

Feasibility and effects of a multimodal EEG-fNIRS neurofeedback platform for motor imagery

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Introduction

Neurofeedback (NF) promotes neuroplasticity by enabling users to self-regulate their brain activity in near real-time through sensory representations [1]. In rehabilitation contexts, motor imagery (MI), i.e. the mental simulation of movement, offers a promising approach to stimulate motor-related brain regions without any movement. To optimize NF for MI, current research turns toward the combination of neuroimaging methods that are both ecologically feasible and neurophysiologically accurate. The integration of various portable recording techniques, such as electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS), respectively based on electrical and hemodynamic activity, could enhance the characterization of brain responses and subsequently improve NF performance. Multimodal EEG-fNIRS systems could address this need by combining complementary signals [2]. To our knowledge, no study has yet combined EEG and fNIRS within a NF paradigm targeting upper-limb MI for post-stroke motor rehabilitation. This study evaluates the feasibility and the effects of a multimodal EEG-fNIRS NF system for upper-limb MI.

Methods

A custom platform was developed for real-time signal processing of both EEG and fNIRS recordings in order to provide continuous unimodal or multimodal NF scores via a visual gauge [3]. Following an initial baseline calibration block used to determine individual regulation thresholds, thirty healthy participants (15 women, 25 ± 4 years) completed three randomized MI-NF conditions: EEG-only, fNIRS-only, and multimodal EEG-fNIRS (Fig 1). Each condition comprised two runs of 10 blocks alternating 15 s of rest and 15 s of active NF task. The NF score was derived from the right primary motor cortex (M1) activity during left-hand MI. The EEG feature was the alpha-band event-related desynchronization (ERD, 8–13 Hz; [4]), while the fNIRS feature was the change in oxyhemoglobin concentration (ΔHBO_2 ; [5]). To evaluate the effect of the NF-MI session, brain activity was computed offline as the average ERD and ΔHBO_2 across conditions and participants. Following each condition, participants also assessed their subjective feeling of success and the mental strategies used to modulate the feedback. All variables were compared using repeated measures ANOVAs (significance level of $\alpha = .05$).

Results

The average online NF scores (mean scores: EEG-NF = 45.88%, fNIRS-NF = 44.30%, EEG-fNIRS-NF = 48.00%) significantly exceeded the threshold set during calibration, confirming successful online regulation. No significant difference in displayed NF scores was observed across the three conditions. Offline analysis of brain activity at the level of right M1 revealed no significant difference in EEG-ERD or fNIRS- ΔHBO_2 between conditions (all $p > .05$). Participants reported a higher perceived sense of control over the feedback in the EEG and EEG-fNIRS conditions compared to fNIRS-only ($p < .05$).

Conclusions

All participants successfully modulated their NF score across every condition relative to calibration, confirming the overall validity of the paradigm. However, under the current protocol, the EEG-fNIRS combination offered no measurable advantage over unimodal approaches, either at the level of brain activity or perceived control. The lower subjective sense of control in the fNIRS-only condition may reflect the inherently slower hemodynamic response compared to electrophysiological signals [6], but will require further investigation. Future work will also explore additional brain regions beyond M1 and investigate the use of repetitive sessions of multimodal NF training on motor learning. Such a platform holds strong clinical potential, particularly for post-stroke upper-limb motor rehabilitation.

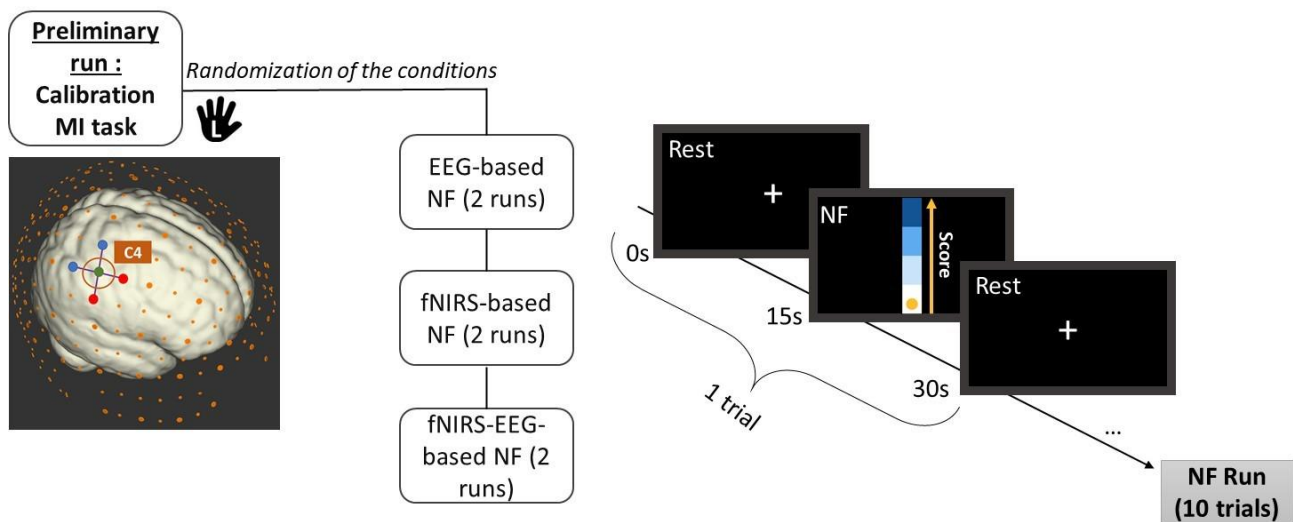


Figure 1. The protocol includes a MI run for calibration, followed by six runs of NF (EEG-fNIRS, EEG-only, and fNIRS-only based NF), with a block design alternating 15s rest and 15s left upper limb MI tasks, with NF scores calculated from right primary motor cortex activity.

References

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