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Investigating the overlap of ERD/ERS modulations for a Median Nerve Stimulation-based BCI

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Synopsis

Motor-Imagery-based Brain-Computer Interfaces (MI-BCIs) show promise but face challenges for a wider adoption due to accuracy and usability issues. It has been proposed that BCIs based on median nerve stimulation (MNS) could significantly improve the efficacy of BCIs. Indeed, when MNS occurs during a MI, post-stimulation neuronal synchronization is significantly reduced, potentially aiding MI-BCIs in distinguishing MI with stimulation from stimulation alone. However, MNS-based BCI only actually works under optimal timing conditions (i.e. when the MNS occurs precisely during MI). Understanding how the ERD/ERS components of mu and beta rhythm interact with each other when MNS is close, but not perfectly aligned, to MI is essential. This study examines 14 participants in two motor conditions: MI with MNS and MNS alone, assessing timing effects on EEG activity. The results show that when stimulation occurs before or at the onset of MI, the ERD of MI tends to abolish the ERS of the MNS.

Background

The field of Motor-Imagery-based Brain-Computer Interfaces (MI-BCIs) has experienced significant growth in recent years and has successfully overcome several challenges like cursor control through imagined hand movements or stroke rehabilitation (Clerc 2016). These advances are promising, but several issues persist for widespread usability: (i) insufficient accuracy (i.e., the rate of correctly recognized mental states remains insufficient, typically below 75% for two MI classes (Lotte 2018)), (ii) high inter- and intra-subjects variabilities (Fairclough, 2020; Dreyer 2023), and (iii) limited usability (i.e., many of them rely on synchronous active communication, where users are explicitly prompted to perform a specific action following an auditory or visual signal (Rimbert 2019)). Addressing these challenges, studies have shown that using median nerve stimulation (MNS) during MI enhanced BCI effectiveness (Rimbert 2019a, Rimbert 2019b). As a reminder, MIs exhibit power variations (i.e., Event-Related (De)-Synchronisation called ERD/ERS) in EEG mu and beta bands over the motor cortex (Pfurtscheller, 2006). Prior to and during MI, there's a gradual power decrease in mu/alpha (7-13 Hz) and beta (15-30 Hz) bands, followed by a beta band power increase after MI (Pfurtscheller 2006). Interestingly, MNS induces EEG activity changes similar to MI, including ERD during stimulation and post-stimulation ERS (Rimbert 2024). Notably, if MNS occurs during a MI, post-stimulation ERS diminishes or reduces significantly, potentially aiding MI-BCI in distinguishing MI with stimulation from stimulation alone (Rimbert 2019a, Rimbert 2019b).

Although it is now accepted that a MNS-based BCI can address the above-mentioned challenges, it only actually works under optimal timing conditions. Indeed, in previous studies, MNS occurred 750 ms after the beginning of the MI (e.g., two seconds long), which would be the best case for an asynchronous MNS-based BCI (Rimbert 2019a, Rimbert 2019b). In other words, if MNS-based BCI stimulates the median nerve every 5s, then it is possible for the user's MI to occur before, after or during the stimulation. Unfortunately, in a real-BCI use, we would have no control over the precise timing of the MI in relation to the stimulation generated. This is why we need to investigate the influence of the temporal phase in which the MNS appears in relation to the MI. To do this, we should observe how the EEG response due to an MNS performed at regular intervals is modified by an MI performed at random times, as will happen in

the real use case. If MI can occur before, during or after MNS, how will the ERD and ERS corresponding to the stimulation be modulated? Understanding how the ERD/ERS components of mu and beta rhythm interact with each other when MNS is close to an imagination of MI is essential. Indeed, we can suppose that when MNS occurs before or after MI, then the ERS of stimulation would be less abolished by the ERD of motion imagination. Such information is fundamental for determining the ideal parameters of a MNS-based BCI, in particular the time required between two stimulations of the MNS.

