion

We investigated the effects of periodic motion perturbations on learning a RAMIS training task. Participants trained under motion perturbations showed significant improvement in *CET* scores. The performance levels of both control and experimental groups were similar after training, suggesting that learning to cope with these perturbations did not hinder overall skill acquisition. Importantly, participants who trained with perturbations demonstrated an advantage over the control group when faced with both familiar and new perturbations. Our study highlights the potential for training with periodic perturbations to enhance RAMIS skill acquisition, demonstrating that such methods can prepare trainees for the dynamic environments encountered in real surgical settings.

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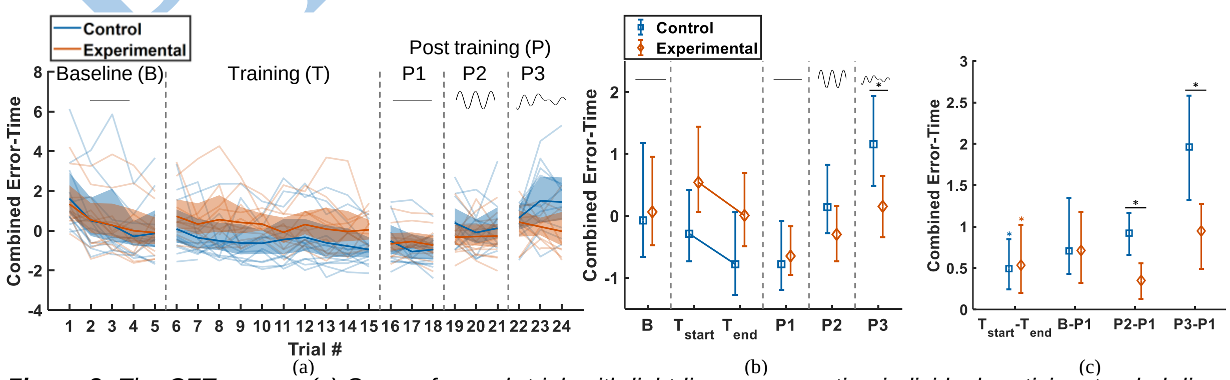

Figure 2: *The CET scores. (a) Scores for each trial, with light lines representing individual participants, dark lines indicating means, and shaded areas showing 95% bootstrap confidence intervals. (b) Average values for different experiment phases. (c) Average individual differences between phases. Markers represent means, and error bars indicate 95% bootstrap confidence intervals. Statistically significant values are marked by asterisks.*

Haptic Communication and Role Dynamics in Human-Human and Human-Robot Collaboration

Yiming Liu [a,d], Raz Leib [a], David W. Franklin [a,b,c]

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Keywords

Motor Control, Robotics, Virtual Reality, Haptic Communication, Human-Robot Collaboration.

Highlights

- Humans use haptic communication to enhance interpersonal coordination in physical collaboration.
- Collaborating humans adopt leader and follower roles, adjusting these roles dynamically based on partner behavior and communication quality.

Introduction

In recent years, there has been a growing emphasis on developing robots capable of physical collaboration with humans in daily life and industrial settings. Achieving mutual understanding between humans and robots requires deeper insight into human interpersonal interactions, particularly how we collaborate, communicate, and adapt to each other [1, 2]. Research over the past two decades has underscored the importance of haptic feedback as a communication channel through which humans can infer their partners' movement intentions and status, enhancing coordination [3].
To extend research from simplified tasks to complex object manipulation, we designed a task based on the classic ball-beam control problem, requiring participants to coordinate closely with their partners. Our studies explored how haptic communication influences interpersonal coordination, role distribution, and strategy adaptation in collaborative tasks.

In the first study, we asked two human participants to collaborate under different haptic conditions [4]. We analyzed their collaboration patterns under different haptic conditions and the emergence of leader-follower roles. In the second study, participants collaborated with non-adaptive artificial agents, allowing us to observe how humans adjust their control strategies in response to different agent behaviors [5]. These studies provide new insights into the role of haptic communication, offering guidance for designing adaptive robots that better understand and anticipate human behavior through haptic interaction.

Methods

The experiment was conducted in a virtual reality environment. Participants used two haptic devices (Phantom Touch, 3D SYSTEMS) to control each end of the board and perceive force feedback (Fig. 1). The task required moving a ball on a board into a target area and stabilizing it as quickly as possible. The task was performed under two pairing conditions: bimanual (a single participant using both hands) and dyadic (in human-human or human-agent teams).

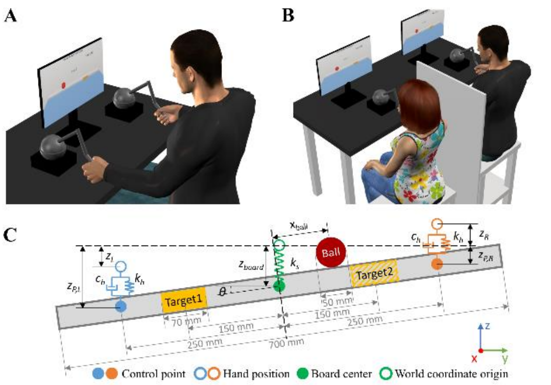

Figure 1: *The experimental setup. A) The bimanual condition. B) The dyadic condition. C) The dynamics of the virtual experiment model.*

In the first study, two participants collaborated across five haptic feedback conditions: full haptics, partner only, environment only, no haptics, or unrelated haptics.
In the second study, participants collaborated either with or without haptic feedback, with artificial agents that are either more active or more passive than the participants.

Results

We found that participants exhibited similar task performance in terms of completion time, regardless of the availability of haptic feedback. However, when haptic feedback was provided, participants demonstrated improved coordination, indicated by more cooperative behavior ($p=0.02$), less competitive behavior ($p<0.001$) and better synchronization ($p=0.03$). This enhanced coordination was primarily driven by partner-sourced rather than environment-sourced haptic feedback. Participants also naturally adopted leader-follower roles during collaboration, despite having symmetric information and mechanical leverage. We used four different metrics to quantify leadership, consistently identifying each participant's role as leader or follower. The participant with better individual skills typically became the leader in the collaboration and gradually became more dominant as the experiment progressed. When collaborating with artificial agents, participants adjusted between leader and follower roles based on the agent's behavior. Notably, coordination improved only when humans acted as followers, not leaders. Additionally, in the absence of haptic feedback, leaders became more dominant and followers more passive, suggesting a potential coping mechanism for low-quality communication.

Discussion

Our studies extend research on haptic communication from simplified tasks to a more complex scenario involving the manipulation of an object with internal degrees of freedom. Our findings highlight the distinct roles of each source of haptic feedback in collaborative tasks, demonstrating different effects of haptic communication on leaders and followers. These results provide novel insights into human collaboration, emphasizing the unique impact of different haptic feedback sources on coordination and role dynamics. A deeper understanding of the human interactions can guide the design of human-centered robotic systems.

Acknowledgement

This work was supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - project number 467042759 and the Imperial-TUM Joint Academy of Doctoral Studies (JADS), where YL was supported by the TUM International Graduate School of Science and Engineering (IGSSE).

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Manipulating Tactile Sensory Feedback Affects the Perception of Delayed Stiffness

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Keywords

Motor control, Motor cognition, Robotics, Perception, Multisensory integration.

Introduction

Information transfer in bilateral teleoperation systems suffers unavoidable delays caused by the distance between the operator and the remote robot. The effects of delay on the system were widely studied in the context of stability, with increasing attention to the impact on the human operator and their perception of mechanical properties. For example, a surgeon may use the perception of the mechanical properties of a tissue for diagnosis as well as to determine how strong they need to grip a scalpel while cutting it. One mechanical property that we need to estimate in such cases is stiffness, i.e., the ratio between the distance the tool traveled into the object and the force feedback from the object.

Information delay, such as in a teleoperated system, greatly affects stiffness perception. In this case, as we move and interact with a tissue, the force feedback that we receive is delayed. In such a case, the delayed force feedback generates a nonlinear relation between force and distance traveled into the tissue, which makes us underestimate the tissue's stiffness [1].

When estimating external force applied to us, we rely on two primary force-sensing modalities: kinesthetic and tactile. The kinesthetic information is sensed by muscle spindles and Golgi tendon organs, which also provide information regarding the arm's position, while tactile information is sensed by cutaneous mechanoreceptors in the skin.

Interestingly, amplifying the tactile sensory feedback has a reverse effect on stiffness estimation compared to information delay. We overestimate stiffness when the skin is stretched more than usual [2]. This suggests that artificial skin stretch can help overcome the possible perceptual bias of stiffness surgeons experience during teleoperated surgeries. We hypothesize that during a stiffness estimation task when participants experience force feedback delay, introducing and tuning artificial skin stretch [3] could reduce or eliminate the perceptual bias caused by the delay.

Methods

We used a stiffness perception task implemented using a virtual reality setup. Participants held a skin stretch device that was mounted on a robotic device. The robotic device recorded the hand position and generated forces to simulate the objects (Figure 1A). The skin stretch device (based on the design in [2]) was used to artificially stretch the skin of the index and thumb fingers that were used to hold the device (Figure 1B). The skin stretch device also had a force sensor to record the applied grip forces (data not presented here).

During the task, we asked participants to interact with two elastic objects and decide which object is stiffer (2-alternative force choice paradigm). The participant had to probe each object, each of which had a different color, and answer which is the stiffer object by indicating the object's color. We used a *comparison* object with a stiffness value of 85N/m and compared it with eight standard objects with stiffness values ranging between 50-120N/m.

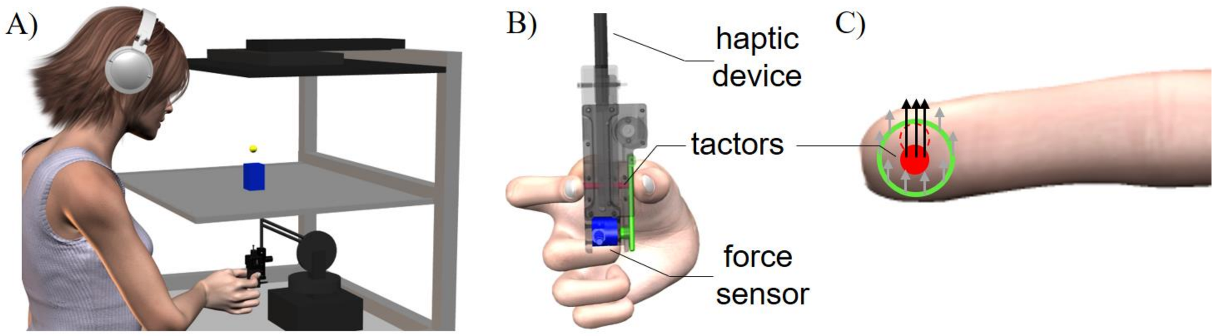

Figure 1: *Experimental setup. A) participants held the skin stretch device while observing a virtual blue or red object. Participants were asked to move vertically so they could press and release the virtual elastic object. They could not see their hand or the deformation of the object during movement. B) The skin stretch device was assembled from a motor that moved two tactors (red) that were in touch with the skin of the index and thumb fingers. C) To create an artificial, elevated skin stretch, the tactor (red circle) stretches the skin by moving upward (dashed red circle). This motion stretched the skin that was in touch with the tactor more than the natural stretch of the surrounding skin that was in touch with the aperture of the tactor (green circle).*

The force each object produced when participants pressed and released it was calculated using Hooke's law $F(t) = -k \cdot (x(t) - x_0)$ where k (N/m) is the object's stiffness, and x_0 (m) was set individually outside of the reachable area so participants will experience continuous force during the interaction. x(t) (m) represents the position of the hand. We similarly calculated the force to simulate an elastic object with delayed force feedback, using a delayed hand position signal. That is, the equation was $F = -k \cdot (x(t-\tau) - x_0)$ where τ is the delay value set to 50ms. The artificial skin stretch was generated using two tactors that were in touch with the skin of the index and thumb fingers. The amount of stretch depended on the hand's position and was calculated according to $S = -g \cdot (x - x_1)$ where g (mm/m) is the skin stretch gain, which was set to 40mm/m. x_1 was set based on the start position of the probing movement into the object. During the experiment, the force-position relation for the standard objects was always calculated according to Hooke's law (i.e., a spring). For the comparison object's force-position relation, we had three conditions: (i) spring, (ii) spring with delayed force feedback, (iii) spring with delayed force feedback, and skin stretch.

Results

We show that the artificial skin stretch reduces the bias created by the delayed force feedback. As expected, we found that objects' stiffness was underestimated when force feedback was delayed. Amplifying the skin stretch during interaction reduced this bias and, in some cases, made participants overestimate stiffness.

Discussion

This study sheds light on the processes that underlie the representation of mechanical properties of the environment around us during manual exploration and how haptic devices can manipulate them. These processes are critical for a basic understanding of the human sensorimotor system and for designing efficient human-machine physical interaction devices for various applications such as teleoperation, haptic simulation, and robotic rehabilitation.

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Symposium:

Technik und Taktik im Leistungssport der Sportspiele

Karen Zentgraf[a]

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In diesem Symposium werden verschiedene leistungssportlich relevante Aspekte der Technik und Taktik beleuchtet. Von der Kölner Gruppe wird zum Bereich Individualtaktik das Entscheidungsverhalten mithilfe des Optionsgenerierungsparadigmas in zwei Sportarten, unter anderem mit Spitzensportlerinnen und -sportlern aus dem Leistungssportprojekt „in:prove“, beleuchtet. Fokussiert wird auch die Relevanz, die diese Leistungskomponente für Spielsportathletinnen und -athleten im Besonderen hat. Im Bereich Technik werden vornehmlich Überkopfbewegungen, also Schlagbewegungen, bewegungsanalytisch betrachtet. Die Grazer Gruppe wird auf die Armzugbewegung beim Angriffsschlag von Männern fokussieren, die Frankfurter Gruppe stärker auf die Kinematik der gesamten Angriffsschlagaktion und ihre Leistungsvoraussetzungen im Bereich Kraft. Karen Zentgraf wird als Moderatorin des Symposiums einen kurzen Abriss zu internationalen Forschungsthemen im Bereich Technik und Taktik der Sportspiele geben, um die Originalarbeiten der Autorinnen und Autoren dieses Symposiums besser einordnen zu können.

Kinematic analysis of different arm swing techniques during spikes in competitive volleyball players

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Keywords

Sport, Motor Skills and abilities, Upper limbs, Spike, Shoulder

Highlights

- We observed clear differences in the elbow trajectories between techniques
- We identified differences in situations of varying complexity highlight challenges in applying unfamiliar techniques

Introduction

Already since the 1970s scientists reported substantially different arm swing techniques in competitive volleyball players [1]. These techniques were called elevation and backswing style respectively and show specific differences during the wind-up and cocking phase. Decades later, Seminati et al. [2] investigated these techniques regarding kinematics and ball speed and observed advantages of the backswing technique with regard to safety and performance. Recently, Giatsis & Tilp [3] reported even five distinct techniques in world class volleyball players defining the techniques by the relation of shoulder, elbow, and hand positions. The most prominent difference is that during the wind-up phase, the elbow is positioned above the shoulder in the three elevation-style techniques (Straight, Bow and Arrow high, Bow and Arrow low) but at the same level or below the shoulder in the two backswing-style techniques (Snap, Circular). Looking at the kinematic data presented in [2], it seems that the backswing techniques applied by the players do not fully coincide with these definitions as the elbow was above the shoulder in both techniques. Furthermore, differences between the techniques were greater when players performed them in a standing position without a ball compared to a real-life simulation of a spike including a ball. It appears that players had difficulties to apply the technique they were not familiar with. However, identifying the differences between techniques requires players to execute each technique correctly for accurate comparison. Therefore, our aim was to compare the elevation and backswing techniques and ensure that the applied techniques are in line with current definitions [3]. Furthermore, we investigate if competitive volleyball players are able to apply arm swing techniques correctly during spikes in easy (standing without ball) and complex (jumping with ball) tasks.

Methods

The kinematics of arm swing movements from 15 semi-professional male volleyball players were examined. We asked the players to perform both an elevation-style and a backswing technique. For each technique, the players completed two attempts while standing without a ball (easy task) and two attempts while jumping and spiking a thrown ball across the net (complex task). The players' movements were recorded using a Qualisys 3D motion capture system. The shoulder flexion angle and the position of the elbow in relation to the shoulder were calculated using Visual 3D software. For comparisons, the start and end of the movement were defined based on shoulder flexion angles and the movement was standardized to a duration length of 100 values using a Matlab script. Thus, 30 attempts were recorded for each of the four movement types. Two attempts per type had to be discarded due to incorrect movements. Hence, 28 attempts for

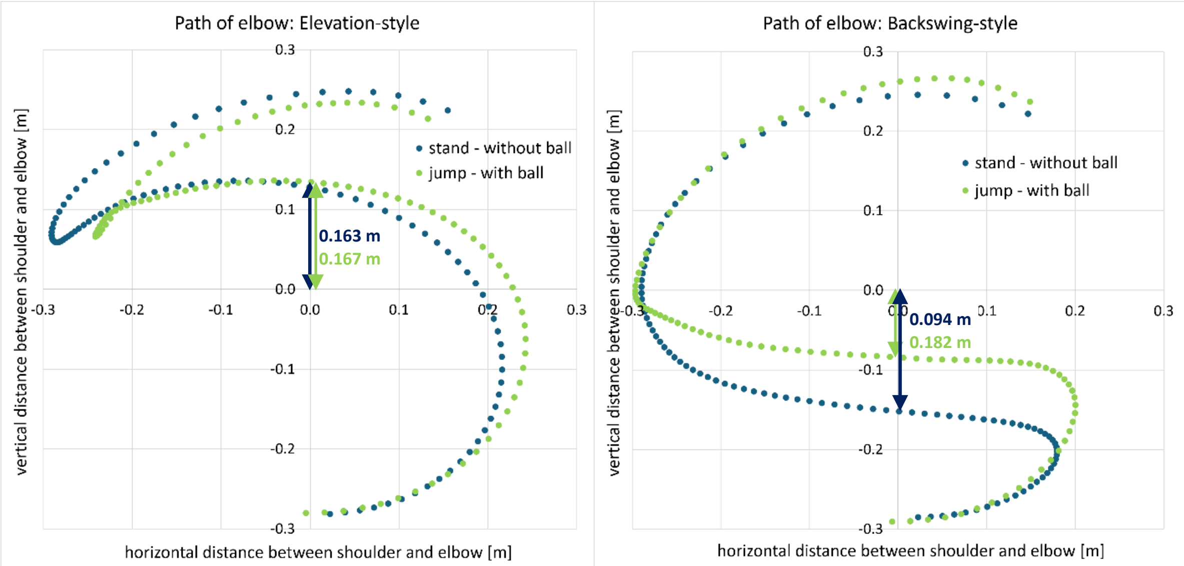

Figure 1: *Mean (n=28) path of the elbow in relation to the shoulder in the different technique variations (left panel elevation-style, right panel backswing-style). The origin of the coordinate system corresponds to the shoulder joint. The arrows indicate the distance between the elbow and the shoulder when the elbow crossed the vertical projection from the shoulder.*

each type of movement were taken for the analyses. Comparisons of the different techniques were done qualitatively. Possible differences between the easy and the complex task were assessed by comparing the vertical difference between the elbow compared to the shoulder (d_{es}) at the instant when the elbow crossed the vertical projection from the shoulder with paired t-tests.

Results

Thirteen of the 15 players were classified as players that usually use the elevation style while two used a type of backward style. Following the demonstration and some training attempts, all players were able to perform both styles correctly without a ball. Fig. 1 shows that there are clear kinematic differences of the elbow trajectories between the two techniques. Comparing the easy with the complex task within each technique, differences of the elbow trajectory were observed for the (unfamiliar) backswing- (d_{es} = -0.18±0.13 vs. d_{es} = -0.09 ± 0.07, p = 0.01) but not the elevation (d_{es} = 0.16±0.11 vs. d_{es} = 0.17±0.07, p = 0.86) style.

Discussion

Differences between arm swing techniques during easy movement simulations are very clear (Fig. 1). In the elevation technique, the elbow is above the shoulder during the greatest part of the movement. Especially in combination with greater shoulder abduction angles, this could lead to impingement and shoulder problems. The time equidistant points in the trajectories of Fig. 1 also show that a correct backswing (circular) technique as observed during the easy task is a rather continuous movement while the movement almost stops at the end of the cocking phase in the elevation technique. This implies decelerations and accelerations which induce greater forces in the shoulder joint. Players also had difficulties to apply unfamiliar techniques in complex situations. Differences in the elbow trajectories between the tasks imply that more intense training of the unfamiliar technique would be favorable when spike techniques are compared.

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Performance requirements of the volleyball attacking strike.

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a: Karen Zentgraf, Movement Science and Training in Sports, Institut for Sports Science, Frankfurt am Main, Germany

Keywords

Sport, Motor skills and abilities, Upper limbs, Kinematics, Strength

Highlights

- Ball velocity in volleyball attacks can be predicted by strength and kinematic variables only for male athletes.

Introduction

Attacking the ball so speedy that the ball cannot be defended is an important factor in scoring points at top-level volleyball. In addition to strike technique, bodily strength is assumed to be required for generating high ball speed [1]. So far, most studies focusing on kinematics of the offensive strike examined men. First studies, however, suggest that there could be gender differences in the technical characteristics of the strike [2]. While differences in absolute strength parameters can be expected among the sexes, evidence is not so clear for relative strength values and kinematic parameters in volleyball. The question, therefore, remains whether and to what extent ball velocity in attacking depends on the aforementioned parameters (strength, technique) and whether and where gender differences might be detected.

Methods

As part of a BISp-funded 'GendAttack' project, 57 (youth) national team and first and second Bundesliga volleyball players have been measured so far (w = 31, M_{age} = 17.68 ± 4.2 years). All participants had to perform a maximally fast strike in the direction of a radar gun which recorded ball velocity. The ball was placed in a still position at a self-selected height and could be hit self-initiated. Kinematics of the shots were captured using fourteen cameras (Opti-Track) which record trajectories of markers attached to the players (see figure 1). Three technique parameters were kinetically analyzed: The shoulder-hip angle (*SHA*) in the backswing phase, the lateral distance of the elbow to the shoulder (*Accel-phase*) in the acceleration phase, and the extension of the elbow at the ball contact point (*Ball contact*).

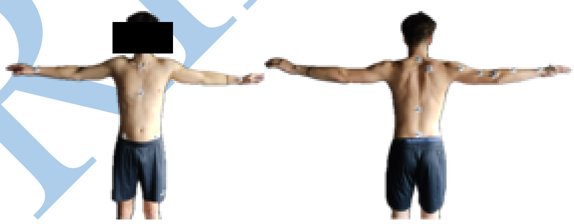

Figure 1: *Marker set utilized on participants consisting of 21 reflective markers on the upper body.*

Strength tests resulted in following values: glenohumeral strength of the internal and external rotation of the shoulder (as sum, *GH*) using a hand-held dynamometer, the distance in the lateral medicine ball throw (strike arm side, 3 kg, *MBT*), and the maximum isometric strength of trunk flexion in a David device (*Flex*). All strength parameters were normalized to body weight. As a parameter for shoulder mobility, the glenohumeral internal rotation deficit of the striking arm shoulder was measured (*GIRD*).

For the analysis, a multiple linear regression was conducted for both sexes with the three technique parameters mentioned above, the three strength values, as well as GIRD as independent variables. Ball velocity was the dependent variable. In addition, all parameters included in the model were tested for differences (*t*-tests) as post-hoc analyses. Alpha level was set to 0.05 for the regression models and Bonferroni-corrected for multiple *t*-tests (0.006).

Results

For men, a statistically significant linear regression ($F_{(6,25)} = 3.66$, $p = 0.014$) indicates a high explanation of variance (adjusted $R^2 = 0.389$) of ball velocity based on *MBT*, *Flex*, *SHA*, *Accel-phase*, *Ball contact* and *GIRD*. Due to multicollinearity, *GH* was not used in the model for men. *MBT* is a significant predictor of ball speed ($p < 0.001$, $\beta = 0.721$). For women, no statistically significant linear regression model was detected ($F_{(7,30)} = 1.76$, $p = 0.144$). Means and standard deviations of all parameters used in the models are listed in Table 1, as are the *p*-values of *t*-tests of the parameters tested for differences in gender.

Table 1: *Mean ±standard deviation of all used parameters divided between men and women. P-value of t-tests between gender with Bonferroni corrected p-value (< 0.006).*

	Men	**Women**	**p- value**
Ball velocity (km/h)	77.3 ±8.7	60.5 ±6.7	**<0.001**
MBT (m/kg)	0.12 ±0.1	0.10 ±0.1	**<0.001**
GH (N/kg)	3.71 ±0.6	3.16 ±0.5	**<0.001**
Flex (N/kg)	1.98 ±0.4	1.87 ±0.4	0.239
SHA (°)	53.3 ±6.2	45.8 ±8.4	**<0.001**
Accel-phase (au)	0.47 ±0.1	0.41 ±0.2	0.195
Ball contact (°)	142.7 ±10.4	136.7 ±8.9	0.160
GIRD (°)	33.9 ±8.6	33.2 ±12.7	0.784

Discussion

Results show that ball velocity can only be determined for men, but not for women, using *MBT*, *Flex*, *SHA*, *Accel-phase*, *Ball contact* and *GIRD*. A significant model for men shows that a valid prediction of ball velocity is possible using three technique parameters, two strength scores, and one mobility parameter. The strength value *MBT* (medicine ball throw) was identified as a significant predictor: the longer the throw, the faster the strike. This result is consistent with other studies that have also found a high correlation between strength values and ball velocity [3].

While a high variance explanation is achieved with the selected parameters for men, the parameters for women do not result in a significant model for predicting ball velocity. This difference emphasizes the previous imbalance in research, in which women have been studied less and - therefore - the relevant parameters may be less known. Strength parameters do not appear to be as dominant as they are for men. Especially in the strength values, there are gender differences in two out of three values (*MBT* and *GH*) - despite relative strength values. There is only one significant gender difference for the technique parameters (*SHA*), with lower values in *SHA* for women. There seems to be no significant difference in the upper arm movement (*Accel-phase* & *Ball contact*).

While men tend to focus on strength as a requirement for a fast attacking strike, the crucial parameters for women require further analyses and investigation.

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Individual tactics “take-the-first”? Comparing decision making of elite athletes from two sports games

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Keywords

Sport, Development, Sportpsychology

Highlights

- Among elite ice hockey and volleyball players, players with a higher level of expertise use TTF heuristic more often.

Introduction

In the realm of high-level sports, expert performance is a complex and multifaceted phenomenon involving a dynamic interplay of physical, motor, and cognitive skills[1]. Focusing on cognitive skills, particularly decision making is crucial for developing sports expertise[2]. Decision making is at the core of athletic success, determining how well athletes adapt to rapidly changing environments[3–5] and effectively execute their decisions. One theoretical model explaining decision-making processes in sports is the "Take-the-First" (TTF) heuristic. The TTF heuristic suggests that experienced athletes often simplify decision making by generating options in order of validity and choosing the first viable option that comes to mind, making them efficient[3–6]. By bypassing more time-consuming deliberative processes, the TTF heuristic has been shown to enable athletes in different team sports to generate and select options efficiently. Most studies on athletes' decision making have primarily focused on contrasting novices with experts. However, examining decision making in a group of elite athletes and across different sports disciplines offers an intriguing perspective, allowing researchers to explore how distinct sports environments may shape cognitive processes. In this line of research, we are conducting a systematic review and meta-analysis on option generation in sports, with preliminary results forming the basis of this empirical study. This study compares cognitive decision-making processes within an elite sample of specific sports disciplines, i.e. volleyball and ice hockey. These sports vary in spatial constraints, player interactions, and game pacing, allowing the investigation of shared and distinct cognitive demands. Comparing volleyball and ice hockey players’ decision-making processes thus provides a richer understanding of how sport-specific contexts influence option generation and decision making in elite athletes. We hypothesized that ice hockey players would generate fewer options and choose their first option more often than volleyball players due to the higher speed of the game. In addition, we hypothesized that even within the group of elite athletes, higher expertise levels would be associated with more efficient decision-making processes in both sports (i.e., fewer options, more TTF)[3].

Methods

The study stems from the in:prove project funded by the German Federal Institute for Sport Sciences (Speaker Prof. Karsten Krüger, Prof. Karen Zentgraf; Grant No. 081901/21-25). A subsample of national squad volleyball (*n*=7) and ice hockey players (*n*=31) participated in this study, with additional data currently being gathered. We used a sport-specific video-based option generation paradigm (Figure 1). The verbally generated mean number of options and the TTF % (number of times the first option was selected as a choice) were analyzed. The expertise level was coded as described by Zentgraf et al. (2024). Pearson correlations and an ANCOVA to test for sports differences while controlling for expertise were conducted in JASP.

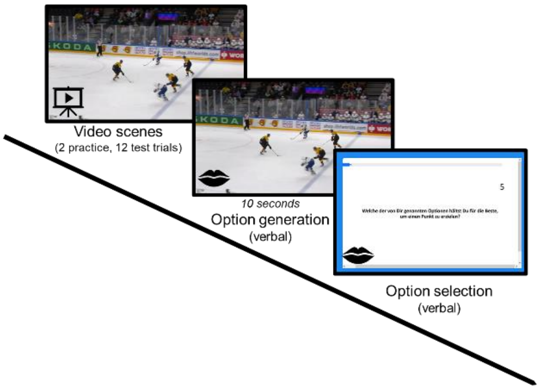

***Figure 1:** Video-based sport-specific option-generation paradigm (ice hockey example).*

Results

Volleyball players in this study generated an average of 3.5 (*SD*=1.11) options and selected their first option on average in 41% of the trials (*SD*=24%). As hypothesized, ANOVA results showed that ice hockey players generated fewer options (*M*=2.32, *SD*=0.44; $F(1, 35)=20.87$, $p<.001$, $\eta^2=.37$) and chose their first option more often (*M*=69%, *SD*=17%; $F(1, 34)=13.84$, $p<.001$, $\eta^2=.28$) than volleyball players (Figure 2A, B).

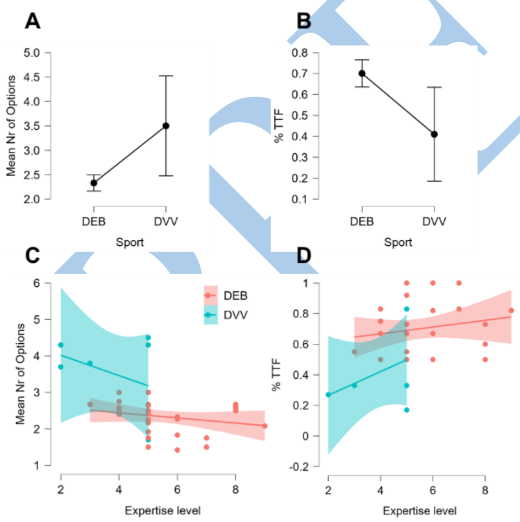

***Figure 2:** Video-based sport-specific option-generation paradigm (ice hockey example).*

As hypothesized, Pearson correlations revealed that higher expertise levels were associated with fewer options generated ($r=-.44$, $p=.006$; CI95[-.14; -.67]) and a higher TTF % ($r=-.42$, $p=.012$; CI95[.66; .10]). This trend was consistent when analyzing volleyball and ice hockey players separately. After controlling for expertise level in an ANCOVA, the effect of sport type on the number of options ($\eta^2=.21$) and TTF % ($\eta^2=.16$) remained significant (Figure 2C, D).

Discussion

This study highlights differences in option generation and selection between team sports. Elite ice hockey players applied TTF heuristics more often than elite volleyball players, irrespective of their level of expertise. The results suggest that different sports disciplines impose varying cognitive demands and that experiencing faster gameplay encourages individuals to rely more on heuristic decision-making processes[3,4,5]. Additional data is being gathered and the results will be synthesized with the forthcoming meta-analysis. Moreover, higher levels of expertise among elite players were associated with more frequent use of the TTF heuristic[3]. Limitations, future research directions, and practical implications will be discussed.

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Symposium:

dvs Exercise Science meets Motor Control: Physical activity to improve postural control and stability

Sabrina Forster[a] & Waltraud Stadler[b]

a: University of Saarland, b: Technical University of Munich

Cortical and subcortical brain changes in response to balance training

Marco Taubert[a]

a: Otto-von-Guericke University Magdeburg

Physical exercise stimulates the brain and its cognitive and sensorimotor functions. We have used balance task learning as a model to investigate the neural processes involved in motor learning and to identify potential brain-related mediators by which endurance exercise stimulates learning in healthy populations. Our results support the emerging view that motor skill acquisition and storage involve a cascade of steps from early neural circuit exploration and expansion towards later circuit selection and refinement. This cascade of steps in the learning process is reflected in the brain's response to balance task learning and the temporal dynamics of frontal cortical and subcortical parameter changes obtained via non-invasive MRI. The learning-induced neuroplasticity provides the basis for an investigation of brain-related mediators of the positive exercise effect on learning. Our recent findings demonstrate that brain changes in frontal white matter tracts and in cerebral blood flow mediate the positive exercise effect on learning the balance task. This suggests that regular intense exercise may increase brain energy supply and neurotransmission required for optimal motor learning. Potential implications for the treatments of clinical populations and optimization strategies during training are discussed.

Cycling on the motor engram Exercise as a strategy to enhance motor memory consolidation

Simon Steib[a]

a: Heidelberg University

Exercise has been shown to enhance cognitive performance, including long-term memory formation. It has been suggested that acute bouts of exercise induce transient effects at multiple

levels of the brain, including cellular, molecular, and systems-level changes, thereby providing an optimal environment for neural plasticity and consequently memory formation. Emerging evidence suggests that exercise may also improve motor skill learning and memory; however, findings are mixed and mainly derived from young adult populations using laboratory-based fine motor tasks. It remains unclear whether these effects extend to more ecologically valid tasks and other populations. This talk will summarize findings from several studies examining the impact of acute exercise on balance motor learning in young and older adults, as well as people with Parkinson´s disease. The data suggest that while exercise may be an effective and low-cost strategy to improve motor learning in older adults and people with Parkinson´s disease, effects in young adults appear to be negligible. Potential mechanisms and moderators will be discussed, alongside with future research directions in this field.

Current therapeutic and training approaches to improve body balance control in individuals with acquired brain injury

Leif Johannsen[a]

a: RWTH Aachen

Abstract: It goes without saying that physical activity is a critical ingredient for any motor rehabilitation efforts following stroke. This is especially true for training approaches targeting the sensorimotor control of body balance during standing and walking to counter an increased fall risk. Optimal balance performance relies on control mechanisms that entail predictive processes based on knowledge gathered by previous experience. From a therapist's perspective, however, it cannot be assumed that a patient's sensorimotor and cognitive systems possess accurate representations of its body's current physical properties and dynamics. For instance, body representations can be directly affected by a lesion or will become inaccurate due to physical inactivity and the resulting lack of experience ('learnt non-use' and 'maladaptive neuroplasticity'). The longer the time since lesion has progressed the increasing lack of movement experience will lead to gradually more inaccurate motor solutions. This presentation will discuss a theoretical concept which argues that therapists treating patients after stroke need to engage in a mindset which assumes that balance deficits result from limited predictive capacities that can only be restored by massed movement experience in diverse contexts.

Symposium:

Exoskeleton and Wearables Enhanced Prevention and Treatment” (TUM Innovation Network eXprt)

Joachim Hermsdörfer[a] & Philipp Gulde[a].

a: Technical University of Munich

The ability to carry out instrumental activities of daily living (ADL) is key for independent living and is often threatened in the face of ageing and disease. The TUM Innovation Networt eXprt tries to better understand:

… which factors impact ADL ability.

… which assessments and technologies can be used to predict ADL ability.

… which assistive devices can support ADL ability.

… and how the use of assistive devices shapes our brain.

In this symposium, we invited four speakers to present the state-of-the-art of their research in this area and show how Europe’s top universities engage with this topic to sustain independent living for persons with physical and cognitive limitations.

The talks will cover topics like the impact of executive functions on kinematic ADL performance in persons with mild cognitive impairment, the validity and responsiveness of clinical upper-limb measures and sensor-derived real-world arm use in persons with stroke, or factors that shape the perception of manual ability in persons with multiple sclerosis.

Executive functions in older adults with mild cognitive impairment and their association with activities of daily living performance.

Lucas Wolski[a], Paula Villa-Fulton[b], Joachim Hermsdörfer[b], Timo Grimmer[a]

a: Centre for Cognitive Disorders Department of Psychiatry and Psychotherapy, TUM School of Medicine & Health TUM, b: Chair of Human Movement Science, Department Health and Sport Sciences, TUM School of Medicine & Health, Technichal University of Munich

Keywords

Activities of daily living, Executive Functioning, Mild Cognitive Impairment, Dementia, Neuropsychological Assessment, Sensorimotor control

Introduction

Current prevalence rates concerning mild cognitive impairment (MCI) in older adults are estimated to reach up to 131.5 million by 2050 globally [1]. Subtle changes in the brain, associated with MCI, are frequently accompanied by losing the ability to get along with activities of daily living (ADL), e.g., performing chores [2]. Executive functions (EF) have shown the highest predictive in the conversion of MCI to dementia in this context [3]. EF comprise higher order cognitive processes that allow to execute different activities (i.e., planning, coordinating, and persevering activities). Besides, findings by Verreckt et al. (2022) point out that especially cognitive flexibility as well as working memory play a crucial role in performing ADL in older adults [4]. Yet, it is still not clear, which aspects of EF are key for the performance of complex, multi-step ADL. In this study, different neuropsychological tests addressing EF were examined for a possible association with kinematically quantified ADL performance in a sample of persons with MCI.

We hypothesized that especially *working memory* (figural and verbal fluency) as well as *task switching* measures are strongly associated with ADL performance in patients with MCI. We further hypothesized that these relations might be mediated by sensorimotor capacity in the sense of motor speed.

Methods

15 participants with MCI (8 female, 7 male; age: 69.5a ±9.0a, 59-83a; MMSE: 26.8 ±2.9, 18-30), diagnosed according to NIA-AA criteria, in the presence of an Alzheimer´s Disease (according to elicited cerebrospinal fluid biomarkers) were recruited by the Centre for Cognitive Disorders of the university hospital of the Technical University of Munich (Germany). Each participant completed the following standardized neuropsychological assessments focusing on different aspects of EF: *1) Digit Symbol Substitution Test (DSST, WAIS-IV)* to address cognitive flexibility, *2) Trail-Making-Test A (TMT-A)* to assess the interplay of motor speed, visual scanning and number sequencing abilities and *Trail-Making-Test B* to assess cognitive flexibility, *3) 5-Point Test (5-PT)* assessing figural fluency as well as finally the *4) Verbal Fluency (LF)* test from the LPS50+ battery. Participants were able to follow all instructions. ADL performance was preliminarily quantified by the trial duration (TD; general task performance) and kinematically (optoelectronic motion capturing at 100Hz; post-processing with MATLAB R2021a) quantified assessing the length of trajectories of both hands (path length, PL; efficiency of task solution) during the preparation of *a cup of tea* in TUM's *living lab* (i.e., an instrument kitchen). The association of ADL performance and EF measures were explored via Pearson correlations. α was set to 0.05.

Results

Some significant associations between EF measures and ADL performance were found (Tab. 1), namely TMT-A, 5-PT, and DSST. PL and TD were strongly correlated ($r=0.83$, $p<0.001$).

Table 1: *Coefficients of correlation between EF measures and ADL performance. Significant associations are marked with an asterisk *.*

EF	TD	*p*	PL	*p*
DSST	**-.60***	*.018*	**-.54***	*.039*
TMT-A	**.77***	*<.001*	**.81***	*<.001*
TMT-B	**.46**	*.087*	**.47**	*.077*
5-PT	**-.56***	*.029*	**-.63***	*.011*
LF	-.42	*.123*	-.37	*.181*

Annotations: *Lower scores in DSST, 5PT and LF point out a poorer performance concerning cognitive flexibility, figural fluency and verbal fluency. In the remaining tests, higher scores/values are indicators of worse performance.*

Discussion

Here, we explored the association of different aspects of EF with ADL performance in a sample of persons with MCI. First, TD and PL were strongly associated with each other and revealed similar associations with neuropsychological measures, indicating that task performance was driven by efficiency (as expressed by PL) rather than motor speed. 5-PT and DSST, assessing working memory and cognitive flexibility, were good predictors of ADL performance, emphasizing their significance for complex, multi-step activities, where one has to switch between sub-tasks while simultaneously monitoring their progress (e.g., adding a teabag to the cup while waiting for the water to boil). Further, in accordance with literature [5], sequencing appears to be a driving factor, as seen by the strong correlation of ADL performance with TMT-A. Interestingly, TMT-A was more strongly associated with ADL performance than TMT-B. Apparently, task sequencing in combination with task switching, as assessed by the TMT-B has a stronger emphasis on task switching and working memory update, attenuating the relevance of sequencing on overall task performance in the TMT. Interpreting these findings, it has to be noted that due to the small sample size, some associations were closely below and some closely above the significance level, though being within a common range. To summarize, we were able to see efficiency as the driving factor of ADL performance and TMT-A as a strong predictor, while other measures of EF were moderately associated. This indicates that, while working memory and cognitive flexibility are, as hypothesized, important factors for ADL performance, retrieving and processing visual information to complete a - most likely well-known [6] - sequence (and therefore without strong demands on problem solving) is most crucial. In the future, a larger sample and performance of a set of different instrumental ADL will shed further light on the associations with different aspects of EF. The knowledge elicited contributes to tailoring effective interventions, maintaining the ability to live independently with MCI.

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Prediction of perceived manual ability in multiple sclerosis

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Keywords

Health, Upper limbs, Activities of daily living, Sensorimotor performance, Clinical research

Introduction

Persons with multiple sclerosis (pwMS) frequently report reduced quality of life, which is driven by impaired abilities in activities of daily living (ADL) [1]. However, self-reports often suffer from psychometric limitations and the reliability of data can be questionable [2]. Further, carried out ADL tend to be in the submaximal spectrum of a person's capability [3], making predictions on the basis of clinical capacity tests difficult [1]. To face these methodological challenges, we used clinical capacity tests, the affective state, and data of everyday-life behavior to predict the perceived manual ability, assessed by the Rasch-conform ABILHAND questionnaire [4], in a sample of pwMS. We hypothesized that the perceived manual ability could be predicted by clinical capacity tests of the upper-limbs in combination with everyday-life kinematics that represent the translation of capacity into performance (interaction of organism, environment, and task) and from performance to perception. We further hypothesized that the reported ability is influenced by the affective state [1].

Methods

We collected data of 22 pwMS (age: 47a ±11a, 22-62a; EDSS: 2.2 ±1.7, 0.0-6.0), including clinical capacity tests (i.a., grip strength, finger tapping, simple reaction times, peg test speed, two-point discrimination), the affective state as the vector magnitude of positive and negative affect (PANAS [5]), and wrist-worn IMU-derived kinematics of outside the lab, everyday behavior (accelerometer and gyroscope at 64Hz over 4h for each hand) using the 2MPAC algorithm [3] (the final analysis will cover a full week of IMU data). As the ABILHAND is not hand specific, we calculated sum- and laterality- (|Δ|/Ø) scores of the metrics, where applicable. ABILHAND scores have a maximum of 46 points, with lower scores indicating stronger impairments. We used a model of multiple linear regression to predict the ABILHAND score. We set the critical variance inflation factor (VIF) to 2.5, α to 0.05, and report effect-sizes as beta-weights.

Results

Our sample reported ABILHAND scores of 42 ±5 (28-46), indicating mostly none-to-light impairments of manual ability, with 7 (32%) participants reporting no impairments at all. The model of multiple linear regression had 7 predictors and an $R^2_{adjusted}$ of 0.88 ($p<0.001$) (*Tab. 1*). Faster reaction times, faster peg-test performance, better sensitivity, a lower body mass index, a stronger affective state, higher average acceleration during activities, and a more pronounced laterality of movement smoothness predicted higher ABILHAND scores.

Discussion

Here, we predicted perceived manual ability in a sample of persons with mild-to-moderate multiple sclerosis by clinical capacity tests and everyday-life behavior kinematics. As hypothesized, a combination of clinical capacity tests, the affective state, and everyday-life kinematics was able to explain the perceived manual ability. When considering both included kinematic measures, smoothness laterality (*quality* [3]) and average acceleration (*intensity* [3]), these could indeed be dimensions of upper limb-performance in everyday-life that are noticed by an individual and are therefore shaping the perception of ability.

Table 1: *Predictors of perceived manual ability in pwMS ($R^2_{adjusted}$=0.88, p<0.001).*

Predictor	Beta-weight	p-value VIF
Reaction times	-0.62	<0.001 1.07
Peg test speed	0.43	<0.001 1.48
2-point discrimination	-0.19	0.039 1.18
PANAS	0.30	0.003 1.22
Body mass index	-0.27	0.004 1.03
Mean acceleration	0.27	0.007 1.25
Laterality smoothness (acceleration)	0.70	<0.001 1.46

The fact that higher lateralities of smoothness predict better ability, although the ABILHAND includes a range of bimanual activities, questions the validity of the metric. A post-hoc analysis, however, revealed significant associations with other capacity lateralities as well as capacity sums, validating the metric. Within the model, there is a mediation of capacity and laterality, resulting in a stronger loading of, i.a., the peg test speed when introducing the laterality metric and vice versa. Therefore, the laterality could indicate successful performance *despite* sensorimotor limitations and would emphasize the role of problem solving for ADL capability [6]. The impact of the affective state implies that, as hypothesized, even in a Rasch-conform questionnaire under- and overreporting can be faced [7]. The impacts of the clinical capacity tests are meaningful, as sensitivity of the fingers and dexterity in the manipulation of small objects are well-responding to the ABILHAND items on content-level as well. The strong impact of reaction times indicates that information processing speed could play a role in quickly retrieving anecdotal information and evaluating past performance to make an estimate of one's own ability (i.e., filling out the ABILHAND questionnaire) or could be an indicator of the affective state (although the VIF was low in reactions times and PANAS). Lastly, the body mass index could be, in addition to the physical properties of the body, associated with other psychological constructs like self-efficacy [8], influencing the evaluation of past performance. To conclude, perceived manual ability in pwMS is influenced by experienced capacity, everyday behavior, and the retrieval and evaluation of anecdotal information, making quantitative assessments inevitable.

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Estimation of self-motion from conflicting sensory cues in human balance control

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Feedback is differently relevant to children and adults: Neural correlates of error processing in a daily-based motor task

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Head engagement during interception in aging

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Observational practice: Successful perceptual-motor response mapping induces learning advantages

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Keywords

Motor learning, Motor control, Sensorimotor performance, Observational practice, Context information

Highlights

- Observation surpasses physical practice
- Successful perceptual-motor response mapping induced learning advantages

Introduction

It is widely recognized that physical practice is not the only way to acquire a motor skill. Observational practice facilitates the learning of a wide range of motor skills [1, 2]. However, observational practice is considered less effective than physical practice. Findings supporting such a conclusion about observational learning consisted of demonstrations of a single specific movement pattern performed in a relatively stable environment such as the slalom-ski simulation task [1]. Part of the advantage of observational practice is that the observer does not use cognitive and attentional resources to prepare and perform the movement. He/she can use these resources to observe techniques or strategies that are ineffective/effective to perform the task [3] or to discover important contextual information in the task environment. Even though examples are obvious in real-life sport settings like in tennis or beach volleyball, limited research attention has been directed to tasks where individuals must respond to changing environmental/perceptual demands. In this type of task, motor processes must be mapped with perceptual processes to ensure successful execution of the response. An open issue addressed in the following experiment was to determine whether an observational practice protocol increases the likelihood of using information in a task that presents contextual information in a randomly changing environment.

Methods

Undergraduate students of sport sciences (N = 28) participated in the experiment for course credit (14 male, 14 female; mean age = 21.71 years; SD ± 4.02 years). In a yoked design, participants were randomly assigned to one of two groups: an observational practice (OP) group where the participants only observe another person performing the task, and a physical practice (PP) group where participants physically practice the task. The task was a computerized perceptual-motor task, where individuals were required to intercept as many balls as possible by moving a paddle. The balls dropped from the top of the screen (see Figure 1). A colored line at the top of the screen provided information about the direction of the dropping ball. Acquisition consisted of 10 blocks of 20 trials each.

