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Toward EEG discrimination of fingers movements during motor imagery vs passive movement

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Abstract

This study investigates the potential of passive finger movements as an alternative to motor imagery (MI) for the calibration of brain-computer interfaces (BCIs). Twenty-six participants performed both MI tasks and passive movement tasks involving finger flexion and extension, while their electroencephalographic (EEG) brain activity was recorded and analyzed. Brain activity in the α (8–12 Hz) and β (20–25 Hz) bands was significantly stronger during passive movement tasks compared to MI tasks. Additionally, task conditions and movement types had independent and significant effects. These findings suggest that passive movements could improve the accessibility and reliability of BCIs, particularly in applications requiring precise finger control such as extended reality applications.

1 Introduction

A brain-computer interface (BCI) records and analyzes brain signals, converting them into commands to control external devices (Kim et al., 2013). Non-invasive BCIs have applications in entertainment, such as video games, and healthcare, where they enable prosthetic control and assistive technologies like smart wheelchairs (Kim et al., 2013). They also have been increasingly investigated in the context of extended reality (XR). In virtual environments, BCIs can improve user interaction by enabling hands-free control, enhancing accessibility, and providing adaptive feedback based on real-time brain activity (Lécuyer et al., 2008). For example, BCIs have been used to navigate virtual environments, manipulate virtual objects, or adjust immersive experiences based on the user’s cognitive state. A common approach involves imagining right or left hand movements to control the position of a character in a virtual environment.

Non-invasive BCIs often use electroencephalography (EEG) to measure brain activity. This is a painless process where electrodes are placed on the scalp to detect residues of electrical activity arising from neuron communication. This method is popular for its affordability, ease of use, and high temporal resolution compared to other neuroimaging techniques, making it suitable for research and clinical applications.

To generate brain signals that a BCI can reliably interpret, users must perform cognitive tasks that activate large groups of neurons, creating distinguishable patterns of brain activity. One widely used approach is motor imagery (MI), where users mentally simulate motor actions, such as moving a hand or foot, without physically performing them. This induces distinct patterns of activity in the motor cortex, making the corresponding EEG signals more recognizable for the BCI system (Morash et al., 2008).

BCIs rely on patterns of event-related desynchronization (ERD) and synchronization (ERS). During motor imagery or movement ERD occur in the alpha (8–12 Hz) and beta (13–30 Hz) bands within sensorimotor regions (Pfurtscheller et al., 2006) followed by an ERS rebound. Motor imagery tasks involving finger movements often result in lower BCI performance (Anam et al., 2019), primarily due to overlapping EEG signals from adjacent brain regions controlling different fingers. Additionally, extensive training and lower intuitiveness compared to other control methods limit user adoption (Alazrai et al., 2019).

Previous studies have shown that voluntary movements, passive movements and motor imagery produce similar ERD/ERS patterns in sensorimotor areas of the brain (Cassim et al., 2001). According to the literature, it is possible to use passive movements to calibrate BCI systems, offering an efficient alternative for the participants as they ensure the task is performed correctly, unlike motor imagery, which participants may find less familiar (Ang et al., 2011). In passive movements, limbs are moved by an external source, reducing cognitive and physical load.

Thus, passive movements are emerging as a promising alternative to motor imagery for the calibration of BCIs. This study aims to explore the use of passive movements for more complex tasks involving fingers, to determine whether this method can improve the accessibility and effectiveness of BCIs.

2 Materials and methods

Participants completed a 2-hour experiment where they: (1) performed MI and (2) experienced passive movements (applied by a custom-built exoskeleton).

2.1 Participants

Twenty-six healthy right-handed participants took part in the study (19 men, 7 women; age 22–48, $M = 29$, $SD = 6.7$). None of them had any history of neurological or psychiatric disorder.

2.2 Experimental protocol

Both motor imagery and passive movement tasks involved flexion and extension of the index, middle, and ring fingers, performed individually and together. The sequence of tasks was randomized, with 30 trials per movement type. Each trial included a random rest period (2.5–3.5 s) followed by a 6 s task. During the task, a visual cue of an animated hand playing a 3-key piano was shown. In the motor imagery condition, participants imagined the movements, while in the passive movement condition, an exoskeleton performed them.

2.3 EEG Recordings & Signal Processing

EEG data was recorded with 30 active electrodes and filtered using notch filter and a 0.5-40 Hz band-pass filter. Automatic artifact rejection, independent component analysis and common average reference were applied to limit artifacts. Event related spectral perturbation (ERSP) representations were computed with only significant effects displayed (see Figure 1).

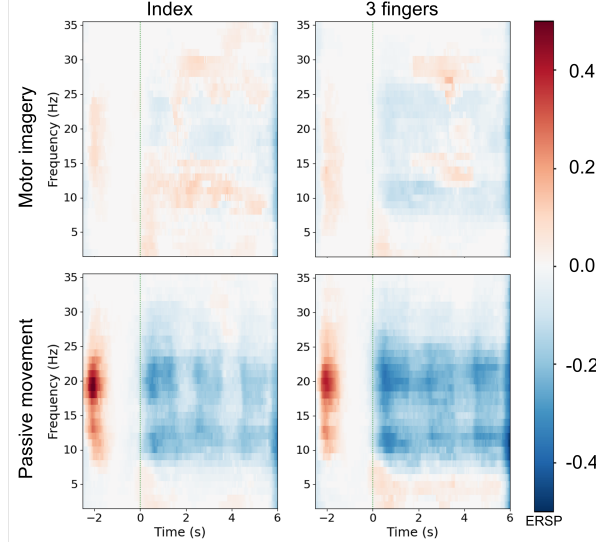


Figure 1: Grand-averaged ERSP at electrode C3 for MI and passive movement tasks for right index finger and three-fingers movements. Significant ERD are depicted in blue, while significant ERS are represented in orange.

3 Results

In the α (8-12 Hz) and sub-part of β (20-25 Hz) bands, a greater number of significantly stronger event-related desynchronizations (ERDs) were observed during the passive movement tasks than during the MI tasks. A repeated measures ANOVA on ERDS values between 8 to 25 Hz and 1 to 5 s after task onset revealed a significant effect of the experimental condition ($F = 19.77$, $p < 10^{-3}$, $\eta^2 = 0.12$) and the movement type ($F = 8.16$, $p < 10^{-2}$, $\eta^2 = 0.02$) on these values. However, the interaction between condition and movement is not significant ($F = 0.87$, $p = 0.45$, $\eta^2 = 10^{-2}$), indicating two independent factors.

4 Conclusion

In accordance with the literature, passive movements consistently elicited stronger contralateral ERD in the motor cortex compared to MI (Kaiser et al., 2011). It highlights the potential of passive movements as a reliable alternative to MI for BCI calibration, particularly in tasks involving fine motor control. We also observed significant differences in brain activity between various finger movements, suggesting that distinct neural activation patterns are associated with individual and combined finger tasks. These results

seem promising, and could lead to an increase in the number of instructions usable in BCIs, opening up new prospects for their integration into XR technologies.

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