B. Mu + Beta band (8-30 Hz)

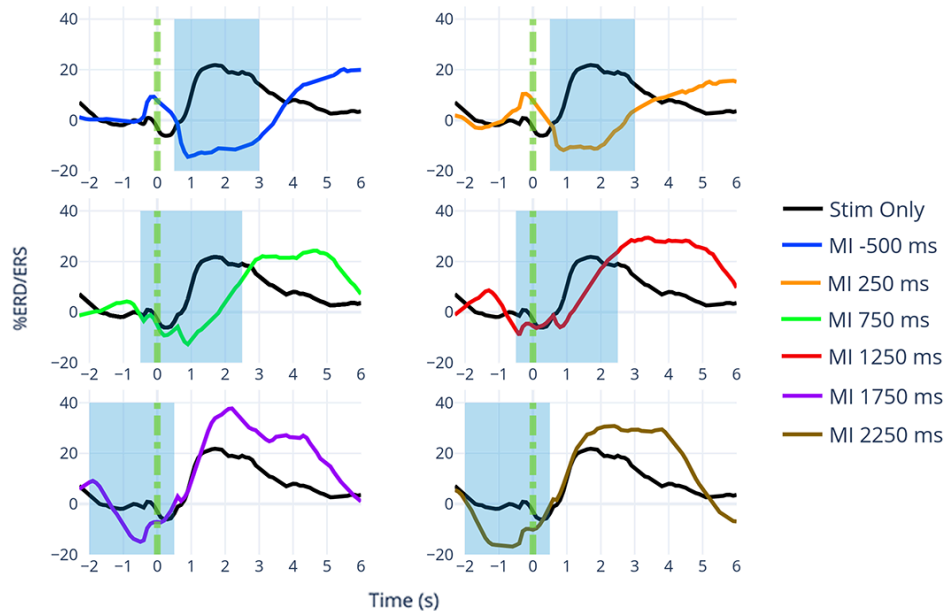


Figure 1. ERD/ERS modulations grand average ($n=14$) for electrode C3 in mu + beta (8-30 Hz) frequency bands for MNS alone (black) and MI + MNS at different times ($t_1=-500$ ms; $t_2= +250$ ms; $t_3= +750$ ms; $t_4= +1250$ ms; $t_5= +1750$ ms; $t_6= 2250$ ms). The dotted green bar at 0 ms corresponds to the moment of stimulation.

Methods

14 healthy volunteers (7 women; aged 18 to 48) were recruited for the study. Participants signed an informed consent form that was approved by Inria's ethics committee. For this study, participants performed two motor conditions: (i) MNS during MI (MI + MNS) and (ii) MNS alone. During the MI + MNS condition, subjects had to perform MI while their median nerve was stimulated at different times after, during or before the start of the MI task ($t_1=-500$ ms; $t_2= +250$ ms; $t_3= +750$ ms; $t_4= +1250$ ms; $t_5= +1750$ ms; $t_6= 2250$ ms) (Figure 1). A low-frequency beep indicated to the subject when he should start MI and a high-frequency beep indicated when he should stop it. For the MNS condition alone, the subject was simply given an MNS while at rest. EEG signals were acquired using the OpenViBE software via a Biosemi EEG amplifier with 128 electrodes. All processing was carried out using Matlab 2016b and the EEGLAB toolbox. Finally, ERD/ERS modulations were calculated for the mu+beta frequency band (8-30 Hz) for all subjects. Figure 1 shows the grand average for all subjects for electrode C3.

Results

As expected (Figure 1), when stimulation occurred before (-500 ms) or at the onset of movement imagination (+250 ms and +750 ms), the ERD of MI tended to abolish the ERS of the MNS. On the other hand, the more the MNS was applied at the end of MI (+1250 ms, +1750 ms, +2250 ms; Figure 1), the more the beta rebound due to MNS reappeared, although greatly reduced compared with MNS condition alone.

Discussion

This study has enabled us to consider several strategies for addressing this question: the BCI device that we wish to design could analyze the EEG signal (i) after each MNS, (ii) before and after each MNS or (iii) in an adaptive manner, i.e. by adapting this time window as a function of the delay between the stimulation and the imagination of movement. In the future, we need to design a method based on adapting a specific window according to the delay between the MNS and the MI, which seems the most promising. Classification accuracy scores will have to be evaluated according to this new method.

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