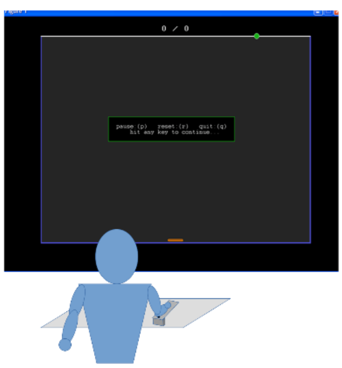

__Figure 1:__ Schematic illustration of a participant performig the computerized perceptual-motor task.

In a retention test (20 trials), 10 min later, all individuals physically performed the task. In a post experimental interview all participants were

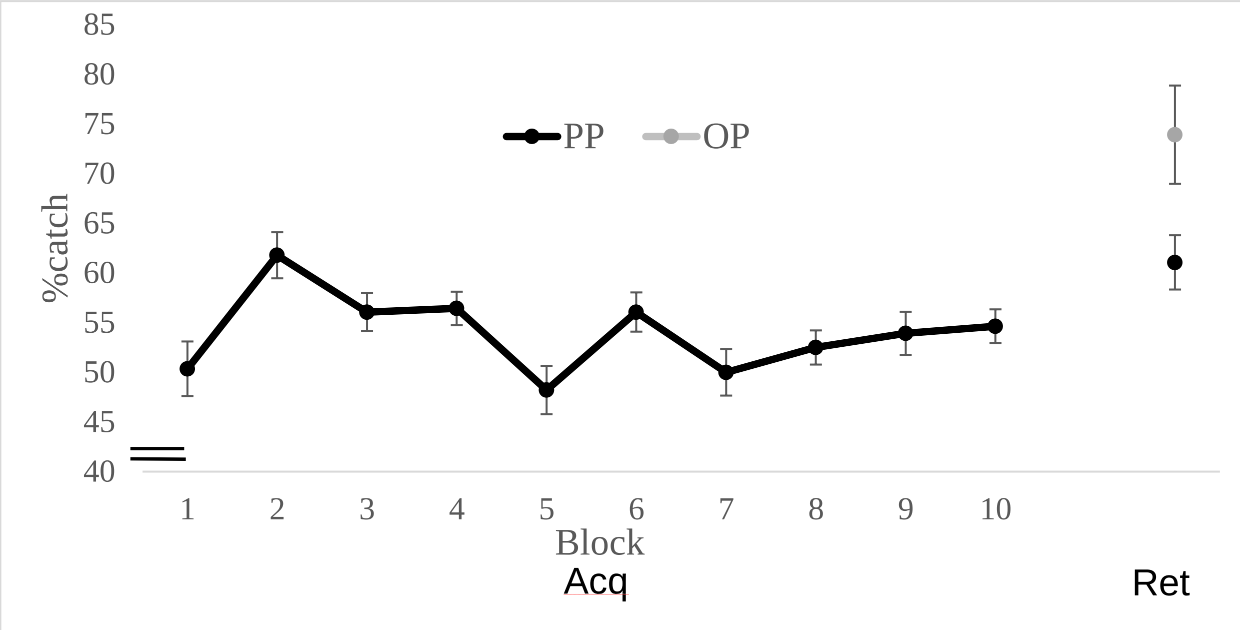

Figure 2: *Means and SEM of the acquisition phase for the PP group (Acq) and retention test (Ret) for the PP and OP group.*

asked if they recognized that the color of the line was associated with the direction of the dropping balls. The depended variable was the percentage of caught balls (%catch).

Results

Figure 2 provides the mean %catch and the standard error of the means (SEM) across acquisition and retention. The individuals of the PP group improved their performance during acquisition, $F(9,117) = 3.55$, $p < .001$, $\eta^2_p = .22$. On the retention test, a t-test indicated a significant difference, $t(26) = 2.27$, $p < .05$, $d = .86$. Participants in the OP group caught significantly more balls, (73%) than individuals of the PP group (61%). The analysis of the post-experimental interview indicated a significant difference, χ^2 (1) = 5.60, $p = .018$, $\omega = .44$ in the distribution of the recognized and not recognized association of the colour bars and the direction of the dropping balls. Eight individuals from the OP group recognized that the colors of the bars were associated with the direction of the dropping balls, but only 2 from the PP group.

Discussion

The present experiment demonstrates that observational practice induced learning advantages and increases individuals' likelihood to utilize information in a task with specified contextual information in a changing environment. It enables individuals to enter practice with a minimum of event uncertainty. Observational practice can surpass physical practice, when motor processes have to be matched with perceptual processes for successful response execution.

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The acquisition of sequence representations in action imagery practice and action observation practice

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Keywords

Motor learning, Motor control, Imagery practice, Sequence learning, Serial reaction time task

Highlights

- Evidence for effector-dependent representations in AIP and AEP, but not AOP
- Kinesthetic perceptions stronger in AIP and AEP than AOP
- Internal prediction of action consequences provokes motor learning

Introduction

Action-Imagery-Practice describes the repetitive imagination and Action-Observation-Practice the repetitive observation of an action [1]. Both Action-Imagery-Practice and Action-Observation-Practice are assumed to involve similar motor mechanisms as Action-Execution-Practice [2], resulting in subsequent performance improvements [3], but with a lower effect as compared to Action-Execution-Practice [4]. While it has already been shown that effector-independent [5] and effector-dependent [6] representations can be acquired with Action-Imagery-Practice, this remains to be resolved for Action-Observation-Practice. We expected Action-Observation-Practice to provoke similar representations as Action-Imagery-Practice.

Methods

All 125 participants practiced serial key press reactions to auditory stimuli in ten practice sessions with 1200 consecutive responses (100 sequence repetitions) in each session. Five separate groups either physically executed the responses (Action-Execution-Practice, n = 23), imagined the responses (Action-Imagery-Practice, n = 23), observed keypresses with an animated hand (Action-Observation-Practice, n = 24), observed animated keys (Observation-Without-Action, n = 26), or completed a control condition in which they listened to the stimuli (Auditory-Control, n = 29). Practice followed a deterministic sequence of 12 elements. The practice sequence and control sequences were tested in execution with a pretest and a posttest 24-48 h after the last practice session. Motor performance was measured as response times (RT). Sequence-specific effector-independent representations were expected to evolve in shorter RTs in the practice sequence than in the control sequence (Sequence-Learning-Index) in the transfer hand. Sequence-specific effector-dependent representations were expected to evolve in a larger Sequence-Learning-Index in the practice hand than in the transfer hand.

Results

ANOVAs and theory-driven post-hoc comparisons revealed the following results. The Sequence Learning Index (see Fig. 1) in the Posttest with the Transfer Hand (indicating effector-independent intrinsic representations) was significantly higher after Action-Execution Practice than after Observation Without Action (p = .007, d = 1.04) and Auditory Control (p = .007, d = 1.02). Action-Imagery Practice and Action-Observation Practice did not significantly differ from the other groups ($p \geq .118$, $d \leq 0.74$). Further, comparisons between hands indicating effector-dependent representations in the Posttest were significant after Action-Execution Practice (p = .027, d = 0.5) and Action-Imagery Practice ($p < .001$, d = 0.81), but not in the other groups ($p \geq .276$, $d \leq 0.23$).

Hence, evidence for effector-dependent representations was obtained after Action-Execution-Practice and Action-Imagery-Practice, but not after Action-Observation-Practice and Observation-Without-Action. Although all groups acquired partial sequence knowledge, sequence recognition was stronger related to kinesthesis than to the tones alone after Action-Execution-Practice and Action-Imagery-Practice.

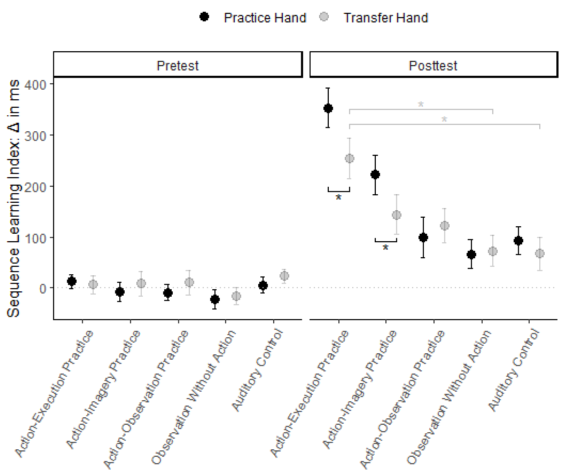

***Figure 1:** Means and standard errors of sequence learning (Δ RT in ms: practice sequence – control sequence) depending on test block and hand, separately for groups.*

Discussion

It is concluded that effector-dependent representations can be acquired via Action-Imagery-Practice even though actual feedback is not available [7]. Possibly, effector-dependent learning was provoked by forward models that predict the action consequences in Action-Imagery-Practice, but not in Action-Observation-Practice where the action consequences were externally presented on screen [8].

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Prior Belief in Another Agent Directly Tunes Our Sense of Agency

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Keywords

Sense of Agency, Bayesian, Motor Control, Motor cognition, Virtual Reality.

Introduction

The sense of agency originates from the ability of the individual to discriminate between self-made and other-made actions based on the outflow of motor commands and the inflow of sensory feedback. That is, given a particular outcome, we need to combine multiple aspects of movements and consequences to understand whether we are responsible for the outcome. Specifically, self-agency is formed when the observed outcome matches our actions and the high belief that the agent responsible for the outcome is us. This formalization suggests a Bayesian-based inference that is the basis for self-agency.

Although the idea of Bayesian inference as the basis for the sense of agency was suggested in the past to account for mental illnesses such as schizophrenia [1], there is only limited and indirect evidence for the validity of this model in healthy individuals. Here, we aimed to change the sense of agency by directly changing the prior belief in the acting agent. That is, we caused participants to form a representation of another acting agent and tested how this representation altered the ability of participants to claim ownership of the action's outcome.

Methods

Thirteen Participants played a virtual game similar to shooting an arrow using a bow. Participants grasped the handle of a robotic manipulandum while observing a projection displaying the virtual environment (Figure 1A). The task was to shoot a ball toward a target in front of them. The ball movement was constrained to 1D motion. After playing the basic game (30 trials), which allowed participants to familiarize themselves with the system's dynamics, they played against a second virtual player (420 trials). The

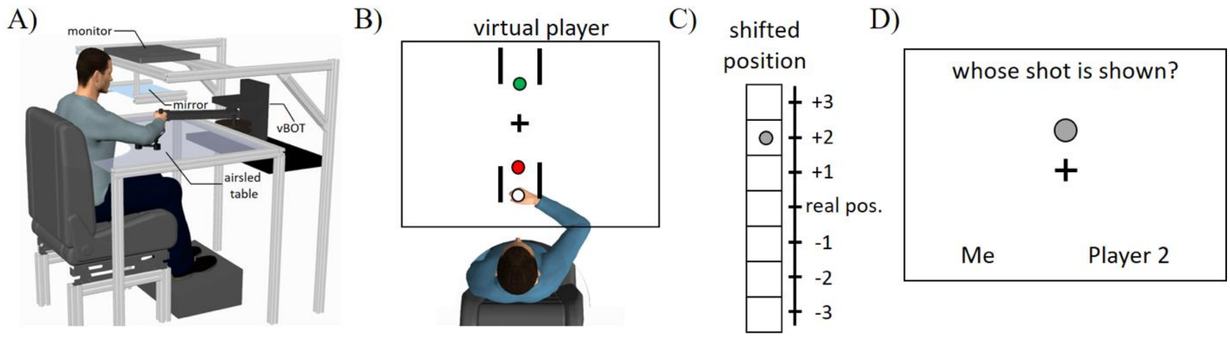

Figure 1: *A) Experimental setup. Participants were sitting in front of a robotic manipulandum (vBot), while observing the virtual environment. B) Participants were asked to shoot a ball to the center of a cross target. During the joint game, a virtual player was also shooting a second ball to the same target. C) In some trials, we displayed a single ball that was based on the participant's shot but could be shifted. In this example the shift was 2cm forward than the actual hit position. D) Agency question screen. Participants were asked to choose whether the displayed hit position was theirs or the virtual players' ('player 2').*

virtual player aimed to shoot a second ball toward the same target as the human player (Figure 1B). We used two types of virtual players that differ in their shooting probabilities. The first type was the *sharpshooter* virtual player whose shots were distributed accurately around the target position. The shots were randomly chosen from a normal distribution with a mean equal to the target position and a standard deviation of 1. The second type was the *amateur* virtual player whose shots were distributed away from the target position. To implement this player, we randomly chose a shot position from a bimodal distribution, which consisted of two normal distributions with a mean equal to the target position shifted by ±2.5 cm and a standard deviation of 1. This player's shots were always under or above the target position with a mean shift of 2.5 cm. We introduced the two players in a block design; in the first half of the experiment, participants were playing against one of the players (sharpshooter or amateur), and then we switched the virtual player to the second type in the second half of the experiment. The order of the virtual players was counterbalanced across participants. In each trial, both players had to shoot their balls toward the target, and the player whose ball was the closest to the target center got points. Once the participant made their shot, we displayed their hit position and the virtual player's hit position. The general objective during this phase was to get more points than the virtual player. In 1/3 of the trials, after the participant made their shot, we did not display the two hit positions, but instead, we displayed a shifted version of the participant's hit position (Figure 1C). The shifts were chosen from a discrete uniform distribution between (-3) and (+3) (including zero shift). After showing the landing position, we asked the participant to judge whether the displayed hit position resulted from their shot or the virtual player's shot (Figure 1D).

Results

We found that participants tended to answer that the displayed hit position belonged to the virtual player according to the shooting distribution that we used. That is, when participants played against the sharpshooter player, they had a higher tendency to answer that the displayed hit position

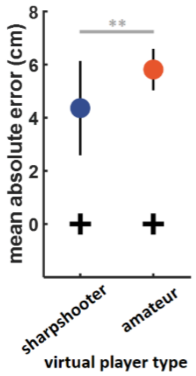

Figure 2: *Mean difference (error) between the displayed hit position and the target position (black cross) across the trials in which participants assigned the displayed hit to the virtual player playing against the sharpshooter and amateur player. Vertical lines represent standard deviation.*

belonged to the virtual player when it was closer to the target (t_{12}=3.09, p=0.009). When playing against the amateur player, participants assigned more hit positions to the virtual player when it was away from the target (Figure 2). We also found a general bias between the mean distributions that we set for the virtual players (sharpshooter was set to 0 cm and amateur to 2.5 cm) and the positions in which participants tended to assign the displayed hit position to the virtual player (sharpshooter 4.36 cm, amateur 5.8 cm).

Discussion

These results show the direct effect of elevated prior belief in other-agent actions on the sense of agency. The prior conditioning effect provides more evidence against a comparator model (such as a forward model) for forming self-agency since such a model is based solely on comparing actions and outcomes without accounting for past experiences. Further testing this effect and how the prior belief is shaped can help to understand how the sense of agency is formed and whether Bayesian integration-based models can explain this process [2].

Acknowledgments: This work was supported by funding from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation), project num. 467042759.

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Coordination coefficiency in social interaction: A pilot study for the object-transport task in a real-life context

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Keywords

Motor cognition, Activities of daily living, Sport psychology, Joint action, Object-transport task

Highlights

- People minimize collective costs during joint actions when performing the object-transport task in a real-life context.

Introduction

People tend to minimize the overall path length when walking between two locations [1]. This seems to be also true when acting together with a partner. Accordingly, in a virtual sequential object-transfer task, it has been demonstrated that people choose between different paths in a way that ensures the minimization of collective costs [2]. Here, we test this coordination coefficiency during social interaction in a real-life context.

Methods

Thirty participants (10 females, 20 males; age = 22.0 years old) were asked to carry a ball from a start location on one corner of a 10x10 m square to a goal location in the diagonal corner on the opposite side (Figure 1). The square was divided by a horizontal barrier with two openings to the left and right side of the midline and a vertical barrier of the same or different lengths on either side of the midline. Participants performed alone and in dyads by handing the ball over to another participant at one of the two openings in the horizontal barrier. Because of the different lengths of the vertical barriers (from 1 to 4 units), this resulted in 16 congruent conditions, where the short subpath from an individual perspective corresponded to an overall shorter path length for the dyad, in 16 incongruent conditions, where the short subpath led to an overall longer path length for the dyad, and to 8 neutral conditions, where the two overall path lengths were equal. Hence, participants performed in 40 individual trials and in 40 dyads.

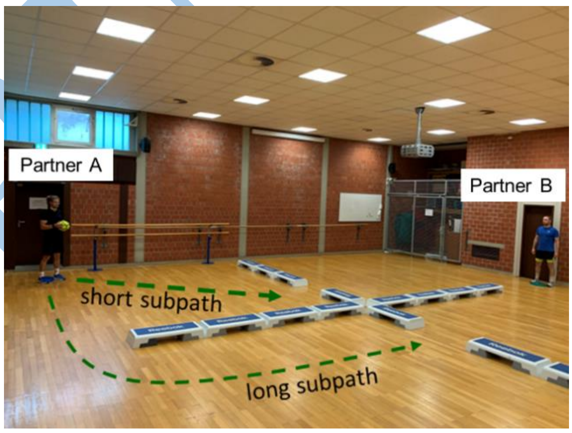

Figure 1: *Displayed is the neutral condition with an equal amount of units on each side of the vertical barriers. Here, both subpaths lead to equal total path length, i.e., no differences for coordination coefficiency.*

For data analyses, we calculated the proportions of path choices for the short and long subpath under congruent, incongruent, and neutral conditions for the individual trials and the dyads in a first step. In a second step, the efficient path choices under congruent and incongruent conditions were evaluated for the different degrees of asymmetry (i.e., ratios of 4:0, 4:1, 4:2, 4:3 for the different units) between the two possible pathways and submitted to a 2 (trial condition) x 4 (path-length asymmetry) x 2 (social-interaction context) ANOVA. In a third step, we examined the choice of subpaths under the neutral conditions in the individual trials and in dyads and ran a 2 (subpath) x 2 (social-interaction context)

ANOVA on the proportions of short and long subpath choices.

Results

Figure 2 displays the path choices when participants performed in individual trials and in dyads. The ANOVA revealed a significant main effect of the factor path-length asymmetry [$F(3,87) = 7.792$; $p < 0.001$; $\eta^2_p = 0.212$], indicating a decrease of efficient path choices for smaller asymmetries between the two pathways. Also, the main effect of the factor social-interaction context was significant [$F(1,27) = 25.130$; $p < 0.001$; $\eta^2_p = 0.464$], but was modulated by the two-way interaction with the factor trial condition [$F(1,29) = 5.795$; $p < 0.05$; $\eta^2_p = 0.167$]. Accordingly, efficient path choices were lower under incongruent conditions when participants performed in dyads.

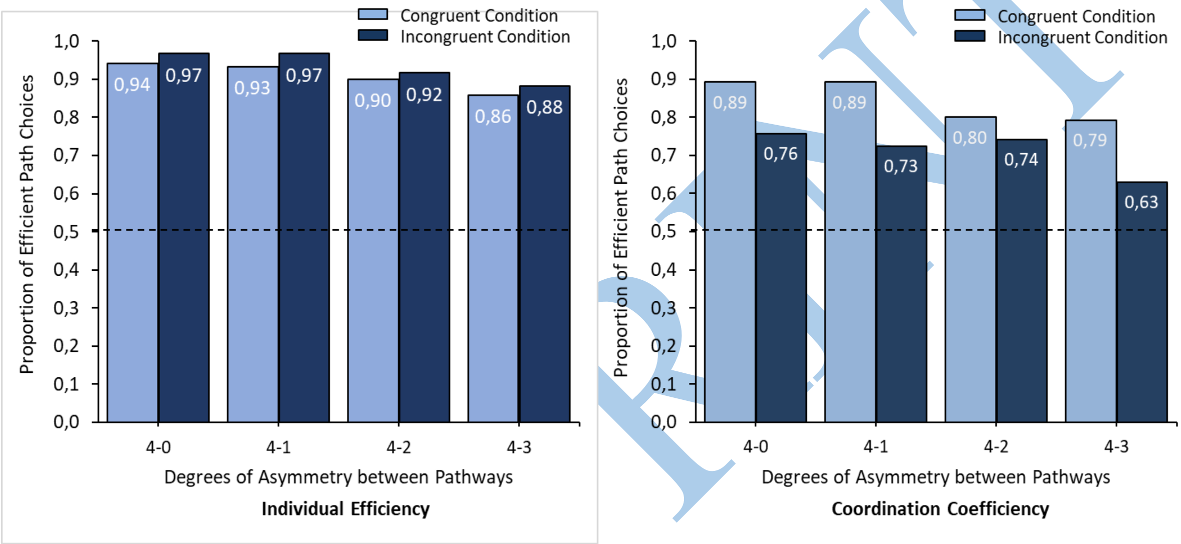

Figure 2: *Efficient path choices relative to the degree of asymmetry between the lengths of both pathways in individual trials (i.e., individual efficiency) and in dyads (i.e., coordination coefficiency).*

For the neutral conditions, the proportions of short (0.49) and long (0.51) subpath choices were not significantly different in the individual trials [$t(29) = .214$; $p = .832$], while they were significantly higher for short (0.65) than long (0.35) subpath choices in dyads [$t(29) = 2.397$; $p = .023$].

Discussion

The pilot study confirms the observation by Török et al. [1] that people minimize collective costs during joint actions when performing the object-transport task in a real-life context. Accordingly, participants' path choices reflected the strategy to minimize the overall path length under congruent and incongruent conditions when acting alone and with a partner. However, as the two path lengths became more similar, participants were somewhat less efficient in their path choices, while still opting to minimize costs in most of the trials. Interestingly, they behaved less altruistic in the neutral condition when acting in dyads, rather striving for individual efficiency than for reducing the costs of the partner. Future research should investigate if this effect is related to physical effort.

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Evaluation of Contextual Cues in a Simulated Robot-Human Handover

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This work was supported by the Lighthouse Initiative Geriatronics by StMWi Bayern (Project X, grant no. 5140951), the Deutsche Forschungsgemeinschaft (DFG) - project number 467042759, and the TUM MIRMI Seed Fund.

Keywords

Human-Robot Interaction, Contextual cue, VR, AR, Motor learning, Robotics

Highlights

- Predictive scaling of GF with presentation of contextual cues
- Kinematic cue results in more effective separation between object masses

Introduction

In the evolving field of assistive robotics, seamless human-robot collaboration (HRC) is crucial, especially in physical tasks such as object handovers – a foundational yet challenging skill [1]. For a smooth handover, both involved control systems must act in synchrony, while simultaneously coordinating the manipulation of the object. In a human-human handover, this can only be achieved by accurately predicting the partner's movements and the object's physical properties, as human feedback loops are too slow to allow for purely reactive control [2]. Such predictions can be informed by various cues, such as size, material, or position, with cues on familiar features being much stronger [3]. Our previous work demonstrated that in a simulated agent-human handover scenario, humans can learn to interpret the kinematic cues of an agent handing them an object to scale their predictive grip forces [4]. In this study, we investigate the efficiency of a color cue on predictive force scaling and compare the two cue types for a better understanding of HRC. We hypothesise that due to its familiarity, the kinematic cue would be learnt faster than the color cue.

Methods

Seven healthy, right-handed adults (3 M/ 4 F; 21.9±1.5 years) participated in the experiment. We used a virtual grasping setup consisting of two haptic robots for position and force feedback and a monitor-mirror system providing visual feedback (see Figure 1). Participants had to grasp and hold a box-shaped object handed to them by a virtual agent. The agent reached toward the object, lifted it, and then transported it toward the participant's hand. Throughout the experiment, participants encountered three object masses, each cued by a fixed color. After an initial practice phase, the set color-mass pairs were presented in three parts: Random 1 (random sequence of object-mass pairs), Blocked (same color-mass pair presented multiple times), and Random 2.

Figure 1: *Virtual grasping setup consisting of two haptic robots for position and force feedback and a mirror-monitor system for visual feedback*

To quantify participants' prediction of the object mass, we computed the anticipatory grip force ($GF_{ant.}$) just before the agent release of the object during handover. To summarize this metric across object masses, we pooled values over multiple repetitions per mass and participants and fit a linear regression resulting in slope and intercept values. These values were then compared to a kinematic cue from a previous study with the same setup and design [4], where a different mass was indicated by a different trajectory (peak velocity) of the simulated agent.

Results

One participant was excluded from the analysis as they did not recognize the connection between object color and mass. All other participants reported to have noticed the link. Across the experiment, participants learned to scale predictively $GF_{ant.}$ to the object's mass. This adaptation was learned even when objects were presented in random order and was strengthened with repeated presentation of a color-mass pair in the blocked part.

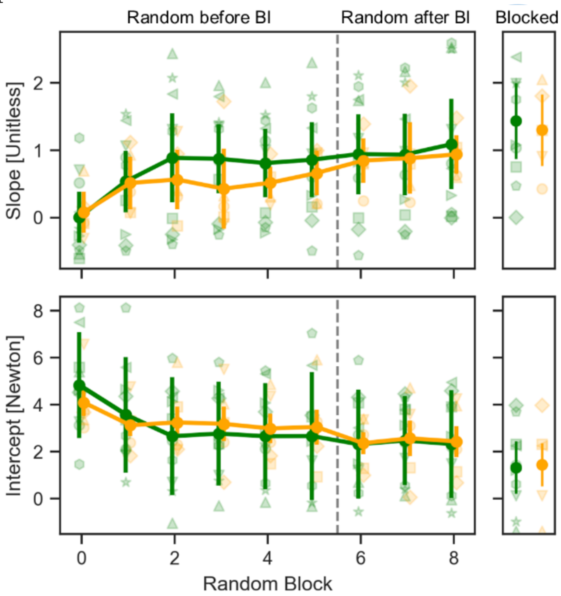

Figure 2: *Anticipatory grip force values for the random and blocked parts of the experiment for the color (orange) and kinematic (green) cue. The dashed line indicates the position of the blocked part within the experiment (shown on the right).*

When presented repeatedly with the same color-mass pair (Blocked), participants scaled $GF_{ant.}$ perfectly to the corresponding object gravitational force (F = m*g) as evident in slope values of ~1 (see Figure 2). When presented with the objects in random order, participants initially applied identical forces to all objects but gradually improved their force scaling. However, in contrast to the kinematic cue, where the scaling was evident for all object masses [4], participants only seemed to apply higher grip forces to the heavy object (mean±std in Random blocks 3 to 5: 5.1 ± 1.3 N), but did not differentiate between light (4.2 ± 1.7 N) and medium objects (4.4 ± 1.4 N). Only after exposure to each color-mass pair in the blocked part of the experiment, this scaling was evident for all three objects and converged to the same values for the two cues.

Discussion

While participants were able to predictively scale grip forces according to color and kinematic cue after some repetition, adaptation for the kinematic cue seemed to be stronger. This is evident in the lower slope of the linear regression fit to anticipatory grip forces by object mass. As object color is an entirely arbitrary cue, the relationship between color and mass must be explicitly learned. In contrast, the movement cue of the agent's reaching movement can be directly linked to object mass through simple physics and corresponds to daily life experience. This is in line with previous work demonstrating that more natural and thus more familiar cues are stronger and easier to learn (e.g. [3]). Therefore, we assume that with increasing task complexity, e.g. more object masses, the difference in cue strength will increase. We believe that our work provides a first indication that kinematic cues could inform developments of more intuitive robot-human handovers.

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Binocular Saccade Velocity in Mild Traumatic Brain Injury

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Keywords

Clinical Research, Health, Mild Traumatic Brain Injury, Eye Movements, Motor Control

Highlights

- Abnormal horizontal velocity profiles for left versus right eye in mTBI.
- Distinct patterns providing insight into the underlying pathophysiology.

Introduction

Mild traumatic brain injury (mTBI) can result in significant deficits affecting vision and eye movements, including vergence, saccades, pursuit, and the vestibulo-ocular reflex [1-3]. These issues can result in problems with balance, eye-head coordination, and visual-motor transformations underlying goal-directed movements. The deficits can occur after multiple head trauma events, and in some cases after a single mild TBI event. The symptoms can persist for years after the original trauma [4]. and become progressively worse over time. In that regard, effects of natural aging processes will interact with the pathophysiology resulting from the TBI.

The general aims for this research are to characterize, in mTBI, the coordinated movement of the two eyes, to gain insight into underlying oculomotor control problems, and to identify possible biomarkers.

The specific aim for the present work is to determine whether the movements of the two eyes are well-synchronized during horizontal saccades.

Methods

For the present analysis there were 16 normal controls without any neurologic or neuro-ophthalmologic conditions and 18 subjects with chronic mTBI (blunt or blast trauma; one or more events greater than 6 months prior to testing; no other neurologic conditions other than those attributable to the mTBI). At the time of testing, those with mTBI were symptomatic for gaze instability with movement, blurriness not due to refractive errors, difficulty with tasks involving eye-head-hand coordination, or problems with visuo-spatial orientation and postural stability.

The visual target was a red laser beam projected onto a black background one meter in front of the subject. The target was abruptly displaced to the left and right of the center. The time between target jumps was randomly varied between 1 and 2 sec. The target displacement was randomized between 5^{O} and 25^{O} from center, but only saccades to displacements >= 10^{O} were analyzed.

Video images of both eyes were sampled at 250 Hz with a Spryson (Neuro Kinetics) i-Portal system, synchronized to the laser target.

Custom Matlab software was used for analyzing the eye movement data. This included removing artifacts, spontaneous and extraneous eye movements, and the secondary saccades (after the primary one) that are used to bring the eye to its final gaze position. The peak velocity for the right eye of each saccade identified for analysis was scaled to 350 deg/sec. Then all the velocity data points for that saccade for both eyes were multiplied by that scale factor. The resulting scaled velocity data for each subject were fitted with 2^{nd} order polynomials. There were 4 separate regressions for left eye velocity vs. right eye velocity: rightward and leftward directed saccades; acceleration and deceleration phases of individual saccades. Also, there were 4 separate regressions for the difference, right minus left eye velocity, vs. right eye velocity. Finally, the areas under the velocity difference regressions were calculated and divided by the square of the peak right eye velocity (350 deg/sec^2) for a dimensionless variable, ap^2, providing a magnitude estimate of the effect of the quadratic nature of the velocity relationship between the two eyes.

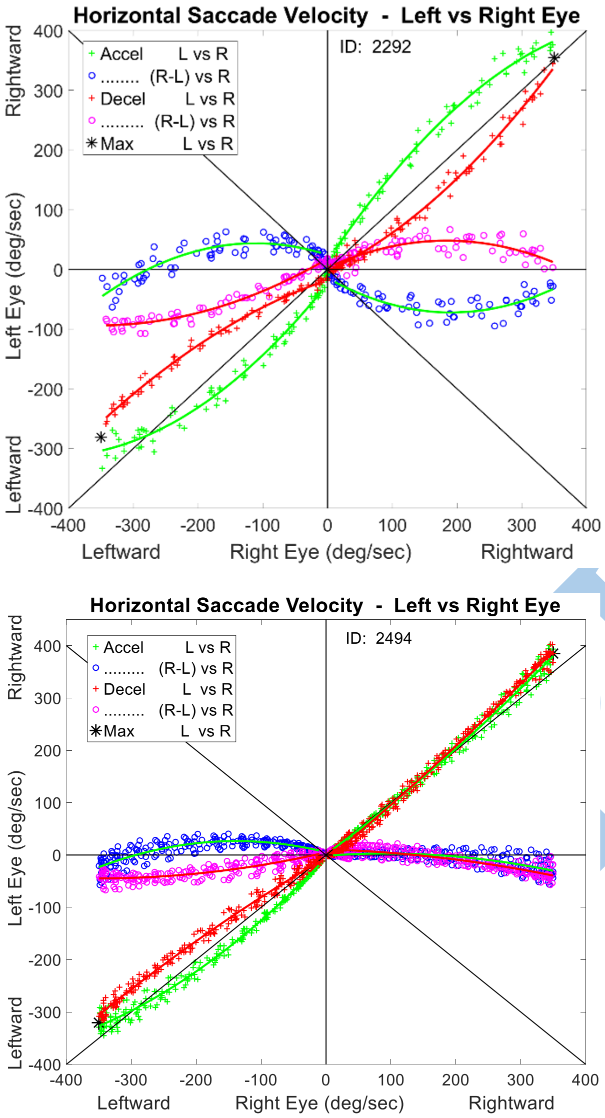

Figure 1. *Saccade velocity ('+') and velocity difference ('o') during acceleration (green / blue) and deceleration (red / magenta). 1A: top (# 2292). 1B: bottom (# 2294).*

Results

Figures 1A and 1B show data for 2 mTBI subjects, each with a distinctive pattern for the relation between the left and right eye velocities. In 1A the left eye is moving faster (at each time point) during acceleration (green; both rightward and leftward) compared to the right eye. During deceleration, it is the opposite. For other mTBI cases, the pattern might be the reverse. In 1B there is a contrasting pattern. There is a slight but significantly greater velocity for the adducting eye (left eye for rightward and right eye for leftward saccades). In other cases, it can be that the abducting eye has a greater velocity. A discriminant analysis using the regression coefficients, which represent the patterns, showed a significant separation of mTBI from control subjects.

In both Fig. 1A and 1B the'o' data points show the right minus left velocity difference. The variable, ap^2, was different compared to controls, with data clustered along the diagonal, where the velocities are equal. Across mTBI subjects, there were significant differences in ap^2 compared to controls.

Discussion

These results indicate abnormal binocular control of horizontal saccades that can be similar or different during the acceleration compared to the deceleration phase, corresponding to distinctive patterns across mTBI subjects. These patterns might be correlated with certain pathologies, as for the patient in Fig. 1B, who had a clinical vergence excess and correspondingly showed a greater saccadic velocity during acceleration for the adducting eye.

Further work will evaluate a larger number of subjects to identify possible sub-groups of mTBI characterized by certain velocity patterns. A bilateral, parametric model for individual saccades, including motor control signals, might provide some insight into the underlying pathophysiology and possible treatment/therapy strategies.

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Motor-sensory systems cannot countervail balance deficits in concussed athletes

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Keywords

Health, Motor control, Gait and postural control, Neural correlates, Clinical research

Highlights

- Increased brain oxygenation in motor-sensory cortices of symptomatic and concussed athletes with balance deficits.
- During unstable surface balance conditions symptomatic and concussed athletes present increased activation.
- During postural control conditions with eyes closed symptomatic and concussed athletes showed reduced neural activation within motor-sensory cortices.

Introduction

Neural compensation may constitute a mechanism to uphold cognition and behavior during pathological situations [1]. Neural activation during balance tasks was found to be increased among individuals with neurodegenerative conditions [2]. Long-term effects of concussion have been associated with neurodegeneration [3], [4], [5]. We investigated the hypothesis that athletes with ongoing symptoms after sport-related concussions (SRC) may be characterized by neural upregulation within the motor-sensory cortex to uphold motor functions and to counteract postural deficits.

Methods

66 athletes (27 ± 13 years; 50 men, 16 women) from various sports participated in the study. 22 concussed athletes reported high post-concussion symptoms (PCS; symptomatic group) and 22 concussed athletes reported low PCS (symptomatic group). 22 healthy non-concussed athletes served as a control group. *Postural control* was assessed by a pressure distribution measuring plate (parameters: COP area, COP track length) during four balance conditions with eyes closed and/or eyes open whilst either standing on a stable or an unstable surface (Figure 1). *Brain oxygenation* (parameters: ΔHbO2, ΔHbR) was collected during postural control tasks by functional Near InfraRed Spectroscopy (fNIRS) above motor-sensory cortices of both hemispheres (8x8 NIRSport 2, NIRx, Medical Technologies LLC, Berlin, Germany; wavelengths of 760nm and 850nm; sampling rate 10.2 Hz). *Statistical analysis:* Comparisons of the mean(s) (repeated (rmANOVA) and univariate (uniANOVA) analyses of variance) were performed for postural control (COP area, COP track length) and brain oxygenation parameters

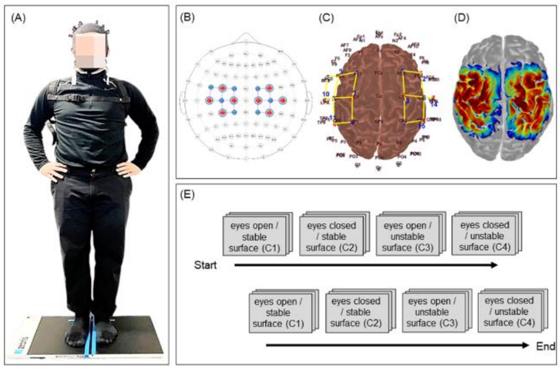

Figure 1: *(A) Exemplary participant; (B-D) fNIRS optode placement; topographical layout; sensitivity map; (E) Study design.*

(ΔHbO2, ΔHbR) for the within-subjects factors vision (eyes opened/closed), and surface (stable/unstable surface). The between-subject factor group was calculated between symptomatic, asymptomatic and control individuals. Furthermore, t-contrast values of brain activation during postural control were calculated applying the general linear model (GLM).

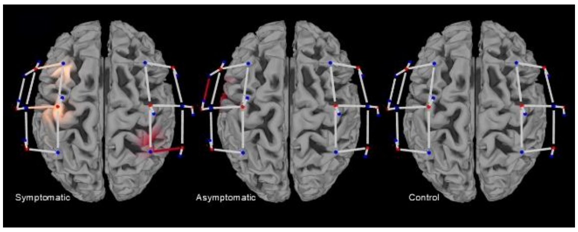

Figure 2: *Postural control on an unstable surface versus stable surface condition in symptomatic, asymptomatic, and control athletes (red dots:*

Results

The rmANOVA for both COP area and COP track length revealed a statistically significant effect for the factor group ($F(2, 63) = 2.888$, $p < 0.05$, partial eta squared [$\eta 2$] = 0.084). Post-hoc pairwise comparisons showed a significantly increased COP area in the *symptomatic* group when compared to the *control* group ($p < 0.05$). The uniANOVA for $\Delta HbO2$ showed significant group effects in ch4 ($F(2, 63) = 5.454$, $p < 0.01$, $\eta 2 = 0.148$), ch5 ($F(2, 63) = 5.736$, $p < 0.01$, $\eta 2 = 0.154$), ch9 ($F(2, 63) = 3.483$, $p < 0.05$, $\eta 2 = 0.1$), and ch15 ($F(2, 63) = 3.161$, $p < 0.05$, $\eta 2 = 0.091$). Post-hoc pairwise comparison revealed significantly higher $\Delta HbO2$ in the symptomatic group when compared to the asymptomatic group in ch4 ($p < 0.01$), ch5 ($p < 0.01$), and ch9 ($p < 0.05$). No significant post-hoc differences were observed in ch15. The symptomatic group showed significantly increased $\Delta HbO2$ on the unstable surface condition when contrasted to stable surface condition in ch1 ($t = 2.204$, $p < 0.05$), ch5 ($t = 2.261$, $p < 0.05$), ch9 ($t = 2.040$, $p = 0.054$), and ch18 ($t = 2.618$, $p < 0.05$; figure 2). The asymptomatic group showed significantly increased $\Delta HbO2$ during the unstable surface condition when contrasted to stable surface condition in ch2 ($t = 2.249$, $p < 0.05$). The control group showed no significant contrast results.

Discussion

Symptomatic concussed athletes were characterized by an increased postural sway when compared to athletes without experienced concussions. The fNIRS analysis revealed increased brain oxygenation in motor-sensory cortices overall balance conditions in symptomatic concussed athletes. Higher brain oxygenation was also observed in symptomatic athletes during postural control with open eyes and when compared to asymptomatic athletes and the control group. The calculation of t-contrasts (applying the GLM) revealed for unstable versus stable surface balance conditions increased activation in motor-sensory cortices of the symptomatic group. When contrasting postural control conditions with eyes closed versus eyes open symptomatic, concussed athletes showed only minor brain activation.

We conclude that athletes with persisting symptoms after SRC are not effectively controlling posture within motor-sensory brain regions. The results therefore indicate that potential compensatory neuronal mechanisms in concussed and symptomatic athletes cannot countervail for post-concussion balance deficits.

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Aging relies on predictive gaze during interception.

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Keywords

Gaze, visuomotor control, sensorimotor performance, motor skills and abilities, upper limbs.

Highlights

- Older adults rely on predictive gaze when intercepting moving targets.
- Predictive gaze can come with improved interception performance.
- Such predictive gaze may be compensating for age-related sensorimotor decline.

Introduction

Aging comes with a decline in various functions, including sensation and behavior [1-2]. One way through which older adults could compensate for such a decline is to rely stronger on predictive mechanisms that allow earlier access to relevant sensory information. However, evidence for this notion is mixed [3-4]. Here, we examine whether aging leads to stronger reliance on predictive gaze allocation when performing a spatiotemporally demanding manual task (interception).

We hypothesize that older adults will shift gaze to task-relevant locations (i.e. interception location) earlier than younger adults. This could compensate for slower sensorimotor functioning in older adults, as earlier gaze shifts to positions of interest allow earlier sampling of relevant visual input. Thus, we also expect that interception performance will improve with earlier gaze shifts to the interception location.

Methods

Twenty younger (20-34 years) and 21 older adults (55-76 years) joined the study. They were right-handed, had normal vision and cognitive functions, and no known musculoskeletal or neurological issues that could impair their participation. The position of a marker at the participants' right index fingernail was recorded at 250 Hz with an Optotrak Certus camera, and movements of the right eye were sampled at 500 Hz with an Eyelink II.

Participants sat in front of a monitor, where we presented a white circle (i.e. target, 1° diameter) moving along eight possible unpredictable paths toward one of five possible hit zones (disc, 2° diameter). These zones were either directly visible or hidden behind a long arc that covered all potential five zones. Thus, the location of the hit zone was either certain (disc) or uncertain (arc). The target entered the hit zone 2.75 sec after it started moving and exited it 400 ms later. Successful interception was achieved if the target was hit while it was within the hit zone. Eighty trials were presented in a single block, with pseudorandom order of the conditions. A depiction of the conditions is shown in Figure 1. In a second experiment, we tested the same participants in the same paradigm but with the target moving along linear, predictable paths.

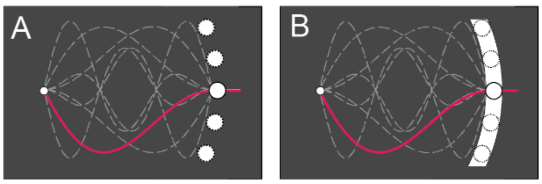

Figure 1: *The target moved along one of eight possible paths toward the (A) certain and (B) uncertain hit zone. Only the white small circle (target) and one of the discs in (A) or the complete arc in (B) were visible in each trial. Dashed and red lines, and the discs over the arc in (B) are shown for illustration.*

We were interested in when participants looked and fixated the hit zone. We first determined the saccade that brought gaze within the hit zone in each trial and was followed by the longest fixation in that trial. We then calculated the latency of this saccade relative to when the trial started.

Thus, latencies shorter than 2.75 sec reflect saccades to the hit zone *before* the target entered that zone. We obtained the median latency across trials of each condition separately per participant and then averaged across participants of each group. To examine effects of certainty and aging on saccade latencies, we submitted these values to a mixed 2 x 2 ANOVA.

Results

Both age groups looked earlier to the hit zone of high than low certainty ($F_{1,40}$ = 38.92, p < .001; Fig. 2), likely because there is no clear advantage in tracking a target while already knowing where exactly to intercept it. Importantly, older adults looked at the hit zone earlier than younger adults ($F_{1,40}$ = 4.24, p = .046). This was pronounced when the target moved toward a disc than arc ($F_{1,40}$ = 7.02, p = .012). Similar results were found when the target moved along linear paths.

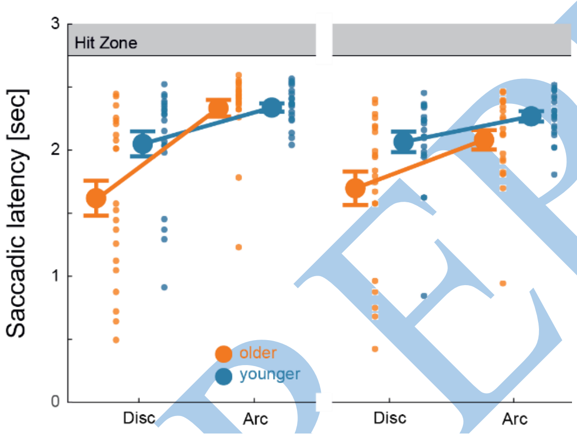

Figure 2: *Saccadic latencies relative to trial start for unpredictable (left) and linear paths (right). Values smaller than 2.75 sec indicate predictive gaze shifts. Individuals and averages (± SEM) are shown in smaller and larger symbols, respectively.*

Gaze allocation was idiosyncratic, and participants who looked earlier at the hit zone typically also hit closer to the center of that zone (Fig. 3). This is particularly evident in older adults, who displayed variations in saccadic latencies, whereas most younger adults shifted gaze to the hit zone rather late, suggesting that they mainly pursued. Although both groups had similar interception rates, aiming closer to the center of the hit zone allowed tolerance in motor variability.

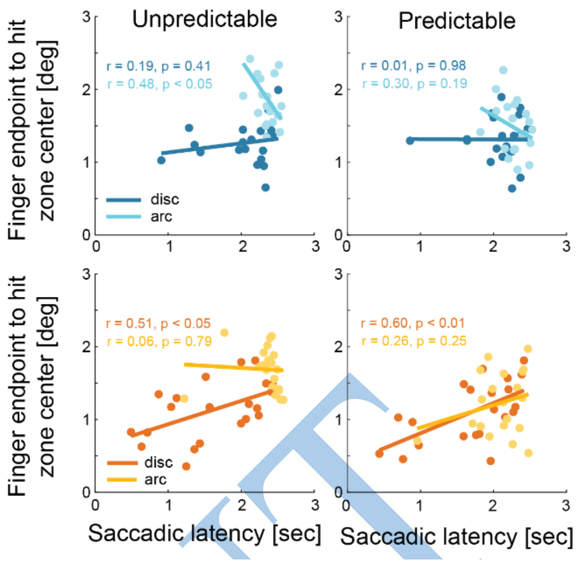

Figure 3: *Relation between saccadic latencies and interception endpoint. Upper and lower rows are for younger and older adults, respectively. Earlier gaze shifts come with interceptions closer to the center of the hit zone. Spearman correlation coefficients and p-values are color-coded within each panel.*

Discussion

Aging comes with a decline in sensorimotor functions, but it still requires efficient motor performance. We report that aging also comes with predictive mechanisms that can preserve motor execution. In two experiments, older participants allocated their gaze in a predictive manner, especially when intercepting a moving target at a predefined hit zone. Earlier gaze shifts to those zones also come with more efficient interception performance. We conclude that aging not only causes physiological decline, but it also comes with sophisticated compensatory mechanisms.

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Retrospective analysis of mental fatigue's influence on reaction times to peripheral stimuli in virtual reality

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Keywords

Motor cognition, Virtual / Augmented Reality, Sensorimotor performance, Peripheral Vision, Mental Fatigue

Highlights

- Mental fatigue affects peripheral vision
- Ecological validity of reaction tests can be improved by virtual reality

Introduction

Reaction times (RTs) to peripheral stimuli are crucial in various sports, as they enable athletes to respond swiftly to events outside the central visual field [1]. Mental fatigue (MF), defined as a decline in the psychobiological state following prolonged cognitive activity, has been documented to negatively affect performance on reaction tests involving stimuli in the central visual field. This could impact sports relying on quick responses, like table tennis [2]. However, the effect of MF on RTs to peripheral stimuli has, to our knowledge, not yet been examined, though it could be critical in sports or daily activities like driving, where peripheral vision and rapid responses under cognitive strain are crucial.

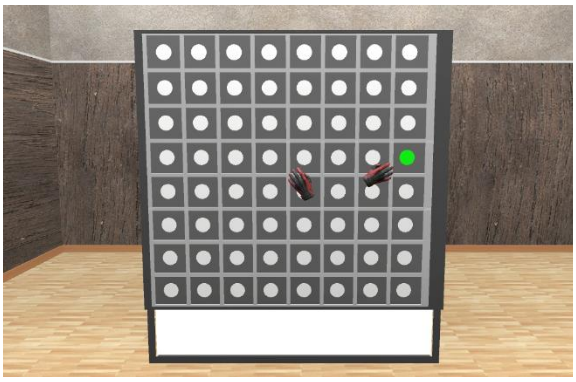
Virtual reality (VR) was used to assess RTs to peripheral stimuli using the same test in two different studies, entailing different levels of MF. As some participants took part in both studies, this exploratory analysis aims to compare RTs to peripheral stimuli under varying MF conditions, potentially laying the groundwork for further research. As for central stimuli, we expect longer RTs with increased MF.

Methods

This retrospective analysis includes results from two studies, using the same peripheral reaction test. Nine participants (3 f, 6 m, age: 26.3 ± 4.8 years) took part in both studies, with two months in between. In the first study, the high MF condition (HF), participants completed a cognitive fatiguing test, a six-minute-long VR Simon Task, requiring responses to peripheral stimuli. In the second study, the low MF condition (LF), three versions of the reaction test were completed: the standard version, and versions with either peripheral or central distractors. Only results from the standard reaction test are analyzed here. As the three versions were administered in randomized order, the standard test could be conducted at the first, second, or third trial.

The reaction test was identical in both studies. Participants held two HTC VIVE Controllers (2018) visualized as virtual hands and viewed the virtual environment via a Pimax Vison 5k super head-mounted display (HMD). The test, created using Blender (version 3.2.1) and Unity (version 2021.3.11f1), consisted of a reaction wall with 8x8 targets (Figure 1). During the test, one target illuminated and was meant to be virtually touched, after which another target illuminated. Both studies encompassed three one-minute trials of this test. The RT (between target illumination and first controller movement toward it) and the angle of view (between the vector from the HMD to the target and a forward-projecting vector from the HMD) were recorded at the time the target became visible. As eye-tracking was lacking, participants' gaze was approximated using the forward-projecting vector. RTs were grouped into near- (8°-30°), mid- (30-60°), and far-peripheral (>60°) regions, as suggested by [3].

