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Exploring the Potential of Motor Imagery-Based BCIs for Targeted Motor Function Recovery

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Introduction: Motor imagery (MI)-based brain-computer interfaces (BCIs) activate motor-related brain regions and, through neurofeedback, foster neuroplasticity, offering significant potential for neurorehabilitation [1]. While MI-BCIs have shown success in restoring hand function after stroke, their use in mitigating upper-limb impairments in multiple sclerosis (MS)—a chronic neurodegenerative disorder characterized by impaired motor control and coordination—remains underexplored [2]. This study presents a preliminary investigation into the feasibility of using MI-BCI for targeted therapy of two specific motor function deficits. Using two representative hand tasks—one requiring coordination and the other control (see Figure 1A-B)—the objectives were: 1) to examine whether MI of these tasks alters corticospinal excitability (CSE), indicating the potential for fostering neuroplasticity and improving hand function, and 2) to determine if distinct task-specific neural activation patterns can be detected via electroencephalography (EEG), suggesting they may be targeted with BCI-based neurofeedback training.

Material, Methods and Results: Data from twenty-one healthy participants (8 males; mean age: 41.35 ± 8.36 years) were analyzed for this study. Transcranial magnetic stimulation (TMS) was used to assess changes in CSE due to MI of the coordination and control tasks. A single TMS pulse was delivered during intervals of MI and rest and resulting motor-evoked potentials (MEPs) were measured from the first dorsal interosseous (FDI) muscle (Figure 1C). For the control task, MI significantly increased MEP amplitudes (Δ=37.43 μV, p = .005), and decreased MEP latencies (Δ=−0.38 ms, p = .003), compared to rest. For the coordination task, MI significantly decreased MEP latencies compared to rest (Δ=−0.25 ms, p = .008), but MEP amplitudes were not significantly different (Δ=29.69 μV, p = .19). CSE was also assessed during actual execution of the tasks (ME), and changes in both MEP amplitudes and latencies were significantly different from rest for both tasks (control: Δ=508.94 μV, p < .001; Δ=−1.94 ms, p < .001; coordination: Δ=528.23 μV, p < .001; Δ=−1.71 ms, p < .001).

In a separate session, 64-channel EEG was recorded as participants performed 60 intervals each of MI and ME of the two tasks, as well as rest. Data were analyzed using the Filter Bank Common Spatial Patterns (FBCSP) algorithm (using delta, theta, alpha, beta, gamma frequency bands) and Linear Discriminant Analysis (LDA) (see Figure 1D). The control and coordination tasks could be distinguished from rest with average accuracies of 76.3% and 70.2% for MI, and 83.3% and 87.2% for ME. While the average classification accuracies for control vs. coordination were just 61.3% (MI) and 63.6% (ME), accuracies for 9 participants for MI, and 6 for ME, exceeded 70%. The statistical threshold for chance for all accuracies is 58.3% (for n=120 trials, α=0.05, based on binomial distribution).

Conclusion: Increased MEP amplitudes and decreased latencies indicate that CSE increased during the MI tasks, suggesting the potential of these tasks to foster neuroplasticity. On average, the distinct neural patterns differentiating motor control and coordination were detected with accuracy greater than chance, and for some participants with very high accuracy. The results suggest the potential for targeted BCI-based therapy for improving motor control and coordination, though further work is needed to more reliably and specifically identify the neural activation patterns associated with these functions.

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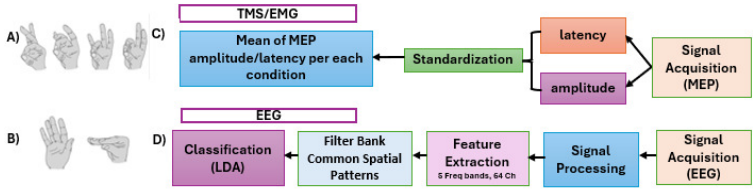

Figure 1: (A) Motor Coordination: Touch each finger to the thumb sequentially, and repeat throughout interval.
(B) Motor Control: Extend the hand fully, then bring the four fingers and thumb together, and repeat throughout interval.
(C) TMS/EMG Workflow: Key steps for processing MEP amplitude and latency.
(D) EEG Workflow: Signal acquisition, processing, feature extraction, and classification using LDA to identify neural patterns.

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