

Identifying brain activity patterns in multimodal neurofeedback: A joint EEG Alpha/Beta analysis

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Introduction

Neurofeedback (NF) enables individuals to self-regulate their neural activity through real-time feedback. Combining electroencephalography (EEG), which captures electrical activity, with functional near-infrared spectroscopy (fNIRS), which reflects the hemodynamic response, may provide a richer description of brain activity and help define more precise NF targets [1]. When NF relies on motor imagery tasks (MI; i.e., imagination of a movement without physical execution), the brain activity to be regulated is distributed across motor, premotor, and parietal regions [2]. To our knowledge, it remains unclear whether multimodal EEG-fNIRS NF modulates MI-related brain activity across this network differently from unimodal NF, and how this is reflected in the EEG signal. As a first step to understand this network, this study specifically focused on the EEG signal to characterize MI-related brain activity across motor, premotor, and parietal regions under multimodal and unimodal NF.

Methods

EEG data were extracted from a previously acquired database of 30 healthy right-handed participants performing left-hand MI under visual NF [1]. Each participant completed three randomized NF conditions (unimodal: EEG and fNIRS; multimodal: EEG-fNIRS), with two runs per condition and 10 blocks per run alternating 15 s MI/NF and 15 s rest. This study focused on 18 EEG channels organized in 3 regions of interest (ROIs, motor, premotor and parietal; Fig 1). Raw signal was band-pass filtered (1–40 Hz), submitted to independent component analysis with automatic classification and removal of non-neural components (ocular, muscular, cardiac, or line noise), and segmented on rest/task markers. Event-related desynchronization (ERD) was computed in the alpha (8–12 Hz) and beta (13–30 Hz) bands as the percentage power change during task (0–15 s) relative to the last 5 s of the preceding rest; negative values indicate desynchronization [3]. For each participant, ERD was averaged across runs, ROIs and hemispheres (i.e., ipsilateral and contralateral). Alpha and beta ERD were analyzed jointly in a repeated-measures multivariate analysis of variance (MANOVA) with condition, ROI, and hemisphere as within-subject factors, and condition order as a nuisance factor, using the modified ANOVA-type statistic (MATS) with parametric bootstrap p-values. Post-hoc comparisons were done with Benjamini-Hochberg method. Preprocessing was performed in MNE-Python, and statistical analyses in R with the MANOVA.RM package.

Results

In all three conditions, MI-NF induced ERD across the sensorimotor ROIs in both alpha and beta bands. The multivariate analysis showed a significant main effect of ROI ($p = .003$), with no significant effect of condition or hemisphere and no significant interactions (all $p \geq .161$). Corrected post-hoc comparisons indicated stronger ERD in the parietal region than in the motor ($p = .008$) and premotor ($p = .006$) regions (Fig 2). Descriptively, this regional effect was mainly driven by alpha ERD, which was more pronounced in parietal region than in motor and premotor regions.

Conclusions

In this multimodal NF study, MI-related EEG-ERD engaged the extended sensorimotor network with robust parietal dominance, but was neither modulated by the feedback modality nor significantly lateralized. The absence of a multimodal-specific or contralateral effect, together with the parietal focus, suggests that left-hand MI in this paradigm recruited a bilateral sensorimotor network, whose electrophysiological signature was mainly driven by parietal alpha and beta desynchronization, potentially reflecting the high visuo-spatial demands of the feedback loop [4]. These findings inform NF target definition and motivate further work on inter-individual variability and the complementarity of recording modalities to optimize NF protocols.

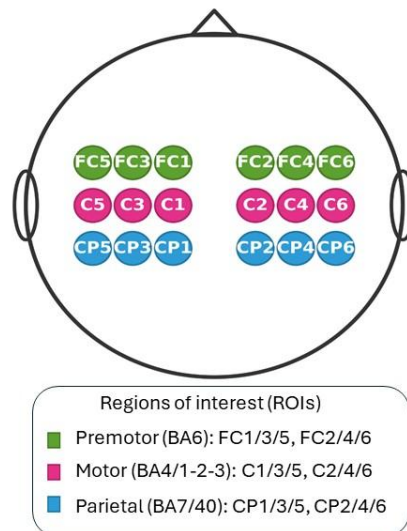


Figure 1. EEG channels map by regions of interest (ROIs). Map according to the 10-10 international system across the 18 channels above the sensorimotor ROIs (BA: Brodmann Areas)

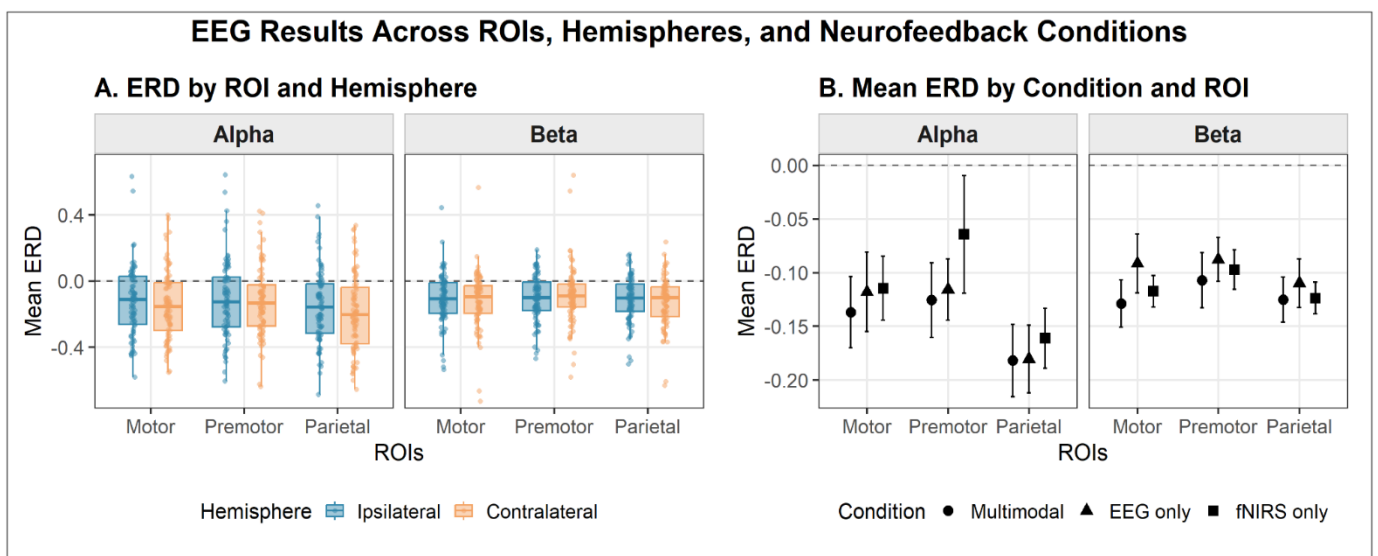


Figure 2. EEG ERD desynchronization across the sensorimotor network. (A) ERD distribution by ROI and hemisphere in alpha and beta bands. (B) Mean ERD by NF condition and ROI.

References

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