***Figure 1:** Virtual reaction wall with illuminated target (green) and two virtual hands.*



RTs were compared using an ANCOVA with the within-subject factors ‘Fatigue’ (HF, LF) and ‘Eccentricity’ (near, mid, far) and the covariate ‘trial order in second study’ (first, second, third trial), to compensate for this factor. Additionally, correlation coefficients were calculated between HF and LF for the different peripheral regions.

Results

***Table 1:** Means and standard deviations of RTs in the different conditions.*

Reaction time (M ± SD)	High fatigue	Low fatigue
Near [s]	0.367 ± 0.038	0.338 ± 0.031
Mid [s]	0.486 ± 0.043	0.405 ± 0.058
Far [s]	0.692 ± 0.097	0.446 ± 0.073

RTs’ descriptive statistics for both MF conditions separated for eccentricity regions are shown in Table 1. After adjusting for the second study’s trial order, the ANCOVA revealed a significant effect for ‘Fatigue’ ($F(1, 7) = 19.280$, $p = .003$, $\eta_p^2 = .734$) and the ‘Fatigue x Eccentricity’ interaction ($F(2, 14) = 8.303$, $p = .004$, $\eta_p^2 = .543$). The main effect of ‘Eccentricity’ ($F(1.181, 8.269) = 4.285$, $p = .067$, $\eta_p^2 = .380$) was non-significant. Post-hoc comparisons of the interaction (Table 2), indicated a progressively larger negative effect of MF on RTs with greater stimulus eccentricity.

Strong correlations emerged between RTs of both MF conditions for all eccentricity regions (near-peripheral ($\rho = .800$, $p = .010$), far-peripheral regions ($\rho = .900$, $p < .001$), though the mid-peripheral correlation did not reach significance ($\rho = .567$, $p = .112$).

***Table 2:** Bonferroni-corrected post-hoc comparisons of the ‘Fatigue x Eccentricity’ interaction.*

Comparison		*p*-Value	Cohen’s *d*
Near	HF vs. LF	.005	1.381
Mid	HF vs. LF	.006	1.391
Far	HF vs. LF	<.001	5.752
High fatigue	Near vs. Mid	<.001	2.662
	Near vs. Far	<.001	3.490
	Mid vs. Far	<.001	2.392
Low fatigue	Near vs. Mid	.007	1.661
	Near vs. Far	.007	1.605
	Mid vs. Far	.049	1.046

Discussion

Despite its retrospective nature, the analysis showed similar results to [2], as MF also increased RTs to peripheral stimuli. Although a comparable effect to that in [2] emerged in the near-peripheral region, it was more pronounced in the far periphery. One reason could be that directing attention to greater eccentricities may be more demanding anyway, resulting in stronger influence. Despite a small sample size, the results of both studies showed strong correlations, suggesting robust findings. The analysis has several limitations, including the trial order in the second study, lack of eye-tracking, or potential learning effects. Nonetheless, these findings warrant further study and again prove VR suitable for RT assessments, highlighting its potential for ecologically valid testing environments.

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Pupil Size Reflects the Attenuation of Motor Fatigability by Reward

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Keywords

Motor fatigability, Motor control, Pupillometry, Upper limbs, Sensorimotor performance

Highlights

- Reward attenuates motor fatigability.
- Reward-induced changes in pupil size and tapping speed are linked.

Introduction

Reward can enhance motor performance even in a fatigued state [1], though the underlying mechanisms driving this effect remain unclear. Previous research indicates that reward enhances the effort invested into a movement [2], which correlates with heightened activity in the locus coeruleus (LC) in monkeys [3]. Motor fatigability, here quantified as a decrease in movement speed, can be induced by fast, repetitive movements [4]. This decrease in movement speed is referred to as "motor slowing" and has been linked primarily to supraspinal mechanisms [4]. The role of the LC in these processes remains unclear. In this study, we investigate whether the LC might contribute to the mechanisms by which reward mitigates motor fatigability. To approximate LC activity, we measured pupil size under constant ambient lighting, as pupil size correlates positively with LC activity in humans [5]. We expected the effect of reward on pupil size to be linked to its effect on motor slowing.

Methods

We asked 25 healthy participants (age: 27 ± 4 y; 13 females) to participate in a combined wrist tapping and reward task. Participants were asked to tap at their maximal voluntary speed between two force sensors by flexing and extending their right wrist. In each trial, participants tapped for 40 s. After the first 20 s of tapping, a cue was presented to them, indicating whether the current trial was a reward or a neutral trial. For half of the participants, ∪ was the reward sign and ∩ the neutral sign; for the other half, the signs were reversed. During reward trials, participants had the chance to win 1 CHF by tapping faster on average than in the previous reward trial. In neutral trials, participants could not win a reward. The experiment consisted of 10 trials per condition, which were presented in a pseudorandomized order. For the statistical analyses of each assessed outcome, the data was divided into 10 s bins before we fitted linear mixed-effects models (LMEM) with the fixed factors *Time* (i.e., 0-10s, 10-20s, 20-30s, 30-40s) and *Condition* (i.e., reward, neutral), including random intercepts per participant and random slopes for the average effects of condition. In addition, to test whether the baseline-corrected pupil time series differed between the reward and the neutral condition, we subjected the time series data to a non-parametric equivalent of a paired t-test using the SPM1D toolbox. As we were interested in whether there is a link between reward-induced changes in pupil size and tapping frequency, we correlated the cue-evoked change (difference between mean 5s post-cue and mean 5s pre-cue) in pupil size with the cue-evoked change in tapping frequency.

Results

As anticipated, our paradigm induced motor slowing (LMEM main effect of *Time*: $p < .001$,

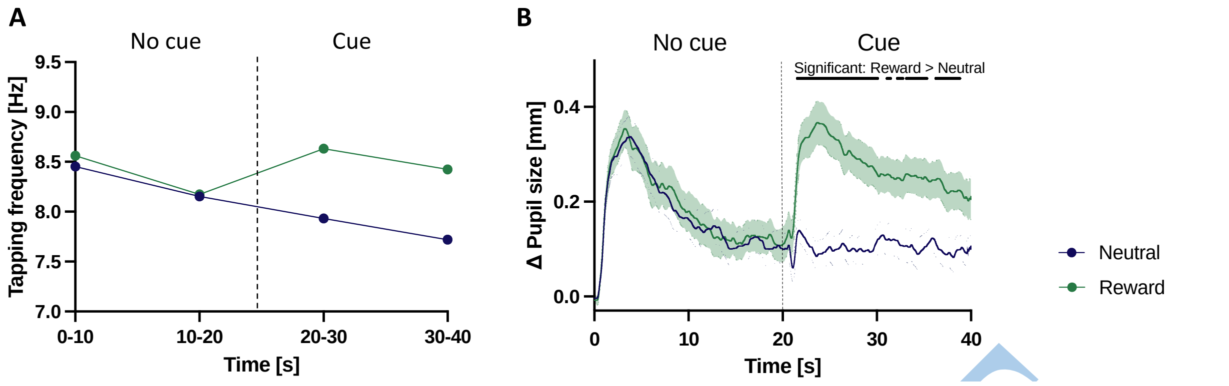

***Figure 1:** Results. Tapping frequency (**A**), and baseline-corrected pupil time series (**B**) over time averaged across participants for reward (green) and neutral (blue) condition. The black line/dots in (B) indicate clusters, in which a significant difference between the two conditions (rewards vs. neutral) was detected. Shaded areas indicate SEM.*

$\eta_p^2 = .02$; post hoc comparisons within the neutral condition revealed significantly slower tapping frequencies during bin 3 and bin 4 compared to bin 1: $p < .001$; Figure 1A). The presentation of the reward cue led to a significant increase in tapping speed compared to the neutral cue (interaction effect *Time* x *Condition* $p < .001$, $\eta_p^2 = .02$; driven by significant differences between conditions during bin 3 and bin 4 with $p < .001$). Similar to the results of the tapping analysis, there was a significant effect of *Time* on pupil size (LMEM main effect of *Time* $p < .001$, $\eta_p^2 = .03$; Figure 1B) with significantly smaller pupil sizes during the last three bins compared to the first bin in the neutral condition (all $p < .001$). Furthermore, the reward cue presentation led to a significantly larger pupil size compared to the neutral cue (interaction effect *Time* x *Condition* $p < .001$, $\eta_p^2 = .03$; driven by significant differences between conditions during bin 3 and bin 4 with $p < .001$). An additional analysis of the baseline-corrected pupil size time series revealed that, beyond the mean binned values, the time series itself differed significantly between conditions, showing pronounced pupil dilations in response to the reward cue but not to the neutral cue (Figure 1B). Our hypothesis that both tapping speed and pupil size respond similarly to the reward cue was supported by a positive correlation between cue-evoked changes in tapping speed and pupil size (Pearson's r = .488, 95%-CI: [.128, .742]). In contrast, no significant correlation was observed for the changes evoked by the neutral cue (Spearman's r = .062, 95%-CI: [-.496, .570]).

Discussion

This study shows that our paradigm induces motor fatigability and that presenting a reward cue leads to an increase in tapping speed, even in a fatigued state. Importantly, pupil size followed a similar pattern as tapping speed. Furthermore, the positive relationship between reward-cue evoked changes in pupil size and tapping speed indicates that pupil size, as a proxy for LC activity, may reflect the effort invested in the task. These findings align with previous research in monkeys demonstrating that reward enhances the effort invested in movements, which was linked to increased LC activity. Our findings suggest that also in humans, the LC is involved in producing effort and that is a potential contributor to the effect of reward in a fatigued state.

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Finger Tapping at Maximal Speed Evokes a Crossover-Fatigability Effect

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Keywords

Motor control, Upper limbs, Sensorimotor performance, Motor fatigability, Crossover fatigability

Highlights

Crossover-fatigability can be evoked by maximal speed finger tapping and manifests in a depression of tapping speed.

Introduction

Crossover-fatigability (CF) is a phenomenon that describes a fatiguing effect of one effector on the contralateral homologous effector that has not been involved in the movement. The mechanisms responsible for CF and whether CF can robustly be evoked are still a matter of debate [1]. Here, we use a rapid finger-tapping paradigm to induce fatigability and to detect the existence of a CF effect. Fatigability is assessed through 'motor slowing', a decrease in movement speed that occurs when maximal tapping speed cannot be maintained [2]. Fatigability through motor slowing has been associated with a predominantly supraspinal mechanism [e.g., 3, 4] and therefore serves well as a model to explore the supraspinal involvement in CF. In this work, we show that CF can be evoked through a motor-slowing finger-tapping paradigm.

Methods

30 participants (24 +/- 3.7 years, 17 female, 29 right-hand dominant) performed finger tapping at maximal voluntary speed with the index finger of the dominant (DH) and the non-dominant hand (NDH). The task consisted of tapping with one hand (*Pre)* followed immediately by tapping with the other hand (*Post)* and then by 30 s rest. The first hand consisted of either a 10 s or a 30 s tapping condition, the second hand always tapped for 30 s, resulting in 4 different overall conditions (Figure 1). The experiment was made up of 6 trials per condition in pseudorandomised order.

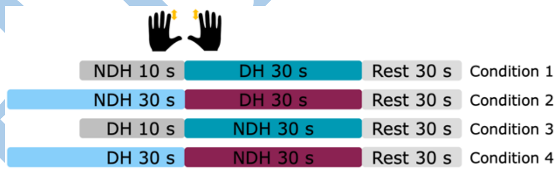

Figure 1: *Experiment Design. A single trial consisted of one condition: tapping with one hand (DH or NDH) for 10 s or 30 s (pre), followed by tapping with the other hand (NDH or DH) for 30 s (post). After every trial, both hands rested for 30 s.*

Data of the second hand of conditions 1 and 3 (Figure 1) are referred to as 'no CF', as the 10 s tapping served as a control condition, whereas conditions 2 and 4 are referred to as 'CF'. The tapping data was averaged into 10 s bins. Statistical analyses were performed using linear mixed-effects models (LMEM) with random intercepts of participants and interaction of all factors. Three models were tested: (i) Tapping frequency of the second hand (*Post)* was analysed in dependence of 3 factors: *Time* (bin 1, bin 2, bin 3), *Condition* (CF, no CF), *Hand* (DH, NDH). (ii) CF Effect (percentage change in tapping speed from bin 1 of *Pre* to bin1 of *Post*, calculated separately for each hand) was analysed in dependence of *Condition* (CF, no CF) and *Hand* (DH, NDH). (iii) Slowing (percentage decrease in tapping speed from bin 1 to bin 3, [5]) was analysed in dependence of *Condition* (pre, no CF, CF) and *Hand* (DH, NDH). Note that for

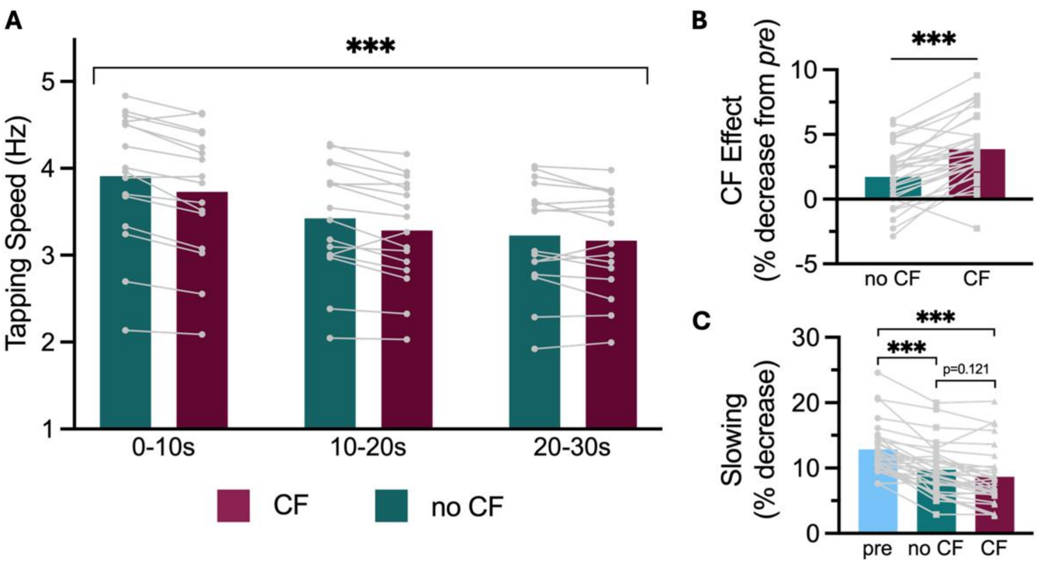

Figure 2: *Results. A: Tapping speed over time for CF and no CF conditions. B: CF effect, calculated as percentage change from first bin of pre to first bin of post, for CF and no CF conditions. C: Motor slowing, as percentage decrease in tapping speed from time bin 1 to time bin 3, for pre, no CF, and CF.*

pre, only the 30 s conditions could be used (Figure 1, Condition 2 and Condition 4).

Results

First, we found motor slowing to be present (LMEM (i) main effect of *Time p<.001*, Figure 2A). Further, we observed that tapping speed was, on average, significantly lower for the *CF* condition and the *NDH* (main effects of *Condition* and *Hand p<.01)*, without significant interaction effects (*p>.05*). Model (ii) indicated that CF effect was indeed present (significant main effect of *Condition*, Figure 2B), but did not differ between the hands (main effect *Hand* and interaction effect *p>.05*). Lastly, we found that motor slowing significantly depended on the previously executed task (significant main effect of *Condition p<.001*, Figure 2C) and on which hand was used (significant main effect of *Hand p<.001*). The DH showed less motor slowing (9.1% +/- 0.5%) than the NDH (11.8% +/- 0.6%).

Discussion

We show that CF can be evoked using a fatiguing finger-tapping task. This CF effect was observed as a reduced tapping speed of the second hand. Additionally, we found that motor slowing, i.e., the decrease in movement speed, is reduced if the first hand performed even 10 s of finger tapping. Thus, it seems that 10 s of maximal speed finger tapping is enough to induce a change in the fatiguing behaviour of the second hand. As motor slowing is a phenomenon predominantly associated with supraspinal mechanisms, we propose that CF may have a strong cortical involvement.

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MMA- A Multilayer Model of Automatization.

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Keywords

Motor control, Motor cognition, Motor skills and abilities, Automatization, Hierarchical control

Highlights

- New Model of the process of automatization
- Automatization emerges from the architecture of single control units in hierarchical control system

Introduction

When practicing a certain task extensively, the learner is supposed to pass through different stages, the final stage being described as "automatic". The practiced skills are executed in a seemingly effortless manner. It is fast and runs without attentional control. Over the past decades various theories offered different ideas describing the characteristic features of such an automatic state. Yet, there is still an ongoing debate on how to conceptualize the transition from a non-automatic to an automatic processing regime, particularly on the mechanisms effectuating this transition. Here, we present a model that demonstrates how automatization emerges by means of practice as a direct outflow of the architecture of the control system.

The model

The basic proposition of our "multilayer model of automatization" (MMA) is that control of movements is accomplished by hierarchically organized systems with multiple control units (CU) distributed over different processing levels. CUs in superordinate levels control the activity of CUs at subordinate levels. In each processing step, first, the tasks need to be determined in order to specify the control policy. Furthermore, output and feedback need to be monitored. Any of these processing steps cause additional costs in terms of time and effort. However, all of the CUs in the MMA are adaptive and can learn to recognize regularities. On this basis they can anticipate upcoming tasks and generate goal-directed outputs ahead of time. If the system encounters tasks with high contingencies in information flow during the learning episodes, lower-level units become more and more independent from input by superordinate levels. Processing activities at higher control levels are progressively reduced, freeing processing capacities at these levels. In the model, we specify the necessary and sufficient prerequisites and mechanisms for automatization to emerge without any further external process governing the process of automatization. In the basic model, the relevant features are defined on a functional level of description. Yet, we also provide a publicly available (https://osf.io/95x78/?view_only=2376b3fbb0364a1fa9d62b0a80a6afa6.) simulation tool where a model version is worked out in every detail. This demonstration tool allows to inspect basic features of the model and its predictions. Yet, the behavior of the system, particularly the phenomenon of automatization, is not limited to a particular instantiation of the model. We explain and discuss how the properties of MMA transfer to human automatization processes, thereby allowing to derive predictions on the extent and the speed of automatization in learning tasks with characteristic profiles of contingency in the information flow.

The Effects of Intensive Exercise on Cortical Hemodynamics During Early Motor Memory Consolidation

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Keywords

Motor learning, Neural correlates, Neuroplasticity, Consolidation, Cardiovascular exercise

Highlights

- Activity shifts to PFC after HIIT
- Increased shift towards PFC may interfere with motor memory consolidation

Introduction

High-intensity interval training (HIIT) performed following motor skill practice has been shown to improve the consolidation of motor memories [1]. However, as the number of experiments has increased, findings have become equivocal, especially for motor tasks encoded largely explicitly. It has been suggested that the consolidation of explicitly encoded motor sequences involves an interaction between the declarative and procedural memory systems [2]. Therefore, interventions that affect prefrontal cortex (PFC) and motor cortex (M1) activity following motor skill practice have been shown to modulate consolidation [3]. During HIIT activity shifts towards M1, while a rebound surge has been suggested after the end of HIIT, resulting in increased PFC activity [4, 5]. This shift to the PFC could theoretically allocate resources to the declarative system (i.e., competition suppression model), thereby disrupting procedural consolidation and reducing offline motor skill improvements [3]. Consequently, an exercise-induced shift in activity between the PFC and M1 may provide a possible explanation for the contradictory findings in explicitly encoded motor tasks [4]. Moreover, it has been suggested that the activity shift may be particularly excessive in individuals with low cardiorespiratory fitness, for example, due to a higher release of catecholamines in response to exercise [2]. Thus, the aim of this study was to explore the effects of post-encoding HIIT on (i) the consolidation of explicitly encoded motor sequences, (ii) on PFC and M1 activity during the early stages of motor memory consolidation, and (iii) the potential associations between exercise-induced cortical activity changes, motor memory consolidation, and VO_{2peak}. We hypothesized an exercise-induced activity shift to the PFC, which we expected to negatively correlate with motor consolidation, especially in individuals with lower fitness.

Methods

15 healthy males (age: 23.4 ± 2.9 yrs.; VO_{2peak}: 50.7 ± 5.6 ml/kg/min) participated in a counterbalanced within-subject design. Participants practiced an explicit motor sequence learning task (i.e., finger tapping task, 12 blocks à 30 sec) followed by either (i) HIIT (90%/60% W_{max}), or (ii) seated rest (REST). We measured resting-state PFC and M1 activity using functional near-infrared spectroscopy (fNIRS) before (i.e., baseline), as well as 10, 30, and 60 min after HIIT or REST. Motor memory retrieval was tested 24h later (i.e., 3 blocks à 30 sec). To assess consolidation, we calculated the relative change in the number of correct sequences from the end of encoding to the 24h retention test and compared the offline change scores between conditions using a

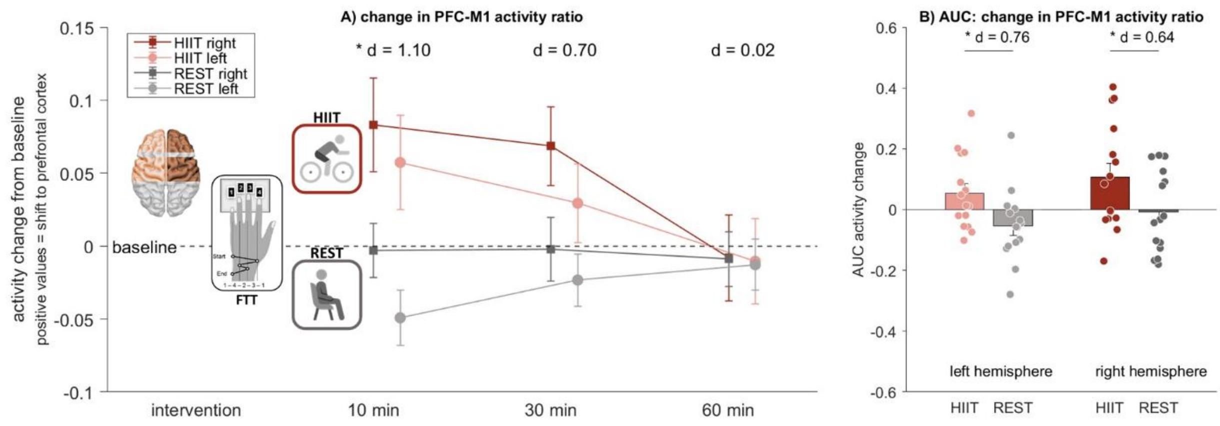

Figure 1: *Effects of HIIT on PFC-M1 activity ratio (A) over time; (B) area under the curve (AUC); * = sig. difference*

paired t-test. Relative changes from baseline in PFC activity, M1 activity, and normalized PFC-M1 activity ratio were analyzed using separate 3 (TIME: 10, 30, and 60 min) x 2 (CONDITION: HIIT vs. REST) repeated-measures ANOVAs. Associations between exercise-induced changes in PFC-M1 activity ratio, consolidation, and VO_{2peak} were tested using Pearson's correlation.

Results

We did not find enhanced motor memory consolidation in the HIIT condition ($t(14) = -0.278$; $p = .785$; $d = 0.07$). HIIT resulted in a greater activity of the PFC (CONDITION: $F(1,14) = 45.67$; $p < .001$; $\eta^2_p = .765$) and M1 (CONDITION: $F(1,14) = 31.52$; $p < .001$; $\eta^2_p = .692$). As expected, there was a greater shift in activity ratio towards the PFC (CONDITION: $F(1, 14) = 10.41$; $p = .006$; $\eta^2_p = .427$; Figure 1). Notably, we found a negative correlation between the exercise-induced change in PFC-M1 activity ratio 30 min post-HIIT and motor consolidation (Table 1), indicating that a greater shift towards PFC resulted in reduced consolidation. In addition, the activity shift towards PFC was larger in participants with higher VO_{2peak} (Table 1).

Table 1: *Correlations between PFC-M1 activity ratio, consolidation, and VO_{2peak}. AUC = area under curve; Δ = difference between HIIT and REST; * = sig.*

time	Δ consolidation	VO_{2peak}
Δ activity ratio AUC	*r* = -.374	*r* = .529*
Δ activity ratio 10 min	*r* = -.348	*r* = .424
Δ activity ratio 30 min	*r* = -.570*	*r* = .324
Δ activity ratio 60 min	*r* = .349	*r* = .520*

Discussion

Contrary to previous findings, HIIT did not improve motor memory consolidation. Our results indicate an exercise-induced increase in PFC and M1 activity, with a greater increase in PFC. This supports the idea of a post-HIIT rebound surge in brain activity [3]. Interestingly, this activity shift to the PFC may partially explain the lack of beneficial effects on consolidation in our study, possibly due to a resource allocation to the declarative system competing with procedural processes during consolidation [4]. However, since a higher activity shift to the PFC was only negatively associated with consolidation 30 min post-HIIT, this notion needs to be replicated in further experiments. In addition, the PFC activity shift appears to be more pronounced in participants with higher cardiorespiratory fitness. This is in contrast to previous hypotheses [2] but might be explained by the dual-mode model, suggesting an involvement of the PFC in the suppression of aversive stimuli following HIIT in fitter individuals [5].

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Transcutaneous Spinal Direct Current Stimulation (tsDCS) improves Balance and Sprint Performance

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Keywords

Transcutaneous Spinal Direct Current Stimulation, Neuromodulation, Balance, Sprint, Sports performance

Highlights

- Anodal tsDCS enhanced balance and sprint performance
- Cathodal tsDCS impaired performance

Introduction

Transcutaneous spinal direct current stimulation (tsDCS) has primarily been applied in therapeutic settings, especially in neurological rehabilitation [1]. It has shown potential in various contexts. Previous studies have demonstrated that tsDCS can modulate spinal excitability, resulting in improvements in motor function, such as muscle activation, after anodal stimulation [2,3], and impairments after cathodal stimulation [3]. However, its potential influence on athletic performance metrics like balance and sprinting remains largely unexplored. These abilities are essential components of numerous sports, reducing the risk of injury and offering a competitive edge during high-speed, complex movements. Given that tsDCS can modulate neural excitability at the spinal level, this study aims to test the following hypotheses: Balance(H_1) and sprint (H_2) performance will improve significantly in the anodal stimulation group compared to the sham, while it will worsen in the cathodal stimulation group compared to the sham. If proven effective, this non-invasive stimulation technique could serve as a valuable tool for coaches and sports scientists aiming to improve athletic performance without pharmacological interventions.

Methods

In this double-blind, placebo-controlled, randomized, crossover study, 21 healthy adults (aged 18–35 years) participated in three tsDCS sessions: anodal, cathodal, and sham, with a washout period of at least 5 days between sessions. Each session involved 20 minutes of 1.5 mA stimulation targeting the S1 spinal level, based on prior research [3]. Balance performance was assessed using the Y-Balance test in which the combined-leg score was calculated in three directions (anterior, posterolateral and posteromedial) separately for analysis. Sprint performance was evaluated using the Flying 20-m sprint test, in which photocells were placed after 10m and at the end of 30m. To analyze the data, repeated-measures ANOVA was conducted with factors intervention (3: anodal, cathodal, sham) and time (2: pre, post). Post-hoc comparisons with Bonferroni correction were applied. Effect sizes for pairwise comparisons were calculated using Cohen's d for paired samples. Partial eta-squared (ηp^2) was calculated for the main effects and interaction, and statistical significance was set at $p<0.05$.

Results

A repeated-measures ANOVA revealed a significant intervention×time interaction for balance performance in the posteromedial direction ($F(2,40)=13.58$, $p<.001$, $\eta p2=0.36$) and sprint performance ($F(2,40)=14.53$, $p<.001$, $\eta p2=0.42$) indicating that the changes in the Y-Balance test and the Flying 20-m sprint test from pre- to post-intervention differed across the three stimulation conditions. Post-hoc analyses with Bonferroni correction showed that balance performance improved significantly in the anodal condition

(Mdiff=4.55±4.08cm; p<.001; d=1.42) compared to sham (Mdiff=0.42±1.96cm). Conversely, performance deteriorated significantly in the cathodal condition (Mdiff=−3.11±4.24cm; p<.001; d=-0.91) compared to sham. Similarly, sprint performance improved significantly in the anodal condition (Mdiff=−0.03±0.06s; p<.001; d=-0.64) compared to sham (Mdiff=0.01±0.03s), whereas it declined significantly in the cathodal condition (Mdiff=0.03±0.04s; p<.001; d=0.83) compared to sham.

studies, and optimized stimulation parameters (e.g., intensity, electrode placement) to enhance effectiveness. This study adds to the growing field of neuromodulation for performance enhancement, establishing a foundation for further research in this area. Since tsDCS is a non-invasive, easy to administer stimulation method, it holds promise as a novel tool for enhancing athletes' balance and sprint performance. If effective, it could be considered a form of neuro-enhancement and transform competitive sports.

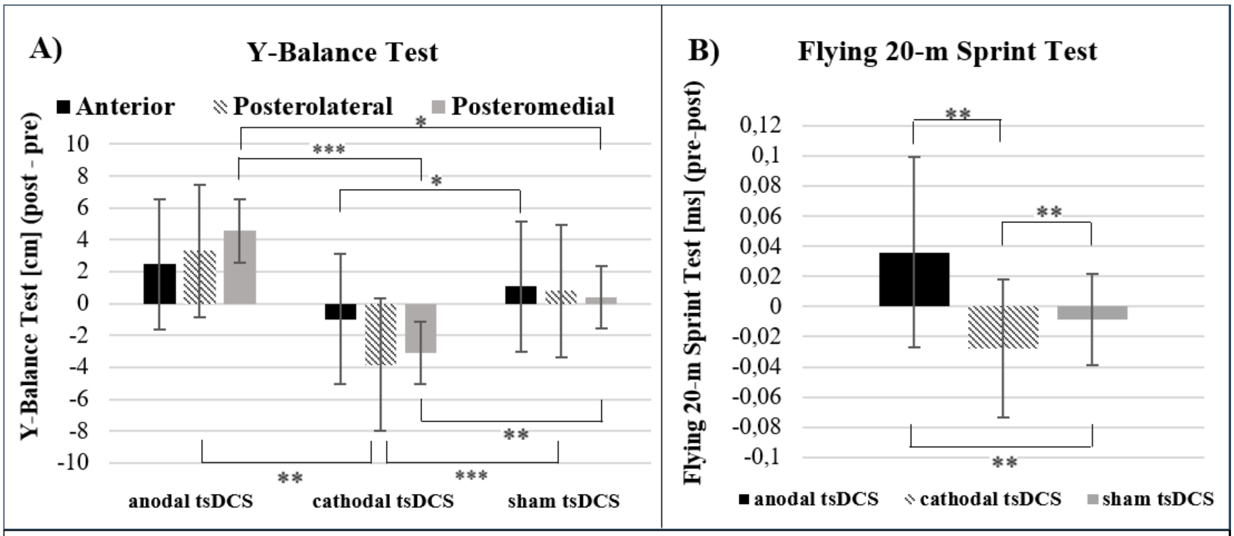

Figure 1: *Comparison of interventions (anodal, cathodal, sham tsDCS) on A) the Y-Balance Test and B) the Flying 20-m Sprint Test. Significant differences are marked as *p < 0.05, **p < 0.01, ***p < 0.001.*

Discussion

This study demonstrated that anodal tsDCS enhanced both balance and sprint performance, while cathodal tsDCS led to diminished performance compared to sham stimulation. These results align with previous research showing that anodal tsDCS can improve motor performance by enhancing cortical excitability and synaptic plasticity [4]. In contrast, cathodal tsDCS likely inhibited cortical excitability, which could explain the decline in performance [3]. Such a decrease in excitability could reduce the efficiency of motor control and coordination, resulting in poorer performance. The findings support the hypothesis that tsDCS can exert differential effects on motor functions depending on the polarity of the stimulation. However, potential practice effects from the lack of counterbalancing of the intervention sequence warrant caution. The sample size of 21 limits generalizability, underscoring the need for larger cohorts, long-term

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The effects of different shoe stack heights on running coordination at different running speeds

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Keywords

Sport, Motor control, Gait and postural control, Uncontrolled manifold, Running coordination.

Highlights

- An uncontrolled manifold approach was applied using a 3D full-body model
- Shoe stack height did not modulate the structure of motor variability
- Synergy stabilizing center of mass became weaker at a higher speed

Introduction

Running shoes are important as they can potentially influence running performance and injuries. Stack height is a highly discussed design feature of running shoes, but its effects are not well understood [1]. Running coordination is very important for running performance [2]. Various factors can influence running coordination such as speed, expertise level and shoes. Most of the running coordination studies focused on lower extremities in 2D. However, non-sagittal planes and upper body motions are also important in the 3D full-body running movement [3]. To date, no study focused on the stack height effects on the full-body running coordination. One of the possible methods to investigate the full-body running coordination is the uncontrolled manifold approach (UCM). UCM is used to analyze how the central nervous system coordinates the elementary variables (EVs) of a redundant system to stabilize the performance variable (PV). Thereby, the structure of motor variability is decomposed into its components in terms of its effects on PV [4].

This study aimed to investigate the effects of different stack heights on running at different speeds by using the UCM to decipher the coordination of redundant degrees of freedom (DOFs). It was hypothesized that a higher stack height increases the joint angle coordination variability that affects the center of mass (CoM) movement (H1) and that this effect is more pronounced at a higher speed (H2).

Methods

Seventeen healthy male experienced runners participated. The experiment was conducted on a motorized treadmill (h/p/cosmos). After a familiarization to treadmill and warm-up protocol, the participants ran with three running shoes differing in stack height (H = 50 mm, M = 35 mm, L = 27 mm) for 90 s at 10 km/h and 15 km/h with a 2-min break between speeds and 5-min break between shoes. The order of shoes was parallelized. Borg Scale was asked in order to control fatigue level (≤ 12 (light) [5]). Kinematic data were collected using 16 Vicon cameras operating at 200 Hz (Vicon Motion Systems, Oxford, UK). UCM was applied with a 3D full-body model in which the joint angles were the EVs, and the CoM was the PV [3]. The portion of variability that does not affect the CoM is referred to as $UCM_{\parallel}$, whereas the portion that affects CoM as $UCM_{\perp}$. The ratio of $UCM_{\parallel}$ and $UCM_{\perp}$ (UCM_{Ratio}) is used to operationalize the strength of synergy stabilizing CoM [3]. By statistical parametric mapping (SPM) rmANOVAs with the dependent factors shoe (H, M & L) and running speed (10 km/h & 15 km/h), the differences between the shoe and speed conditions were analyzed for three UCM parameters separately ($UCM_{\parallel}$, $UCM_{\perp}$, and UCM_{Ratio}).

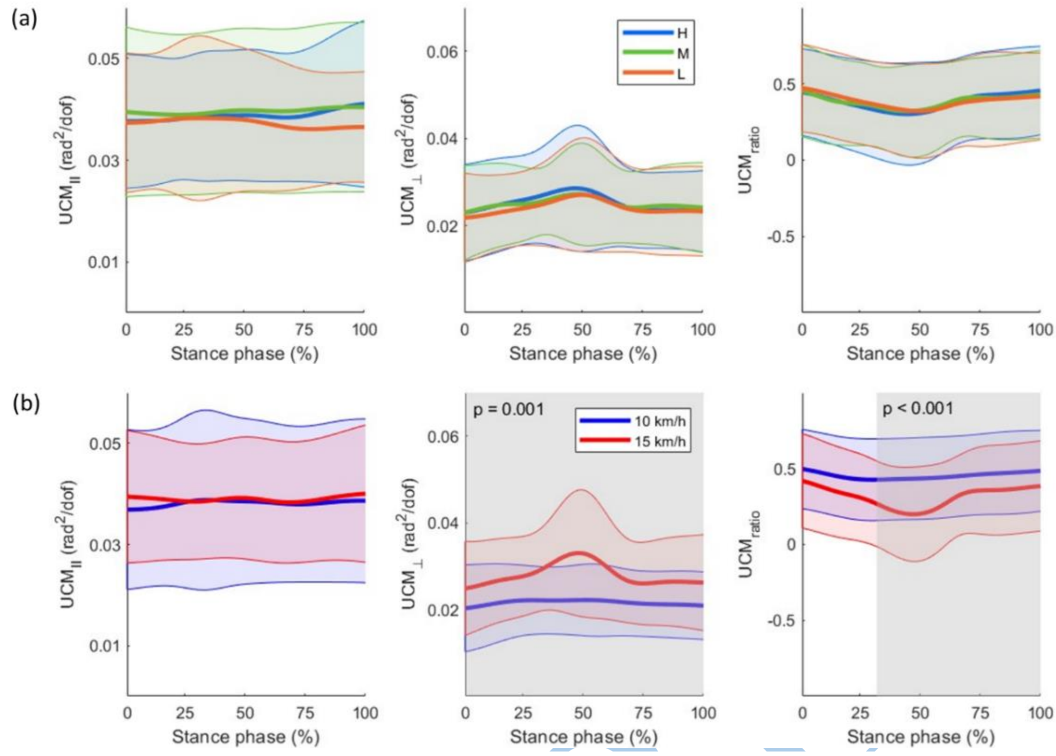

Figure 1: *The results for the three UCM components (UCM∥, UCM⊥, UCMRatio) as mean ± standard deviation for different **(a)** shoes (H = 50 mm, M = 35 mm & L = 27 mm) and **(b)** speeds (10 km/h & 15 km/h). The average of two speed and three shoe conditions are represented, respectively. The significant speed effects in SPM rmANOVA are shown as the gray shaded areas with the corresponding p-values.*

Results

The results of the $UCM_{\parallel}$, $UCM_{\perp}$ and UCM_{Ratio} are shown for different shoes and speeds in Fig. 1(a) and 1(b), respectively.

The statistical analysis revealed that (1) the $UCM_{\perp}$ (variability component affecting CoM) was lower at 10 km/h compared with 15 km/h and (2) the UCM_{Ratio} (synergy stabilizing CoM) was higher at 10 km/h compared to 15 km/h. Remaining effects were not significant.

Discussion

The key findings were that (1) the tested shoes did not change the motor variability structure which was against H1& H2; (2) regardless of the shoe condition, the joint angle coordination variability affecting the CoM increased as speed increased from 10 km/h to 15 km/h, and (3) the synergy stabilizing the CoM weakened due to increase in this variability component. The findings complement a study on fatigue [3] and shows that the variations in the tested running speeds influenced the running coordination, whereas the variations in the tested shoes were not large enough to cause a change.

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Empowering or disempowering?

Coach-created motivational climates in rhythmic gymnastics

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Keywords

Sport, Development, Sport psychology, Training, Motivation

Highlights

- Almost 65% of athletes feel empowered.
- Positive motivational climates lead to higher engagement and team cohesion.

Introduction

Coaches play a crucial role in the training and development of athletes. Rhythmic gymnastics involves a complex and specific training process that allows coaches to shape athletes' gymnastics journeys [1]. Coaching practices can create a training atmosphere that influences athletes' outcomes, performance, and development, either positively or negatively. Some outcomes are motivational, tied to athletes' drive to improve and intention to continue participation, while others are social, referring to interpersonal relations, a sense of belonging and team cohesion [2]. The "Empowering/ Disempowering coaching" concept identifies three positive (task-involving, autonomy-supportive, socially supportive) and two negative climate dimensions (ego-involving, controlling coaching) [3]. Values-based behaviours can support coaches in creating an empowering climate with common values among successful elite coaches, including hard work, respect for others, responsibility, trust, discipline, and positivity [4]. However, the limited research on the coach-created psychosocial climate in this sport limits our understanding of athletes' perceptions of this environment.

This study aimed to investigate athletes' perceptions of the coach-created motivational climate in rhythmic gymnastics and its relation to their motivational and social outcomes. We hypothesised that an empowering climate would be positively related to athletes' engagement and team cohesion.

Methods

A total of 88 adolescent and adult (19% >18 years old) rhythmic gymnasts (49% national, 43% international and 8% recreation-level athletes) completed an online survey consisting of basic demographics and standardised questionnaires about athletes' engagement, team cohesion, and the five dimensions of the perceived coaching climate (e.g., Athlete Engagement Questionnaire). After computing the descriptive statistics, we verified our predictions running two multiple regression models and a k-means cluster analysis.

Results

We observed positive correlations between engagement and the positive dimensions of coach-created motivational climates (ρ=0.669, ρ=0.556, ρ=0.527; all $p<0.001$), as well as between team cohesion and the same dimensions. Also, a discernible negative correlation was observed between engagement and ego-involving climate (ρ=-0.429, $p<0.001$).

In two regression models, autonomy-supportive (β=0.425, $p<0.001$) and task-involving climates

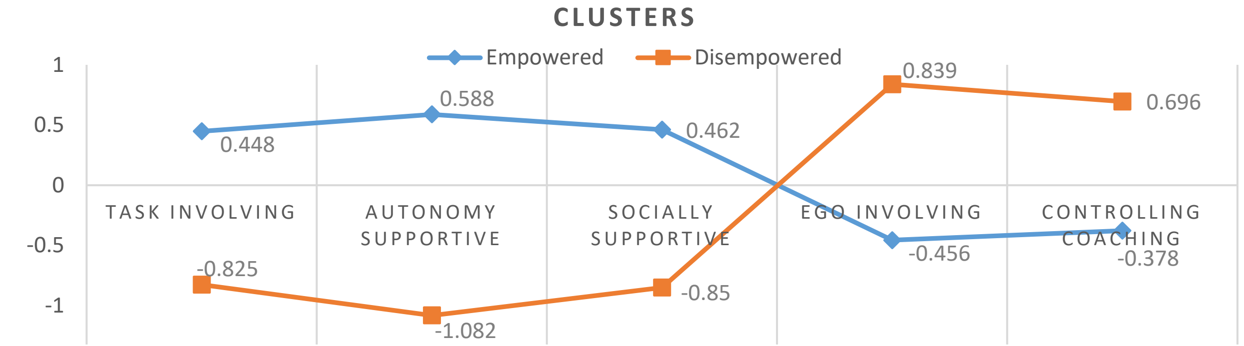

Figure 1: *"Empowered" and "disempowered" gymnasts: K-means clustering.*

(β=0.309, p=0.004) were positively related to engagement (R^2=0.441) (Table 1). Task-involving (β=0.377, p<0.001) and autonomy-supportive climates (β=0.363, p<0.001) were also positively related to team cohesion (R^2=0.446) (Table 2).

K-means clustering divided participants into two groups: Cluster 1 (N=57) had higher scores than Cluster 2 in task-involving (0.448), autonomy-supportive (0.588), and socially supportive climates (0.462), while Cluster 2 (N=31) exhibited higher scores in ego-involving (0.839) and controlling coaching (0.696) (Fig. 1). Furthermore, a larger proportion of participants were feeling "empowered" (64.8%, p=0.007).

Table 1: *Athlete engagement - Dimensions of coach-created motivational climate as factors (stepwise)*

	Resulting model		
Summary	F (2, 85) = 33.576, p<0.001, R^2=0.441, Adjusted R^2=0.428		
	β$_{Stand}$	**95%CI**	**p**
Autonomy support	0.425	[0.177, 0.516]	<0.001
Task involving	0.309	[0.096, 0.493]	0.004

Table 2: *Team cohesion - Dimensions of coach-created motivational climate as factors (stepwise)*

	Resulting model		
Summary	F (2, 85) = 34.226, p<0.001, R^2=0.446, Adjusted R^2=0.433		
	β$_{Stand}$	**95%CI**	**p**
Task involving	0.377	[0.439, 1.510]	<0.001
Autonomy support	0.363	[0.345, 1.261]	<0.001

Discussion

The coach-created motivational climates emphasising autonomy support and task involvement were linked to higher engagement and team cohesion. Participants were categorised as "empowered" and "disempowered" gymnasts. Consistent with our predictions, coaches who emphasize autonomy and task orientation while avoiding social comparisons and control may enhance athletes' positive sports experience. This environment is important for athletes, as no more than two-thirds of participants in this study perceived the climate as empowering and motivating, while a third of them perceived the climate as disempowering. In addition, embracing values-based coaching behaviours grounded in transformational and servant leadership may further support coaches in creating an empowering climate.

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Supported by GAUK (263923), SVV (260 731/2023), & Cooperation (res. area SBOP).

Age Differences in Object Manipulation Tasks: Old Individuals Take Longer to Adapt to Object Properties.

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Keywords

Motor control, Motor cognition, Upper limbs, Sensorimotor performance, Aging

Introduction

Humans frequently reach, grasp, and replace objects in everyday tasks. They utilize internal models [1] to scale their grip and load-forces in anticipation of the object weight for precise manipulation. When object weight is unknown, people rely more heavily on feedback control. Further, when the object weight is known, lift delay (LD, time between first contact and lift-off) and maximum lift velocity (mLV) remain rather constant regardless of weight [2], but they vary when the object weight is unknown [3]. Consequently, the peak grip force rate (pGFR) can serve as a measure for weight anticipation [4], and therewith feedforward control whereas changes in LD and mLV are markers of incorrect weight anticipation and therefore related to feedforward and feedback control. Prior research has demonstrated that ageing leads to the production of overshooting grip forces when lifting objects and seems to have a negative effect on the predictive feedforward control of grip force [5, 6]. It remains unknown, however, if and how older adults' pGFR, LD and mLV differ from that of young adults in object manipulation conditions where the object weight is unknown, i.e., in conditions where even younger individuals rely heavily on feedback control. Therefore, this study investigated age differences in a replacement task with randomly changing object weights. Since feedforward control is less accurate with randomly changing weights, we expect that age has no effect on feedforward control (as the pGFR). In contrast, for the parameters LD and mLV, a general slowdown is expected for old participants.

Methods

Seventeen healthy young participants (12 female) aged 22.1 ± 2.8 years (range 18–28 years) and 17 healthy, old participants (5 female) aged 81.6 ± 2.3 years (range 79–86 years) took part in the experiment. All participants had normal or corrected-to-normal vision. One young and three old participants were ambidextrous, all other participants were right-handed. In the replacement task, participants sat at a table and, after an auditory cue, grasped an object and replaced it to another position (Figure 1). They were asked to perform the action naturally. After replacement they returned their hands to the starting position and started another trial.

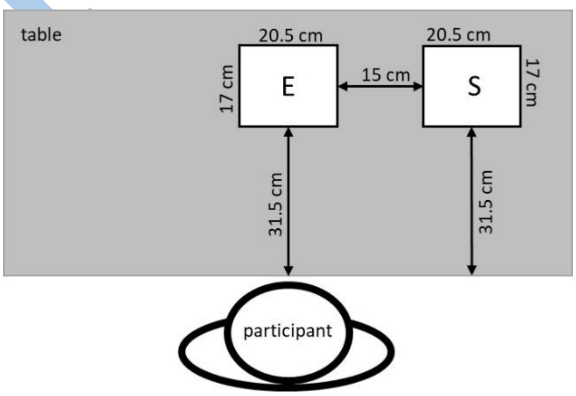

Figure 1: *Task setup with start position (S) and end position (E).*

Movement data was captured using a Vicon Motion System (10 cameras, 100 Hz) with two markers tracking the wrist position to measure mLV. The grip force data was collected using custom 3D printed objects with integrated 3D force-torque sensors. The objects had identical bases which allowed for the exchange of weights without changing the visual appearance of the objects. This resulted in three weight classes (400 g, 700 g, 1000 g) and two object sizes (5 and 8 cm). Infrared LEDs enabled synchronization with the Vicon system. For each weight class and object size, 10 trials were carried out, resulting in a total of 60 trials per participant. Analyses were conducted using R [7]. Three discrete parameters where extracted: *LD*, *mLV* and *pGFR*, for details see [3]. Within-subject (size-weight) and between-subject (age) ANOVA was used for statistical analysis.

Results

A total of 2040 trials were recorded. However, 94 trials were excluded from the analysis due to technical issues (the data of one young participant had to be excluded entirely) and outliers, resulting in a total of 1946 trials being included. For pGFR, ANOVA revealed a significant effect of age ($F(1,31) = 6.97$, $p = .013$, $\eta 2g = 0.16$) and an age x weight interaction ($F(2,62) = 4.23$, $p = .019$, $\eta 2g < 0.01$) (cf. Figure 2). For LD, a significant effect of weight ($F(2,62) = 36.63$, $p < .001$, $\eta 2g = 0.12$) and an interaction between age and weight ($F(2,62) = 23.31$, $p < .001$, $\eta 2g = 0.08$) were shown (cf. Figure 2). And for the mLV, we found significant effects of age ($F(1,31) = 4.18$, $p = .049$, $\eta 2g = 0.05$) and weight ($F(2,62) = 23.12$, $p < .001$, $\eta 2g = 0.10$), as well as an age x weight ($F(2,62) = 14.51$, $p < .001$, $\eta 2g = 0.03$) and an age x weight x size interaction ($F(2,62) = 3.26$, $p = .045$, $\eta 2g < 0.01$) (cf. Figure 2).

