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Temporal Dynamics of Neural Activation and Inhibition Patterns During Motor Imagery

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Introduction: Motor Imagery (MI), the mental simulation of movement without actual physical execution, plays an important role in motor learning and rehabilitation. Previous studies have identified the involvement of specific brain regions and suppression from supplementary motor area to M1 during MI [1], [2]. However, the precise temporal dynamics of neural activation and inhibition patterns across different phases of motor imagery remain uncovered, due to the limitations in temporal resolution of conventional neuroimaging techniques such as functional magnetic resonance imaging. Based on the high temporal resolution of stereo-electroencephalography (sEEG), this study used sEEG to investigate neural activation and inhibition during the preparation phase and the execution phase of motor imagery. We aim to provide more detailed insights into the rapid neural processes underlying motor imagery that have been elusive in previous fMRI-based research.

Material, Methods and Results: A total of seven epileptic patients were collected in this study and implanted electrodes were distributed in seven different brain regions. Participants were implanted with SEEG electrodes for presurgical assessment of seizure focus. During the experiment, participants were asked to imagine either moving their left/right hands or dorsiflexing their left/right foot. The sEEG signals were downsampled to 1000Hz and a notch filter was used to remove the powerline noise. No epileptic activity was observed in the data. After that, the data was re-referenced using the bipolar re-referencing, where each channel was re-referenced to its adjacent channel on the same electrode shaft. Then, power spectral density (PSD) was calculated using the Welch method with 1000 ms Hann window and 500 ms overlap. From calculated PSD, 8–33 and 65-116 Hz averaged broadbands were calculated, and the signed r-squared cross-correlation was calculated between PSDs of rest and preparation, preparation and imaging stage [3]. An unpaired two-sample t-test was performed for each channel and each movement type. For each movement, the features were screened for all significant levels ($p < 0.05$) in the different phases and their corresponding relevance were multiplied to calculate the trend of each channel, reflecting its dynamic contribution in the different phases. In multiple patients, we observed some suppressions in the high-frequency band within the caudal anterior cingulate cortex, inferior part of precentral gyrus and the pars triangularis of right inferior frontal gyrus. Regardless of lateralization or the specific body part involved in motor imagery, a notable suppression was detected during the transition from the resting state to the preparatory phase ($Rp = -0.453 \pm 0.016$). Conversely, a strong activation emerged during the transition from the preparatory phase to the motor imagery phase ($Rp = 0.693 \pm 0.030$).

Conclusion: Our findings show a unique pattern of neural activity during MI, where in some specific brain regions, high-frequency inhibition occurs in that brain region prior to the onset of real imagined movement. And this temporal variation is independent of both imagined limb site and lateralization type.

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