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Challenges in Common Spatial Pattern Reliability for Neurofeedback

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Introduction: Motor imagery (MI)-based neurofeedback requires precise extraction of physiologically significant brain activity from EEG signals. A key challenge is the individualization of targeted activity, as commonly used methods like the Laplacian filter [1] may not capture subject-specific neural dynamics. Common Spatial Patterns (CSPs) [2] provide a personalized approach by extracting spatial filters from individual brain activity. However, CSPs are sensitive to noise and artifacts in EEG data, which can impact their reliability [3]. This study examines CSP reliability and explores the use of Representational Similarity Analysis (RSA) [4] to select neurophysiologically relevant CSPs. Preliminary findings highlight the challenges in isolating MI signatures with CSPs and the need to refine their selection to enhance neurofeedback protocols.

Material, Methods and Results: We used the EEG data from 21 participants (28 active electrodes) recorded during 10 alternating trials of rest and right-hand MI (8 seconds / trial; [1]). A virtual hand displayed clenching movement as visual stimulation during MI. The EEG signals were band-pass filtered between 8 and 30 Hz to focus on motor-related frequencies. CSPs were calculated and, for each subject, the most physiologically relevant CSP among the top six ones was visually selected by the authors (Figure 1a). The result highlighted the inter-individual variability of CSP decomposition, evidenced by the variable rank of the selected CSPs and the frequent presence of ocular artefacts signatures. This variability is further emphasized by Figure 1c, representing the average of the selected CSPs, and Figure 1d, showing the associated standard deviation across subjects, where high variability in temporal regions extending to the motor region can be seen. To evaluate the reliability of CSPs in isolating motor-related activity, CSPs pattern were then compared to the grand average difference topography between MI and rest (MI – Rest) using a leave-one-out RSA approach (Figure 1b). A match between the CSPs selected by the experts and those identified by RSA was observed in 45% of the subjects, with a RSA score of 0.24 ± 0.12 (mean ± SD).

Conclusion: This study underscores the variability and challenges in isolating physiologically relevant motor-related activity using CSPs. Preliminary results reveal that CSPs captured motor imagery patterns in 45% of the cases, emphasizing a lack of reliability. These findings underline the necessity of exploring alternative approaches to improve CSP selection, such as region-specific computations, advanced artifact correction techniques [5], or automated methods to detect and exclude artifact-contaminated CSPs. This also opens opportunities to explore innovative methodologies to address CSP limitations, aiming to improve their reliability and support the implementation of personalized neurofeedback protocols.

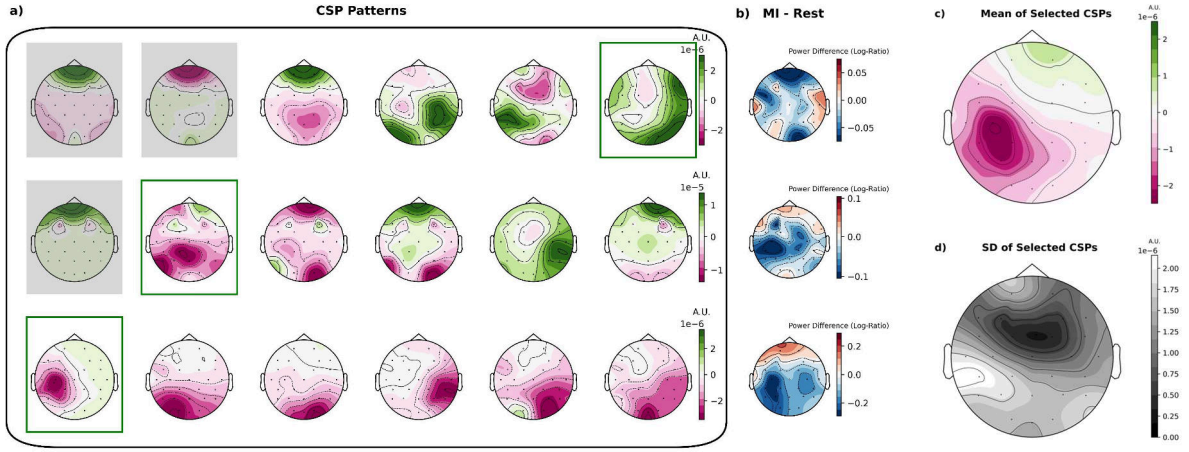

Figure 1: a) CSP patterns for three representative participants. Green boxes highlight the CSPs selected by the experts. Gray-shaded boxes indicate CSPs identified as contaminated by artifacts. b) MI-Rest topographies for the same three participants, illustrating MI-related activity. c) Mean and d) standard deviation of the CSPs selected by the experts across all participants.

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