Discussion

We showed that older and younger adults differ in their predictive grip force control. For LD and mLV we found a significant main effect for weight but not size. The effect of weight, on LD and mLV seems to be more pronounced in older participants as indicated by the age-weight interaction. This suggests that feedback control takes longer for older than for younger people.

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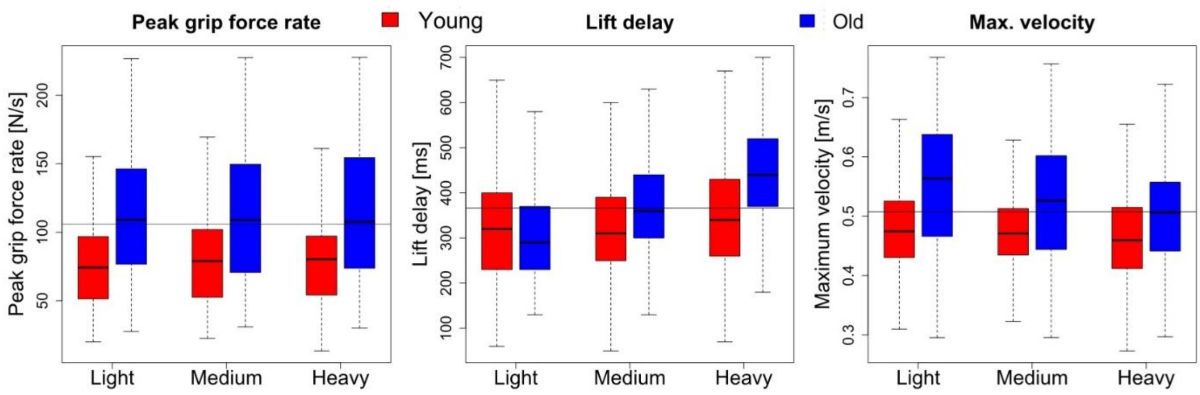

Figure 2: *Boxplots of pGFR, LD, and mLV by object weight and age class. The horizontal lines indicate the mean.*

The influence of the left ventro-dorsal stream on mechanical problem solving: a TMS study

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Keywords

Apraxia, Neural correlates, Neurorehabilitation, Neuropsychology, Mechanical Problem Solving

Introduction

Observing patients affected by apraxia, including their deficient use of tools, raised the need to investigate the neural correlates underlying tool use performance. Past studies demonstrated that typically, a tool is recognized, and existing semantic knowledge, including instructions on how to use it, is retrieved [1]. Mechanical problem solving, however, represents an alternative way to properly use a tool without retrieving semantic information [2]. The tool's function can be inferred by processing the tool's visual and tactile details along with a general understanding of mechanical and physical principles. This ability plays a fundamental role in scenarios where tool-related experience is lacking due to impaired memory access or inexperience with the tools because of their novel characteristics. Within our past fMRI study, participants carried out tasks from the Novel Tool Test, a standardized assessment for testing the individuals' ability to apply mechanical problem solving inside the scanner [3]. Based on this study, the left ventro-dorsal pathway, including the inferior parietal lobe (IPL) and the precentral gyrus (PRE), was identified as being similarly involved in the planning phases of selecting and using a novel tool properly. However, the extent to which these regions *causally* contribute to mechanical problem solving in healthy participants remains unclear. Thus, we conducted a further experiment, including transcranial magnetic stimulation (TMS), which allowed the stimulation of these identified regions while participants were again carrying out tasks from the Novel Tool Test. We were particularly interested in the effects of stimulation on the kinematic characteristics of this task execution.

Methods

Our previous fMRI study [3] identified two clusters in the left precentral (PRE) and inferior parietal lobe (IPL) as target areas to stimulate accordingly. A total amount of 46 participants were recruited and randomly assigned to one of these target locations, which were located by considering each individual's structural MRI scan while following a neuro-navigation approach. The TMS protocol consisted of 3 pulses (10 Hz) with a simulation intensity of 120% (resting motor threshold), determined individually by EMG recordings. Pulses were delivered randomly 100-300ms after trial onset but before the signal to start the movement. Moreover, a placebo stimulation served as a control condition.

In a within-subject design, each task, consisting of one specific tool-cylinder-combination, was presented twice, once under effective and placebo stimulation. The task itself included the presentation of three unknown tools besides a cylinder. Participants were instructed to only use the left hand, reacting upon a starting signal to select the most appropriate tool, grasp it, attach it to the cylinder, and lift it out of the socket (Fig. 1). As we were particularly interested in the kinematic profile of these movement tasks, the Qualisys Motion Capture System was used to capture participants' hand movements. The calculation of the movements' maximum velocity during the reaching phase represents the preliminary outcomes, reported here. Due to the applied stimulation protocol, it is hypothesized that participants show disturbed kinematic performance under effective compared to placebo stimulation.

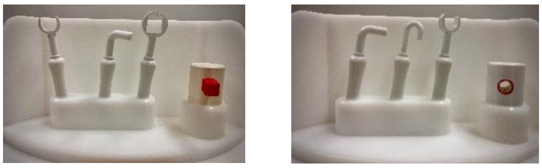

Figure 1: *Stimuli of the task: three unknown tools besides one cylinder which had to be lifted out of the socket by using the correct tool.*

Results

An example of the velocity profile is shown in Figure 2, and preliminary results of a subsample of 33 participants' maximum velocity (mm/s) during their reaching movements are illustrated in Figure 3. It is shown that the achieved maximum velocity varies slightly based on the location and type of stimulation. The analyzed data show a trend potentially indicating that effective stimulation revealed lower maximum velocity rates under effective stimulation within the precentral group ($F(1,32)=3.56$, $p=.059$).

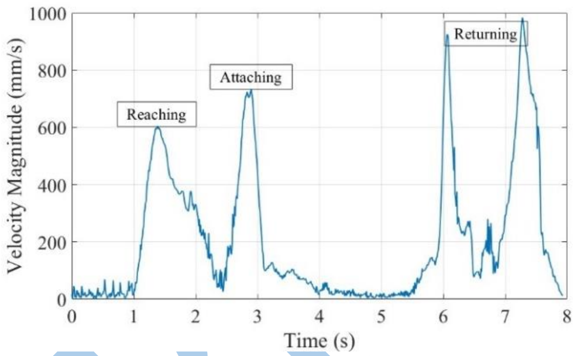

Figure 2: *An exemplary velocity profile of one participant.*

Discussion

The preliminary results of the current TMS study show small differences in the maximum velocity rates depending on the location and type of stimulation. A slightly reduced maximum velocity is observed in participants assigned to the precentral group. This finding possibly indicates the causal contribution of the precentral gyrus in mechanical problem solving tasks. Compared to the placebo stimulation, the reduced velocity of hand movements during effective stimulation may indicate disruption of cognitive processes, resulting in slower movement execution. Overall, however, the observed differences between the effective and the placebo stimulation are very small, questioning the perturbation of the region's functionality by the effective stimulation. Instead, surrounding areas that were not directly stimulated may compensate for these perturbations. Future analyses beyond these preliminary findings should consider various kinematic parameters, participant performance rates, and brain network characteristics, such as connection strengths, to provide a more comprehensive understanding of the effects of stimulation on cognitive processes involved in these tasks.

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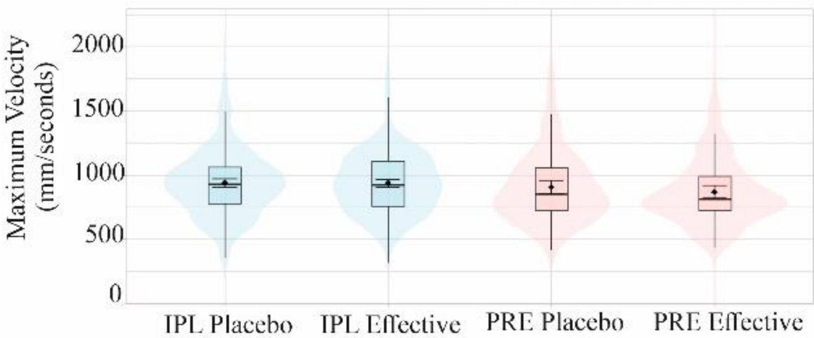

Figure 3: *Maximum Velocity rates for the different stimulation locations, differentiated by placebo and effective stimulation.*

Motor and proprioceptive learning transfers to untrained limb segments within and across the body hemisphere

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Keywords

Motor learning, Motor control, Neurorehabilitation, Somatosensory, Robotics

Introduction

The transfer of learning refers to how an acquired skill can be executed in a new context, a new workspace, or how a learnt motor pattern transfers from one effector system to another. There is evidence that untrained limb systems exhibit signs of motor learning without practice (e.g., [1]). Moreover, empirical evidence indicates that proprioceptive and motor learning is bidirectional. That is, gains in motor performance are associated with concurrent gains in proprioceptive function. However, how such gains of motor and proprioceptive learning transfer within and across limbs is unknown. Here, we report on two studies that determined the magnitude and extent of transfer of motor and proprioceptive learning within and across the upper limbs [2,3].

Methods

Using a robotic wrist exoskeleton, 30 right-handed healthy adults (ipsilateral transfer group age: 23.5 ± 4.9 yrs, 4 males; contralateral transfer group age: 24.67 ± 4.19 yrs., 8 males) learnt a visuomotor task that required them to make increasingly precise, small amplitude wrist movements (90 training trials in 45 minutes). Before and after training, participants performed a goal-directed wrist and/or elbow pointing task that they had not practiced in order to assess motor learning transfer and 24-hour retention.

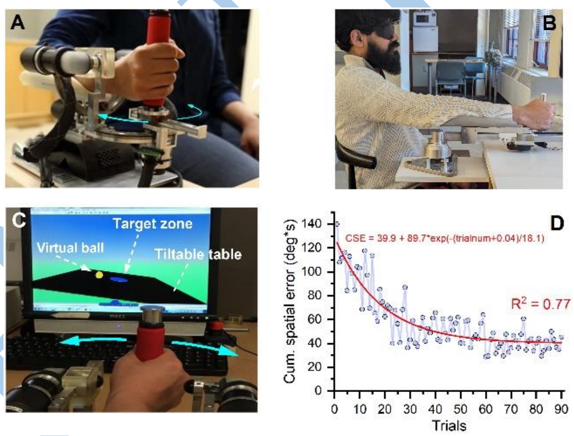

***Figure 1:** Experimental setup. (**A**) Frontal view of the 3-DOF robotic wrist exoskeleton. (**B**) The elbow-joint manipulandum used for the transfer task. (**C**) Visual display as seen by the learner. Wrist flexion/extension movements tilted the virtual table. Learner attempted to roll the virtual ball into the target zone. (**D**) Learning effect on movement trajectory formation as measured by Cumulative Spatial Error (CSE). Each data point represents the mean CSE of all participants for a particular trial. Note the decline of CSE over successive trials. Red line indicates the fit of the exponential decay function.*

Outcome measures. We determined *just-noticeable difference* (JND) position sense thresholds of the trained right wrist, at the untrained left wrist and the adjacent right elbow as markers of proprioceptive learning. Spatial motor learning during practice was assessed computing a *Cumulative Spatial Error* (CSE) for each trial calculated based on the lateral deviation of the current wrist position relative to neutral wrist position. For the untrained pointing task, a *Movement Accuracy Error* (MAE) was calculated as the absolute angular error between the target position and matching position across all trials.

Results

Transfer to contralateral wrist. The main results were: First, practice reduced mean JND thresholds (-27%) and MAE (-33%) in the trained right wrist. Sensory and motor gains were observable 24 hours after training. Second, in the untrained left wrist, mean JND significantly decreased (-32%) at post-test. However, at retention the effect was no longer significant. Third, motor error at the untrained wrist declined slowly. Gains were not significant at post-test, but MAE was significantly reduced (-27%) at retention. **Transfer to ipsilateral elbow.** First, mean JND threshold decreased significantly by 30% in trained wrist and by 35% in untrained elbow. Second, mean MAE in untrained pointing task reduced by 20% in trained wrist and the untrained elbow. Third, after 24 hours the gains in proprioceptive learning persisted at both joints, while transferred motor learning gains had decayed and were no longer significant at the group level.

Discussion

Our findings document that a one-time sensorimotor training induces rapid learning gains in proprioceptive acuity. In addition, it improved untrained motor performance at the practiced joint, indicating within-joint motor transfer at the same degree-of-freedom. Importantly, these motor and proprioceptive gains transferred almost fully to the proximal elbow joint/forearm system and to the contralateral wrist/hand system. This research documented that motor practice can lead to sensory and motor gains in untrained tasks within and across the trained body hemisphere.

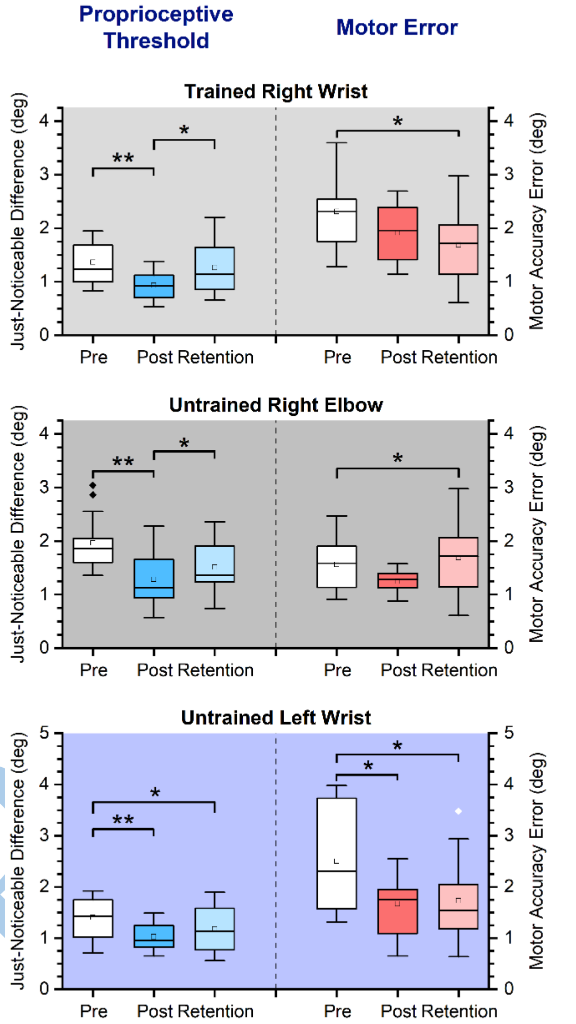

Figure 2: *Practice-induced change in position sense acuity and motor performance in the untrained motor task for the trained wrist, and the transfer to the ipsilateral elbow and contralateral wrist joint. Boxes represent the range between 25th to 75th percentiles. Line within the box represents the median. The upper and lower whiskers extend to +1.5 / −1.5 interquartile range. ***indicates p < 0.001, * indicates p < 0.05.*

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Force field adaptation requires specific muscle synergies

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Keywords

Motor control, Motor learning, Upper limb, Muscle synergies, Robotics

Highlights

- Muscle synergies as representations of internal models in force field adaptation

Introduction

When tennis players change their rackets, the first shots will likely hit the net or go out of bounds. However, after several shots, performance is as good as before the racket change. They have adapted an internal model, which serves as motor memory and can be reused the next time they play [1]. However, how internal models are represented at the muscular level is unknown. A prominent hypothesis suggests that movements are employed by low-dimensional control using muscle synergies. Instead of controlling every single muscle, the central nervous system controls functional groupings of co-activated muscles. An extensive behavioral repertoire is established by flexibly combining and sharing muscle synergies across tasks [2]. In visuomotor adaptation, muscle synergies representing unperturbed reaching can also explain the muscle patterns when adapted through an altered amount of recruitment [3]. However, muscle synergies in force field adaptation have not been examined thoroughly. Moreover, literature on single-muscle EMGs suggests that several muscles acting in opposite directions of the force field are activated early in the movement and that co-contraction does not only occur when the force field is first experienced [4,5]. Therefore, we investigated whether an altered activation of unperturbed reaching synergies enables adapted reaching in the force field or whether specific muscle synergies are needed.

Methods

Thirty-six male, healthy volunteers performed 15cm reaching with their right arm while sitting at a robotic manipulandum (KINARM, Kingston, ON, Canada). After unperturbed reaching to targets at -90°, -45°, 0°, 45°, and 90°, they adapted while reaching to 0° in a viscous, counterclockwise force field with a magnitude of 20 Ns/m (Figure 1). The maximum perpendicular distance (PD_{max}) between a virtual straight line connecting the start and target and the actual trajectory, and the force field compensation factor (FFCF), a correlation between the actual endpoint force and the force ideally compensating the force field, reflected if participants adapted.

Twelve EMG electrodes captured trunk and right arm muscle activity. Muscle synergies were extracted from the baseline EMG using non-negative matrix factorization (NMF, [6]) to investigate if they could reconstruct (no difference in R^2) the patterns of the adapted state reaching (last 20 force field trials). To test the alternative that specific synergies for the adapted state were required, a bootstrap approach was used to disentangle synergies shared between baseline and adapted state and specific to either phase [7]. Similar synergies were grouped across participants with hierarchical and subsequent k-means++ clustering.

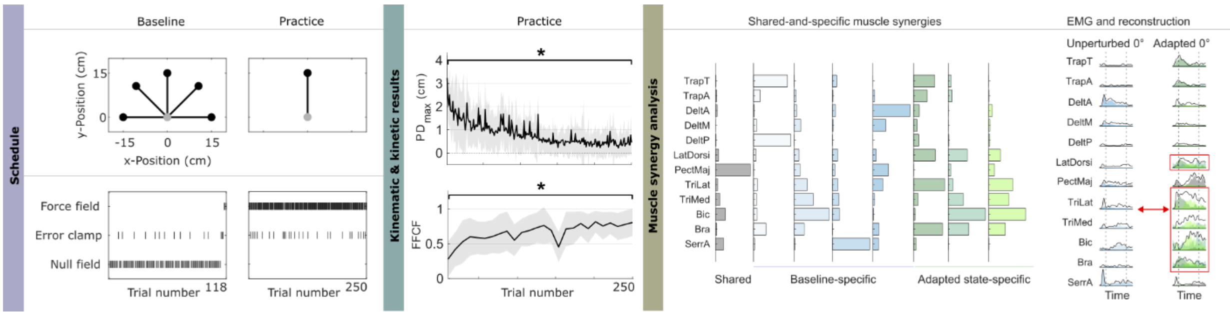

Figure 1: *Experimental schedule and results. Left: Directions and trial types. Middle: Kinematic and kinetic results (mean and standard deviation). Right: Shared-and-specific muscle synergy extraction of an exemplary participant.*

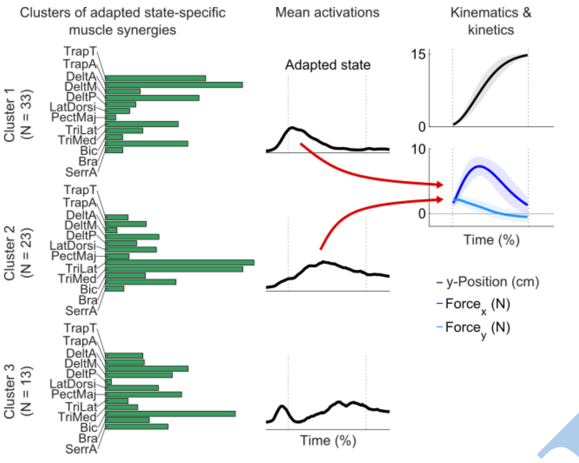

Figure 2: *Adapted state: Left, middle: Muscle synergy centroids and mean activations. Right: Kinematics and kinetics.*

Results

Participants adapted to the force field (PD_{max} and FFCF, each $p < 0.05$, Figure 1). The 3.7 ± 0.8 baseline muscle synergies could reconstruct well the baseline but significantly worse the adapted state muscle pattern (R^2 difference = 0.98 ± 0.69, $p < 0.05$). We found that 1.47 ± 0.74 synergies were shared between baseline and adapted state, but 1.92 ± 0.60 adapted state-specific synergies were necessary. Accordingly, baseline synergies cannot explain the muscle pattern when adapted. The adapted state synergies reflect a four-phasic modulation (Figs. 1-2). After a synergy that shows high co-activation and high activation of muscles antagonistic to the movement and force field direction (Cluster 3), two synergies representing agonistic muscles are activated with distinct but overlapping activation peaks (Clusters 1-2). Then, a synergy responsible for deceleration becomes active (Cluster 3). The overlapping synergies constitute the EMG modulation (Fig. 1), contrasting unperturbed reaching. Interestingly, the two overlapping synergies produce one smooth, gaussian-shaped $force_x$-curve (Fig. 2, Cluster 1 & 2).

Discussion

We found that synergies underlying unperturbed reaching cannot explain the muscle pattern after adapting to a perturbing force field. While in line with studies [4,5] on single muscles, we propose a novel characterization of muscle activation from a low-dimensional muscle synergy perspective. Reaching in an environment with altered dynamics requires structural changes to muscle synergies compared to unperturbed reaching, suggesting the tennis player recruits muscle synergies specific to their new rackets.

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Limb Impedance Effects Adaptation to Novel Dynamics

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Keywords

Impedance control, Muscle co-contraction, Motor learning, Motor control, Motor skills and abilities.

Highlights

- Increased limb impedance stabilizes instability but also affects adaptation in subsequent tasks.

Introduction

Mechanical impedance is the resistance to motion that a system exhibits in response to perturbation by external forces, which is generally comprised of inertia, damping and stiffness. The sensorimotor control system can influence the impedance of the musculoskeletal system through changes in limb posture and muscle contraction [1-5]. Increasing co-contraction of antagonistic muscles increases muscle viscoelasticity, and therefore limb impedance independent of changing endpoint forces. This ability to use co-contraction to increase impedance is exploited by the CNS, as part of its strategy to control movement in unstable or unpredictable environments [1-6].

While there is a benefit to employing such impedance control in an unstable environment, it is relatively unclear how this might affect adaptation in subsequent tasks. Prior work has shown that co-contraction speeds learning in a reaching task [6]. However, it could not determine how this effect arises, nor how it affects generalization of the learned motor memory. Here we test the effect of increased impedance on learning novel dynamics and examine its effect on the spatial generalization of the motor memory.

Methods

Volunteers provided informed consent and were randomly assigned to low impedance or high impedance groups. Participants were seated and grasped the handle of a Kinarm Endpoint robotic manipulandum (BKIN Technologies), while performing reaching movements. These were made between the start target and 1 of 13 others arranged in a semi-circle, 20cm away at 15° intervals (0°, ±15°, ±30°, ±45°, ±60°, ±75°, ±90° from start), where 0° was the straight-ahead movement. Electromyographic activity (EMG) was recorded (Delsys Bagnoli system) from 6 arm muscles (3 antagonistic pairs): Pectoralis major and Posterior deltoid; Biceps brachii and Triceps Longus; Brachioradialis and Triceps lateralis.

Experiments followed a block structure of familiarization, pre-exposure, conditioning and exposure phases. The design was identical for low and high impedance groups, with the exception of the conditioning phase.

Familiarization was 50 reaches toward the 0° target in a null field (NF). Pre-exposure was 390 NF trials distributed evenly across all 13 targets. Pre-exposure also included randomly distributed trials in a mechanical channel[7]. These were performed in all target directions and used to examine generalization of the force fields. Conditioning was 1000 trials in a NF plus randomly-distributed channel trials (low impedance group), or divergent force field (DF) plus randomly-distributed channel trials (high impedance group). NF or DF were applied towards the 0° target only, to promote differences in the co-contraction (impedance) between the two groups. Channel trials were performed in all 13 target directions, to enable validation of successful conditioning (force compensation against the DF).

The exposure phase was comprised of 1000 trials in either: (1) a counterclockwise curl field (CF) applied during reaches towards the 0° target; (2) channel trials applied during reaches to all 13 target directions, to assess generalization.

Results

EMG validated that exposure to DF increased co-contraction (and therefore limb impedance) in the high impedance group compared to the low impedance group. The effect of elevated impedance on learning a novel task was quantified by comparing the rate at which low and high impedance groups adapted to the CF. The learning rate was calculated by fitting an exponential function to the force compensation during the adaptation process.

The high impedance group produced small kinematic errors, relative to those of the low impedance group. The low impedance group demonstrated higher variability of adaptation, however, both groups had similar speeds of adaptation to the force field. This may be due to a rapid increase in co-contraction in the low impedance group. The difference in the initial errors affected the spatial generalization of learning. Participants in the high impedance group exhibited more localized adaptation versus the low impedance group, who generalized across a wider range of target directions.

Discussion

We found no difference in the speed of adaptation. Our results are different from prior work, which suggests increased co-contraction directly increases the speed of learning [6]. However, we found that co-contraction changed the spatial generalization of adaptation. By adapting to error, induced (by DF) in only the 0° target direction, the high impedance group may have been preconditioned to correct errors in the same space, as they were generated in the subsequent task. These results support the idea that adaptation occurs through a motion referenced learning frame [8] in which adaptation of local neural basis functions [2] occur only in the state space that is reached during the learning phases.

Overall, our research supports and helps explain a mechanism for increasing the rate of sensorimotor learning, and how it affects generalization. It could be applied to improve rehabilitation protocols: while increasing co-contraction may expedite adaptation, it also limits the extent of generalization that occurs with training. Future work is needed to confirm the neural basis of this mechanism.

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“In-vivo histology” of motor skill learning-induced white matter plasticity in the human brain

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Keywords

Motor learning, Neural correlates, Neuroplasticity, Microstructural changes, Intervention

Highlights

- White matter microstructural changes using tractometry

Introduction

The mechanisms underlying motor learning in the intact human brain remain incompletely understood. However, a better understanding is crucial to improve the development of preventive and therapeutic exercise strategies for disorders of the nervous system. For example, insights into myelin-related processes could enhance the understanding and management of conditions such as multiple sclerosis, whereas synapse-specific processes are highly relevant for dementias or Parkinson’s disease. In a recent magnetic resonance imaging (MRI) study with young, healthy adults (N = 24), we demonstrated that learning a dynamic balancing task (DBT) over a 4-week period resulted in behaviorally relevant increases in the complexity of neocortical microstructure in motor regions of the brain [1], supporting the notion of synaptic remodeling [2]. Because motor learning is based on the interaction between distributed cortical and subcortical areas [2], we focus here on learning-induced changes in the microstructural composition of the fiber tracts that connect crucial nodes of the motor network.

Methods

We employed a within-subject design with a 4-week "life-as-usual" control period followed by an equally long period of learning a dynamic balance task (DBT) practice, as detailed in [1]. Quantitative MRI (qMRI) contrasts sensitive to diffusion, relaxation times and magnetization transfer in the brain were measured at baseline (MRI1) and directly before (MRI2) and after the learning phase (MRI3). Advanced biophysical models of tissue microstructure were applied to the MRI data, producing parameter maps reflecting brain tissue density, neurite orientation and density, myelin, and iron [3, 4]. White matter fiber tracts were virtually dissected using tractography and neural network-based bundle recognition [5], and qMRI metrics were subsequently projected onto these bundles. Finally, along-tract statistical analysis of latent microstructural changes over time was conducted [6]. Behaviorally relevant neuroplasticity is concluded if results show significant latent microstructural changes over time (comparisons between MRI1 and MRI3, and MRI2 and MRI3), and correlated change between brain structure and DBT learning rate. Additionally, significant alterations in the principal component (PC) factor loadings of any qMRI parameter were computed.

Results

Non-overlapping 95% bootstrap confidence intervals (CIs) for factor scores across time points indicate significant learning-induced plasticity in segments of major association tracts (anterior thalamic radiation) and projection tracts (corticospinal tract, premotor-thalamic tract and frontopontine fibers). By analyzing factor loadings on the trajectory of latent changes over time, we identified two primary drivers of neuroplastic change in these tracts: the first process is dominated by metrics sensitive to myelin (see Figure 1, for an exemplary result), the second process is dominated by general tissue density.

Discussion

In this study, we have characterized the complex microstructural changes in white matter that occur in response to motor learning with unprecedented biological specificity. For instance, our findings reveal evidence for myelin plasticity as predicted based on animal models [2]. Looking forward, we expect this study to serve as a foundation for a more comprehensive understanding of the mechanisms underlying motor learning in both normal aging and neuropathological conditions, such as movement disorders.

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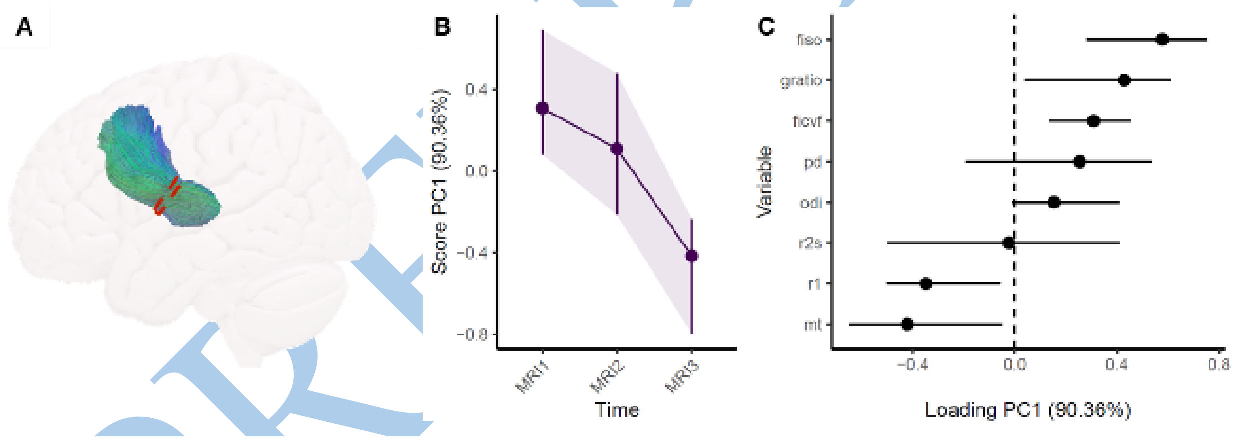

Figure 1: *Myelin-related changes in premotor-thalamic connections (right hemisphere) after DBT learning.* A: 3D representation of the tract with location of statistically significant tract segments highlighted in red. *B:* , RM-ASCA+ [6] extracted a general pattern of change as represented by the first principal component (PC1), explaining 90% of the variability in the data set. Note that there is no overlap between the bootstrapped CI's of the post-learning measurement (MRI3) vs the measurements conducted during the control period (MRI1, MRI2), thus indicating significant learning-induced change. C*:* Significant loadings on PC1 show, among others, that myelin-related microstructural metrics such the g-ratio, magnetization transfer and longitudinal relaxation rate correlate with the trajectory of PC1.

Effects of the COMT Val158Met polymorphism on neural augmented-feedback processing and motor automatization

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Keywords

motor learning, feedback, neuropsychology, genetics, motor automatization

Introduction

Findings in motor learning often reveal individual differences in motor automatization, which cannot be explained by different practice conditions or other moderating variables [1]. As some mechanisms of motor learning are influenced by processes of the dopamine metabolism, genetic differences in the dopamine system might be suggested as a possible explanation [2]. In this context, the catechol-O-methyltransferase COMT Val158Met (rs4680) polymorphism affects the dopamine availability in the prefrontal cortex (PFC), with higher enzymatic activity in carriers of the Val-allele as compared to carriers of the Met-allele [3].

A mechanism that might be affected by the Val158Met polymorphism is the processing of valence-dependent feedback during practice, which in turn strongly affects motor automatization [4]. According to the reward-prediction-error hypothesis [5], an outcome better than expected increases the firing-rate of dopaminergic midbrain-neurons which leads to long-term potentiation and learning. An outcome worse than expected results in a decreased dopaminergic level which in turn provokes a disinhibition of the anterior cingulate cortex (ACC), leading to higher attention-dependent processing for error correction. In this regard, the feedback-related negativity (FRN) is interpreted as a neural correlate indicating prediction errors, with higher amplitudes after negative feedback [6].

The current study aims to examine if processes of motor learning (i.e., motor automatization measured as reduction of dual-task costs in a secondary task) are influenced by the COMT-genotype, and further, if the COMT-genotype affects the neural processing of valence-dependent feedback during practice. It is expected that the amount of motor automatization is moderated by the number of Met-alleles. Further, it is expected that carriers of the Val-allele are likely to show higher FRN-amplitudes, this effect is expected to be moderated by extensive practice.

Methods

60 participants were tested. For data analysis, the final sample size consisted of 47 students (mean age 21.33±1.71, 20 females). Participants learned a sequential arm-movement comprising three movement reversals with 192 trials in each of five practice sessions. Quantitative error information was presented after every trial based on a performance-adaptive bandwidth for qualitative feedback. EEG was recorded in the first and last practice session. The degree of motor automatization was tested according to a dual-task paradigm in a pre-post-test-design for a secondary task (visual-spatial 2-back task), and the motor task being prioritized. COMT-genotype was determined for each participant resulting in 12 Val/Val-, 19 Val/Met- and 16 Met/Met-genotypes.

Results

With respect to motor automatization, the 2 (*time*: pre-test, retention test) x 2 (*condition*: single-task, dual-task) x 3 (*COMT*: Val/Val, Val/Met, Met/Met) ANOVA for the 2-back task revealed main effects for *time* (η^2_p=.42) and *condition* (η^2_p=.75), further, the interaction of *time* and *condition* (η^2_p=.13) was significant. Dual-task costs were lower in the retention test (*M*=.61; *SD*=.54) as compared to the pre-test (*M*=.86; *SD*=0.50). There was no main or interaction for the factor COMT (COMT, η^2_p=.01; *test*condition*COMT*, η^2_p=.01; *test*COMT*, η^2_p=.01; *condition*COMT*, η^2_p=.06).

Regarding the FRN, the 2 (*practice*: Practice 1, Practice 5) x 2 (*valence*: positive, negative) x 3 (COMT: Val/Val, Val/Met, Met/Met) ANOVA revealed a main effect for *valence*, η^2_p=.26. FRN-amplitudes were more negative (*M*=3.62; *SD*=4.36) after negative feedback as compared to positive feedback (*M*=4.79; *SD*=4.81). There were no main effects for the factors *practice* (η^2_p=.07) or *COMT* (η^2_p=.02), and no significant interactions (*valence*practice*COMT*, η^2_p<.01; *valence*COMT*, η^2_p=.02; *practice*COMT*, η^2_p<.01).

Discussion

In the current study, expectations with respect to the COMT-factor could not be confirmed. Neither the degree of automatization of the motor task nor FRN-amplitudes during practice were influenced by the COMT-genotype.

With respect to the FRN, the valence-effect in the current study was rather small, compared to another study, that found an influence of the COMT-genotype [6]. As a possible explanation the feedback design could be considered. In the present study, quantitative error information was also transported with qualitative positive feedback which may have led to ambiguous feedback-categories. Further, the current study differed with respect to task type with a sequential motor task (three turning points of the end-effector in Euclidian space) as compared to a cognitive task with simple button press as response. Thus, ambiguous valence-categories and the specific task requirements may have moderated the effect of the COMT-genotype on feedback-processing.

However, the COMT Val158Met polymorphism is not the only aspect that affects the dopamine metabolism. According to the reward-prediction-error hypothesis, the prediction error affects the firing-rate of dopaminergic midbrain-neurons. In this context, the dopamine active transporter (DAT) enables the restitution of released dopamine. With respect to the DAT, a variable number of tandem repeat polymorphism influences the dopamine-availability in the midbrain [7]. To further investigate how the genotype influences processes of motor learning, the DAT polymorphism should also be examined, or evaluated, in combination with the COMT polymorphism.

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Just like riding a bike? Learning to ride a reversed bicycle

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Keywords

Motor learning, Motor control, Sensorimotor performance, Bicycle riding, Unlearning

Highlights

- Catch trials might reduce the unlearning of the normal bicycle with little effect on reversed bicycle learning

Introduction

Riding a bicycle is a well-established motor skill. We often refer to skills we can maintain for a long period of time as "Just like riding a bike". A recent study challenged this idea by introducing a reversed bicycle [1], which temporarily disrupts the ability to ride a standard bike. This bicycle inverts the steering wheel leading to a right wheel turn when the handlebar is turned to the left and vice versa. Despite appearing straightforward to learn, it was shown that this skill is challenging to acquire because it contradicts the familiar mechanics of riding a regular bicycle. We aim to investigate the learning process of the reversed bicycle and the simultaneous unlearning of the normal bicycle more closely by using 3D motion capture.

Methods

Five subjects (one female; age: 23-26 years; height: 162-199 cm; weight: 56-97 kg) participated in this study over the course of four days. Before the first learning session with the reversed bicycle, baseline trials were captured using a normal bicycle. Following this, we performed pre-tests with the reversed bicycle. Participants then were given 20 minutes of self-guided training with interleaved catch trials using the normal bicycle. After the last session, we aimed to assess the process of relearning the normal bicycle by including pre-tests, ten minutes of self-guided normal bicycle practice followed by post-tests (see Figure 1). The reversed bicycle is a normal city bicycle modified with two gears mounted on the frame that changed the handlebar's rotation direction. We used 3D motion capture (Vicon Motion Systems, Oxford, UK) at 250 Hz using twelve infrared cameras to track markers placed on the handlebar, frame, and participants' body parts. Participants were instructed to ride in a straight line through a six-meter capture volume. To quantify the learning process, we analyzed the distance covered, the steering angle variability as standard deviation of the steering angle, and the straight-line deviation.

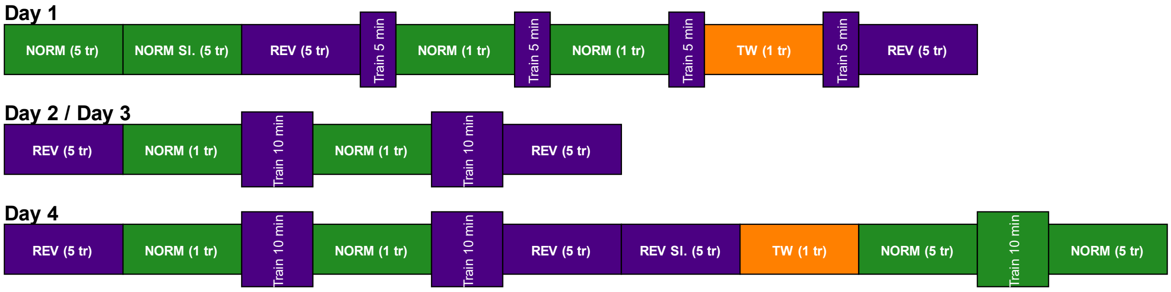

Figure 1: *Experimental procedure. NORM: Normal bicycle. REV: Reversed bicycle. Sl: Slalom. TW: Training Wheels. tr: Trials*

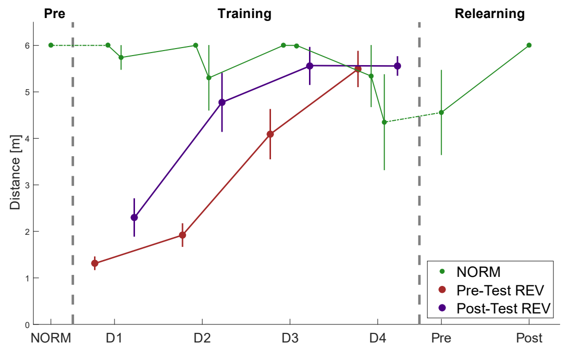

***Figure 2:** Riding Distance. Left: Baseline with normal bicycle. Middle: Reversed bicycle Pre- and Post-Tests and Catch Trials with normal bicycle in between training. Right: Relearning the normal bicycle Pre- and Post-Tests. The x-axis represents days (D1 to D4).*

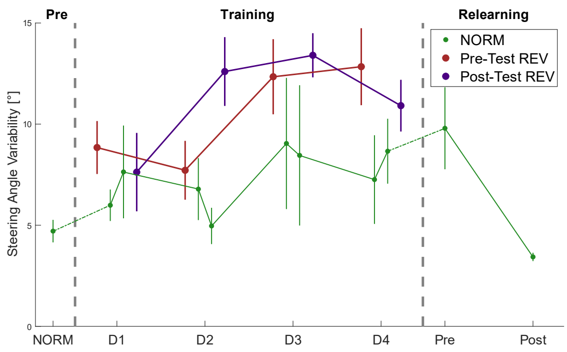

***Figure 3:** Steering Angle Variability. Left: Baseline. Middle: Learning. Right: Relearning. The x-axis represents days (D1 to D4).*

Straight-line deviation was calculated as the root mean square deviation of the difference in lateral position from a straight line, divided by the distance covered. This normalization allowed better comparisons between trials of varying distance.

Results

During normal bicycle riding, participants achieved the maximum distance (6 meters) with low steering angle variability and minimal straight-line deviation. For the reversed bicycle, the distance achieved increased in both pre-tests and post-tests over the training days. The steering angle variability appeared to rise by day two and remained high thereafter. The straight-line deviation increased in pre-tests but showed a decrease in post-tests from day two to day four, indicating improved control in straight line riding with the reversed bicycle.

In catch trials with the normal bicycle during the reversed bicycle training, we see little change in distance, steering angle variability, and straight-line deviation in early catch trials. However, the interference effect became stronger in the catch trials on day four and in the pre-tests for relearning the normal bicycle. After ten minutes of training, the memory of normal bicycle riding seemed to remain intact with comparable distance, steering angle variability, and straight-line deviation to those recorded in pre-tests.

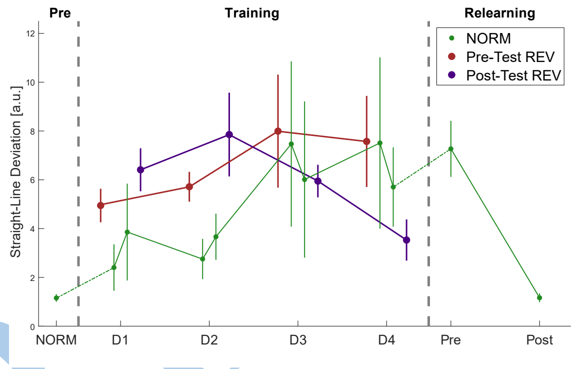

***Figure 4:** Straight-line deviation, normalized by riding distance. Left: Baseline. Middle: Learning. Right: Relearning. The x-axis represents days (D1 to D4).*

Discussion

Reaching the full six meters with the reversed bicycle required approximately two sessions of twenty minutes training, indicating the complexity of adapting the inversed steering. In comparison to the findings of Magnard et al. (2024), we observed limited interference on normal bicycle riding until day four. The inclusion of catch trials may have contributed to this reduced interference. Interestingly, the catch trials did not seem to disrupt the learning process for the reversed bicycle, suggesting little anterograde interference.

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Investigating the effects of post-encoding cardiovascular exercise on motor memory consolidation in the elderly

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Keywords

Health, Motor learning, Gait and postural control, Neuroplasticity, Aging

Highlights

- Pre-registered study based on pilot experiment examining post-encoding CVE on motor consolidation in older adults

Introduction

An age-related decline in neuroplasticity has been associated with deficits in motor memory formation. Lifespan studies suggest that this decline already begins between the ages of 50 and 60 [1]. Age-related motor memory deficits are partly explained by impaired consolidation – the process of stabilizing newly encoded information following motor skill practice [2]. Cardiovascular exercise (CVE) has been suggested as a candidate strategy for promoting neuroplasticity and motor memory formation [3]. While in young adults a single bout of CVE performed in close temporal proximity to motor practice has been shown to improve consolidation, the few studies in older adults are equivocal [4]. This notion might at least in parts be attributed to differences in the timing of CVE relative to skill encoding, with most studies in older adults implementing the exercise pre-encoding. Results from a recent pilot experiment in our lab revealed, however, a large effect of CVE on the consolidation of a balance skill in older adults when CVE was performed post-encoding. However, given the pilot nature of this study, these findings require confirmation. Thus, the aim of the present experiment is to investigate the effects of post-encoding CVE on motor memory consolidation in community-dwelling healthy older adults. We hypothesize that post-encoding moderate-intensity CVE will lead to enhanced motor memory consolidation after 24 hours.

Methods

In this pre-registered experiment, we will test 74 community-dwelling, physically active older adults aged 60 to 80 years with no known neurological or acute musculoskeletal conditions. The required sample size was estimated based on data from our pilot experiment. Following a pre-examination to assess demographics, cardiorespiratory fitness, physical activity, sleep, and global cognitive function, participants are randomized to either a (i) cardiovascular exercise (EXE) or (ii) seated rest (REST) group. During the main experiment, participants practice the motor memory task (i.e., stabilometer), which requires the participants to balance a platform in a horizontal position for 15 practice trials. Immediately following motor skill practice, participants perform either (i) a moderate-intensity CVE bout on a cycle ergometer (60–70% of heart rate reserve; EXE) or (ii) seated rest (REST) for 30 minutes, depending on group allocation. Motor memory consolidation is assessed 24 hours later in a retention session. We will calculate the time in balance (i.e., platform within ± 5° of horizontal; TIB) for each trial and compute relative offline changes (i.e., percentage change in TIB from the end of practice to retention test) to evaluate consolidation. To test for potential group differences in consolidation, we will conduct an analysis of covariance (ANCOVA) with relative offline changes as dependent variable, group as independent variable, and skill performance at the end of encoding and biological sex (stratification criterion) as covariates.

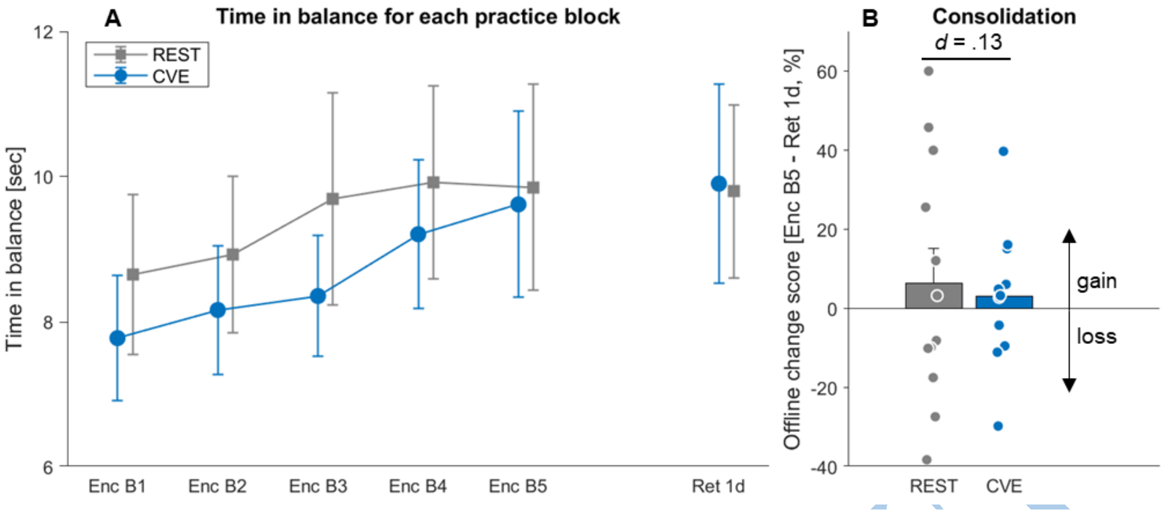

Figure 1: *A) Time in balance for each practice block; B) Between sessions offline change score*

Results

To date, we have successfully collected data from n = 23 participants (age = 69.7 ± 5.0 years, biological sex = 11 female, VO_{2max} = 32.8 ± 6.6 ml/kg/min, MoCA = 26.7 ± 1.5 pt.). Preliminary descriptive analyses show that both groups successfully improved performance during practice, with 22.9 ± 22.9 % in the EXE group and 17.9 ± 37.3 % in the REST group. Preliminary data on offline changes do not indicate major between-group differences (EXE: 3.1 ± 17.8 %; REST: 6.3 ± 30.7 %; d = 0.13). In the talk, we plan to report data from an anticipated sample of n = 40 participants. The following analyses will be presented:

(i) the primary analysis on between-group differences in motor memory consolidation,
(ii) exploratory analyses on variables potentially affecting CVE effects (i.a., age, cardiovascular fitness, sleep, global cognitive function, and subjective task load).

Discussion

To the best of our knowledge, this is the first preregistered study to examine the effects of post-encoding CVE on motor memory consolidation in community-dwelling older adults. Aging is associated with a decline in motor memory consolidation, while the transfer of motor information into long-term memory is a prerequisite for maintaining and restoring function and mobility in old age. A single bout of CVE may represent an effective strategy to partially counteract this age-related deficit, and thus our study can have important implications for an aging population.

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Arm immobilization affects motor memory reactivations during sleep

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Keywords

Motor learning, Neuroplasticity, Upper limbs, Sleep, Memory consolidation.

Highlights

- Immobilization induces local cortical synaptic depression and affects memory representations.

Introduction

Behind every learned motor skill lies a period of practice and rehearsal. The newly formed memory continues to be processed “offline” after practice. The consolidation of motor memories has long been shown to be favored by a night of sleep and is thought to be mediated by sleep spindles during non-rapid eye movement sleep (NREM). They are transient thalamocortical oscillations (11-16 Hz), playing a critical role in the consolidation processes by reactivating cortico-sub-cortical networks associated with the acquired memory trace [1]. Recent evidence highlights the essential contribution of spindles’ clustering and rhythmicity for memory consolidation [1]. More specifically, spindles tend to cluster in ‘trains’ on a low-frequency time scale of 50 seconds. These (grouped) spindles in trains can be differentiated from isolated ones, which have a more sporadic onset between trains. However, cortical networks activated during spindle-related memory reactivations are poorly described and need to be studied while taking into account their clustered organization. Using a short-term upper-limb immobilization procedure, combined with the recording of behavioral and electroencephalographic (EEG) night sleep measures, the aim of the present study was to determine the effects of daytime sensorimotor experience on motor memory reactivations and associated cortical activity during sleep spindles.

Methods

Thirty right-handed young healthy adults were equally divided into a left-limb immobilization group (IMMO) or a control group without immobilization (CTRL) (Fig. 1A). The immobilization procedure (13 hours) was administered to promote local synaptic depression in contralateral sensorimotor cortical regions [2], immediately following the practice of an 8-element motor-sequence task with the left-hand fingers. See [3] for further details and analyses of the behavioral results. Sleep EEG recordings were collected the night before and after motor sequence learning with a 64-channel EEG cap. Sleep spindles were detected on all NREM stage 2 (NREM2) epochs at channel C4. To determine the degree of connectivity (synchronization) between distinct cortical regions, EEG coherency maps were computed by estimating the imaginary part of the coherency (iCoh) between each pair of electrodes during each spindle epoch (2s duration from spindle onset). The clustering coefficient (CC) has been computed for each electrode to assess networks local efficiency. All statistical tests were corrected for multiple comparisons using max permutation tests (10000 permutations) or the Benjamini-Hochberg procedures, when appropriate.

Results

Slow oscillation (SO; 0.5-1.25 Hz) activity is a marker of daytime-induced synaptic plasticity. Previous work has shown that SO power decreases during the first part of the night after temporary arm immobilization, locally over the contralateral sensorimotor cortex [2]. Our findings confirmed the induction of local synaptic depression after immobilization, as reflected by significant local decreases in the SO spectral power during the first 20 minutes of sleep in the IMMO group (IMMO-CTRL contrast), mainly over the affected sensorimotor cortex (Fig. 1B). Then, we sought to assess the effects of immobilization-induced synaptic depression on the reactivation of memory-related neural networks during spindles. One sample t-tests were performed to assess the significant connections of the networks activated during sleep spindles. Large cortical networks were found for both IMMO and CTRL groups and each spindle type (Fig. 1C, D, E). Significant changes in network local efficiency were found following immobilization with local modulations of the clustering coefficient mainly over the left parietal and frontal cortical sites.

Discussion

We found that temporary immobilization of the left upper limb affected the local synaptic plasticity over the contralateral (right) sensorimotor cortex. Here, we provide additional evidence regarding the effect of sensorimotor restriction on cortical memory representations during sleep consolidation. We showed that reduced daytime sensorimotor experience following motor learning induced sleep-dependent reorganization of memory-related neural networks during spindles, in different ways depending on whether they appear grouped or isolated. Surprisingly, such neural network reorganization mostly occurred over the left hemisphere (ipsilateral to the immobilized limb) when considering all spindles or isolated spindles only, but not much for grouped spindles. Hence, alteration of the memory trace through immobilization may have reduced the neural network strengthening, theoretically conveyed by grouped spindles, while isolated spindles may instead have created memory-instability conditions potentially leading to bilateral cortical reorganization suitable for skill generalization [1,3].

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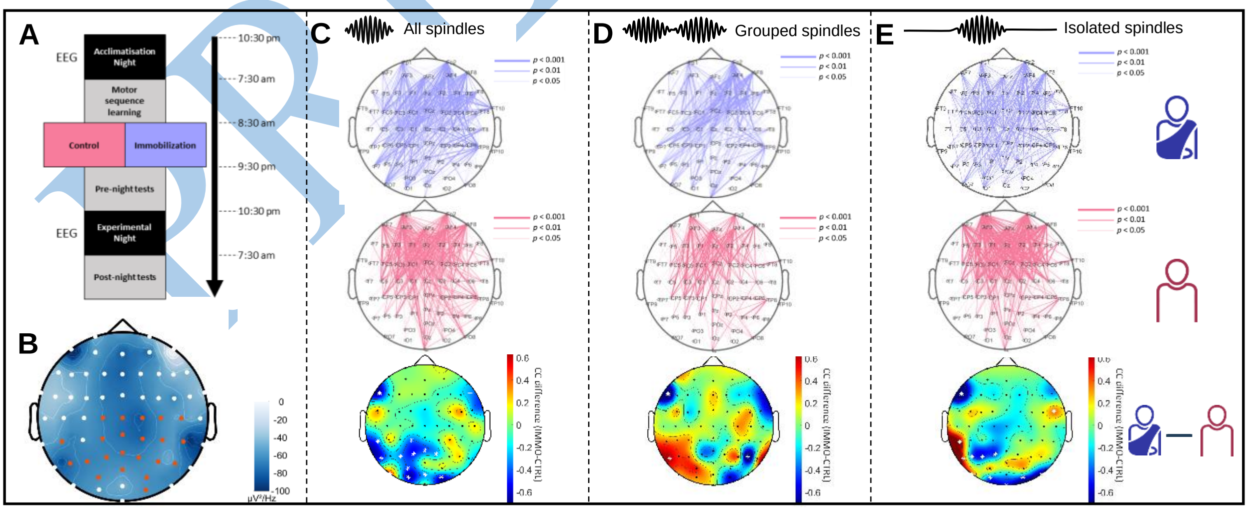

Figure 1: *Effect of sensorimotor restriction on cortical activity during sleep. (**A**) Experimental design. One-half of the participants had their left upper limb immobilized (n = 15, IMMO group) for a period of 13 hours during the day, while the other half were not (n = 15, CTRL group). (**B**) Topographical map of the difference in SO spectral power groups during the first 20 minutes of NREM2 sleep (IMMO-CTRL contrast). Red dots highlight statistical difference after correction (Ntest = 63). (**C, D, E**) Cortical networks activated in the spindle frequency band (11-16 Hz) for the IMMO (purple; upper panel) and CTRL (pink; middle panel) groups, considering all spindles (**C**), grouped spindles (**D**) and isolated spindles (**E**). Significant connections after correction (Ntest = 1953) are displayed. The lower panel represents differences in network local efficiency (IMMO-CTRL contrast) highlighted by the clustering coefficient (CC) metric. White stars represent significant difference after correction (Ntest = 63).*

Impaired anticipatory head motion stabilization during walking in children and adolescents with cerebral palsy.

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Keywords

Cerebral palsy, Head stabilization, Motor control, Gait and postural control, Sensorimotor performance

Highlights

- Individuals with cerebral palsy show a reduced amount of anticipatory head motion control during walking.

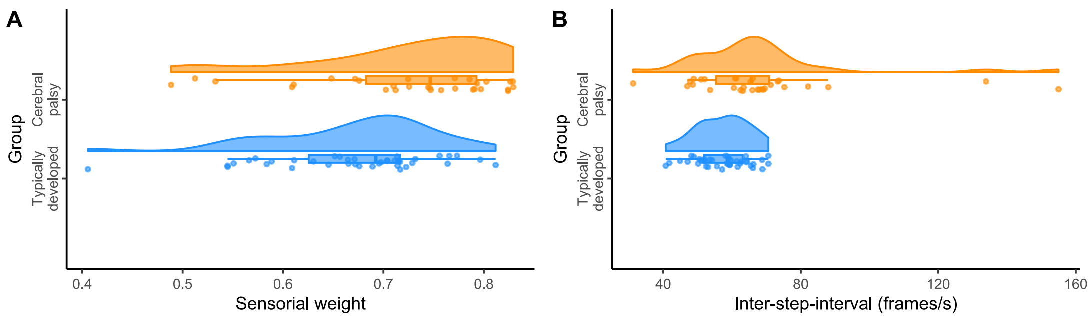
Introduction

The vestibular system drives the mechanisms that stabilize head orientation as well as gaze during walking (1). It has been suggested that the head acts as a locomotor inertial guidance platform and is stabilized to gravity in an anticipatory fashion (2). Specifically, it seems that vestibular cues of head orientation are replaced (or suppressed) by locomotor efference copies (3). The gait pattern of individuals with cerebral palsy (CP) often demonstrates excessive trunk and head sway with an observable en-bloc head on trunk coordination lacking neck articulation (4). Strong self-induced vestibular stimulation, however, contrasts with the tendency of typically developing individuals (TD) to suppress vestibular input. To understand potential balance deficits during locomotion in CP individuals, it is important to explore causes why they do not stabilize their heads in the typical manner. We hypothesize that individuals with CP demonstrate abnormal anticipatory head control impacting their locomotor performance.

Methods

A convenience sample of 30 children and adolescents (f:14, m:16; mean age SD, 9.4±4.2y; mean height SD, 131±23cm; mean weight SD, 32.3±17.6kg) with CP were recruited. Participants with CP needed a Gross Motor Function Classification System (GMFCS) level of III or higher to participate. Individuals were excluded if any other impairments were reported that could either affect locomotion or communication. Another convenience sample of 40 TD individuals (f:16, m:24; mean age SD, 9.8±4.4y; mean height SD, 143±26cm; mean weight SD, 37.9±17.4kg) were recruited as a control group. The study was approved by the medical ethical committee of the Technical University of Munich, and all participants or their guardians gave written informed consent.

Participants walked at a self-selected pace in a straight line for 6x over a distance of 10 m. Inertial measurement units (Xsens, 60Hz) were fastened to the forehead and both ankles laterally. The orientation of the inertial sensors in all 3 planes was processed unfiltered by a custom processing toolbox in Matlab (2023b). Phases of steady-state walking were extracted manually by segmenting all trials based on sensor data from the leg reported as dominant. Cadence was determined as the average time interval between single steps by the number of data frames sampled in this period. Predictability of head motion during walking was quantified as the variance explained by the stereotypical head movement over the average stride cycle (5). Here, head motion predictability is related to vestibular sensorial



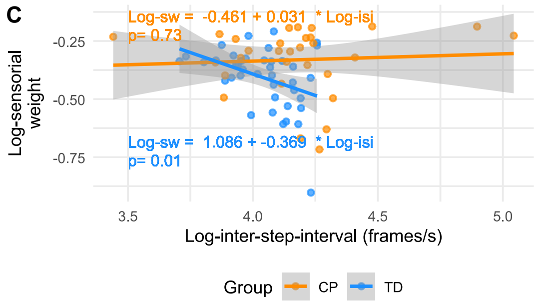


Figure 1: Differences in performance between the group of individuals with cerebral palsy (Orange) and the group of typically developed individuals (Blue): (A) Sensorial weight of head motion, (B) Cadence of walking in terms of the inter-step-interval (ISI), and (C) linear relationships between cadence and sensorial weight.

weight based on two key assumptions: (a) average head movement provides a conservative estimate of efference copy mechanisms, and (b) noise in sensory signals scales with signal magnitude. Thus, the vestibular sensorial weight depends on the ratio between vestibular information uncertainty and motor efference copy uncertainty. A smaller ratio indicates a greater influence of the efference copy on balance control during locomotion.

One-way ANOVAs were calculated between the group of CP and TD participants for sensorial weight and stepping cadence. Linear regressions and correlations between both log-transformed variables were also calculated for each group. A p-value of 0.05 was used to define statistical significance.

Results

The group of CP participants demonstrated a sensorial weight greater than the TD participants ($F(1,68)=6.45$, $p=0.01$, partial $\eta^2=0.09$; Fig. 1A) and they tended to walk with a lower cadence ($F(1,68)=7.19$, $p=0.009$, partial $\eta^2=0.10$; Fig. 1B). The relationship between sensorial weight and cadence was significant for the TD participants (Fig. 1C; sensorial weight was lower when cadence was lower; $F(1,38)=6.72$, $p=0.01$; $r=-0.39$) but not for the CP participants ($F(1,28)=0.12$, $p=0.73$; $r=0.06$).

Discussion

Individuals with CP showed greater dependency on concurrent vestibular feedback when controlling their balance during walking, while anticipatory mechanisms contribute to a greater degree in typically developed individuals. These differences may indicate either a deficit for or a developmental delay in predictive balance control in individuals with CP.

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Occurrences in the gait pattern of children with achondroplasia compared to an age-matched control group

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Keywords

Motor control, Gait & postural control, Achondroplasia, Scaling of body proportions

Introduction

There is various research regarding gait analysis of many different cohorts. For the matter of comparing two cohorts with different anthropometric characteristics, there is a need for gait analysis to scale the parameters to provide a normalized comparison. Common methods are dividing the parameters through body height or leg length or through body weight to achieve a ratio [1]. However, it is rarely known what those relative parameters are stating. Authors in the past used the scaling method as well to provide a possibility to compare people with achondroplasia (ACH) to a control group but barely discuss them in their research [2]. ACH is a type of dwarfism with a prevalence of 1 in every 25.000-30.000 births caused by a gene mutation of the fibroblast growth factor receptor-3 (FGFR3) and results in a shorter stature, disproportionate extremities and axis misalignments of the extremities [3]. Therefore, there is an open question of how to interpret those normalized parameters properly. Furthermore, there is the question of which differences occur in spatiotemporal parameters during a gait cycle between ACH and an age-matched group of children with average height (CAH). This work aims to primarily investigate differences in the spatiotemporal parameters between ACH and CAH and furthermore aims to interpret the results of the normalized parameters

Methods

In total 26 children in the age range of 6 to 12 years participated in this study (see Table 1). Anthropometric data were measured and a mod. PiG model [4] was set up on the participant. The participant was then asked to walk repeatedly an approx. 10 m path being captured with a 3D motion capture system (Vicon Nexus, Oxford, UK). Data was processed through the Vicon Nexus software, and the following parameters were obtained: leg length, pelvic width, walking speed, step length, step width, cadence, single – and double-stance time, stance and swing phase. Walking speed, step length, cadence and step width were additionally normalized through leg length or respectively for step width through pelvic width. Statistical analysis was done via SPSS (Version 28.0.1.0). Descriptive statistics were presented as median and range. A Mann-Whitney U Test was used to investigate the differences between the two cohorts. α was set to 0.05.

Table 1 Anthropometric data are presented as median and range. Alpha set to 0.05. Effect size presented as r.

	ACH (n=13)		CAH (n=13)			
Parameter	**Median**	**Range**	**Median**	**Range**	**p-value**	**r**
Height (cm)	115.4	100.8-121.4	140.6	125.5-154.3	**<.001**	0.85
Weight (kg)	29.2	21.56-51.35	31.2	23.99-47.60	0.204	0.26
Sitting Height (cm)	74	67-83	73.6	65-79.5	0.724	-0.08
Standing/Sitting Ratio (%)	0.66	0.61-0.68	0.53	0.49-0.53	**<.001**	-0.85
Leg Length (cm)	0.47	0.38-0.50	0.73	0.64-0.84	**<.001**	0.85
Pelvic Width (cm)	19.4	16.7-26.0	20.1	18.3-24.3	0.336	0.20

Results

For the anthropometric data, significant differences were found for height, standing/sitting height ratio and leg length (see Table 1). For the spatiotemporal parameters for the non-normalized parameters, significant differences were detected for walking speed, step length, cadence and single stance time. For the normalized parameters the normalized step length and cadence differ significantly (see Table 2).

Discussion

This work aimed to investigate the spatiotemporal differences between ACH and CAH and the effect of the normalized parameters. The reduced walking speed and decreased step length as well as a higher cadence is in agreement with the literature [2] and can be explained due to the shorter leg length of ACH. Also, the single stance time was significant and indicates that ACH passes less time in an unipedal movement. With a look at the normalized parameters, those parameters for walking speed and step width are quite equal between both groups and the normalized cadence is still of a greater value, indicating that despite the normalization ACH maintains a higher cadence. However, looking at the normalized step length interestingly the value is greater for ACH, whereas the step length was the opposite. This might be explained by the fact that the normalized parameters are presented as a ratio of the leg length to the step length. Given the shorter legs (~47 cm for ACH) and a step length of ~42 cm for ACH, the ratio is closer to 1 for ACH in comparison to CAH (~73 cm leg length and ~59 cm step length). This means that ACH is relatively creating a longer step in relation to their leg length to walk more efficiently. Despite the reduced walking speed and step length, the temporal-related parameters are equal between both groups, except for the single stance phase. This indicates that overall, ACH can trigger the same motor control as CAH to fulfill a gait cycle. Nevertheless, future work is needed to understand why the single stance duration is shorter for ACH.

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Table 2 Gait parameters are presented as median and range. Alpha set to 0.05. Effect size presented as r.

	ACH		CAH			
Parameter	**Median**	**Range**	**Median**	**Range**	**p-value**	**r**
Walking Speed (m/s)	1.03	0.57-1.32	1.29	0.77-1.53	**0.014**	0.47
Normalized Walking Speed	0.48	0.28-0.64	0.49	0.27-0.59	0.479	-0.15
Step Length (m)	0.42	0.28-0.50	0.59	0.47-0.69	**<0.001**	0.82
Normalized Step Length	0.96	0.68-1.05	0.81	0.58-0.95	**0.003**	-0.15
Step Width (cm)	13	5.0-18.5	12.5	8.0-21.0	0.762	0.07
Normalized Step Width	0.62	0.26-0.93	0.63	0.39-1.15	0.880	0.04
Cadence (steps/min)	143.17	129.8-178.5	127.83	97.7-150.7	**0.004**	-0.54
Normalized Cadence	6.75	6.07-8.70	4.72	3.46-5.86	**<.0.001**	-0.85
Double Stance (s)	0.19	0.12-0.20	0.17	0.09-0.26	0.724	-0.07
Single Stance (s)	0.32	0.28-0.37	0.39	0.27-0.49	**<0.001**	0.66
Stance Phase (%)	60.82	58.5-62.9	59.51	57.4-61.5	0.05	-0.39
Swing Phase (%)	39.18	37.1-41.5	40.5	38.5-42.7	0.05	0.39

Developing a Virtual Reality Tool to Diagnose Developmental Coordination Disorder

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Keywords

Health, Motor control, Virtual / Augmented Reality, Motor skills and abilities

Highlights

- VR-based assessments offer an object quantification of motor skills.
- This study describes the development and validation of a tool to diagnose developmental coordination disorder (DCD).
- The tool is feasible, although of limited diagnostic value in its current form.

Introduction

Developmental Coordination Disorder (DCD, or dyspraxia) is a congenital motor skills disorder impacting around 5-6% of school-age children, often leading to difficulties in physical, social, and emotional development [1]. Traditional diagnostic tools, while effective, can be resource-intensive, stress-inducing, and time consuming [2]. Prior to formal diagnosis, parental-report surveys provide rapid, but crude, screening. This project investigates the potential of the motion tracking capabilities of immersive Virtual Reality (VR) as a tool which could occupy the space between screening and formal diagnosis for this population. Here, we describe the process for the development of motor assessment tasks in VR based on established tasks from the Movement Assessment Battery for Children, and our engagement with dyspraxic adults and children to co-develop a tool which aims to be a more accessible, objective, and engaging alternative to traditional diagnostic tools. The goal of this ongoing work is to improve the speed and reliability of the diagnosis process for children with DCD.

Methods

Development

The Virtual Reality (VR) screening tool was developed through a collaborative, iterative co-development process involving expert consultation, patient and public involvement (PPI), and rigorous testing with the target population. Initially, we consulted with researchers experienced in working with the target population, who highlighted the importance of including practice phases, using age-appropriate engaging designs, and tailoring tasks to mimic traditional assessments. Feedback on the prototype was collected from four neurotypical children (7-11 years), five children with dyspraxia (11-16 years), parents of children with dyspraxia, two adults contributed based on their personal experiences, and a professional VR game designer with dyspraxia. This feedback identified practical issues like difficulty with certain mechanics, which were addressed iteratively to create the final screening tool.

Evaluation

To establish its feasibility and its diagnostic utility, the final screening tool was tested with 36 children with DCD (8 girls, mean age 12.9 years) and 35 typically developing (TD) children (17 girls, mean age 12.5 years). Participants underwent two assessments: the Movement Assessment Battery for Children-2 (MABC-2) and the novel VR screening tool. The MABC-2 served as the gold standard for diagnosing motor coordination impairments. Each participant completed the VR tasks in approximately 20 minutes. MABC-2 assessments required 30-90 minutes. Kinematic data from the VR system were extracted for 67 performance metrics. Independent samples t-tests compared group performances to evaluate the VR tool's diagnostic validity. Findings were analyzed to determine which VR tasks aligned most closely with MABC-2 results.

VR screening tool

The final VR screening tool was composed of four gamified tasks:

Coin Collection (Figure 1A) – Assessing manual dexterity, participants picked up virtual coins and placed them into corresponding slots. Performance metrics included completion time, accuracy, and hand path length (https://osf.io/m2p59).

Maze Tracing (Figure 1B) – Inspired by handwriting tasks, participants traced a path within boundaries. Metrics included time, path accuracy, and deviation percentages (https://osf.io/gh48k).

Table Tennis (Figure 1C) – Measuring gross motor coordination, participants returned virtual balls to targets. Metrics included successful hits, speed, and path consistency (https://osf.io/byz7g).

Ski Balance (Figure 1D) – Evaluating postural control, participants navigated a slope using head sway. Metrics included center-of-pressure (COP) path length and head sway measurements (https://osf.io/h2gkc).

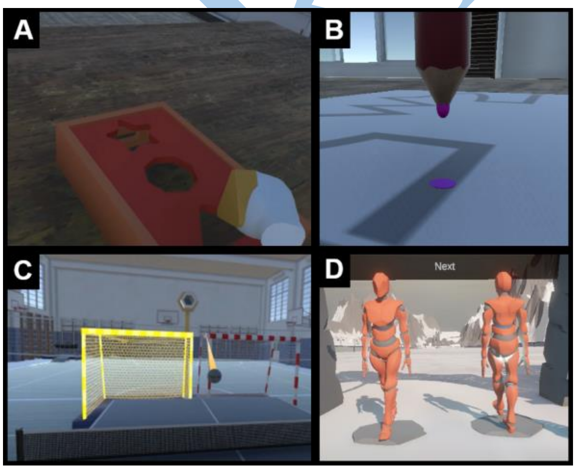

Figure 1. *The VR screening tool designed to assess motor abilities in dyspraxic children. The tool comprised four games: (A) Coin Collection, (B) Maze Tracing, (C) Table tennis and (D) Ski Balance.*

Results & Discussion

We successfully collected kinematic data and extracted movement-related dependent variables from all participants. No adverse effects were reported, and children reported enjoying the screening tool. We extracted 67 dependent variables to capture facets of successful motor performance. While some of these variables were able to distinguish between the DCD and TD children (Figure 2), the majority were not. Moving forward, we will develop the tool using tasks which showed the highest diagnostic potential and investigate the utility of classification methods to analyze salient features of movement kinematics.

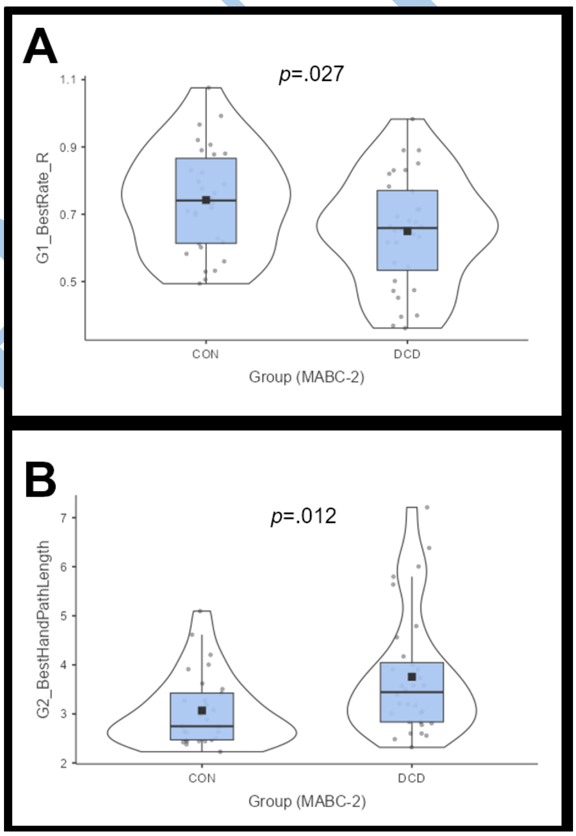

Figure 2. *Comparison between DCD and TD groups in terms of (A) their coin moving rate in the Coin Collection task and (B) their hand path length in the Maze Tracing task.*

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Motor neuron-computer interface for motor control in tetraplegia

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Keywords

Spinal cord injury, Electromyography, Motor control, Neuroplasticity, Neurorehabilitation

Highlights

- Movement intention from paralyzed muscles can be decoded in real-time.

Introduction

In cervical motor complete spinal cord injury (SCI), even though movement is not possible below the injury level, motor neuron activity can still be detected during attempted movements [1-2]. Motor neurons represent the final neural code of movement, and their activity can be detected directly using electromyography (EMG). With EMG as motor neuron-computer interface, decoding of movement intention in SCI opens new possibilities. Despite limited treatment options for SCI, evidence of voluntary muscle control below injury level can be leveraged for rehabilitation and use of assistive devices. However, the mechanisms underlying this spared activity are not well understood, as well as potential adaptations in these neurons. Our research aims to understand the neural control of motor units (MUs) after SCI and develop a motor unit (MU) computer interface tailored for individuals with SCI based on their spared motor neuron activity.

Methods

We recruited eight participants (three women) with motor complete SCI at the C5-C6 level, age 40.7 ± 7.3 years, with and time since injury of 5-24 years, and twelve uninjured individuals (two women) as a control group, age 27.1 ± 3.4 years. We applied grids of electrodes to the forearm of the participants. High-density surface EMG (HDsEMG) signals were recorded while the participants attempted (SCI group) or performed (control group) eight types of cyclical hand tasks (finger flexion and extension, grasp, two- and three-finger pinches) instructed by a virtual hand (Fig.1). We assessed whether the SCI group presented residual muscle activity. To analyze individual MU activity, HDsEMG signals were decomposed. We compared MU properties between the groups, such as discharge rate, amplitude, area of activity, common input and phase difference with virtual hand kinematics. Later, we tested if a few participants of the SCI group could control their MU activity in real-time. They were provided visual feedback through either a virtual hand or a cursor on a screen, based respectively on EMG activity and real-time EMG decomposition. Experiments with implanted intramuscular EMG were also performed to assess MU activity.

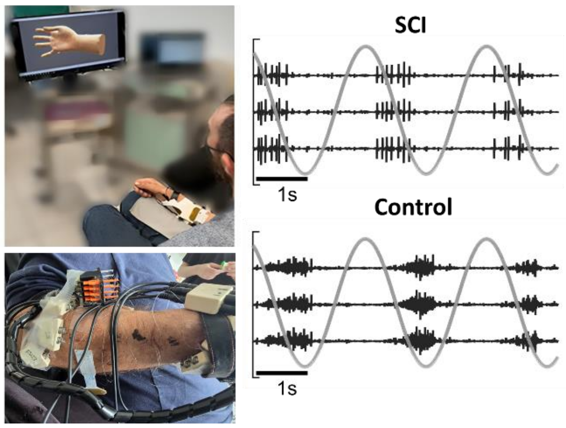

Figure 1: *Study overview. Left: Individual with spinal cord injury attempting hand tasks with surface (top) and intramuscular (bottom) EMG electrodes, instructed by a virtual hand video. Right: Example of raw HDsEMG signal from SCI and control groups.*

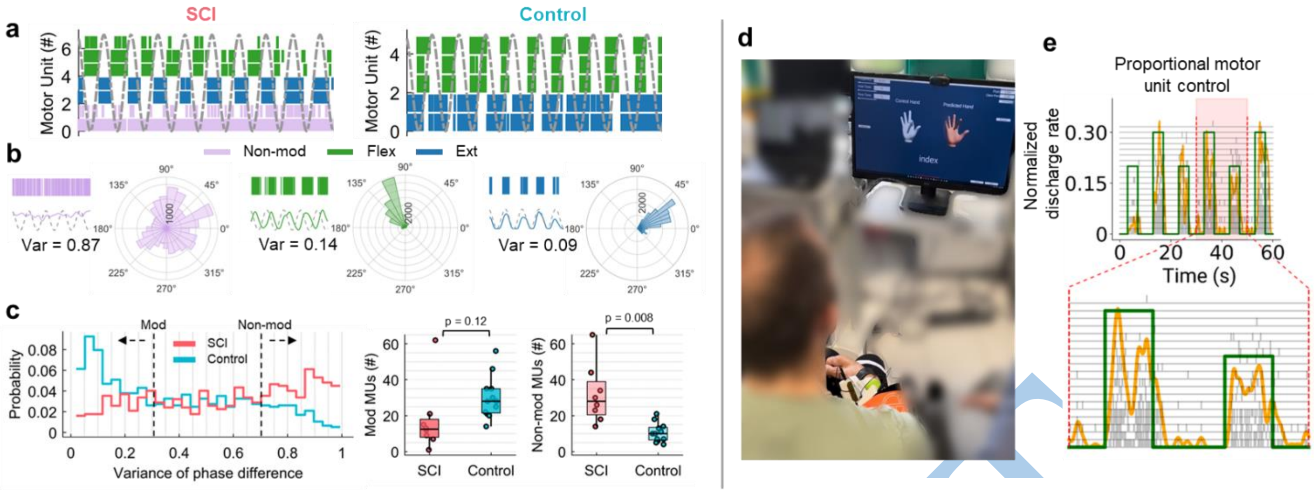

Figure 2: *Study results. Left: a) Raster plot with identified motor units (MUs) for SCI and control participants during a ring finger task. b) Examples of non-modulated, flexion and extension MUs. c) Distribution of variance of phase difference between smoothed MU firings and kinematics reference; number of modulated and non-modulated MUs between groups. Right: d) Participant with SCI controlling a virtual hand in real-time with EMG activity. e) Example of control of MU activity based on discharge rate.*

Results

Spared MU activity was detected for all the participants with SCI [2]. When analyzing neural and peripheral properties of the MUs, we found a similar number of MUs and comparable MU discharge rate and peak-to-peak amplitude in both SCI and control groups. A higher area of MU activity was found for the SCI group indicating anatomical changes after the injury.
We used non-negative matrix factorization to analyze common input to MUs and observed that two modes described most of the variance in both groups, corresponding to flexion and extension of the digits. We also analyzed the phase difference between smoothed firings of individual MUs and the kinematics of the virtual hand (Fig. 2b). Based on this phase variance difference, we classified MUs into two groups: MUs with very low variance (< 0.3), task-modulated, those with high variance (> 0.7), non-modulated. We observed a high number of non-modulated units in the SCI group (Fig.2c). This finding aligns with the real-time and intramuscular recordings. Some MUs appear to fire tonically or irregularly in SCI, with the participants having difficulty to derecruit and modulate their activity, even with visual feedback.

Discussion

Our results emphasize the potential of EMG as a neural interface. With this interface, we can detect spared MU activity, analyze their discharge characteristics, and have demonstrated this activity can be voluntarily controlled in real-time in a proportional and intuitive way. Despite differences between SCI and control groups in the number of non-modulated MUs, there are still active MUs in paralyzed muscles, enabling the decoding of movement intention in SCI. However, non-modulated MUs affect interface control, particularly at rest, as they remain active even when the intention is to relax the hand. A MU computer interface for SCI would benefit from removing these MUs to improve decoding of movement intention. Although there is variability in the number of modulated MUs among SCI participants, detecting even a single MU can enable effective control due to redundancy. Future steps include improving accuracy of real-time decomposition and integration of the interface with assistive devices. These findings highlight the potential of high-density surface EMG and intramuscular EMG as methods to develop neural interfaces for SCI, leveraging spared motor neuron activity to restore movement.

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POSTERS

Title only:

External relative to internal focus enhances motor performance and learning in children with different spatial working memory capacity

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Hemispheric specialization for imitation and matching of hand and finger postures in hemispherectomy individuals.

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Probabilistic modeling of redundant dimensions in multi-joint human movement using forward kinematics

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Motor Control Benefits Short-Term Recall of Item-Outcome Associations.

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Developmental dynamics of motor-cognitive planning

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Keywords

Sport, Development, Sportpsychology, Motorcognition, Kinematics

Highlights

- Developmental dynamics of motor-cognitive planning were tested in three studies using a climbing paradigm.

Introduction

Acting goal-directedly is essential for managing everyday life and requires planning what to do and how. Taking an embodied-cognition perspective, this interaction between cognitive and motor planning processes is theoretically described as a continuous, dynamic feedback loop[1]. Especially during childhood, when the body and mind change rapidly[2], studying motor-cognitive interaction can inform theories concerning the interdependence of such and intra- and inter-individual developmental change[1,3]. By taking a developmental-embodied-cognition perspective[1,4], this research program aims to scrutinize the mechanism underlying planning and how motor-cognitive planning evolves with experience (i.e., age, training). To study motor-cognitive planning from a developmental embodied-cognition perspective, a climbing paradigm has been created[3]. The paradigm was used in a systematic research program to study: 1) the relation to general motor and cognitive skills, 2) inter-individual development, and 3) the training of motor-cognitive planning in children compared to adults. Concerning the *relation*, a positive correlation between climbing-specific motor (cognitive) planning and general motor (cognitive) planning was expected, as to general motor (cognitive) skills. Regarding inter-individual development, embodied planning should improve with age until late childhood (motor) or adolescence (cognitive), followed by a leveling off[5,6]. Regarding *training*, motor, cognitive, and motor-cognitive planning training should lead to task-specific improvements in embodied planning from pre- to post-test, with stronger improvements for motor-cognitive and motor training than cognitive training. Last, motor-cognitive training will show the strongest near-transfer effects for embodied planning[7]. Children are hypothesized to benefit more than adults.

Methods

In studies 1-3, participants performed the embodied-planning paradigm consisting of three experimental tasks: motor planning (moving along pre-defined routes), cognitive planning (planning routes on a tablet), and motor-cognitive planning (planning and moving along the routes)[3], placing differential demands on the participants. The dependent variables (DV) initial planning time, total time, number of planning steps (i.e., holds), and the movement kinematics immobility-to-mobility ratio (IMR[8]), and geometric index of entropy (GIE[8]) were assessed (Figure 1).

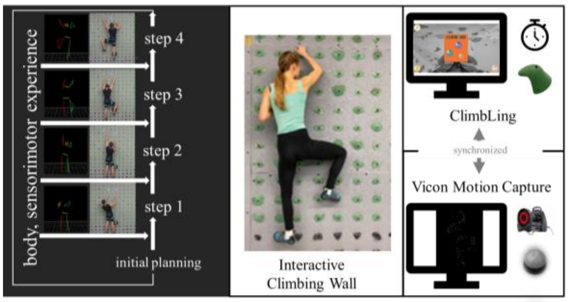

***Figure 1:** Climbing-specific motor-cognitive planning assessed in the climbing lab.*

Study 1: Motor-cognitive relations. *N*=57 participants between the ages of 6 to 12 years completed a motor (Sword-Rotation) and cognitive (Tower of London) planning task, general motor skills (MOBAK), and general executive function task[9]. *Study 2: Development*. *N*=104 participants between the ages of 6 to 32 years, subdivided into four age groups (6–8, 10–12, 14–16, and

>18 years), were tested. *Study 3: Training.* *N*=177 participants completed an 8-week randomized controlled planning-training intervention, assigned to one of four groups: motor (n=43), motor-cognitive (*n*=48), cognitive-oriented (*n*=43), and waiting control (*n*=43).

Results

Study 1: Motor-cognitive relations. Significant Pearson correlations of climbing-specific cognitive (*r*=.29-.59) and motor-cognitive (*r*=.27-.32) planning to general cognitive planning but not to motor planning were found. The climbing-specific motor-planning task did not show significant correlations. Further, climbing-specific cognitive (*r*=.29-.59) and motor-cognitive planning (*r*=.27-.32) were significantly related to inhibition and flexibility, while climbing-specific motor (*r*=.30) and motor-cognitive planning (*r*=.27-.30) were significantly associated with motor skills.

Study 2: Development. Separate linear regression analyses for each DV revealed that with increasing age participants used fewer holds (ß=-.68) and planned faster (ß=-0.49), with no changes in other planning variables. Significant changes were apparent between the ages of 6 and 8 years, indicated by significant slopes (holds ß = -0.44, total time ß=-.44), but not later in development.

Study 3: Training. In separate multilevel analyses for each DV, task-specific *training* effects were revealed by a significant training group × time point × task the number of holds ($p<.001$), total time ($p<.001$), and IMR ($p<.05$). For the number of holds, this finding was further qualified by a significant four-way interaction with age ($p<.05$).

Discussion

This research program provided insights into developmental motor-cognitive mechanisms of planning using an integrative climbing paradigm. In detail, climbing-specific cognitive and motor-cognitive planning requires inhibition and flexibility, while motor and motor-cognitive planning demand general motor skills in children between the ages of 6 and 12 years. Between the ages of 6 to 8, the results of the developmental study revealed significant changes in planning efficiency. For the 6-8 and 9-12-year-olds, and adults, the combined motor-cognitive planning training led to using fewer holds, with 9-12-year-olds in the motor-cognitive group outperforming the other groups in the post-test. Overall, the three training groups led to task-specific planning improvements (post). The results of this research program will be jointly discussed and synthesized with the results of other developmental work on planning. Findings from an ongoing meta-analysis on motor and cognitive planning development during childhood will be particularly considered. The results on the developmental dynamics of motor-cognitive planning will be embedded in an overarching theoretical framework on motor-cognitive development.

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Autonomy support enhances fine motor skill learning in children, regardless of motor competence level

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Keywords

Motor learning, skills, & abilities, Upper limbs

Highlights

- Autonomy support improves motor learning in children.
- Children with low and high motor competence benefit from autonomy support.

Introduction

A key aspect of motivation is autonomy support, which aligns with an individual's need to feel in control of their actions. In this context, motor learning research has shown that autonomy support, as a crucial element of optimal motor learning, benefits motor skill acquisition across various skills and populations. Studies indicate that providing task-related choices can improve motor learning compared to scenarios where such choices are absent [1, 2].

Motor learning difficulties in children with developmental coordination disorder (DCD), a neurodevelopmental condition that affects a child's ability to execute coordinated motor movements, can impede the development of age-appropriate motor skills, ultimately impacting their overall motor competence. These issues are often linked to challenges in visual-motor coordination, which impact both the accuracy and speed of various motor tasks, thereby reducing their motor competence when compared to typically developing children (TDC). Various interventions for DCD have been developed to address these issues, focusing on four primary areas: predictive control, rhythmic coordination and timing, task-focused and cognitive self-management, and activity-based approaches [3]. However, the role of motivational factors such as autonomy support in interventions for children with DCD has been less thoroughly investigated.

The aim of the current study was to examine the impact of a 10-session training program incorporating autonomy support on motor learning of a fine motor skill (e.g., rope knot), in children with high and low motor competence. We hypothesized that integrating autonomy support into a motor skill training program would lead to significant improvements in motor learning outcomes for both children with high and low levels of motor competence, particularly in fine motor tasks.

Methods

A total of 141 children (75 males and 66 females, age range 14-16, Mage = 14.45 ± 0.63 years) from a secondary high school in Madrid, Spain, participated in the experiment. All participants had no physical or mental disabilities. Before the intervention, the children's motor competence was assessed using the Movement assessment battery for children-2 (MABC-2) to categorize them into two groups. None of the participants had prior experience with the tasks involved, and they were unaware of the study's purpose.

Participants were asked to use gym ropes (Figure 1) to tie three types of knots—the overhand knot (simple), shoelace knot (moderate), and double figure-eight knot (challenging)—while standing with their backs against a wall and knees slightly bent.

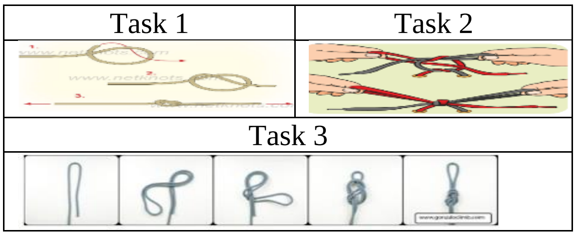

Figure 1: *Rope knots*

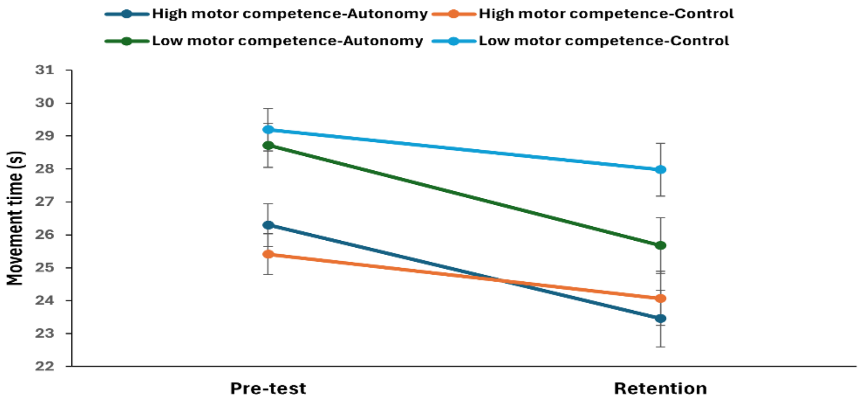

Figure 2: *Average movement time for performing rope knots from pre-test to retention for autonomy support and control groups in children with low and high motor competence *Error bars indicate standard errors*

The study measured the time participants took to complete these three knots. This quasi-experimental design included three stages: a pre-test, an intervention phase (10 sessions over 4 weeks), and a retention phase one week after the last intervention session, with comparisons across randomized groups. On the first day, participants received step-by-step instructions for each knot task under the supervision of an experimenter, followed by two familiarization trials and five pre-test trials. Before the intervention, they were divided into two groups—high and low motor competence—matched motor skill level (using the MABC-2 score). These groups were further divided into control and autonomy subgroups, also matched by gender and age. The autonomy group children could choose the order of tasks by difficulty, while the control group followed a sequence set by others. The task was conducted in pairs in a classroom, without exposure to other students. The control group participant observed the autonomy partner but was unaware of their task order choice.

Results

A three-way mixed-design ANOVA (2: TDC vs. DCD × 2: choice vs. no-choice × 2: time: pretest, retention) revealed that children in autonomy-supportive groups demonstrated significantly superior performance during the retention phase compared to the control group, irrespective of their motor competence level ($p < .05$), although no significant differences were found between autonomy and control groups during the pretest ($p > .05$). Also, children with high motor competence performed better than children with low motor competence in both pre-test and retention phases ($p < .05$) (Figure 2). No significant interactions were found between time and groups group × interventions ($p > .05$).

Discussion

The findings indicate that providing autonomy support by offering choices during a manual dexterity learning task enhances motor learning in children with both high and low motor competence. Specifically, while motor competence may affect initial performance, the inclusion of autonomy support fosters long-term learning and retention of fine motor skills [1, 2]. The findings may be particularly relevant for children with low motor competence, as they highlight how autonomy-supportive strategies can potentially reduce performance disparities, boost confidence, and enhance engagement during the learning process. That is, promoting a sense of control and motivation can support motor skill learning, offering valuable opportunities for designing interventions in educational settings.

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Promoting Writing Motor Skills in Primary Schoolchildren

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Keywords

Development, Motor learning, Motor control, Motor skills and abilities, Handwriting

Introduction

Handwriting can have beneficial effects on children's text comprehension and spelling [1]. According to a study in which around 2,000 primary school teachers from all over Germany were surveyed, 89 per cent of them state that the level of schoolchildren's (SC) handwriting has deteriorated in recent years [1]. This deterioration is reflected in a low level of automation. Therefore, the writing process requires more attention, resulting in lower brain capacity for the acquisition of written content. A more advanced writing technique could enhance the declarative learning process [2]. The reasons mentioned for the deterioration in handwriting include the lack of time for individual support of SC and the lack of further training opportunities for teachers [1]. The proposed solution is a specific training in writing motor skills for SC. The training should enable SC, their parents and teachers (PaT) to check and correct the SC's writing. Writing motor skills are aimed at efficient writing behavior. This includes a high degree of *automation* (*AU*), specified as number of inversions in velocity (NIV; experienced = 1 NIV), to provide more cognitive capacity [2], an appropriate *writing force* (*WF*) [Newton] with which the pen is pressed onto the paper to prevent pain (*WF* < 1.5 N) [3] and an ergonomic *grip position* (*GP*) [%] for fluent writing. A recommended ergonomic *GP* is the 3-point pencil grip (PPG), which means that three fingers touch the pen grip [4]. With this 3-point contact, free and small finger movements are possible, which can facilitate fluent writing. The 4-PPG restricts small finger movements due to the additional grip contact of the ring finger. The 3-PPG is divided into dynamic and static. A dynamic grip is recommended as the writing movements result mainly from the flexion and extension of the fingers [5], which favors fluent writing. With a static grip, the wrist, elbow, and shoulder perform the writing movements, which can lead to faster fatigue [6]. The aim of this prospective study was to evaluate whether a specific training concept has short-term and/or long-term effects on *WF*, *AU* and *GP* in the intervention group (IG) compared to the control group (CG).

Methods

193 first graders from eight Bavarian primary schools (109 SC in IG, 84 SC in CG) participated in this study. The participating classes were randomly assigned to either the IG or CG. The first measurement (T0) took place as a baseline measurement at the beginning of the first grade, when the SC started learning to write. This was followed by a training day on which the SC of the IG, their PaT carried out special exercises aimed at improving their writing skills. These exercises were practiced during the subsequent three-week intervention phase (IP) at school and at home. PaT documented the practice time and exercises in a diary. The CG followed their usual school routine. Follow-up measurements took place three weeks (T1), two (T2), seven (T3), and eleven months (T4) after the training day. Before each measurement, there was a familiarization phase for the measuring pen used. This pen was a special pen (STABILO® EduPen) for recording and analyzing writing motor skills with two acceleration sensors, a gyroscope, a magnetometer, a force sensor, and a pressure sensor. The task was to write the following letter sequences legibly and as quickly as possible with this pen: “AUTO” once, and “ele” and “ana” five times each. The *WF*, *AU* and *GP* were analyzed using a mixed model Analysis of Variance (ANOVA)

with the within-subject factor *time* and the between-subject factor *group*.

Results

36 SC in the IG and 25 SC in the CG were excluded due to missing values. Table 1 summarizes the descriptive statistics for *WF* and *AU*. The IP showed both short-term (p = .004, ηp^2 = .038) and long-term effects (p = .006, ηp^2 = .028) on the IG over *time* for the *WF* compared to the CG. For the *AU*, there was a significant short-term effect (p = .018, ηp^2 = .036), but no long-term effect between *groups* over *time*.

***Table 1:** Descriptive statistics for the writing force and the automation of T0 = baseline, T1 to T4 = follow ups.*

		Measurements (M ±SD)				
		T0	T1	T2	T3	T4
Writing force [N]	IG	1.7 ±0.8	1.8 ±0.6	1.6 ±0.6	1.6 ±0.6	1.6 ±0.6
	CG	1.5 ±0.5	1.8 ±0.6	1.8 ±0.5	1.5 ±0.6	1.4 ±0.5
Automation [NIV]	IG	11.9 ±3.6	9.2 ±3.1	8.1 ±2.9	5.5 ±2.1	5.3 ±2.1
	CG	11.3 ±3.5	10.2 ±3.4	8.7 ±3.2	5.7 ±2.2	5.3 ±2.1

Figure 1 depicts the development of the *GP*s. At T0, most SC used the static 3-PPG, the fewest the 4-PPG. At T3 and T4, approximately one-third of each grip was used in the IG and CG.

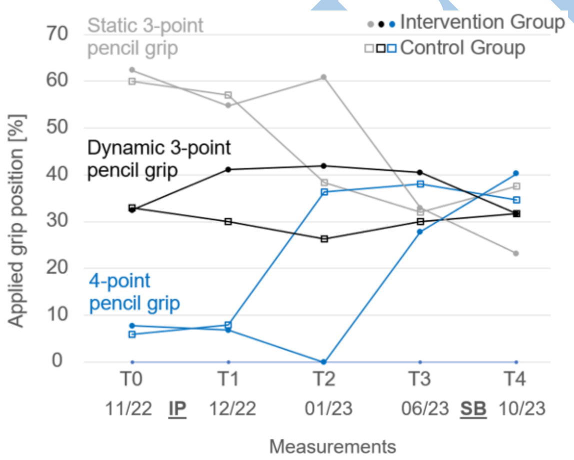

***Figure 1:** Development of the applied grip positions as a percentage of T0 = baseline, T1 to T4 = follow ups; IP = intervention phase, SB = summer break.*

Discussion

The IG had a higher *WF* than the CG at T0. The *WF* is significantly lower (small effect) at T2 in the IG than in the CG, which could be due to the IP. In the long term (T3, T4), the CG reduced the *WF*, however, the IG stagnated at 1.6N. One reason may be that the 3-week IP was too short. Both *groups* achieved an acceptable *WF* over *time* at this school age. Both *groups* showed unsurprisingly poor *AU* at T0; the value of the IG was worse than that of the CG. After the 3-week IP, the *AU* of the IG showed a significantly better *AU* (small effect) than the CG. This effect may not have lasted over *time*, as it takes regular practice to achieve *AU* and the exercises may not have been practiced as intensively over *time* as during the IP. The development of the applied *GP*s varied greatly. This could be because the SC had just started to learn how to write and had not got used to writing with the same *GP*. Another reason could be that the STABILO pen is thicker than a normal pen. Some SC may have been less able to write with the thicker pen than others may. The IG implemented the dynamic 3-PPG after the IP, but a wash-out effect was observed at T4, which could be due to the summer break, during which the SC may not have done much handwriting. The IP showed effects on *WF*, *AU* and *GP*, but quarterly training refreshers are recommended to establish routines.

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Relationship between dynamic spasticity during gait and daily-life mobility in children with Cerebral Palsy

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Keywords

Gait and postural control, Development, Clinical research, Cerebral palsy, Neurorehabilitation

Highlights

- Dynamic spasticity during gait in CP.
- Stretch sensitivity relates to mobility.

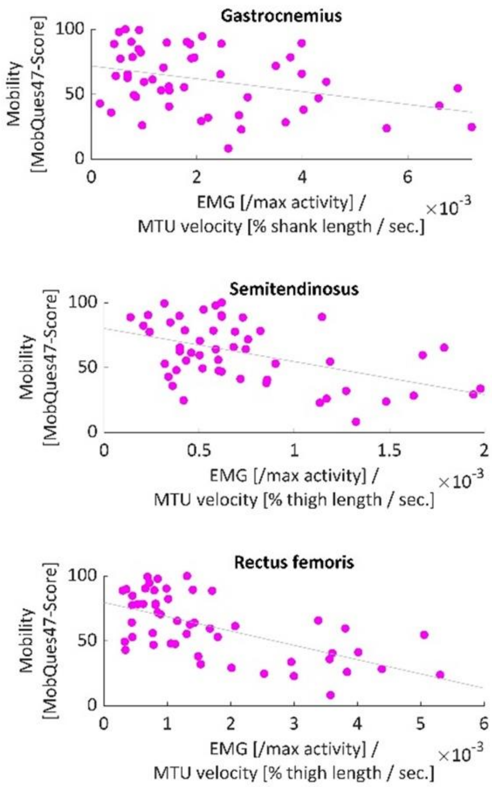
Introduction

Cerebral Palsy (CP), the most common pediatric disability, affects development, mobility, and functionality. Spastic CP, the predominant subtype, is characterized by a velocity-dependent increase in muscle tone due to stretch hyperreflexia [1]. Treatments such as Selective Dorsal Rhizotomy, Botulinum toxin, and oral medications aim to reduce spasticity and improve mobility. Spasticity is often assessed manually via muscle resistance to passive stretch, but these evaluations are subjective and may not capture voluntary motor performance. Bi-articular muscles, crucial for motor control, pose unique challenges, and their role remains debated. Instrumented methods, including gait analysis, musculoskeletal modeling, and electromyography (EMG), provide more precise assessments [2-5]. Previous studies have shown that spasticity in CP correlates with reduced hamstring lengthening velocity and abnormal late-swing activation during gait [2,4]. The interplay between muscle-tendon stretch velocity and muscle activity is considered a potential marker of neuromuscular dysfunction [3,5]. This study aims to examine whether this dynamic spasticity marker, assessed during gait, predicts everyday mobility in ambulatory children with bilateral spastic CP (BSCP).

Methods

59 children with BSCP (mean age: 8.1 ± 4.5 years; N = 12; 28; 19 in GMFCS Levels I, II, III) were included. They were compared to 30 age-matched typically developing (TD). Both groups underwent three-dimensional gait analysis (3DGA) using Vicon Nexus, equipped with 12 Vero cameras at 200 Hz, and a modified PiG model, incorporating surface electromyography (EMG) with Cometa Pico sensors (sampling rate: 1000 Hz). For each participant, at least five gait cycles were analyzed. Muscle-tendon unit (MTU) lengths were calculated for the rectus femoris and semitendinosus using equations from [6], and for the gastrocnemius from [7], supplemented with data on the Achilles tendon moment arm length [8]. MTU lengths were normalized to the thigh or shank length, and lengthening velocities were derived by differentiating MTU length with respect to time, enabling the calculation of peak stretch velocities. EMG signals were high-pass filtered (4th-order Butterworth filter, 50 Hz), full-wave rectified, and processed using a sliding root mean square (RMS) with a 25 ms window to generate EMG envelopes (RMS-EMG). The ratio of RMS-EMG to MTU stretch velocity during the swing phase was calculated for each muscle [3-5]. Peak MTU stretch velocities and the EMG/MTU velocity ratios were compared between the TD and BSCP groups using walking speeds as a covariate in an ANCOVA analysis. Caregiver-reported mobility was assessed using the Mobques47 questionnaire [7]. Correlations between the EMG/MTU velocity ratios and Mobques47 scores were calculated. All analyses were conducted in MATLAB, with $p < 0.05$.

Figure 1: *Relationship of EMG/MTU velocity ratios and Moblity in Children with BSCP*



Results

Peak muscle-tendon unit (MTU) stretch velocities were 21.0%, 39.7%, and 37.7% lower in children with BSCP than TD for the gastrocnemius, semitendinosus, and rectus femoris, respectively. Even after adjusting for slower walking speed, MTU stretch velocities of the rectus femoris and hamstrings remained significantly lower in children with BSCP ($P < 0.01$). Additionally, children with BSCP exhibited a sign. larger EMG-to-MTU velocity ratio compared to TD, a parameter that correlated negatively with mobility scores from the MobQues47 (Fig. 1) with $r = -0.46$ for the gastrocnemius, $r = -0.48$ for the semitendinosus, and $r = -0.65$ for the rectus femoris (all $P < 0.001$).

Discussion

Our findings indicate that the coupling between muscle-tendon stretch velocity and muscle activity serves as a relevant marker for spasticity-related impairments in cerebral palsy (CP), negatively impacting daily-life mobility. This supports the ecological validity of our assessments. Elevated EMG/MTU velocity ratios may reflect increased reflex loop sensitivity, contributing to slower walking and a stiff or flexed knee gait. This aligns with previous research suggesting that a reduced stretch reflex threshold limits peak muscle lengthening velocity during gait. Our instrumental assessment could serve as a comprehensive diagnostic tool to guide both invasive and non-invasive spasticity management strategies in clinical settings and as an outcome measure for interventions.

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Non-invasive spinal cord stimulation is a real alternative to brain stimulation in supporting balance abilities

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Highlights

- The spinal cord is a true alternative to the brain for the application of non-invasive neuromodulation in supporting sensorimotor abilities.
- Anodal HD DCS over the spinal cord supports balance performance, while ACS improves sensory abilities.
- Spinal repetitive paired pulse magnetic stimulation supports balance abilities, and the coil position significantly influences their effects.

Introduction

Gait and balance are complex sensorimotor functions controlled by integrated brain and spinal networks and their neural background is still not fully understood. Neuroimaging data suggests a key role of cerebellum and brainstem, followed by several cortical and subcortical areas [1], while other studies emphasize the crucial role of the spinal cord [2] on balance control. Inconsistent with these observations, the existing Non-Invasive Stimulation (NIS) research focuses on the primary motor cortex (M1) and a few frontal cortex regions. Even if the effective targeting of brainstem and several subcortical regions remains a technical challenge, the cerebellum and spinal cord networks can be successfully modulated by existing tools. Nevertheless, cerebellar stimulation remains underrepresented, and spinal stimulation has hardly been investigated in the field of balance and postural control. Better evidence of these less investigated protocols is urgently needed. We performed three studies that address this topic.

Methods

Three randomized placebo-controlled crossover trials were performed with healthy young elderly people. The first study compared twenty minutes of anodal 1.5 mA Direct Current Stimulation (DCS) over (i) the M1, (ii) the cerebellum, and (iii) the spinal cord, and (iv) sham DCS in forty-two probands [3]. The balance performance (Y Balance Test, Single Leg Landing Test, Single Leg Squat Test) of either leg was tested immediately prior to and after each intervention. The second study tested twenty minutes of high definition (HD) [4] 1.5 mA (i) anodal DCS, (ii) cathodal DCS, (iii) Alternating Current Stimulation (ACS) and (iv) sham stimulation over spinal cord (Th8 level) in fifty-eight subjects. The balance performance (Y Balance Test) and the sensitivity (Monofilament Test, Tuning Fork Test) were tested immediately prior and after each intervention for each leg (Fig. 1). The third ongoing study tests spinal (L2 level) repetitive paired pulse magnetic stimulation (paired pulses at 100Hz applied each 2 seconds, intensity of 70% of rMT, 800 pulses in total) in twenty-seven subjects. Three verum sessions, with a figure of eight coil's handle oriented (i) superiorly, (ii) inferiorly and (iii) laterally, and (iv) one sham session (through sham coil) are applied. The balance ability (Y Balance Test) and the corticospinal pathway functioning (motor evoked potentials, cortical silent period, ipsilateral silent period) were tested for each leg and hemisphere immediately before and after each intervention. Repeated measures ANOVAs with the factors "intervention" and "time" were applied to test intervention-induced effects.

Results

Numerous significant intervention-induced differences between verum and sham as well as between individual verum interventions were detected in our three trials. The first study demonstrated significant effects on the Y Balance Test, but not on the Single Leg Landing Test and the Single Leg Squat Test after 1.5 mA DCS over either region. For the left leg, M1 DCS ($F_{1,40}$ = 8.999; p = 0.005) ($F_{1,36}$ = 18.624; p < 0.001), cerebellar DCS ($F_{1,40}$ = 8.796; p = 0.005) ($F_{1,36}$ = 16.291; p ≤ 0.001) and spinal DCS ($F_{1,39}$ = 13.55; p ≤ 0.001) ($F_{1,34}$ = 8.799; p = 0.005) supported the balance ability in the posterior-lateral and posterior-medial directions as compared to sham DCS. For the right leg, only spinal DCS improved balance performance in the posterior-lateral ($F_{1,39}$ = 11.53; p = 0.002) and posterior-medial ($F_{1,39}$ = 7.943; p =0.008) direction as compared to sham DCS. No significant effects were detected for the anterior direction [3]. The second study demonstrates significant effects of 1.5 mA DCD/ACS over the spinal cord on all tests applied. The Y Balance Test improved after HD anodal DCS ($F_{1,57}=11.997$; $p=0.001$) and HD ACS ($F_{1,57}=4.430$; $p=0.040$) as compared to sham. The Tunning Fort Test was supported through HD anodal DCS ($F_{1,57}=4.627$; $p=0.036$; $F_{1,57}=5.294$; $p=0.025$) and HD ACS ($F_{1,57}=7.501$; $p=0.008$; $F_{1,57}=11.844$; $p=0.001$) as compared to sham and HD cathodal DCS. The Monofilament Test improved after HD anodal HD DCS in comparison to cathodal ($F_{1,57}=7.127$; $p=0.010$) and HD ACS ($F_{1,57}=4.287$; $p=0.043$) (Figure 1). For the third study, the statistical analysis has not been performed so far. However, the current data indicates that (a) the repetitive paired pulse magnetic stimulation over the spinal cord is effective in modulation of both neural networks and balance performance, and (b) the coil orientation in relation to the sagittal axis significantly impacts the intervention-induced effects.

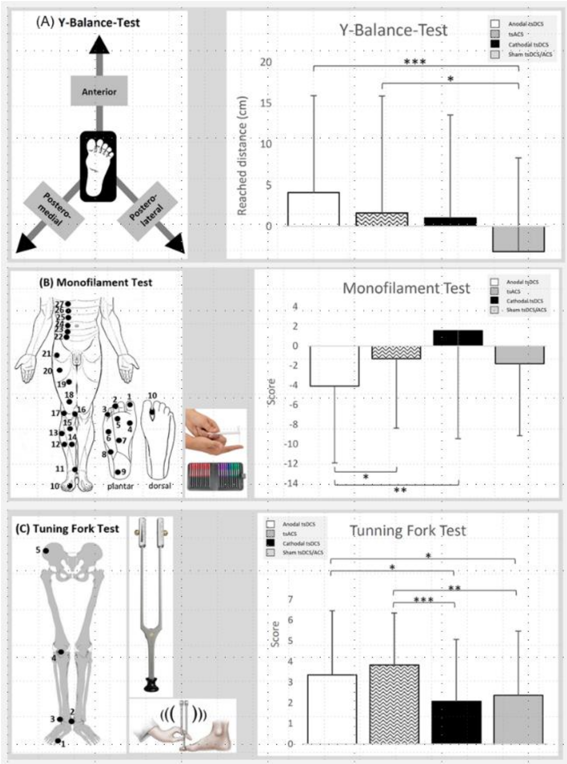

__Figure 1:__ Y-Balance Test, Monofilament Test and Tuning Fork Test showed several intervention-induced effects.

Discussion

Our results show that the spinal cord is a promising alternative to the brain for the application of non-invasive brain stimulation in the modulation of balance, postural control, sensitivity, and corticospinal processing and encourages further investigations of this target in both healthy and disabled cohorts. Spinal stimulation can both directly target spinal networks and indirectly interact with remote spinal and brain regions, such as the brainstem or basal ganglia. Thus, this method may be useful for several neurological diseases, such as stroke patients, Parkinson disease and dystonia patients. All these diseases consistently show not only illness-related changes within the brain networks but also disturbed neural processing within the spinal cord that correlate with the balance disabilities [6,7,8]. The research on healthy subjects should create more evidence for less investigated DCS/ASC and rTMS protocols (in regard to stimulation frequencies, intensities and locations) and test the effects of closed-loop stimulation in supporting balance control.

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Impact of post-stroke retropulsion on rehabilitation duration and outcome

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Keywords

Neurorehabilitation, postural control, motor control, clinical research, backward disequilibrium

Highlights

Post-stroke retropulsion is linked to longer rehabilitation, increased dependence in ADLs, and reduced likelihood of discharge home.

Introduction

Retropulsion is an active backward shift of the center of mass, increasing the risk of backward falls. It is characterized by difficulty shifting the center of mass forward and resistance to passive correction [1,2]. Retropulsion can result from neurological and geriatric conditions and, like lateropulsion, is linked to an impaired internal representation of verticality. We recently showed that retropulsion is frequent in neurorehabilitation and occurs in various neurological disorders [3]. About 71% of stroke survivors showed signs of retropulsion (total score ≥1 on the Scale for Retropulsion, SRP) with great variation in the severity of signs. To date, it has not yet been investigated to what extend retropulsion affects rehabilitation in terms of rehabilitation duration and outcome. Based on clinical experience and data from patients with lateropulsion, we hypothesize that retropulsion prolongs and negatively impacts rehabilitation.

Thus, the objectives of this study were to determine the association of retropulsion with 1) the length of stay (LOS) in inpatient rehabilitation, 2) the ability to complete activities of daily living (ADL, measured with the Barthel Index), and 3) the Barthel Index efficiency during rehabilitation (Barthel Index change/LOS), and 4) discharge destination.

Methods

The observational cohort study was conducted at the Schoen Clinic Bad Aibling, Germany. It was approved by the Ethics Committee of the Ludwig-Maximilians-Universität München. Subjects assessed for retropulsion were ≥18 years, had a stroke and were admitted to neurorehabilitation at the Schoen Clinic Bad Aibling. Subjects with orthopaedic hip conditions hampering hip flexion between 70° and 120° were excluded, as such limitations could interfere with achieving a proper sitting position and trunk movement in that position. Retropulsion was measured using

		Sitting	Standing	Subscores
A	Static postural control	1A = ______	2A = ______	A : ________ (Max. 6)
B	Reactive postural control	1B = ______	2B = ______	B : ________ (Max. 6)
C	Resistance	1C = ______	2C = ______	C : ________ (Max. 6)
D	Dynamic postural control	1D = ______	2D = ______	D : ________ (Max. 6)
		Sitting: ______(Max. 12)	Standing: ______(Max. 12)	Total score: ________ (Max. 24)

Figure 1: *Evaluation sheet of the Scale for Retropulsion.*

the German version of the SRP [2,4]. The scale includes four subscales: A) static control, B) reactive postural control, C) resistance, and D) dynamic postural control. Patients are evaluated in sitting and standing positions, which each subscale scored from 0 (no signs of retropulsion) to 3 (severe retropulsion), yielding a total score ranging from 0 to 24 (Figure 1). The SRP has excellent internal consistency, as well as good to excellent test-retest reliability, interrater reliability and validity in neurological patients [4].

The Barthel Index, a measure of activities of daily living, is assessed weekly by nursing staff in our clinic and was retrospectively extracted from electronic health records for this analysis.

Results

Data of 202 subjects were included in this study (age 72±13 years, 102 female), of whom 148 subjects (73.3%) showed signs of retropulsion (SRP total score ≥1) with a median (Q1, Q3) SRP total score of 12 (5, 19). Thirteen subjects died before discharge from rehabilitation. The average LOS was 70±51 days. Patients with signs of retropulsion had significantly longer LOS than those without retropulsion (78±53 vs. 50±42 days; T=-3.441, p=.001). There was a moderate positive correlation between the LOS and the SRP total score (r_{Sp}=.446, p<.001). Subjects with signs of retropulsion had a significantly lower Barthel Index at the time of SRP assessment (U=1865.000, Z=-5.823, p<.001), which correlated strongly with the SRP total score (r_{Sp}=-.591, p<.001). At discharge, their Barthel Index remained significantly lower compared to patients without retropulsion (U=1871.500, Z=-5.185, p<.001). No significant differences were observed between groups in the Barthel index change during rehabilitation (p=.617) and the Barthel Index efficiency (p=.719). Figure 2 illustrates discharge destinations. Patients with signs of retropulsion at admission were less often discharged home than those without retropulsion (χ^2=4.687, p=.030).

Discussion

Our large cohort study shows that the presence and severity of post-stroke retropulsion are associated with longer rehabilitation duration. The average LOS in subjects with signs of retropulsion was almost 28 days longer than that of those with no retropulsion. The presence and severity of retropulsion was also linked to a lower Barthel Index, reflecting greater functional dependence. While all patients showed similar improvements during rehabilitation, those with signs of retropulsion were discharged with lower Barthel Index scores and were less frequently discharged home. Similarly, longer rehabilitation LOS have been observed in stroke survivors with lateropulsion; however, unlike our findings, with reduced efficiency in functional improvement [5,6]. To sum up, retropulsion is linked to longer rehabilitation stay, increased functional dependence and reduced likelihood of discharge home. Based on the assumption that stroke survivors with retropulsion can achieve meaningful functional improvements, an extending rehabilitation may help enhance independence at discharge and increase likelihood of returning home. Additionally, targeted treatment approaches could improve rehabilitation efficiency.

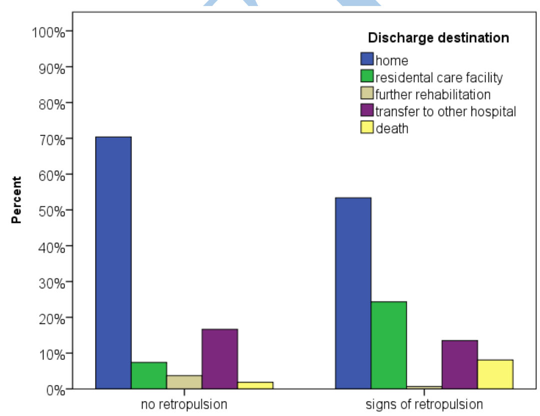

Figure 2: *Discharge destinations of patients with and without signs of retropulsion.*

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Effect of metastable resistance training on trail walking test performance in older adults

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Keywords

Aging, Instability, Health, Gait and postural control, Motor cognition, Motor skills and abilities

Introduction

Aging is associated with a decline in both motor and cognitive function [1]. The Trail Walking Test (TWT) assesses several motor and cognitive functions, such as postural control and cognitive flexibility [2]. Its performance has been reported to decline with age [2] and to predict cognitive impairment in older adults [3, 4]. Metastable resistance training (MRT) on an unstable surface integrates physical training (i.e., strength) and motor training (e.g., coordination, balance), and requires both metabolic [5, 6] and cognitive demands [7]. This combination of metabolic and cognitive demands is thought to be particularly beneficial in counteracting age-related declines in cognitive function [8, 9]. However, the effects of physical and motor training on TWT have not been investigated in healthy older adults. Therefore, the purpose of the present study is to compare the effects of MRT on the TWT with those of traditionally recommended resistance training (T-RT) and balance training (BT).

Methods

Eighty healthy older adults (mean age 70.5 ± 4.5 years) were matched into three groups, which were randomly assigned to either MRT, BT or T-RT programs. MRT involved free-weight resistance exercises (squats, lunges, core exercises) on unstable device (e.g., foam pad, Bosu ball), while T-RT involved machined-based resistance exercises (Smith machine squats, unilateral leg press, core exercises). The BT performed three different stances (bipedal, tandem, single leg) using different instability devices and additional tasks (e.g., eyes open vs. closed, catching and throwing a ball). Each group engaged in their respective exercise programs twice a week on non-consecutive days for a duration of 10 weeks. The TWT2, which involves walking to numbers from 1 to 15 in ascending order, and the TWT3, which requires walking alternately to numbers from 1 to 8 and letters from A to G in ascending order, were administered two times before and after the training intervention period. If a person walked in the wrong direction, their attention was immediately drawn to this while the time continued to run. All errors were recorded. The fastest of two TWT2 and TWT3 trials at each time point was selected for analysis. A 2 x 2 x 3 mixed repeated measures ANOVA was performed to analyze differences between conditions (TWT2, TWT3), time points (pre, post) and between groups (BT, MRT, T-RT).

Results

Errors occurred more frequently in the TWT3 (n = 19) than in the TWT2 (n = 3) condition, and more frequently in the pre-test (n = 17) than in the post-test (n = 5). Figure 1 illustrates the TWT2 and TWT3 performance of each group at each time point. A significant main effect was observed for condition, $F(1, 77) = 203.95$, $p < 0.001$, $\eta_p^2 = 0.73$, with shorter execution time for TWT2 compared to TWT3. Additionally, a significant main effect of time, $F(1, 77) = 5.99$, $p = 0.017$, $\eta_p^2 = 0.07$, indicated better performance at post-test as compared to pre-test. There were no significant interaction effects between condition and time, between condition and group, or between time and group. Additionally, no significant main effect of group was observed.

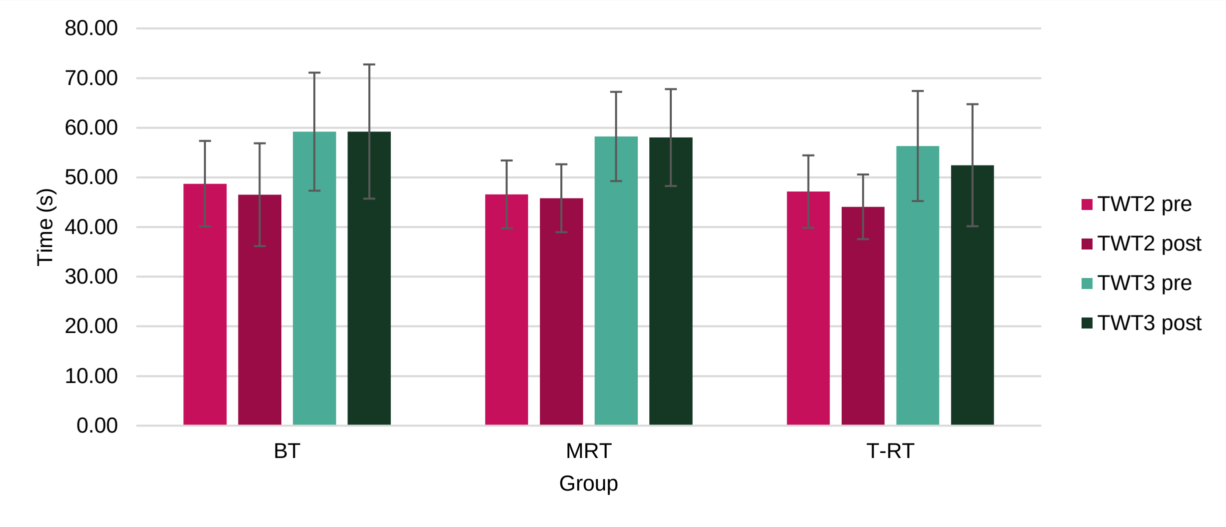

Figure 1: *Pillar plot of the time (in seconds) to complete the TWT2 and TWT3 conditions in each training group for the pre-test and post-test. Error bars indicate the standard deviations.*

Discussion

In both conditions, participants showed shorter walking times in the post-test than in the pre-test, potentially influenced by fewer directional errors (walking in the wrong direction). A beneficial effect of MRT as a combined motor and physical training on TWT performance could not be demonstrated. Since all groups showed improvement over time, the pre-post differences may be due to a learning effect as argued by Eckardt et al. [10] and Forte et al. [11] for the paper and pencil version of the Trail Making Test. In general, the mean execution times in TWT2 and TWT3 are comparable to those reported for healthy older adults in previous studies [2].

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Nine-Hole Peg Test Performance Correlates with Cognitive Performance in Older Adults: A Multimodal Regression Analysis Controlling for Grip Strength, Gait, and Heart Rate Variability

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Highlights

- Nine-Hole Peg Test performance shows strong correlations with cognitive domains even when controlling for other variables.
- HRV, Gait and body temperature measures showed weaker or no consistent associations with cognitive performance.

Introduction

Grip strength, hand dexterity, gait variability, and heart rate variability (HRV) have all been proposed as potential markers of future cognitive impairment. Grip strength, for instance, is a well-established surrogate measure of physical fitness and frailty [1], which has been linked to both current cognitive performance and future cognitive decline [2-4]. Similarly, hand dexterity, assessed using tools like the Nine-Hole Peg Test (NHPT), has been associated with global cognitive scores and executive functioning, particularly in populations with neurological conditions [5-7]. Additionally, gait parameters such as gait speed, variability, and postural control have been shown to correlate with cognitive decline in both healthy older adults and those with neurodegenerative diseases [8-10]. Moreover, heart rate variability (HRV), an indicator of autonomic function, has been linked to executive functions [13]. Body core temperature has been investigated as a potential marker of cognitive health, with changes linked to neurodegenerative pathology [14,15].

Objective

To investigate the associations between domain-specific cognitive performance and upper limb dexterity, grip strength, gait parameters, and HRV, using a multimodal regression framework.

Methods

In this single-center, cross-sectional study, we recruited 98 independently living older adults (≥65 years) between November 2020 and March 2021. Participants underwent neuropsychological testing, including the Quick Mild Cognitive Impairment (QMCI) screen to assess global cognition, the Face-Name Associative Memory Test (FNAME) for associative memory, Trail Making Test Part B (TMT-B) for processing speed and cognitive flexibility, Stroop III for inhibitory control and executive functioning, and verbal fluency tasks measuring semantic memory and flexibility. Physical assessments included the Nine-Hole Peg Test (NHPT) for fine motor dexterity, grip strength measured via three trials per hand (using the mean of the highest forces), and Apraxia Screen of Tulia. Gait assessments included the short physical performance battery (SPPB) as well as a quantitative analysis of cadence, step length, and variability using inertial measurement units. Heart rate variability (HRV) was assessed using textile-based sensors for parameters like SDNN and VLF at rest and standing. Multimodal multiple linear regression models, employing augmented backward elimination, were used to evaluate the independent contributions of these predictors to domain-specific cognitive performance, controlling for age and other potential confounders.

Results

Dexterity, as assessed by the NHPT, demonstrated robust associations with cognitive domains, particularly executive functioning (TMT-B: standardized $\beta = -0.28$, $p < 0.01$) and memory (FNAME: standardized $\beta = -0.42$, $p < 0.001$). Gait variability metrics, including step length variability (standardized $\beta = -0.23$, $p < 0.05$) and swing duration variability (standardized $\beta = 0.27$, $p < 0.01$), significantly predicted cognitive outcomes, particularly in verbal fluency and Stroop III tasks. Specifically, greater step length variability correlated with poorer memory performance, while greater swing duration variability was associated with better verbal fluency scores. HRV parameters, such as SDNN at rest (standardized $\beta = 0.21$, $p < 0.05$), correlated positively with executive functions, indicating higher autonomic regulation supports cognitive flexibility. Conversely, short-term body core temperature measurements showed no significant association with cognitive performance. Multimodal regression models, incorporating age and selected predictors, explained 20.3% of variance in TMT-B scores (adjusted $R^2 = 0.19$) and 34.9% in FNAME scores (adjusted $R^2 = 0.31$). These findings highlight specific physical and physiological parameters correlated with distinct cognitive domains.

Discussion

Physical tests, such as the NHPT and sensor-based gait analysis, show potential as adjunct tools for cognitive screening in older adults. However, the modest effect sizes and limited model fits underscore the need for longitudinal studies to validate these findings and assess their utility in clinical settings. Integration of such measures in motor control assessments could enhance early detection of sensorimotor deficits and cognitive decline, guiding timely interventions.

Limitations: The cross-sectional design limits causal inferences. A small sample size reduces generalizability and power, especially for subgroup analyses. Potential confounding factors, such as undiagnosed comorbidities (e.g., arthritis or neurological disorders), were not addressed.

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Effects of Cardiovascular Exercise on Memory and Cognition in Parkinson´s Disease (EMCo) – a Study Protocol

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Keywords

Motor learning, Motor skills and abilities, Neuroplasticity, Clinical study, Neurorehabilitation

Highlights

- Study protocol of a registered RCT to evaluate the effects of CVE on memory formation in PD

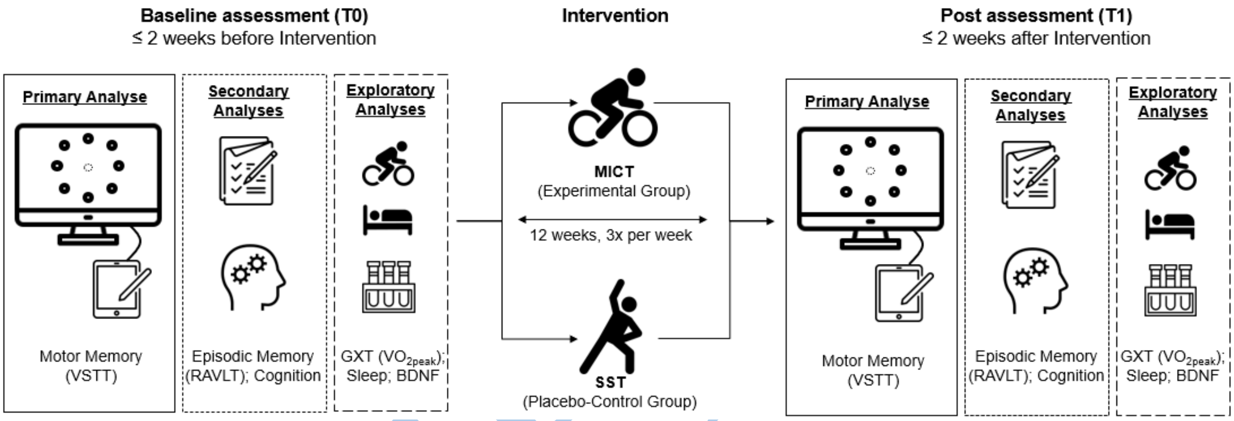
Introduction

People with Parkinson´s Disease (pwPD) experience severe non-motor symptoms, including memory formation deficits and cognitive impairment [1]. Unfortunately, pharmacological therapies are ineffective in addressing these symptoms [1]. Emerging research suggests that cardiovascular exercise (CVE) may improve neuroplasticity and memory formation in young adults, indicating that CVE could be an effective intervention to counteract memory deficits in neurological populations [2]. However, the evidence remains inconclusive, and these findings cannot be directly applied to pwPD [3]. While some studies indicate beneficial effects of CVE on global cognitive function in pwPD, limited data exist on long-term memory formation, particularly procedural memory [4]. A first study by Duchesne et al. [5] demonstrated enhanced encoding of a motor sequence task after 12 weeks of CVE in pwPD, but their study did not examine memory consolidation, the process which is suggested to be particularly impaired in PD [1]. Additionally, the absence of a non-CVE placebo-control group limits the conclusion of these findings. Therefore, the primary objective of this randomized controlled trial (RCT) is to evaluate the effects of 12 weeks of CVE on procedural memory formation in pwPD. For the secondary objectives, we will evaluate effects on episodic memory formation and other cognitive functions. To explore potential mechanisms of the memory enhancing effects of CVE, we will conduct exploratory analyses to examine possible associations between training-induced changes in memory formation, cognitive function, cardiorespiratory fitness, sleep quality, and blood serum concentrations of brain-derived neurotrophic factor (BDNF).

Methods

In this registered RCT (trial number: NCT06580977), 60 participants between 50-80 years, with mild-to-moderate PD (Hoehn & Yahr ≤ 3) will be randomized to either an experimental group performing moderate-intensity continuous cardiovascular training (MICT, 60% W_{max}) or a placebo control group performing static stretching (SST) (Figure 2). Training sessions will occur three times a week over 12 weeks, conducted in supervised small groups of 2-5 participants at the study site. The training will start with a duration of 30 min. In the MICT group intensity (+5% in Watt) and duration (+5 min) will be progressively increased every two weeks. We decided to use a placebo-control group according to similar research to ensure the results are not biased by a placebo effect (e.g., interaction with therapists or other participants) [6]. To avoid increased cardiovascular activity participants in the SST group will perform static stretches in a sitting or lying position (heart rate and self-perceived rate of exertion are monitored). All outcome variables will be collected at baseline (T0) and after the interventions (T1). As primary outcome, we will assess memory formation using a visuomotor serial targeting task (VSTT). The VSTT has been widely used to study motor sequence learning in pwPD and has shown reduced learning gains compared to age-matched controls [1]. In this task, participants are instructed to move a cursor using a digitizing tablet from the center to one of eight radially displayed targets. To assess motor sequence learning, the targets appear in a repeating order. Sequence retrieval will be assessed in a 24h (±2h) retention test. Explicit sequence learning will be assessed using the number of correct anticipatory movements, while implicit sequence learning will be assessed using the spatial error [1]. We will then calculate a global motor learning score, defined as the relative change from the start of encoding to the 24h retention test. For the analysis of secondary objectives, we will use the Verbal Learning and Memory Test (German equivalent of the Rey Auditory Verbal Learning Test, RAVLT) to evaluate episodic memory. Cognitive function will be assessed using the Spatial and Digit Span Tests, the Trail Making Test, and the Stroop Test. Exploratory analyses include the assessment of cardiorespiratory fitness in a graded exercise test (VO_{2peak}), sleep quality using actigraphy, and resting BDNF blood serum concentration. For statistical analysis, we will calculate the change score from T0 to T1 for each outcome variable and analyze between-group differences in the change scores using separate analyses of covariance (ANCOVA) with T0 performance as covariate [7]. To explore proposed mechanisms of the exercise-induced effects on memory formation, we will analyze the associations between changes in memory formation, cognition, cardiovascular fitness, sleep quality, and serum BDNF levels using Pearson correlations and perform mediation analyses.

Figure 2: *study design*



Discussion

This presentation reports the study protocol of the registered RCT, investigating the effects of 12 weeks of CVE on memory formation in pwPD. The EMCo trial started in February 2024 and will collect a unique dataset of 60 pwPD over three years. The results of this research project may have direct relevance to neurorehabilitation and provide an important contribution to the current discussion on the neuroplastic effects of CVE.

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Development and evaluation of an augmented reality-based assessment of activities of daily living

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Keywords

Virtual / Augmented Reality, Motor skills and abilities, Activities of daily living, Motor cognition, Performance assessment

Introduction

Activities of daily living (ADL) are essential in older adults for independent living and reflect routine tasks performed on a daily basis for self-care purpose [1]. ADL disability is associated with reduced quality of life [2], increased costs of care [3], and higher mortality [4]. ADL comprises both motor and cognitive components, which are also interrelated [5]. Currently established ADL assessments, e.g. in clinical settings, are often not sensitive enough to distinguish between these components [6]. Emerging technologies such as augmented reality (AR) or virtual reality (VR) might fill this gap and create promising opportunities regarding the development of novel ADL diagnostic tools [8]. In various healthcare settings, such technologies are already being used for physical activity promotion or improvement of physical and cognitive performance [9, 10]. By integrating virtual elements within the head-mounted display (HMD), predefined ADL can be guided and, ultimately, be replicated and assessed based on speed, execution, and error scoring. Finally, the achieved performance would be automatically evaluated using a specified point system. The overarching aim of this study is to develop and evaluate an AR-based assessment of ADL for older adults, which may ultimately provide more valid insights into motor performance by limiting or eliminating an impact of cognitive impairment. We hypothesize that cognitively unimpaired older adults will not show significant differences in performance between the AR-based ADL assessment and traditional ADL assessments. Conversely, we expect older adults with cognitive impairment to perform significantly better on the AR-based ADL assessment because the influence of cognitive load is reduced.

Methods

We aim to develop a sensitive AR-based tool to assess motor performance during the execution of ADL in older adults with cognitive impairments. Furthermore, we plan to examine whether cognitive load during ADL task execution can be reduced through means of gamification, visual cues, and task-step visualization, which will be particularly critical for assessing motor performance in older adults with cognitive impairments. To this end, the AR-based ADL assessment will be developed and evaluated in four distinct steps. After defining the motor and cognitive demands of specific ADL based on current literature and expert consensus, we will develop the AR software and evaluate the AR-based ADL assessment. To this end, we will conduct two validation studies: one among cognitively unimpaired older adults (aged 65 years and older), and one among cognitively impaired older adults, i.e., with mild cognitive impairment or mild dementia, recruited from nursing homes. Cognitive impairment is assessed using the MoCA with a cut-off of >5 and <26 points. In the first validation study, participants will complete both the AR-based and traditional ADL assessment, with the latter being either performance- or informant-based depending on the specific ADL being evaluated. Three weeks later, the same procedure will be repeated to assess test-retest reliability. Following this, necessary adjustments will be made in a second software development

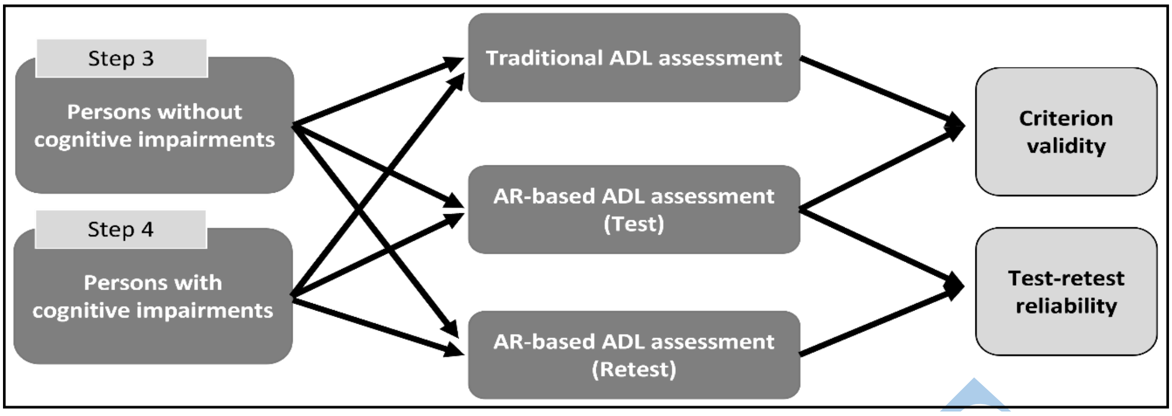

Figure 1: Process for evaluating validity and reliability of the AR-based ADL assessment.

process before the second study is conducted. In the second study, both assessments will again be carried out on two separate occasions with three weeks time in between. Cognitive load will be assessed using a 9-point Likert scale, where participants will be asked to rate how mentally demanding they perceived each task. For a precise overview of the process for evaluating the validity and reliability of the AR-based ADL assessment, please refer to figure 1.

Results & Discussion

We anticipate that cognitively unimpaired older adults will have comparable ADL performance results in established traditional and AR-based ADL assessments, thereby indicating sufficient criterion validity. In contrast, in cognitively impaired older adults, we expect a difference between ADL performance results between traditional and AR-based assessment, and we anticipate that persons will have better ADL performance in the AR-based assessment. Such a finding may indicate that cognitive load during ADL task execution can be effectively reduced by using AR-based assessment tools and would therefore allow for a more valid and sensitive assessment of the motor (as compared to cognitive) component within ADL. The study is currently ongoing, and we will present preliminary results on steps 1-4 as outlined above at the conference.

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Age-dependent effects of arm movement when balancing in a virtual environment.

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Keywords

Virtual / Augmented Reality, Gait and postural control, Motor control, Arm movement, Development

Introduction

It has recently been reported that balance performance is affected by arm movements. In this regard, it has been demonstrated [1] that in healthy, young individuals balance performance is better when assessed under "free" arm conditions compared to "restricted" arm use. More specifically, Muehlbauer et al. [1] showed that children's, adolescents', and young adults' static, dynamic, and proactive balance performance was significantly better when assessed with free compared to restricted arm use. It was further shown that this effect was more pronounced during more difficult tasks (e.g., balancing on a narrow compared to a wider beam) and more pronounced in younger (e.g., children, adolescents) compared to older (e.g., young adults) individuals. Additionally, virtual reality (VR) has been used as a balance training tool especially in therapeutic contexts [2] more recently as it provides the opportunity to visually expose participants to challenging (everyday-)situations while physically remaining in the laboratory. However, it is unknown whether the effects of arm movement are also influenced by VR. Based on the findings from Muehlbauer et al. [1], it could be hypothesized that the supportive role of arm movements may be particularly important when individuals are exposed to situations of high difficulty (e.g., balancing at height) in an unfamiliar visual environment by using VR. Therefore, the aim of the present study was to analyze the effect of arm movement during a dynamic balance task of high difficulty provided through VR in children, adolescents, and young adults. We hypothesized that performance would be better during "free" compared to "restricted" arm movements in all age groups and that performance would increase with age.

Methods

Dynamic balance performance was assessed in 22 children (10.8 ± 0.5 years; 55% females), 20 adolescents (15.0 ± 0.4 years; 60% females), and 22 young adults (24.3 ± 3.1 years; 50% females) who performed a beam-walking task while viewing a posture-threatening virtual environment (VE) through a Head-Mounted Display (Oculus Quest 2, Meta Inc., USA). Using the app "Richie's Plank Experience" (Toast VR PTY. LTD., Australia), participants saw a virtual wooden balance beam (3 × 0.1 m), extending from a skyscraper's 80th floor in the VE. The participants' task was to walk forward to the end of the virtual beam and then reverse to the start while walking backwards. Each participant performed one trial with "free" (i.e., free arm movements allowed) and one trial with "restricted" (i.e., hands placed on the anterior superior iliac spine) arm movement in a randomized order. Before each trial, they were informed about the respective arm condition. The total time to complete the task was recorded and used for analyses. All statistical analyses were performed using JASP version 0.19.

Results

Descriptive results are displayed in Table 1. The repeated measures ANOVA revealed no significant effect of arm condition (F=0.628, p=0.431) and no significant arm condition × age interaction (F=0.261, p=0.771). However, there was a significant effect of age (F=15.001, p<.001), with post-hoc tests indicating larger balancing times in children compared to adolescents and young adults during trials with free (.63<Cohen's d<.73) and restricted (.82<Cohen's d<1.04) arm movement.

Table 1: *Balancing time [s] by age group and arm condition (Mean ± SE).*

Participants	free arm movement	restricted arm movement
Children (*n*=22)	44.91 ± 6.86	46.86 ± 5.35
Adolescents (*n*=20)	22.29 ± 2.33	22.21 ± 1.80
Young Adults (*n*=22)	22.17 ± 1.91	27.24 ± 3.68

In addition, we a posteriori decided to also analyze balancing times by trial number (Table 2). The repeated measures ANOVA revealed a significant effect of trial (F=55.763, p<.001), age (F=15.001, p<.001), and a significant trial × age interaction (F=8.863, p<.001). Post-hoc analyses showed that irrespective of arm movement condition, the first trial was significantly slower than the second trial in children (Cohen's d=1.11), adolescents (Cohen's d=0.91), and young adults (Cohen's d=1.04) and that children took significantly longer than adolescents and young adults during the first (1.04<Cohen's d>1.13) and the second (0.57<Cohen's d>0.60) trial.

Table 2: *Balancing time [s] by age group and trial number (Mean ± SE).*

Participants	1st trial	2nd trial
Children (*n*=22)	59.05 ± 6.21	32.73 ± 4.56
Adolescents (*n*=20)	26.05 ± 2.09	18.44 ± 1.67
Young Adults (*n*=22)	29.83 ± 3.43	19.58 ± 1.88

Discussion

In contrast to our first hypothesis, and in contrast to the results of studies performed in the real visual environment [1], balance performance was not significantly different between trials with free and restricted arm movements in all investigated age groups. The analysis of the balancing times based on trial sequence revealed statistically large performance improvements from the first to the second trial in all age groups. This finding may indicate a general learning and/or habituation effect. More specifically, the unfamiliar visual condition and the postural threat provided through VR may minimize the supportive effect of the arms, especially during the first trial. Our second hypothesis was partially supported, as we found significantly worse performances in children compared to adolescents and young adults when analyzing balancing times with respect to arm condition as well as according to trial number. The postural control system in children is not fully matured and children are known to especially rely on vision in order to maintain their balance [3]. In this regard, it may be hypothesized that they were particularly affected by the virtual environment during the first trial. However, they were also able to quickly adapt to the unfamiliar visual condition as evidenced by the significantly improved balancing time during the second trial.

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Preliminary Study of Adaptive Motor Strategies to Perturbations of Center of Mass

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Keywords

Motor learning, Motor control, Methods, Gait and postural control, Motor skills and abilities.

Introduction

Sudden or incremental changes in our surroundings can cause large kinematic errors in our movements. To stabilize movement, individuals counter perturbations by adjusting the feedback responses to environmental dynamics, increasing co-contraction and aligning the feed-forward adaptation with predictable perturbations. [1]. Much of the research in human motor adaptation has focused on simple planar arm reaching movements emphasizing the motion of a single body segment [2]. In contrast, the adaptation and corrective mechanisms in whole-body movements are less understood, as they involve coordinating numerous degrees of freedom to maintain balance and avoid falling, making them more complex than simple reaching tasks. Recent studies show that adaptation processes in whole-body movements are somewhat similar to the ones during arm reaching movements [3]. However, we still lack a full understanding of how motor adaptation from arm-reaching studies applies to whole-body control. Here, we examined adaptation during upright stance movements.

Methods

In the experiment, 18 healthy human participants (6 females; height 180±5 cm; weight 72±9 kg; age 22±2 years) were standing upright, feet hip-width apart, arms folded on their chest, facing a screen situated at approximately eye level (Figure 1). They controlled a real-time cursor on the screen representing the position of their center of mass (COM). Their goal was to navigate the cursor between two targets. They were performing a series of side to side motions, where they had to move their COM along the X-axis (left to right and vice versa). During the task, participants experienced systematic forward perturbations delivered by a force-controlled mechanism with a magnitude proportional to the horizontal side-to-side velocity of their movements. There were two catch trials (participants were unaware of the absence of perturbation) towards the end of the learning period. The experiment ended with a de-adaptation phase where participants were aware of the absence of perturbation. Paired t-test was used to compare the kinematic error between catch and 1st de-adaptation trials.

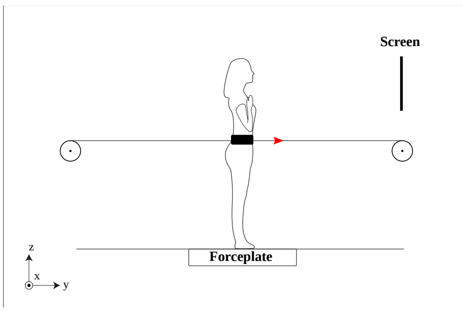

Figure 1: *Experimental setup.*

Results

Initially, perturbation led to significant challenges in executing whole-body movements. Participants were pulled forward which is reflected in a large kinematic error in the direction

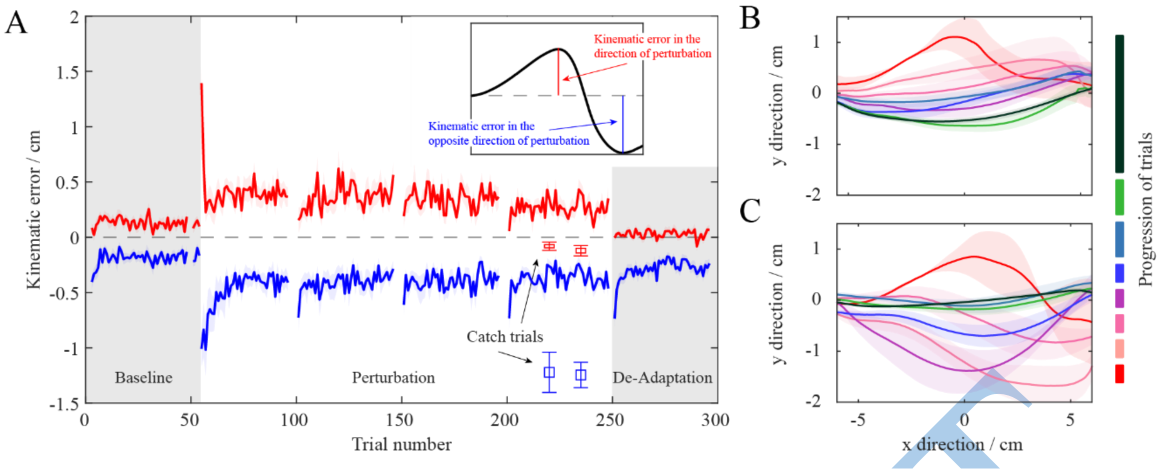

Figure 2: *(A) Kinematic error during adaptation to force-field perturbation averaged across subjects. Kinematic error is defined as maximal perpendicular distance between COM and a straight line between start and end target. Red line shows the kinematic error in the direction of perturbation while blue line shows kinematic error in the opposite direction of perturbation. Error bars show standard error of mean. (B-C) Movement trajectories showing progression over trials for representative participants.*

of perturbation. Some participants then strongly reacted and overcompensated, which is reflected in the increased kinematic errors in the opposite direction as perturbation. Figure 2A shows the kinematic error of the COM in the direction of perturbation (red line) and in the opposite direction as perturbation (blue line). Over time, participants demonstrated notable improvements in their movements reflected in smaller kinematic errors. Interestingly, some participants gradually decreased the error in the direction of perturbation over time (Figure 2B), while others first shifted their trajectories in opposite direction and then gradually decreased the error (Figure 2C). The large kinematic errors in the opposite direction of perturbation during the catch trials show the aftereffects of learning. During the de-adaptation phase, aftereffects are still present, however the kinematic errors are smaller compared to catch trials ($t(17) = 3.53$, $p = 0.003$).

Discussion

This work delves into the dynamics of whole-body human movement adaptation in response to environmental changes. Results show fast adaptation in the beginning, where participants almost instantly decreased the error in the direction of perturbation. This adaptation was swifter compared to previous research in arm reaching and whole body movements [1, 3]. We also observed strong counteractive feedback responses to pulling perturbations reflected in large kinematic errors in the opposite direction of perturbation which are not usually present in arm reaching studies [1, 2]. Motor learning strategies differed between subjects showing inter subject differences that should be further investigated. The differences could result from different movement compensatory strategies (such as bending hip joints), muscle activations, levels of co-contraction or explicit movement strategies. There was also a notable difference between catch and de-adaptation trials pointing to the use of explicit strategies during adaptation.

The study illuminates the complex mechanisms of motor control and adaptation, underscoring the significance of understanding motor dynamics and corrective mechanisms during more complex whole-body movements.

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Effects of motor skill training on cognitive function in older adults – an ongoing study.

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Keywords

Health, Motor learning, Motor cognition, Motor skills and abilities, Neural correlates

Highlights

- Partially blinded 3-armed RCT.
- Group-independent improvement in concentration and attention.

Introduction

Considering that the number of older adults is increasing worldwide, it is important to develop strategies for healthy aging. Aside from physical function, cognitive function (CF) is a key factor in decreasing the risk of morbidity and mortality. Physical exercise and especially endurance training has a positive effect on CF. Recent studies show that also other types of physical activity such as resistance, coordination and multicomponent exercise training have a beneficial effect on CF [1]. A few studies showed that walking leads to a shorter N2 latency and P3 latency [2]. However, it remains unclear whether there are more types of physical training, such as motor skill training, where the focus lies on improving the technique, which have an impact on CF and brain activity. Therefore, the purpose of this partially blinded 3-armed RCT (DRKS00017445, http://apps.who.int/trialsearch/) was to evaluate the effect of a track and field athletic training (motor skill training) on behavioral CF and brain activity of elderly, when compared to walking training (cardiovascular training) and to toning and relaxation training (active control group).

Methods

Sixty-six cognitively healthy older adults were randomized into one of the following groups: Track and field athletics (TFA, short put, long jump and sprint), walking training (WT) or relaxation and stretching (RS). The training took place in a gym hall two times a week for one hour each and lasted for 16 weeks. Participants were inexperienced in all areas of intervention and were screened for physical or mental illness (PAR-Q) and dementia (Montreal Cognitive Assessment, MoCA). Pre and post intervention questionnaires, motoric and cognitive test batteries were completed in two separate days. CF were assessed in different domains: Global CF (Montreal Cognitive Assessment, MoCA), attention (d2-revision Test, Trail Making Test A, TMT), executive function (and TMT B, Flanker task, Stroop task) and working memory (n-back task). In addition, brain activity was measured via Electroencephalography (EEG) during a flanker task by means of 64 Ag/AgCl electrodes (according to the international 10/10 system). Eye movements were monitored. All signals were filtered from 1 to 100 Hz (50 Hz notch filter; sampling rate 500 Hz, and impedance below 10 kΩ). EEG signals were analyzed offline in MATLAB (MathWorks, USA) with EEGLAB Toolbox and ERPLAB Toolbox. The Data was preprocessed and statistically analyzed using R (R Core Team, 2021). Data of CF was analyzed via mixed ANOVA and trimmed for extreme values (boxplots, ± 3 interquartile distance). All participants reached an attendance rate of at least 75 % of all training sessions.

Results

Sixty-six older adults (age 64 ± 5, 55-79; female 33; MoCA 27 ± 2) were included in the analysis. See detailed descriptive data in Table 1. There was no statistically significant interaction between the factors time (2) and group (3) and no main effect of group. A significant main effect for time was found for d2: $F(1, 42) = 26.07$, $p \leq .001$, partial $eta^2 = .383$ and TMT-A: $F(1, 43) = 4.56$, $p = .038$, partial $eta^2 = .096$ (see Figure 1). EEG data is currently being analyzed with a focus on the N2 and P3 component and the error-related negativity (ERN).

Table 1: *Descriptive data of the training groups: Track and field athletics (TFA), walking training (WT) and relaxation and stretching (RS).*

Variable	WT	TFA	RS
n	23	20	23
Drop-out	3	13	3
Sex ♀	11	10	12
Age	63.96 ± 5.54 (65-79)	64.24 ± 5.30 (55-72)	63.81 ± 5.25 (55-72)

Discussion

The analyses so far do not indicate an interaction effect of global CF, executive function and working memory after 16 weeks of WT, TFA and RS. These findings are not in line with a similar study [3], which found an increase in Flanker Task performance accuracy and in Visual Search Task performance accuracy and speed after six months of WT and coordination training when compared to an active control group (RS) in older adults. This could be due to the shorter training period of four compared to six months and to the high drop-out rate, which was due to participants' private reasons, in the TFA group. Ongoing analyses (ERP) investigate effects of physical training on the neurophysiological level. However, we could show a group-independent improvement in concentration and attention. Further research with bigger sample size and larger duration is needed to control methodological aspects. The results may indicate that besides cardiovascular training, also motor skill training and relaxation and stretching training can lead to an improvement in CF in elderly.

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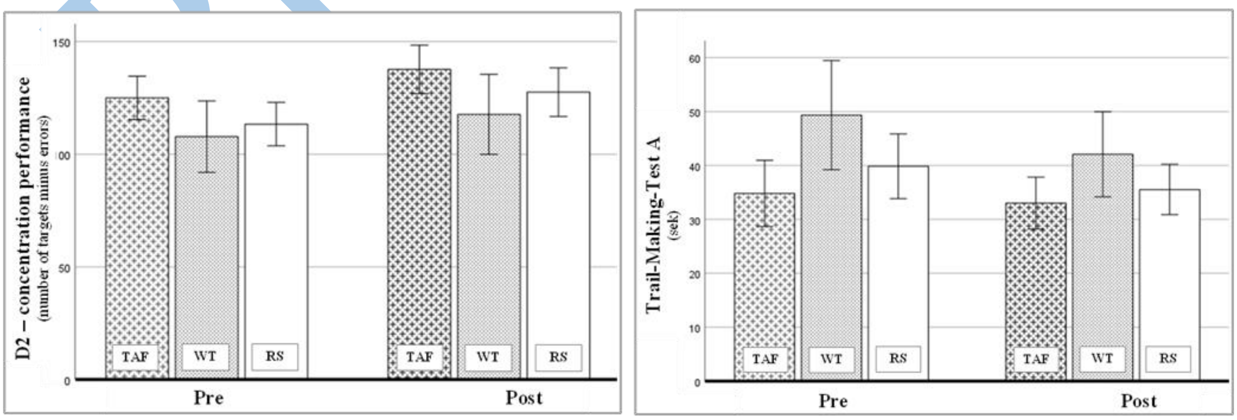

Figure 1: *Mean values of d2 concentration performance and Trail Making Test A for the three intervention groups: Track and field athletics (TFA), walking training (WT) and relaxation and stretching (RS), pre to post.* Error bars: 95% CI.

The Role of Arm Movements in Balance Performance: A Systematic Review and Meta-Analysis.

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Keywords

Motor control, Gait and postural control, Upper limbs, upper-body strategy, task difficulty

Introduction

Traditional frameworks of postural control predominantly emphasize lower limb involvement, focusing on ankle and hip strategies [1]. The ankle strategy, in which the body acts as a single-segment inverted pendulum, is typically employed for tasks with lower stability demands [2]. In contrast, the hip strategy, involving counterphase movement between the ankle and hip, becomes more relevant for challenging tasks [3]. However, these approaches often overlook the role of arm movements, which individuals naturally use to enhance stability during complex balance tasks, such as walking on a narrow beam [4]. Recent evidence suggests an "upper-body strategy" that complements ankle and hip strategies, demonstrating substantial improvements in balance performance with free versus restricted arm movements [5-7]. This systematic review and meta-analysis aims to provide a comprehensive understanding of how free arm movements influence balance performance across static, dynamic, proactive, and reactive tasks, considering varying levels of task difficulty. We hypothesized that allowing free arm movement will significantly enhance balance performance, particularly in tasks with a high compared to low difficulty level.

Methods

A systematic literature search was conducted in PubMed, Web of Science, and SPORTDiscus databases following PRISMA guidelines, covering articles from inception to June 2024. Eligible studies reported at least one balance performance measure in healthy individuals. Tasks were categorized as follows: Static tasks (e.g., tandem or single-leg stance) involve maintaining stability with a stationary base of support, measured by Center of Pressure (CoP) displacement or time in balance. Dynamic tasks (e.g., Beam Walking Forward Test, unperturbed split-belt treadmill walking) assess balance during continuous movement of the center of mass and base of support, evaluated through walking speed or step length. Proactive tasks (e.g., Y-Balance Test) focus on feedforward control by measuring reaching distance during voluntary destabilizing movements. Reactive tasks (e.g., single-step balance recovery after a forward-lean release, analyzing transfer time) evaluate stability recovery after sudden disturbances [8]. Weighted standardized mean differences (SMD) were calculated to quantify balance performance differences between free and restricted arm movements. The use of SMDs allows for the comparison of results across studies with different measurement scales, ensuring comparability and enabling a robust assessment of the impact of free arm movements on balance performance. Positive SMD values indicated improved balance in the free arm movement condition, while negative values favored restricted conditions. Study heterogeneity was assessed using I^2 statistics, and methodological quality was evaluated using the Appraisal Tool for Cross-Sectional Studies [9].

Results

The systematic literature search identified 941 records, of which 25 studies with 725 participants (331 females) were included in the meta-analysis after removing duplicates and excluding ineligible articles. These studies assessed static, dynamic, proactive, or reactive balance outcomes, focusing on youth and adults. Most studies met quality criteria, with all fulfilling at least 4 out of 7 criteria for reporting and study design and 2 out of 3 criteria for risk of bias.

Quantitative analyses showed that free arm movements significantly improved balance performance across all categories: static (SMD = 0.51), dynamic (SMD = 0.66), proactive (SMD = 0.52), and reactive balance (SMD = 0.50). The effects were moderate and more pronounced in high-difficulty tasks, such as static balance under challenging conditions (e.g., standing on one leg with eyes closed, SMD = 0.89) and dynamic balance (e.g., walking on a narrow beam or dual-belt treadmill at increased speed, SMD = 1.04). Due to limited data, task difficulty effects could not be evaluated for proactive and reactive balance.

Discussion

This systematic review and meta-analysis is the first to comprehensively analyze differences in balance performance between free and restricted arm movement conditions across various balance domains in healthy individuals. The analysis of 25 studies revealed positive, moderate effects of free arm movements on balance, regardless of the balance type (static, dynamic, proactive, or reactive). Notably, the positive influence of free arm movement was more pronounced in high-difficulty tasks (e.g., standing with eyes closed) compared to low-difficulty tasks (e.g., standing with eyes opened), highlighting the compensatory role of arm movements in challenging balance situations.

The mechanisms underlying these improvements likely involve mechanical factors, such as increased moment of inertia through arm extension, which enhances stability, as well as neural benefits, such as improved proprioceptive feedback. These findings have important implications for balance assessment and training: allowing arm movements may be more functionally relevant for high-difficulty tasks, while restricting arm movements can create a controlled and challenging testing environment. For training, especially in fall prevention, integrating free arm movements may support progression during exercising balance tasks for populations at risk. Future research should explore how arm movement constraints influence training adaptations and functional outcomes, such as fall risk reduction.

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Exploring the Dynamics of Postural Stability During Egocentric Mental Rotation Tasks

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Keywords

Motor cognition, Gait and postural control, Sportpsychology, Dual-Task, Mental Rotation

Introduction

Mental rotation (MR) refers to the ability to visualize objects being rotated within the mind (Shepard & Metzler, 1971). A particular kind of MR is the egocentric transformation. In testing this, a single figure is typically presented, distinguished by a prominent side feature, for example an arm on a human figure. Participants are then tasked with determining whether this feature is on the right or left side. It is posited that in such transformations, the relationship between the observer and the environment is characterized by the observer envisioning themselves rotating within the environment to accomplish the task (Kessler & Rutherford, 2010). Embodiment research has shown that mental and physical processes are connected (Glenberg, 2010). Furthermore, there is an established connection between mental and motor rotations (Wexler et al., 1998; Wohlschläger & Wohlschläger, 1998), as well as the association between mental rotation ability and an individual's postural stability (Budde et al., 2021; Dault et al., 2001; Hofmann et al., 2022; Hofmann & Jansen, 2023). Therefore, the aim of this study is to examine whether the generally accepted theory of Kessler and Rutherford (2010) can be confirmed with movement data. For this we expect that the trajectory of the so-called center of pressure (CoP), a marker of postural stability, varies while performing egocentric mental rotation tasks that involve figures rotated around its x-, y- or z-axis.

Methods

Based on a G*Power analysis the final sample size of this study is N = 105. The short version of the methods is that MR tasks are solved while standing on a force plate. For measuring postural stability, the CoP course over time was recorded with a force plate (AMTI-OR6-7-2000). Raw CoP-data were low-pass filtered by a 4th order Butterworth filter and a 10 Hz cutoff frequency. The calculated CoP-parameters are “Sway Velocity” [mm/s] (anterior-posterior and medio-lateral) and “Sample entropy” (anterior-posterior and medio-lateral). Each subject was tested for six trials (2 x MR x-axis, 2 x MR y-axis, 2 x MR z-axis). One trial consists of a two-legged narrow stance task on a force plate for 70 seconds (see figure 1). A mean value for the CoP-parameters for each angle of a condition (x-axis, y-axis, z-axis) was calculated. The COP-parameters will only be calculated during the execution of the cognitive tasks. For measuring egocentric mental rotation ability, the stimulus for the mental rotation tasks was a picture of a human male figure, created with Blender 4.1 (see figure 1). The figure was rotated along the x-, y- and z-axis (only one axis at a time). The rotation along each axis happened by 60°-steps (0°, 60°/300°, 120°/240°, 180°). The participants had to decide by a mouse click whether the person shown was stretching out their right or left arm. The parameter reaction time [s] and accuracy [%] were measured. A shorter reaction time and/or a higher accuracy is considered as better mental rotation ability. For this publication, a one-way repeated measures ANOVA was performed with the factor "axis of rotation" (x, y, z) for each sway parameter.

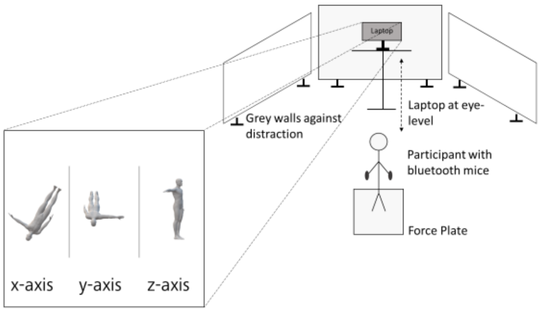

Figure 1: *Exemplary Set-Up*

Results

For none of the four calculated sway parameters was a significant difference found between the axes of the mental rotation tasks (all p > .05). The graphical representation of the sway parameters is shown in Figure 2.

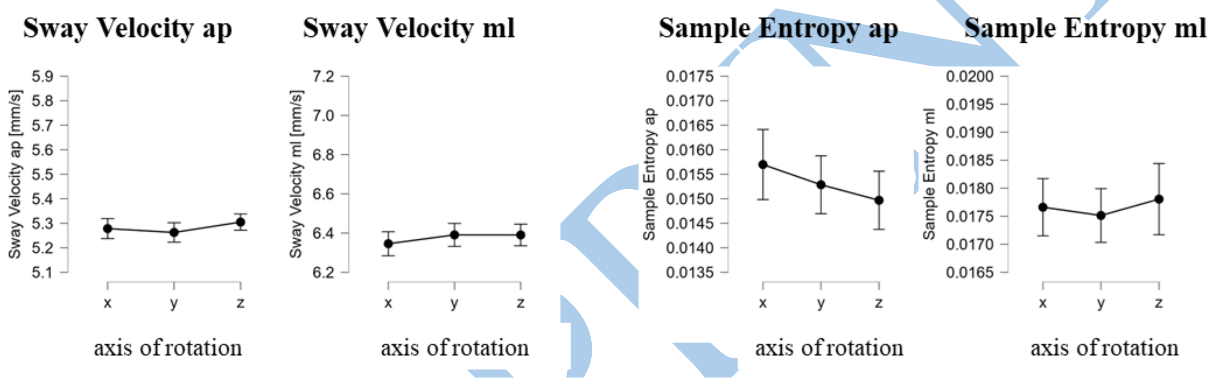

Figure 2: *Postural stability parameters. X-axis shows the different axes of rotation of the mental rotation stimuli.*

Discussion

The assumption that perspective-taking in egocentric mental rotation, as suggested by embodiment theory, would also manifest in motor data could not be confirmed. No differences were found between the axes of the mental rotation tasks regarding postural stability parameters. Thus, we find ourselves at a point where the theory of perspective-taking in egocentric mental rotation must at least be called into question. From research in the field of motor imagery it is known that imagining movements can also be reflected in postural stability data (e.g., Rodrigues et al., 2010). However, further studies are needed in the future to investigate this phenomenon using additional motor diagnostics, to check whether this phenomenon occurs more frequently.

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AOMI – combination of action observation and motor imagery as examined with TMS.

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Keywords

Motor cognition, Neural correlates, Upper limbs, Combined Motor Imagery and Action Observation, Non-invasive Brain Stimulation

Highlights

- Cortico-spinal excitability increased during imagery of object lifting
- Simultaneous weight estimation task counteracted this effect

Introduction

Motor imagery (MI) can be a promising method in neurorehabilitation [1]. As imagining muscle activation can be a demanding task, requiring strong focus and attention, the objective of the present study was to develop a task that facilitates or even automatizes imagery by using the advantages of combining action observation and motor imagery (AOMI) [2]. In a specific AOMI task, a phase of MI was embedded in a task to estimate object weight in an observed lifting action (Fig.1). The potential of this task paradigm to increase cortico-spinal (C-S) excitability was examined with the hypothesis that condition AOMI recruits a broader sensorimotor network [2] leading to higher motor evoked potentials (MEP) than action observation alone (control condition AO).

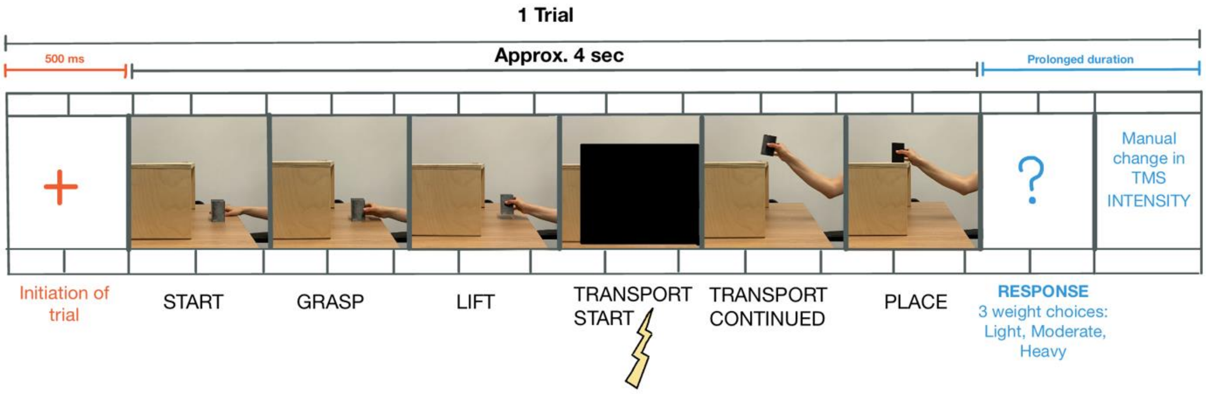

Figure 1: *Trial structure in AOMI condition. Black frame indicates 400 ms occlusion of object transport. Participants were asked to imagine how it feels to continue the action during occlusion. TMS was applied with random onset during this phase and the MEP was recorded over the right FDI muscle.*

Methods

Healthy volunteers (9 m, 9 f, mean age 23±3) performed AOMI and AO tasks in two experimental sessions in counterbalanced order. In each session they watched videotaped object lifting actions and were asked to estimate the weight of the object being either light (111 g), intermediate (566 g) or heavy (1065 g) (30 trials each). The objects were visually identical, but their weights could be differentiated by observing movement kinematics during lifting [3]. Maximum accelerations were highest for the light object (3314 mm/s^2) and lowest for the heavy object (2483 mm/s^2). In the AOMI task, participants were asked to kinesthetically imagine the continuation of the object transport during a transient occlusion of the video lasting for 400 ms (Fig. 1). During the object transport phase, a single pulse of TMS was applied randomly at 5 different intensities (90 - 130% of resting motor threshold) over the M1 representation of the right first dorsal interosseus muscle (FDI). In both task conditions, the MEPs were recorded to determine the excitability of the cortico-spinal tract. The same procedure was applied in condition AO without the occlusion covering the movement and without any motor imagery instructions. Prior to the task in each session, the participants experienced lifting the three different weights themselves.

Results

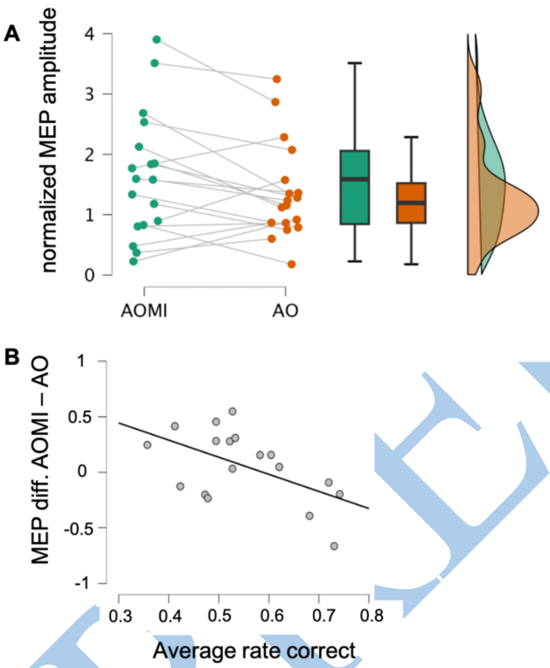

Figure 2: A. *Main effect of imagery with higher mean amplitudes in AOMI than in AO.* ***B.*** *Correlation between weight estimation accuracy (rate correct) and AOMI - AO difference in normalized MEP amplitude. Positive values indicate higher amplitudes in AOMI, negative values higher amplitudes in AO.*

Accuracy in weight estimation - No difference in weight estimation accuracy was found between the conditions. Despite a high interindividual variability (AOMI 53.2 ±0.11%, range 35 - 76%; AO 57.1±0.13%, range 32 - 81%) neither task (AOMI vs AO) nor the weight conditions, nor their interaction had a significant effect on correct rates. **MEP amplitudes** - To examine the effects of imagery (AO/AOMI), object weight (light / medium / heavy) and TMS intensity (5 levels) on z-transformed MEP amplitudes and to account for interindividual differences in weight estimation accuracy, a repeated measures analysis of covariance (ANCOVA) with accuracy as a covariate was conducted. This resulted in a significant main effect of condition ($F(1,16) = 7.02$, $p = 0.017$, $\eta p^2 = 0.31$) (Fig. 2.A) and in significant interactions between condition*accuracy ($F(1,16) = 6.43$, $p = 0.022$, $\eta p^2 = 0.29$) and between TMS intensity*accuracy ($F(4,64) = 3.48$, $p = 0.012$, $\eta p^2 = 0.18$). Correlating the difference between AOMI and AO in MEP amplitudes with weight estimation accuracy (Fig. 2.B) indicated that high amplitudes in AOMI were correlated with low accuracy scores (r = -0.54, p = 0.02).

Discussion

Beneficial effects of MI combined with action observation (AOMI) on C-S excitability were replicated (Fig. 2.A). Combining MI with a difficult weight estimation task requiring careful movement observation might have counteracted this effect. Those participants who were good in weight estimation exhibited lower MEP amplitudes in AOMI than in AO (Fig. 2.B). Assuming that high MEP amplitudes reflect a mental state that engages the sensorimotor system to an extent that C-S excitability is increased, we interpret the results as follows: Although imagining how it would feel to transport the object led to higher C-S excitability, imagery was not necessary for weight estimation. Instead, participants with high correct rates might have used visual cues during observed object lifting [3] which allowed more accurate weight discrimination. This study suggests to modify the tasks for optimal synergies between observation and imagery which will be discussed in the presentation.

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Grip and manipulation forces are controlled independently in a coupled bimanual task

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This work was supported by the Lighthouse Initiative Geriatronics by StMWi Bayern (Project X, grant no. 5140951) and the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - project number 467042759.

Keywords

Motor control, Robotics, Virtual/Augmented Reality, Bimanual manipulation, Grip force control

Highlights

- Grip and manipulation forces are scaled independently in a coupled bimanual task.

Introduction

Grasping and manipulating objects requires humans to adapt both grip and interaction forces. The grip and manipulation forces must be tuned to the object's mechanical properties, such as mass or stiffness [1], and to the forces originating in the environment, such as viscoelastic or gravitational forces [2]. While planning and adjusting our manipulation forces during interaction with an object is challenging when using a single hand, bimanual object manipulation further increases the complexity level by introducing redundancy.

Most research comparing the roles of the left and right hand have used point-to-point reaching movements (e.g. [3]). Since these studies focused on movement in free space, they have examined how redundancy is solved in terms of movement kinematics. However, more complex tasks, such as those requiring force production, can serve as a different approach to unveil strategies that can solve the bimanual redundancy problem. When manipulating an object, we need to generate grip forces on the object's surfaces to generate frictional forces that ensure that the object will not slip from our fingers. Usually, these grip forces are coupled to environmental forces stemming from moving the object. However, it has been suggested that the two forces are controlled and planned individually [4]. While some work extended the results from unimanual to bimanual object manipulation in uncoupled scenarios, to the best of our knowledge, there are no previous investigations on role distribution between hands in terms of force production and especially grip force behavior in coupled bimanual tasks.

Here, we investigate a bimanual virtual needle insertion task where the participants' hands were placed behind one another in the manipulation direction.

Methods

In this study, we investigated the manipulation forces (MF) and grip forces (GF) produced by both hands during coupled bimanual manipulation of a needle object in a virtual environment by 14 participants. The task objective was to puncture a virtual tissue, modeled as a linear spring, and stop immediately after, with the hands arranged in front and back positions in the movement direction. Participants sat in front of a screen and grasped with each hand one of two force sensors, each attached to a haptic robot. After two practice blocks, participants performed the task for four blocks of different tissue stiffness values in randomized order. Each block consisted of 15 trials. In the VR, the needle object was linked to each robot with a virtual spring-damper to move in the X-direction and was fixed by a force channel in the YZ-plane. We analyzed MF and GF with respect to the hand (left, right), hand position in the configuration (front, back), and stiffness of the virtual tissue k_t. We computed $\Delta_{contribution} = C_{front} - C_{back}$ where C is the fraction of contribution in MF of the hand and $\Delta_{slope} = slope_{front} - slope_{back}$ where slope is the slope of the regression line fit to GF vs. MF.

Results

We show that GF is modulated consistently during tissue interaction between front and back hands across participants, but manipulation forces are not. That is, the back hand consistently produced a higher GF scaling than the front hand regardless of hand configuration (Fig. 1B). Conversely, the force distribution of MF did not show one single strategy but varied across hand configurations and participants (Fig. 1A). After the tissue puncture, we again observed consistent GF behavior during the reactive response to the force drop following the puncture. The GF signal exhibited a consistent temporal profile in both the front and back hands with amplitude modulation according to the tissue stiffness in the front hand.

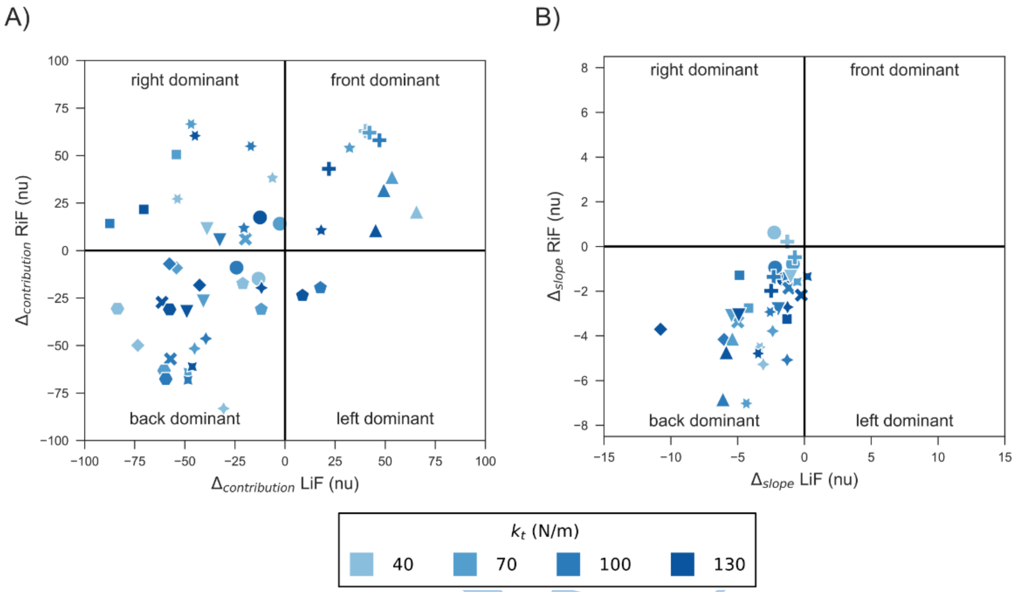

Figure 1: *Manipulation and grip force contributions by hand and hand position. Each Quadrant resembles a different strategy for distribution between hands. A)* $\Delta_{contribution}$ *for the two configurations with different markers per individual. B)*Δ_{slope}*between the two configurations with different markers per individual.*

Conclusion

We demonstrated that while GF strategies were consistent across participants and configurations, showing elevated magnitude in the back hand compared to the front hand, there was no clear pattern in the generated MF. We propose that this separation occurred due to explicit mechanisms mediating MF and implicit mechanisms mediating GF in our experiment. Although there is no evidence for a role distribution between hands in MF data, we show that a preference for stabilizing and actuating roles is evident in the GF data. These roles were not mediated by hand dominance but by hand position (front, back), which is in line with a flexible change of roles in bimanual manipulation according to task requirements.

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Motor memory allocation depends on the weighting of contextual cues

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Keywords

Motor learning, Force field adaptation, Motor memory, Sensorimotor control, Contextual cues.

Highlights

- Recall of motor memory is weighted by combination of contextual cues.

Introduction

Multiple motor memories can be acquired with assistance of appropriate contextual cues [1-2], but these context-dependent motor memories are highly sensitive to changes in the context. For example, changing the pre-movement (lead-in) angle triggered a motor decay compared to the learned premovement angle [3]. However, most daily activities do not produce the identical perfect contextual cue, instead the learned context mostly appears in combination with new contextual information, or with missing fragments of the learned context. It remains unclear how contextual dependent motor memories are affected by changes in the context and more importantly how motor memories get associated with one or more contextual cues when they are presented together. This study aimed to explore the integration process involved in motor memories from simple cues to a compound cue, as well as how a memory learned with a compound cue might be used to respond to simple cues.

Methods

In total, 30 right-handed participants (15 female) without known neurological diseases (aged 26.93 ± 4.20 years old; mean ± std) were randomly allocated to one of three groups (Figure 1). Participants performed reaching movements while grasping a two-dimensional planar manipulandum (vBOT) with their arm supported by an air sled. Each group was exposed to two opposing curl force fields, each of which was associated with a distinct contextual cue. Two groups of participants trained with a simple contextual cue. One group had the two curl force fields associated with two different visual lead-ins and a second group had them associated with different locations in visual space. The third group was presented with a compound cue, where each force field direction was associated with both the visual space and visual lead-in direction (Figure 1C).

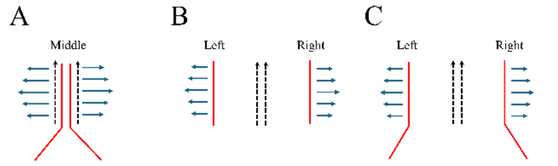

Figure 1: *Experimental protocol for 3 experiments. (A) Learning with simple cue 1 (visual lead-in). Visual lead-in angle of 230° or 310° were used to sepa-*

Despite learning with different visual cues in adaptation phase, baseline and generalization phase shared the same design across three experiments. Each experiment consisted of 1440 trials.

All reaching movements took place physically towards a target located 18 cm forward from the start location which located in the middle of the workspace (Figure 2). However, visual feedback could be provided at one of five different lateral locations (far left, left, middle, right or far right locations), which were evenly spaced by 10cm. In addition, each movement could be preceded by a visual lead-in (10 cm in length) arriving to the start location at one of five angles (190°, 230°, 270°, 310 °or 350°).

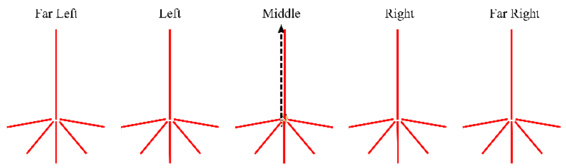

Figure 2: *Overall experimental design. Online visual feedback was displayed in 5 possible visual locations (Far Left, Left, Middle, Right and Far Right) while physical movement (black dotted line) was executed in the Middle. For each visual location, there could additionally be one of five possible lead-in movements.*

The generalization originating from visual location and lead-in angles were each fit with scaled sigmoid functions, allowing us to extract the weights associated with each of these two contextual cues.

Results

Experiments with the compound cue and the two simple cues exhibited gradual adaptation to the force field with learning. Overall, the compound cue showed similar levels of final adaptation to the simple visual location cue (both >60% of perfect force compensation). However, the single visual lead-in cue had lower levels of adaptation to both the compound and visual location cue conditions (post-hoc comparison, $p_{Tukey} < 0.001$).

During the generalization phase, all three experiments showed strong generalization across the weighted combinations of different contextual cues. In all three experiments the pattern of generalization could be well fit by a weighted combination of two sigmoid functions, where one sigmoid represented the generalization due to visual location while the other represented the generalization due to lead-in angle.

The generalization of the visual location cue was best fit by a weighting of 0.651 to visual location and 0.062 to visual lead-in, showing an almost pure allocation to the trained contextual cue. Similarly, the visual lead-in cue generalization showed a weighting of 0.072 to visual location and 0.387 to visual lead-in. Finally, when presented with both contextual cues we found a weighting of 0.602 to visual location and 0.247 to visual lead-in.

Overall, the compound cue produced a weighted generalization or both simple cues. However, the presence of both cues neither increased nor decreased the speed of adaptation. The motor memory could be expressed as a simple weighted sum of the two components.

Discussion

This work showed that motor memory is allocated by the weights of several contextual cues in generalization. To be specific, learning with the visual feedback cue and visual lead-in cue both contributed to the compound cue with a weight similar to how either was learned on their own. Reversely, learning with compound cue also enables weighted transfer to the simple cue of only visual feedback location or visual lead-in angles. The weighted contribution of each cue might relate to its learning ability, suggesting that visual location is stronger than visual lead-in angle. Unlike prior work [4], the motor memory neither vanishes nor transforms into a summation of multiple motor memories in a new context.

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MRI compatibility evaluation of a myoelectric soft hand prosthesis

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*: equal contribution, [+]: equal contribution

Keywords

Robotics, Motor control, Upper limbs, Neuroprosthesis, Neuroimaging

Highlights

- Myoelectrically controlled hand prosthesis supports grasping inside an MRI scanner
- No reduction of MRI signal quality

Introduction

Developing prostheses that seamlessly integrate into the user's sensorimotor system is the final goal of neuroprosthetics research [1]. However, thus far it is poorly understood how using a prosthesis affects the brain. Understanding how prostheses lead to changes in brain activity and neural connectivity might contribute to advancing both medical interventions and prosthetic design [2]. In recent years, fMRI scanning has become a popular tool to investigate neurocognitive processes. However, it is difficult to implement neuroimaging experiments with prostheses due to challenging compatibility requirements caused by the scanner's strong magnetic field. While MRI compatible robots have been developed for more than a decade [3], to the best of our knowledge, no MRI compatible prosthesis has been presented thus far. In this paper, we present an MRI compatible myoelectric hand prosthesis that can support pick-and-place actions during an fMRI sequence. Using data from 5 healthy participants, we show that it is possible to myoelectrically control the hand prosthesis inside the scanner and that the device does not significantly decrease the MRI signal quality, thus demonstrating the feasibility of using the setup for performing future neuroscientific studies.

Methods

MRI compatible prosthesis. The soft hand prosthesis is based on perpendicularly-enfolded-textile actuators (Nassour et al. [4]), with tubes folded inside a housing fabric that can be pneumatically inflated to produce finger flexion and extension. To detect grasping intention, we placed MRI compatible EMG electrodes on the participants' forearm, above the flexor digitorum superficialis, and connected them with a shielded cable to the BIOPAC EMG100C-MRI amplifier. The signal was sampled with 2000 Hz and band-pass filtered between 10-500 Hz with a notch filter at 50 Hz. Afterwards, we computed the root-mean-square (RMS) of the signal and applied a real-time thresholding to detect peaks of activity correlated with grasping intent and trigger prosthesis grasping.

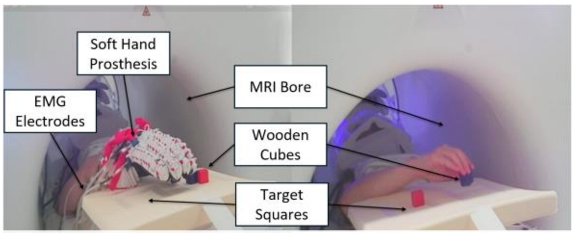

__Figure 1.__ Pick-and-place task with the EMG-controlled MRI compatible prosthesis and own hands.

Experimental Setup. The fMRI experiment consisted of two scanning sequences. The participants' task in both sequences was to transfer wooden cubes between two target squares that were marked on a plastic sheet installed over participants' upper body (Figure 1). During the first sequence, participants did not wear the prosthesis, nor had they EMG electrodes placed on their arms and performed the cube transfers with their own hands. In the second sequence, EMG activation was used to trigger prosthesis grasping.

MRI data acquisition. MRI data was acquired on a Philips Ingenia Elition 3.0T X equipped with a dStream head-32-channel coil. For both conditions (with and without prosthesis), we recorded an fMRI and a resting state sequence.

MRI signal quality analysis. For fMRI analysis, SPM 12 (The Wellcome Centre for Human Neuroimaging, UC London) was used. The preprocessing pipeline included realigning, unwarping, co-registering, segmentation (CAT12 SPM toolbox), normalization to MNI space, and smoothing. For first level analysis, statistical parametric maps were computed using timing information from baseline and task conditions convolved with the hemodynamic response function taking into account six regressors modelling movement parameters for each session. On a single subject level, task activations were scanned for relevant brain regions. SNR values per slice and participant were computed by dividing the MRI signal mean by its standard deviation. To test the statistical significance between both conditions (active prosthesis / without prosthesis), we used a Wilcoxon signed-rank test due to a violation of normality assumptions.

Results

Functional Analysis. All 5 participants were reliably able to grasp, transport, and release the small wooden blocks with the prosthesis by contracting their forearm muscles. Over all participants, we had 60 trials of pick-and-place tasks of which 53 were successful, resulting in a task accuracy of 88.3%.

Signal Quality Analysis. For each of the two conditions (with active prosthesis and without prosthesis), we obtained a signal-to-noise ratio (SNR) distribution including the slices of all participants (Figure 2). The Wilcoxon signed-rank test showed no significant difference between the active prosthesis condition (Md = 18.62, n = 220) and the condition without prosthesis (Md = 19.10, n = 220), z = -0.30, p = .766.

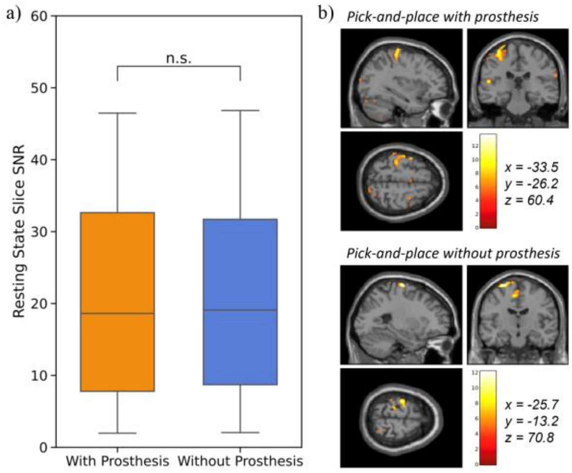

Figure 2. *a) Distributions of Slice SNR values of all 5 participants b) Exemplary first-level activation patterns for prosthesis and hand transfer) on a p<0.05 level (FWE-corrected) in one participant.*

Discussion

Our results show that it is possible to reliably perform pick-and-place actions with an EMG-controlled prosthesis during an fMRI scanning sequence and that using the prosthesis inside the MRI scanner does not lead to a statistically significant SNR decrease. Thus, our setup can be utilized for neuroimaging studies without a negative impact on fMRI data. Knowing that this is not comparable to a statistically significant group analysis and should only be considered as a preliminary result, relevant brain areas during prosthesis control such as sensorimotor regions can be seen. Building up on this feasibility study, future research can investigate neurocognitive correlates of prosthesis use and might lead to a better understanding of the factors that influence intuitive control and prosthesis embodiment.

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Bayesian inference as the basis of sense of agency

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Keywords

Motor cognition, Virtual / Augmented Reality, Sensorimotor performance, Bayesian inference, Sense of agency

Highlights

- We tested a Bayesian inference model of the sense of agency using a virtual air hockey task.
- Participants gave agency judgement after another agent potentially influenced their action.
- Our model predicts participants' agency judgments based on their independently assessed estimations.

Introduction

The sense of agency, which is attributing an action and its outcome to oneself versus outside causes like other agents, is crucial for interacting with the world [1]. It relies on predictions about the sensory consequences of our actions based on motor representations, so-called reafference, or forward-model mechanisms. These mechanisms help us to distinguish self-generated sensory signals from those that are triggered by external stimulation [2]. Changes to our bodies and within our environments require constant adaptation of behavior, even without awareness. However, it is poorly understood how a stable sense of agency is generated and maintained within such an ever-changing environment [3]. In this study, we propose to utilize a Bayesian observer model that quantifies sensory observations of oneself and another agent as likelihoods, to explain the formation of the sense of agency within the logic of Bayesian inference (Figure 1) [4]. More specifically, we sought to relate sensorimotor performance in goal-directed reaching movements to the model's likelihood parameters for self versus other.

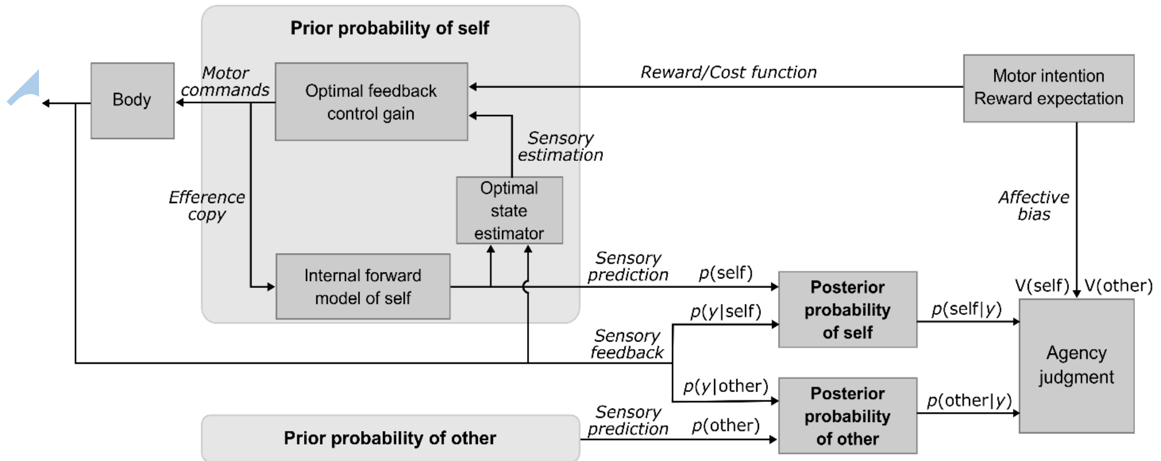

Figure 1: *Modified schematic of the proposed sense of agency formation concept by Izawa et al. (2016). In accordance to the optimal feedback control, actions of the body are initiated by motor commands. Based on the efference copy of the motor command the forward model predicts the sensory consequences of the self-generated actions. The prediction forms the prior probability of the self p(self). Together with the prior probability of the other p(other) and the actual perceived sensory feedback, the information is integrated and processed to the posterior probabilities of the self p(self|y) and other p(other|y).Taking into account the affective bias, the agency judgement is formed based on the ratio of the two posteriors [4].*

Methods

Participants (n=25) performed goal-directed movements to hit a puck toward a target within a virtual air hockey game, in which their actions could be perturbed by another simulated agent (Figure 2). In different phases of the experiment, participants were either asked to hit specific targets, predict the action outcomes of themselves or the other agent, or provide agency judgments along with confidence ratings of their judgments.

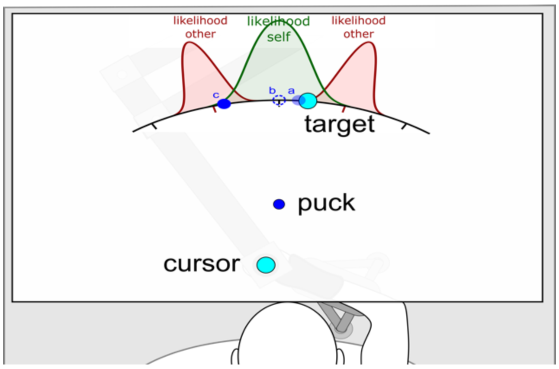

Figure 2: *A robot handle was used to control a virtual cursor. A horizontal stroke was performed to hit the puck. The unperturbed hit position of the participants (a) was combined with a simulated hit position of a computer player. We only displayed this perturbed position (c). In this case, participants had to combine the self likelihood function (centered around (b), which is their estimated hit position) and the likelihood function of the other agent to decide who is responsible for the displayed outcome. The subjective perturbation equals the distance (b) to (c).*

Results

In the absence of perturbations by the other agent, participants considered themselves to be the agent of the observed action with high confidence while they exhibited uncertainty at intermediate perturbation levels. As perturbation magnitude increases, participants were less likely to attribute the action to themselves, while their confidence in the judgment increased again (Figure 3). The Bayesian observer model correctly predicts 82.5% (SD 4.8%) of the agency judgments of participants (Figure 4).

Discussion

These results support Bayesian inference as a viable theoretical framework to explain the formation of a stable sense of agency. Using our experimental design, we could also examine unknown factors in the Bayesian inference model, such as the decision threshold, which is related to the confidence level in participants' answers.

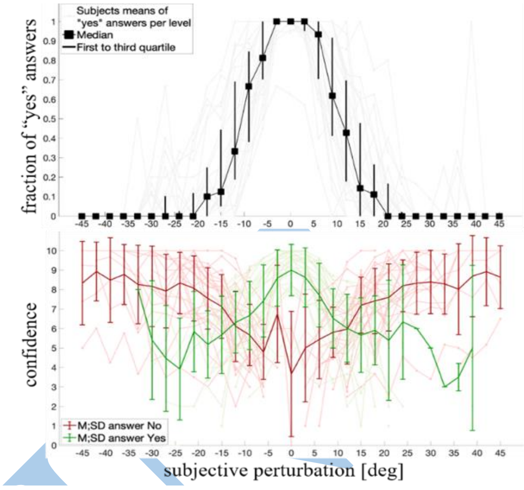

Figure 3: *(top) Self-agency judgment depending on the strength of perturbation and (bottom) confidence in the agency judgment separate for yes/no answers.*

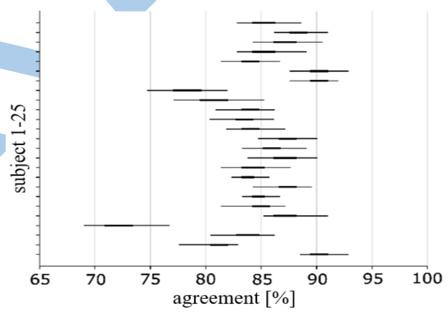

Figure 4: *Agreement between model-simulated answers and actual yes/no agency judgments as highest density intervals (HDI). Thin lines indicate the 97% HDI, and thick lines the 51% HDI.*

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Funded by the DFG, *SPP 2134 - The active self*

Multisensory integration in interpersonal coordination

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Keywords

Sport, Motor control, Sensorimotor performance, Multisensory integration, Joint action

Introduction

Coordinating complex movements with others – may it be in sports, dance or in everyday life – is challenging due to inherent sensory uncertainties [1]. A functional mechanism to deal with these uncertainties is to use information from different sensory systems (e.g., haptic, auditory, visual) and integrate them according to their reliability; a process known as multisensory integration [2].

However, while there is a rich body of research on multisensory integration for perception per se (e.g., [2]) as well as on joint action (e.g., [3]), only a few studies have so far addressed how humans utilize information from different sensory systems in interpersonal coordination, i.e., in perception for action (e.g., [4]).

Skillfully coordinating highly complex movements in real-time is the core of Tango Argentino. Thus, tango dancers are real-world experts in interpersonal coordination, making them a highly interesting population to study how different senses are used and how their weighting might change with increasing experience.

In this study, we thus examine how tango dancers use different sensory modalities (i.e., haptic, audition and vision) to coordinate with a leader in a joint walking task, and whether the reliance on distinct sensory information depends on the level of tango experience.

Methods

48 adult female tango dancers (M_{age}= 46.65±10.93 years) with follower experience participated. They were divided into four groups (12 participants each), according to their years of tango experience: beginner (1–4 years), intermediate (5–9 years), advanced (10–14 years), and experts (≥15 years).

Participants performed a joint walking task (Figure 1). They had the role of the follower, and their task was to coordinate their steps with the leader. The leader was a research assistant specifically trained for the task. The exercise involved walking face to face, back and forth, to tango music. Importantly, the number of backward steps varied and was unknown to the participant, which created uncertainty and challenged the participant to coordinate in real-time. To do so, the follower could use three sources of information: haptic, auditory, and visual.

Figure 1: Joint walking task. The leader is on the left and the follower (participant) is on the right.

To assess the coordination between the leader and the follower, we used motion capture. Whole-body movement data were recorded using 17 OptiTrack cameras and Motive's full body Biomech markerset, containing 57 markers. As a measure of coordination, we compared the temporal difference between the peaks of the velocity and acceleration curves of the leader and the follower.

In the experiment, we manipulated the availability of the information sources (Figure 2). After two habituation trials, the participants performed in four conditions: unrestricted, no touch, no music, and no vision.

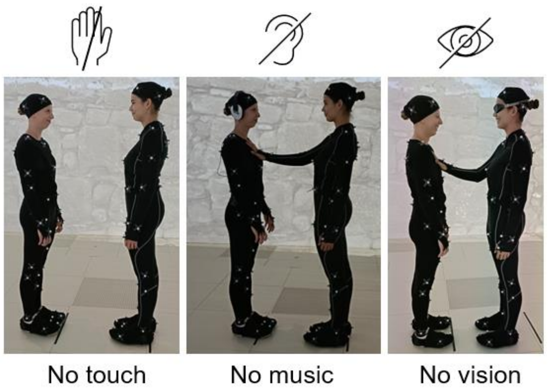

Figure 2: Restricted experimental conditions.

Results

At the time of abstract submission, the results are not yet available but will be at the time of the Conference.

Figure 3 shows exemplary data of expert tango dancers displaying perfect temporal coordination for a 1.5 step in the unrestricted condition. Our experiment will show how coordination is affected by growing tango experience and when sensory information is suppressed.

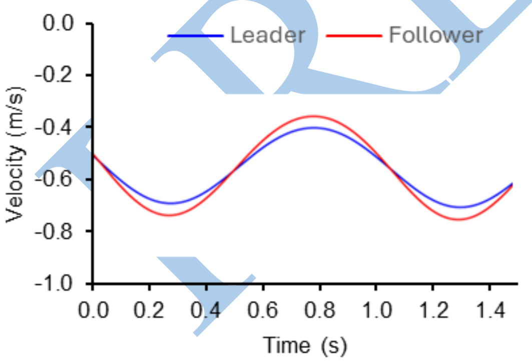

Figure 3: Exemplary data of tango experts. Velocity curves of follower (red) and leader (blue) showing perfect temporal coordination in joint walking.

Our first hypothesis is that followers with more tango experience will be better coordinated with the leader than participants with less tango experience in all conditions (expertise effect).

Our second hypothesis is that the importance of the sensory information sources depends on the experience level. Specifically, we expect that novices mostly rely on vision. In contrast, we predict that the reliance on haptic information increases with higher levels of tango experience. We thus hypothesise an interaction effect between the sensory manipulation (visual vs. auditory vs. haptic) x experience level (beginner vs. intermediate vs. advanced vs. experts), with coordination performances of novices suffering most when vision is suppressed and those of experts when haptic information is removed.

Discussion

The current study will provide empirical data on how humans use and weigh different sources of information in a complex interpersonal coordination task. By examining tango dancers with different levels of experience, the study will provide insights into the relative importance of different sensory sources as a function of expertise.

According to Bayesian theory [2] information sources should be adaptively weighted based on their relative reliability. Our study aims to extend this notion by showing that, in addition to the respective reliability, the expertise-dependent usefulness of different information sources also matters and must therefore be taken into account in Bayesian multisensory integration.

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Stimulus and effector specificity in inhibition measurements – a pilot study.

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Keywords

Motor cognition, Sport psychology, Executive functions, Soccer, Ecological validity

Highlights

- Sport-specific testing of EFs
- Stimulus material and possible response have a significant effect in the groups

Introduction

Executive functions (EFs), such as inhibition, are essential in sports – especially game sports – because they facilitate quick decision-making, impulse control, and efficient responses to unanticipated circumstances. There is evidence that game sports facilitate the development of EFs [1]. EF tests are considered an essential additive performance diagnostic instrument, especially in a sport-specific version. Montouri et al. [2] developed a sport-specific task-switching protocol to assess cognitive flexibility, requiring participants to identify actions as either an assault or defense (task A) and determine shirt color (task B), with cues for each. They observed differences among players in various field positions, suggesting that such executive function (EF) tests could assist in team selection. Musculus et al. [2] created soccer-specific tasks to measure inhibition and cognitive flexibility with reliable results. They found switch effects for reaction speed and accuracy and modified the flanker task for improved validity. Soccer teams may benefit from using these tasks for cognitive diagnostics, with similar reliability for working memory assessments. In general, research on how sport-specific cognitive training enhances EF and how sport-specific evaluations are utilized to gauge this improvement is lacking. We hypothesize that there is a significant difference between soccer players and controls, especially in sport-specific tasks, because of stimulus and effector specificity. Stimulus- and effector specificity means perception, motor skills, and responses are fine-tuned to the specific actions required by the activity. The aim of the study was to describe the differences between particular tasks that could exist due to the sports experience of the soccer group.

Methods

Flanker and Go/No go tasks were used to examine executive functions in adolescent soccer players (N = 30, mean age: 17.6 years, SD: 5.19 years) and an adolescent control group (N = 30, mean age: 19.57 years, SD: 2.51 years, not played soccer for 5 years, never club sports activities in soccer). There was no significant age difference between the two groups.

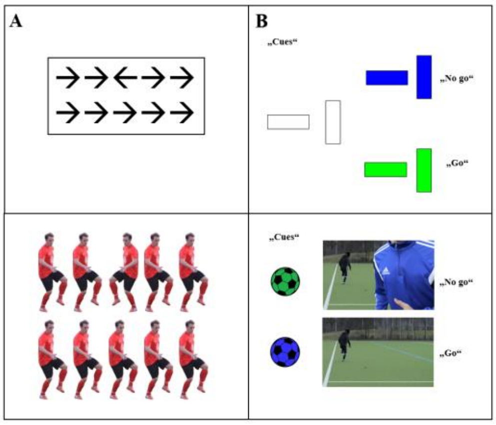

Figure 1: *Flanker task (A) and Go/No go task (B) as the computerized (upper picture) and modified version (lower picture)*

In the Flanker task (Fig. 1), participants viewed a stimulus of five black arrows on a white background, responding to the central "target arrow." On congruent trials, all arrows pointed the same way, while on incongruent trials, the central arrow pointed opposite. Participants pressed the right button if the target pointed right and the left button if it pointed left (4 practice, 70 test trials). In the Go/No-Go task, participants pressed the space key for a green rectangle (Go) and withheld response for a blue rectangle (No-Go). Vertically aligned rectangles (positive cue) indicated an 80% likelihood of green, while horizontal rectangles (negative cue) indicated an 80% likelihood of blue. At least 50 trials were conducted. In the modified tasks, the rectangles (Go/No go task) were replaced by a picture depicting an opportunity to pass a ball or an opponent blocking the pass, and the arrows (Flanker task) were replaced by teammates giving the opportunity to pass the ball to their left or right side (see Fig. 1). Inhibition was measured through reaction times for correct responses (both congruent and incongruent cues), response accuracy for congruent and incongruent trials, and error rates for Go/No go tasks (both cue types). Short reaction times and high accuracy indicated potent inhibition.

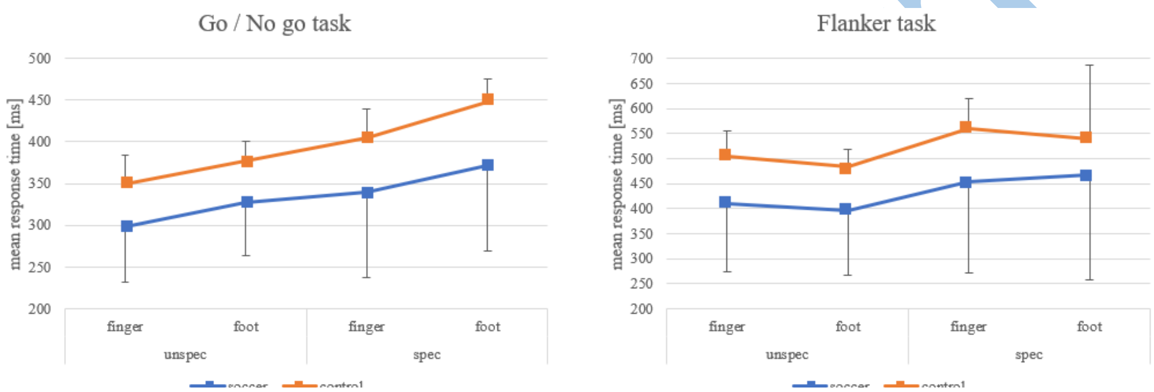

Figure 2: *Results of the Go / No go task and Flanker task for the four conditions (unspec = unspecific computerized task, spec = sport-specific task, finger = task was executed with pressing the key with finger, foot = task was executed by pressing a key with foot, the standard deviation is shown in one direction)*

Results

For the Go/No go (mean response time, see Fig. 2) task, the ANOVA shows significant main effects for the factor condition (F[3,56] = 89.02, p <.001, η^2_p = 0.827) for the factor group (F[3,56] = 15.68, p <.001, η^2_p = 0.213), but not for the interaction (F[3,56] = 2.165, p =.094, η^2_p = 0.036). For the Flanker task (mean response time, incongruent condition), the ANOVA shows significant main effects for the factors group (F[3,56] = 10.44, p <.001, η^2_p = 0.157) and condition (F[3,56] = 6.78, p <.001, η^2_p = 0.108) but not for the interaction (F[3,56] = 0.281, p =.839, η^2_p = 0.005). The same trend could be reported for the congruent condition and flanker effect. There are no significant differences in accuracy parameters.

Discussion

The study shows significant differences between the control group and the soccer group, but the effect is not more prominent in the sport-specific tasks as hypothesized. Similar differences exist for the conditions (unspecific vs. specific and finger vs. foot). That means there are no effects for stimulus or response specificity for the groups but inherent to the group. No significant differences could be reported regarding the accuracy of the tasks, which aligns with the results of Montouri et al. [2]. The variance in the specific tasks (sport-specific stimulus and foot) is slightly higher. This and the expected higher compliance could favor using sport-specific tests to diagnose EF in sports.

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Relationship between crossover gait and foot mobility

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Keywords

Crossover gait, Gait and postural control, Motor skills and abilities, Sport, Treadmill running

Introduction

Running is one of the most popular sports among amateurs worldwide. A 2021 study involving 8,414 participants across 10 countries found that 40% of individuals identified as runners [1]. However, the absence of professional guidance can lead to improper movement patterns, such as crossover gait (CG), which may increase the risk of injuries and strain. CG is a gait pattern where the limb crosses the body's vertical midline during the swing phase. This movement style can be compared to walking on a tightrope. The common consequences of CG include tibial stress fractures, increased hip adduction, and altered ankle eversion [2-5]. These effects negatively impact running biomechanics, although CG remains underrepresented in scientific literature. A study from 2023 reported that CG appears in approximately 30% of runners, with about 16% experiencing it bilaterally [6].

Given the constant interaction between the foot and ground during running, foot function significantly influences overall body alignment. CG is frequently associated with excessive foot pronation, where the foot rolls more inward on ground contact. This over-pronation disrupts alignment along the kinetic chain, pulling the leg inward and increasing the tendency for the feet to cross the midline.

The purpose of this study was to investigate whether limited foot parameters (specifically the mobility of the forefoot and rear foot) contribute to CG during treadmill running.

Methods

The sample consisted of 19 healthy students (13 F, 6 M) with no gait pathologies and with varying levels of daily physical activity. Mean age was 23.8 (1.7) yrs and BMI 22.6 (2.7). The research was carried out with the approval of the Research Ethics Committee of the WUST.

In the first part of the experiment, each volunteer ran on a treadmill at a self-selected speed. A camera positioned behind the runner recorded the trial, capturing a minimum of 15 gait cycles. The recorded footage was then analyzed using KineticLab (KineticLab, Germany) software, which was used to review and detect instances of CG.

The forefoot mobility test assessed the range of motion for pronation and supination while participants were seated in a chair with their knees and hips flexed at approximately 90°. During the pronation test, the cushion of the big toe and the heel remained in contact with the ground, while the cushion of the little toe was lifted. The participant, maintaining the described foot position, performed the maximum possible knee abduction movement. For the supination test, the cushion of the little toe and the heel remained in contact with the ground, while the cushion of the big toe was lifted. Similarly, the participant, maintaining the described foot position, performed the maximum possible knee adduction movement. Foot pressure was monitored using a baropodographic mat FreeMED MAXI (Sensor Medica, Italy).

The analysis of the images consisted of two steps: first, connecting the center of the patella to the center of the ankle, and second, connecting the center of the ankle to the second toe. The angle between these two lines was measured on the outer side (for pronation) and inner side (for supination), respectively. The resulting value was subtracted from 180°. An example of the analyzed images is presented in Figure 1. Additionally, the forefoot sway, defined as the range of motion between the pronation and supination settings, was calculated.

The Pearson correlation coefficient and corresponding p-value were determined to evaluate the relationship between the percentage occurrence of CG during running and the results of each test.

Figure 1: *Analysis of forefoot mobility: pronation (left) and supination (right).*

Results

CG was observed in 37% of subjects for at least one leg. Figure 2 shows the correlation values between the percentage of leg crossing occurrence during running and the results of each individual test. Significant negative correlation coefficients were observed for forefoot mobility in supination and swing range.

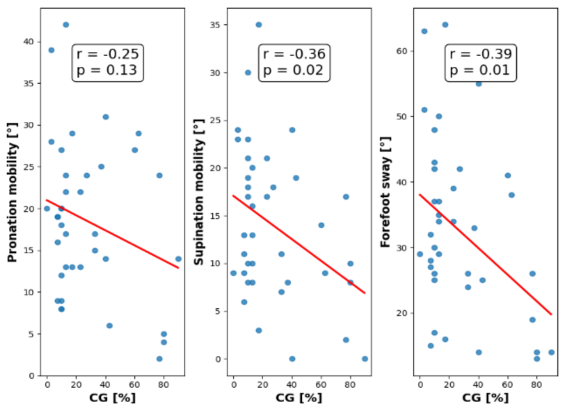

Figure 2: *Correlation coefficients and p-values between the percentage of CG and the test results*

Discussion

The study suggests a potential relationship between foot parameters and running technique. Statistical analysis revealed that a decrease in forefoot mobility during supination and a reduced degree of forefoot sway were associated with an increased incidence of CG. However, it is important to note that footwork is only one of several factors influencing running technique.

These preliminary results have the potential to significantly benefit recreational runners by promoting the development of healthier running patterns. In 2022, the American College of Sports Medicine published a Healthy Habits for Distance Running infographic, which offers guidance to help runners protect their joints and avoid injuries over the long term [7]. A more detailed analysis of clinical parameters, such as the Foot Posture Index, could further improve the assessment of in-jury risk and inform targeted interventions. Future research could also investigate whether functional gait asymmetry in the lower extremities—defined as the dominance of one leg in performing various motor activities [8]—influences running patterns.

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Cortical correlates of motor control in dynamic sidecutting actions – A proof-of-concept study

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Keywords

Sport, Motor control, Methods, Neural correlates, Mobile EEG

Highlights

- EEG measurement in dynamic, sports-specific maneuver
- Concurrent EEG and Motion Capture

Introduction

Anterior cruciate ligament (ACL) injuries are one of the most consequential injuries in game sports. ACL injuries often occur without direct contact during dynamic movements, such as single-legged landings or sidecutting maneuvers [1], suggesting deficient sensorimotor control as potential cause [2]. The investigation of cortical activity during dynamic, injury-related maneuvers has the potential to provide valuable insights into the neural underpinnings of sensorimotor control deficiencies. However, measurements have thus far been limited by their sensitivity to movement artifacts, which has restricted research to laboratory setups that artificially constrain (head-) movements (e.g. [3]), ultimately preventing measurements of cortical activity related to realistic, sports-specific movements.

To address these limitations, the present pilot study aims to validate an experimental setup that allows the investigation of cortical correlates of sensorimotor control in dynamic sidecutting maneuvers, while also enabling the concurrent analysis of biomechanics via motion capture. This pilot is the methodological foundation of a subsequently planned study exploring brain activity and its direct link to injury-related biomechanics.

Methods

Twenty-one injury-free, female game sports athletes between 19 and 27 years (M: 22.6 ± 2.1 years) participated in this pilot study. Exclusion criteria included (i) current injuries or complaints that influence running, jumping or sprinting; (ii) previous ligament, meniscus or cartilage injuries at the knee; (iii) ankle sprain during the last year; (iv) concussion or head injury during the last year and (v) neurological or psychological diseases.

Participants completed 140 sidecutting maneuvers in the lab, divided into four blocks of 35 jumps with a 5-minute break between blocks. Within each block, participants rested for 90 seconds after every seven jumps to minimize fatigue. To initiate the sidecutting maneuver, participants stood on a foot switch mounted on a 30 cm high box (Figure 1). Upon an acoustic signal, participants were instructed to shift their weight forward and fall off the box. When their feet left the foot switch, a direction signal (arrow to left or right, random order) appeared on a screen in 3 meters distance. Participants reacted to the arrow by landing on the contralateral leg and executing a 45° sidecut towards the indicated direction.

EEG data was recorded using a wireless 64-channel system with active electrodes (LiveAmp, Brain Products GmbH, sampling rate: 500 Hz). The EEG cap was placed according to the 10-10 system with two additional electrodes used for electrooculography. The EEG cap was additionally secured with a net head bandage and held down by a chest belt, and the EEG system was stored in a commercially available running backpack. For motion capture, 40 reflecting markers were attached to anatomical landmarks of the participants' lower body and data was collected with a 10 infrared camera system (sampling rate: 200 Hz) with 2 embedded force plates (sampling rate: 1000 Hz). Results of the motion data will not be presented in this talk.

Due to excessive motion artifacts following initial contact (IC), valid EEG data is restricted to the time segment between the direction signal and foot contact with the force plate. To enable precise segmentation of the EEG data (until IC), motion capture and EEG systems were synchronized using TTL pulses generated by the direction signal, which were sent to both systems simultaneously.

EEG data were processed using MNE-Python, including filtering (1 – 90 Hz), artifact subspace reconstruction, automatic removal of highly-contaminated trials (> 200 µV), segmenting (-1000 ms – IC) and independent component analysis. Source-level activity was estimated using the dSPM algorithm with a 3-layer boundary element model. Resultant time series data from the supplementary motor cortex (SMA) and the lower limb region of the primary motor cortices (M1) were extracted according to the BN-Atlas and used for analysis.

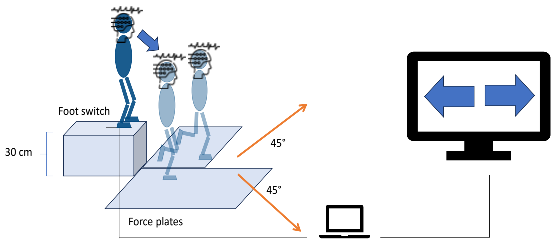

Figure 1: *Experimental setup of the sidecutting maneuver.*

Results

At this point, the data collection is complete, but the data is still undergoing processing and the results are yet to be analyzed. The following will be presented during the talk:

(i) Descriptive statistics of time series and topography of source-localized activity in M1 (Figure 2) to validate measured data according to established lateralization of M1.

(ii) Signal-to-noise ratio in SMA and in M1 to analyze data quality.

(iii) Cronbach's α of the activity in SMA and both M1 to analyze internal reliability.

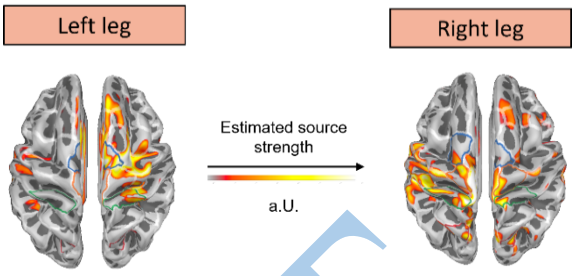

Figure 2: *Preliminary data show the topography of the source-localized cortical activity 50 ms prior to initial contact. The results show the expected activity increase of the contralateral motor cortices.*

Discussion

To the best of our knowledge, this study is the first to explore cortical activity concurrently with biomechanics in a highly dynamic and injury-related sports maneuver. The dataset will serve to validate our experimental setup, thereby establishing a methodological foundation for examining brain activity in a dynamic, sports-specific maneuver and also facilitating the simultaneous analysis of movement biomechanics. By examining cortical processes related to dynamic sidecutting maneuvers that mimic on-field demands of game sports, we gain new insights into the neural correlates of injury-risk biomechanics and skilled athletic performance.

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Effects of coordination related mental demands in sports movements on EEG brain activity: a systematic review

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Keywords

Neuropsychology, Electroencephalography, Sport, Motor Learning, Exercise

Highlights

- EEG alpha and theta brain activity increase during and after mental demanding sports movements.
- Trend towards higher EEG theta brain activity during and after sports movements with a higher mental demand.

Introduction

Sports movements are characterized by a combination of metabolic and mental demands. While metabolic demands refer to the strain on the cardiovascular system, the mental demand refers to the information that must be processed by the brain in parallel. This information during sports movements depends upon a number of factors, including the coordinative demand of the movement, the environmental conditions, and the necessity to react to opponents. Previous studies on the neurophysiological effects of sports movements have primarily examined electroencephalography (EEG) brain activity in movements with varying metabolic but low mental load (e.g. running, cycling). In these studies, an increase in alpha and beta EEG brain activity has frequently been reported [1]. The extent to which an increase in the mental demand of sports movements leads to different neurophysiological effects is still largely unexplored. Therefore, the aim of this study is to review studies on the effects of sports movements with coordination-dominated mental demands on EEG brain activity.

Methods

A systematic review was conducted according to PRISMA (Figure 1). A search across five scientific databases resulted in 13 studies that met the inclusion criteria.

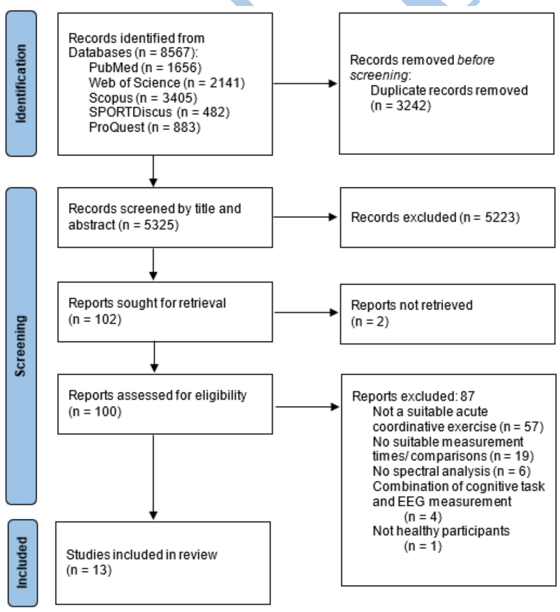

***Figure 1:** PRISMA flow diagram illustrating the literature search.*

The inclusion criteria were: (1) The studies had to have undergo peer-review and be written in English. (2) The subjects were healthy participants. (3) The studies investigated a sports movement with a high level of mental demand. Studies investigating sports movements with a low mental demand, such as endurance activities such as running, cycling or strength exercises such as bench press, were excluded. (4) Studies have made a comparison over a certain measurement time, for example a pre-post- comparison, or a comparison against another type of sports movement. (5) The analysis of brain activity was conducted using EEG spectral analysis, with the exclusion of event-related potentials. The study quality was assessed using a combination of the

Quality Assessment Tool for Quantitative Studies [2] and an assessment tool to evaluate EEG data acquisition and analysis [3]. Overall study quality was rated as moderate (M = 2.38).

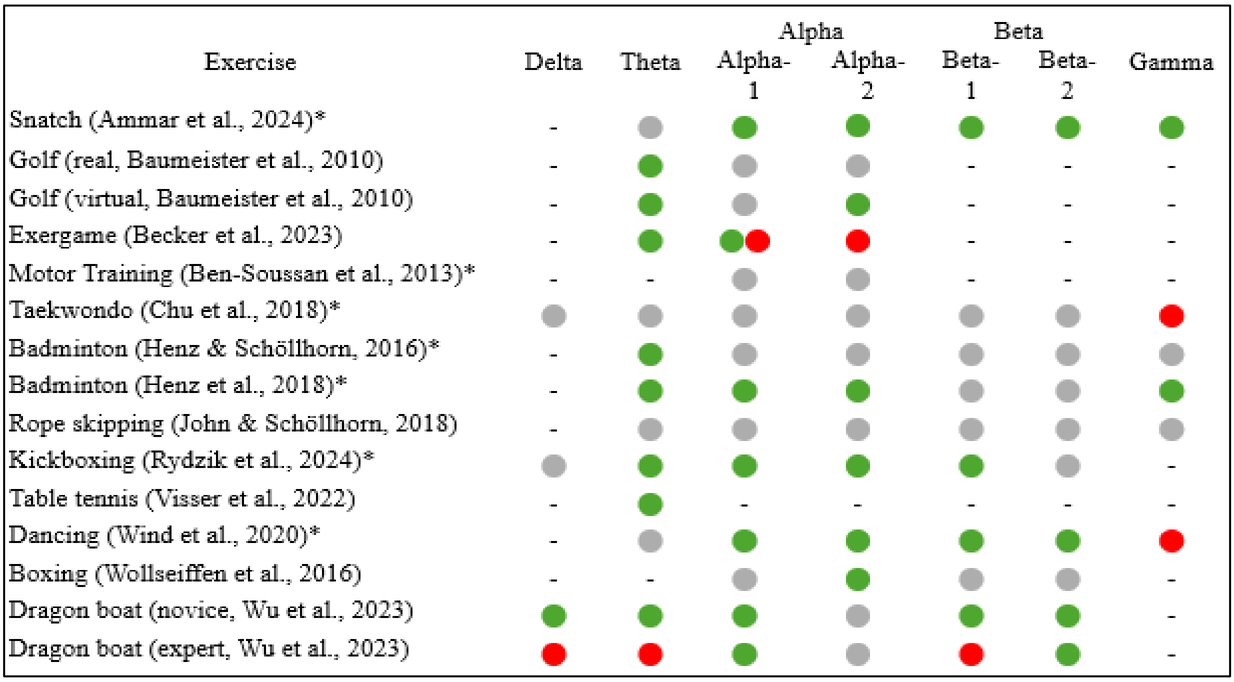

Figure 2: *Overview of the EEG frequency analysis. Green indicates an increase, red a decrease, a combination of both an increase and a decrease. An asterisk after the author indicates that no distinction was made between alpha-1 and alpha-2 or beta-1 and beta-2 (Rydzik et al. (2024) only distinguished between beta-1 und beta-2). A bar (-) indicates that the frequency was not analyzed.*

Results

Seven out of eleven studies (64%, Figure 2) that reported EEG theta activity reported an increase, mainly in frontal and central lobes of the brain. Eight out of twelve studies (67%) that reported EEG alpha activity reported increased alpha primarily in frontal, central and parietal lobes after or during the movement. The remaining EEG delta, beta and gamma activity showed inconsistent results. Comparisons between sports movements with varying mental demands revealed a trend towards higher EEG theta activity for movements with a higher mental demand.

Discussion

The mental demand of sports movements and the resulting amount of information caused by coordination dominated movements that needs to be processed in parallel seems to specifically influence the EEG brain activity. In comparison to previous findings on endurance dominated movements or strength exercises with low mental demand which showed activations in alpha and beta activity, the results reported here shifted towards an increase in theta and alpha activity. A reason for that could lie in movement specific increased demands on executive functions and various attentional processes [4]. Based on a consistent EEG methodology, future research should consider the mental demand of a movement as a moderator of brain activity.

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EEG recording during basketball free-throw shooting – Is there a signal in all the noise?

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Keywords

Motor control, Neural correlates, Methods, mobile EEG, Motor learning

Introduction

Theories suggest that expert performance is associated with a detailed internal forward model of the (motor) task that allows experts to monitor and predict the (sensory) consequences of their actions [1]. These models are developed and refined during training. In the EEG, the error-related negativity (ERN) is thought to reflect the activity of the error monitoring system signaling an impending error based on the predictions of the forward model [1], whereas the feedback-related negativity (FRN) is assumed to be associated with reward prediction errors, signaling that an outcome is better or worse than expected [2]. Fronto-medial theta oscillations are proposed as a common substrate of these two event-related potentials (ERPs) and are generally associated with the activity of an action and performance monitoring system [3]. As these findings are mainly derived from cognitive tasks, the aim of the present study was to verify the occurrence of these neural correlates in a task with a predominant motor component and to contribute to the further development of mobile EEG. Basketball free-throw shooting was used as the experimental task. To account for the massive artifacts caused by the whole-body throwing motion, the dual-layer approach proposed by [4] was followed. In this approach, a second EEG system is used to record only artifacts that can be used to better correct for artifacts in the scalp EEG in mobile recording settings.

Methods

A total of 30 proficient basketball players were tested. In the experiment, they performed 500 free-throws each at their own speed and with breaks as needed. Beginning with the release of the ball, vision was occluded for 400 ms using a PLATO occlusion goggle. After the occlusion period, participants could observe the rest of the ball flight, including knowledge of result.

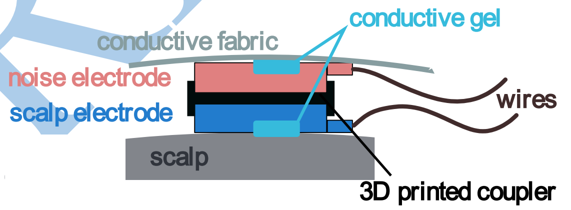

Figure 1: *Schematic illustration of a pair of electrodes in the dual-layer EEG setup.*

For online detection of the ball release, we used a custom algorithm based on the positional data of passive markers on the ball and the participant's hand obtained by a motion capture system. Throughout the session, EEG data were recorded using the dual-layer approach [4]. This approach comprises the simultaneous measurement with two electrically isolated EEG systems. The 'scalp-layer' EEG system measures the EEG data from the participant's scalp, while the electrodes of the 'noise-layer' EEG system are placed on top of the corresponding scalp-layer electrodes, facing outwards and covered by an electrically conductive fabric (see Figure 1), measuring artifacts caused, e.g. by movement and cable sway, but no brain activity. The data were preprocessed using six different pipelines (see Figure 2 for the main differences). The preprocessed data were analyzed statistically with respect to the neural correlates of action and error monitoring (bootstrap statistics for ERN/FRN and cluster-based permutation statistics for theta oscillations). The results are compared between the different pipelines as no 'best practice' exists for the analysis of mobile EEG data from whole body movements yet.

feedback onset. Thus, potential FRN effects at the time of knowledge of result might be obscured. However, theta power is found to be higher for miss trials compared to hit trials around knowledge of result, likely reflecting the activity of the performance monitoring system in the face of uncertainty as described by [3].

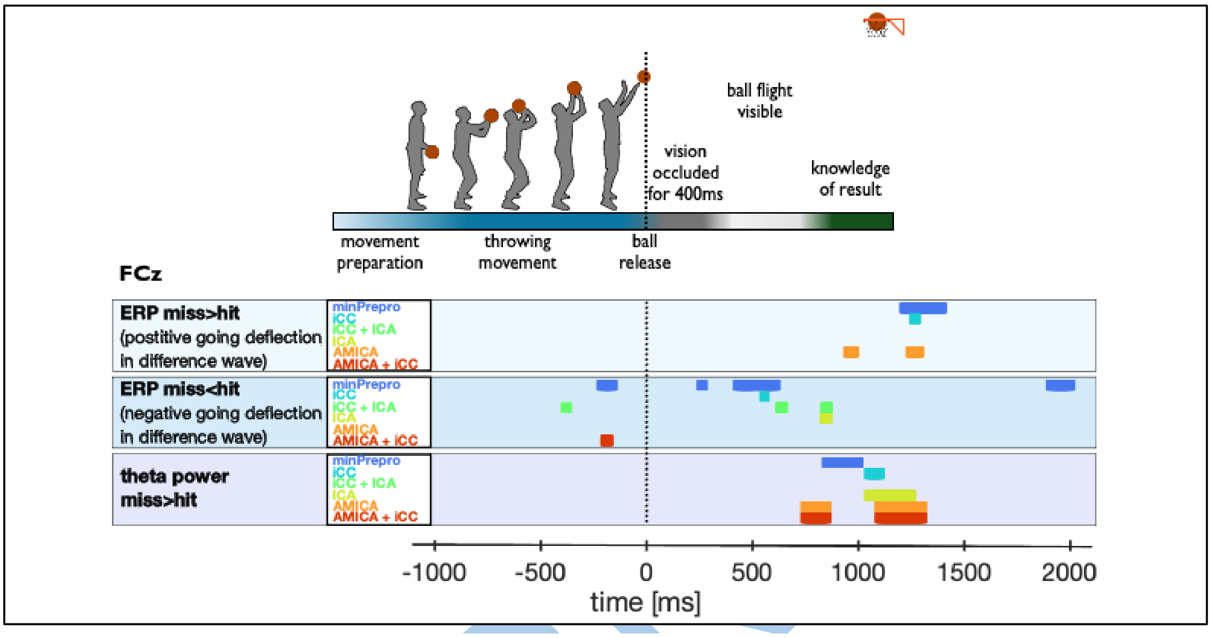

Figure 2: *Summary of the effects found at electrode FCz. Statistically significant differences between hits and misses are indicated by the colored rectangles corresponding to the different processing pipelines.*

Results

For our data we found mixed results with respect to the ERPs of action, error and feedback monitoring. However, very consistently across the different analysis pipelines, fronto-midline theta power is found to be higher for miss trials compared to hit trials around knowledge of result (see Figure 2).

Discussion

The aim of our study was to provide evidence that neural correlates of action monitoring and error processing, indexed by neural correlates such as ERN, FRN, and fronto-midline theta, can be found in the EEG during a real-world motor task such as a free-throw in basketball. Results for ERPs are mixed, with no clear evidence for the occurrence of an ERN or FRN. This may be due to the persistence of large artifacts in the expected effect window of the ERN shortly after the ball is released, and the lack of a clear feedback event and thus no proper synchronization to

Further analysis is needed to confirm our findings and to identify best practices in data collection and processing.

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The Earlier You Know, the Smoother You Act

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Keywords

Motor learning, Motor control, Motor skills and abilities, Juggling, Minimum Jerk Hypothesis

Introduction

Interception is a fundamental aspect of daily activities, such as catching a moving ball in various sports. In ball-catching tasks, the endpoint of a movement can lie anywhere along the target's trajectory [1]. Toss juggling exemplifies a motor skill that requires rhythmic catching and throwing of objects under spatial and temporal constraints. During the catching phase, a juggler's hands begin moving even before fully estimating the target's trajectory, with adjustments made to the targeted position during the movement. Simultaneously, the juggler must coordinate the act of throwing the ball already in hand.

This study investigates anticipatory behavior in juggling, offering insights into movement planning during this activity. Specifically, we compare two juggling conditions: solo 3-ball cascade juggling (condition 1) and dyadic 3-ball cascade juggling (condition 2). Following an approach in [2], our goal is to demonstrate that jugglers can predict a ball's trajectory earlier in solo juggling compared to dyadic juggling scenarios, due to predictions based on internally available information at ball release.

Methods

A total of 18 jugglers participated in the experiment. The jugglers were chosen based on the inclusion criteria that they are able to comfortably sustain a 3 ball cascade pattern for longer than 20 s. All the jugglers were either ambidextrous or right-handed. Handedness was assessed based on the participants' preferred hand for daily activities and writing. The experiment had two conditions. In the first condition, the juggler had to perform a regular 3 ball cascade pattern (*solo juggling*), and in the second condition, the juggler was paired with another juggler with whom they performed a side-to-side shared 3 ball cascade pattern (*dyadic juggling*). For the second pattern, both the jugglers stood next to each other facing forward, and the juggler (*partner*) standing to the left of the other juggler used their left hand, while the other juggler (*initiator*) used their right hand. After each trial, the jugglers switched places, i.e., the *initiator* of the previous trial became the *partner* in the next trial, and vice-versa. In both the conditions, each trial started with the first throw from the right hand (specifically, in the *dyadic juggling* case, by the *initiator*).

In the experiment, participants first performed a 3-ball cascade pattern (Condition 1), followed by the dyadic condition (Condition 2), standing 50 cm apart. Each trial lasted until the experimenter said “STOP!” or if the juggling pattern collapsed within 20s, whichever happened earlier. No instructions on speed or height were given, and all trials started with participants standing in the same spot.

This study explores to which extent anticipation of a ball's trajectory based on internally available information during the throw affects the following catch of that particular ball. Using the method proposed in [2], we examined how predictions based on information from the throwing hand affect the timing of the catching hand's movements. By leveraging the empirical principle that goal-directed trajectories exhibit minimal jerk [3][4], we investigated how early jugglers achieve smooth, goal-directed hand movements in solo juggling (condition 1) compared to when they lack throwing information from the opposite hand (condition 2). This approach evaluates the shortest distance between the hand and the ball's future trajectory over time. Using this one-dimensional trajectory data, the smooth approximation is identified by fitting a minimum jerk trajectory as an analysis tool, where jerk is defined as the third derivative of position with respect to time. A minimum jerk trajectory, J_{min}, minimizes the sum of the squared jerk values along the object's path between an initial time t_o and a final time t_f.,

Results

Our findings align with our hypothesis, demonstrating that jugglers can predict a ball's trajectory earlier when they have proprioceptive feedback from the throwing hand (condition 1). In contrast, their ability to anticipate the trajectory is reduced when this proprioceptive information is unavailable (condition 2). In condition 2, the smooth (goal-directed movement) phase is delayed by approximately 43% compared to condition 1. This highlights the critical role of sensory information from the throwing hand in facilitating early prediction and coordination during juggling.

Discussion

The goal of this study was to demonstrate that proprioceptive feedback from the juggler's throwing hand plays a critical role in determining the timing of the catching hand's movement. In a juggling task, where the ball can be caught at any point along its parabolic trajectory, accurate and early prediction of the ball's path is essential for maintaining stability in the juggling pattern. Our findings further highlight the relationship between sensory input and motor planning, underscoring the importance of proprioceptive information in enabling smoother and more efficient hand movements in complex dynamic tasks like juggling.

Dyadic juggling, in contrast to solo juggling, adds significant complexity to the task. The absence of proprioceptive information for the incoming balls, combined with a sole reliance on visual feedback, likely results in a delay in identifying the target. Additionally, other factors may also contribute to this delayed identification. It is well-established that the ability to catch a ball depends not only on tracking the ball but also on observing the complete throwing action of the partner, in addition to the ball's flight [5]. Future research will further explore this aspect.

Although juggling is theoretically an infinite-horizon task, it can be broken down into a series of finite-horizon tasks, alternating between catching and throwing. During this sequence, the juggler must not only ensure an accurate throw to the other hand but also predict the trajectory of the incoming ball as early as possible, which the same hand will subsequently catch. Further investigation is needed to explore in greater detail the predictive and prospective strategies jugglers employ to maintain the stability of their juggling patterns.

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Soccer players use peripheral vision under time pressure.

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Keywords

Sport, Virtual Reality, Motor skills and abilities, Decision-making, Eye-movements

Highlights

- Time pressure leads to more peripheral vision usage.
- Detecting events with peripheral vision is more accurate under time pressure.

Introduction

Peripheral vision is often used when monitoring the movements of multiple players in different team sports [1,2]. Especially in soccer, high-skilled players report to use their peripheral vision in 3 vs. 3 soccer situations [2]. They anchor their gaze on the player's possession of the ball to monitor peripheral events (e.g., movements of other players). In this experimental laboratory study, we challenged the use of peripheral vision by varying the distance to the direct opponent to manipulate the time pressure to make a passing decision. It was predicted that the closer the opponent to the participant, the more they would rely on peripheral vision, as looking away from the direct opponent would be costly as the moment of the pass could be missed.

Methods

Fourty-six male soccer players (age: *M* = 20.61 years, *SD* = 1.26 years; experience *M* = 6.53 years at least at a regional level) were shown 3 vs. 3 virtual-reality soccer counter-attack situations from the perspective of the central defender. Participants had to detect the overrun of a wing striker on the right, left, or both sides and point to that overrun with their hand(s). The detection of that overrun served as a test if participants were using peripheral vision to monitor the wing strikers. Their task was to defend the direct opponent, who could shoot on goal or pass to the right or left wing striker. The distance between the direct opponent and the participant at the moment of the pass was varied (4, 8, and 12 m). Overrun detection accuracy (trials where they detected the overrun correctly), peripheral detection (trials where they used peripheral vision for the detection), correct peripheral detection (trials where they used their peripheral vision and correctly detected the overrun), and decision accuracy (trials where they correctly responded to the action of the direct opponent) were analyzed. We defined five areas of interest for the gaze analyses (direct opponent, left winger, right winger, and spaces between right/left winger and direct opponent). Body kinematics were captured with retroreflective markers on the feet, hands, and head using a 14-camera Optitrack system. Gaze behavior was captured with a Pupil Labs Core eye-tracker running at 120 Hz (*Figure 1*).

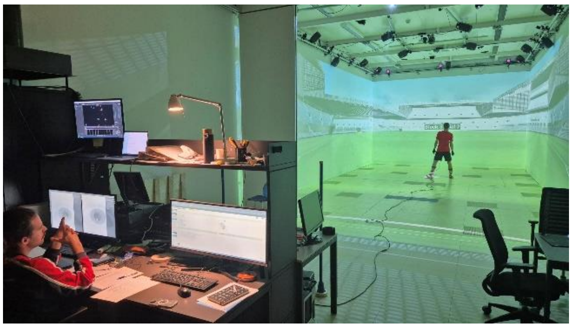

Figure 1: *Experimental setup in the CAVE of our sensorimotor laboratory.*

If data was normally distributed. a repeated-measures ANOVA was conducted for all dependent measures with distance (4, 8, 12 m) as the repeated-measures factor. The Kruskal-Wallis *H*-test was used if the data was not normally distributed. Post-hoc Dunn's tests with Bonferroni correction were used to identify significant distance differences. The “scipy.stats”, “statsmodels” and “scikit_posthocs” packages were used for the analyses in Python (version 3.13).

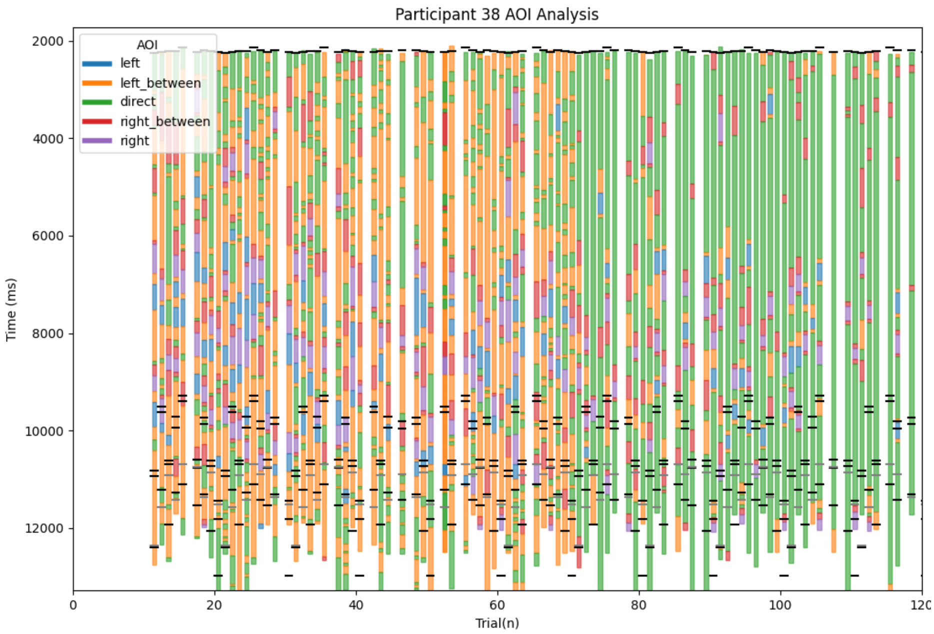

Figure 2: *AOI analysis of the gaze behavior for one participant for all trials (x-axis) and over the time course of each trial (y-axis). This participant changed his gaze behavior over time. In the first 70 trials, he frequently changed his gaze location, as indicated by the color changes. After that, he used his peripheral vision to greater extents (the greener the bars, the more he looked at the direct opponent and, thus, monitored the wingers with peripheral vision).*

Results

The descriptive results can be found in *Table 1*. The Kruskal-Wallis *H*-test revealed no significant difference in overrun detection accuracy, $H(2) = 1.341$, $p = .51$. There was a trend toward differences in peripheral detection, $H(2) = 5.286$, $p = .071$, indicating that peripheral vision was used more often at 4 m compared to 12 m. We observed significant differences for correct peripheral detection, $H(2) = 5.995$, $p = .049$. Post-hoc tests indicated more accurate peripheral detections at 4 m compared to 12 m ($p = .045$). Decision accuracy significantly differed between distances, $H(2) = 10.250$, $p = .005$. Decision accuracy was higher at 12 m compared to 4 m ($p = .004$). An example of the dynamics in gaze behavior can be found in *Figure 2*.

Table 1: *Outcomes for the four dependent variables with Mean (SE) values for each manipulated distance.*

Distance	Overrun detection accuracy	Peripheral detection	Correct peripheral detection	Decision accuracy
4 m	90.05 (1.13)	61.72 (4.94)	43.38 (4.22)	62.9 (2.73)
8 m	91.55 (0.92)	52.2 (5.13)	35.04 (4.06)	70.95 (2.05)
12 m	93.46 (0.91)	45.1 (5.24)	30.14 (4.07)	74.25 (2.43)

Discussion

The results show that the greater the time pressure to make a decision, the more the participants use their peripheral vision. Beyond that, peripheral detection accuracy increased with time pressure. In contrast, response accuracy to the direct opponent's action decreased with time pressure. The peripheral vision results indicate that participants focused on the wing strikers, although they fixated on the direct opponent. The discrepancy between response accuracy in reacting to the direct opponent and the ability to detect the overrun under time pressure suggests that we must train the ability to focus on both foveal and peripheral locations simultaneously [1].

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