

Toward Portable Neurofeedback of Subcortical Targets: Proof-of-Principle of Inferring fMRI Activity from Simultaneous fNIRS Recordings

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Introduction

Real-time fMRI neurofeedback enables modulation of activity in cortical and subcortical brain regions, but its widespread implementation is limited by high cost, accessibility, and technical requirements. Functional near-infrared spectroscopy (fNIRS) represents a promising alternative due to its portability and lower operational costs and increasing use in neurofeedback applications. Previous studies have demonstrated moderate correspondence between fNIRS-derived hemodynamic signals and fMRI BOLD activity across a range of different tasks. However, these investigations have focused on either the cortical regions with simple correlation analyses [1] or estimated the subcortical activity using information from all available fNIRS channels [5]. Thus, it remains unclear to which extent activity in deep brain structures such as the amygdala, and basal ganglia can be inferred from a small number of task-relevant cortical fNIRS channels.

The present preregistered proof-of-principle study investigates whether subject-independent, task- and region-specific regression models can predict cortical and especially subcortical fMRI activity from simultaneously acquired fNIRS signals from few channels during motor and emotion processing tasks. Furthermore, we evaluate the prediction performance, consistency, and generalizability of these models. It hence lays the methodological foundation for potential future fMRI-informed fNIRS neurofeedback of deeper brain regions [4] as they have been successfully developed for fMRI-informed EEG neurofeedback [3].

Methods

We aim to include at least 20 healthy adults who will attend a single-session recording consisting of two runs of simultaneous fNIRS–fMRI data acquisition (16x16 channels, NIRx Sport2 and NIRx Borealis, NIRx Medizintechnik GmbH, Germany). During each run, participants perform a finger-to-thumb opposition (i.e., motor) task and an active emotion matching (i.e., Hariri) task in event-related design while whole-brain fMRI and frontal fNIRS signals are recorded concurrently.

fNIRS timeseries will be preprocessed with a standard pipeline, which includes motion correction, short-distance channel correction, and band pass filtering in addition to hemoglobin concentration level conversion. MRI scans will be preprocessed via fMRIPrep. Task-relevant fNIRS channels (three for emotion task and four for motor task) are identified separately for each task via GLM. Cortical and subcortical fMRI regions of interest are defined a priori based on previous literature and include cortical motor, prefrontal, cingulate, amygdala, and basal ganglia regions. fMRI BOLD data is mapped onto the MD758 functional parcellation atlas [2], and prediction is done for one parcel from each ROI for each task.

fNIRS-based BOLD timeseries prediction will be performed via Support Vector Regression (SVR) with incremental feature selection (i.e., number of channels and chromophore types). The models will be prebuilt in a combination of all possible number of channels and chromophore types. In other words, models range from single channel single chromophore (i.e., HbO or HbR) to three channels both chromophores. Regression will be performed using participant-level nested cross-validation, with strict separation of training, validation, and test subjects to ensure generalizability across individuals as well as no data leakage between training, validation and test sets. Prediction performance is quantified using Pearson correlation between predicted and observed BOLD time

series for each region of interest in each task separately. Secondary analyses will evaluate overall model robustness and compare prediction stability.

Results

Data collection is currently ongoing. Planned analyses will identify the best-performing regression models for each cortical and subcortical target region during motor and emotion processing separately. Model performance will be quantified as the correlation between predicted and observed BOLD activity across repeated nested cross-validation iterations. Additional analyses will assess model generalizability and consistency across participants.

Preliminary analyses of pilot data ($n = 5$) showed prediction performance comparable to that reported in previous studies [5], despite using fewer channels and an event-related task design rather than the block design employed in earlier work. Specifically, the Pearson's correlation between the recorded BOLD timeseries and the predicted BOLD timeseries (via four fNIRS channels located on left M1, right M1, right pre-SMA, and right DLPFC) were 0.55 and 0.46 for right putamen and right mid cingulum parcels in the motor task, respectively. For emotion task, the Pearson's correlation between recorded and the predicted BOLD timeseries (via three fNIRS channels located on right DLPFC, left DLPFC, and right anterior prefrontal cortex) were 0.40 and 0.52 for right amygdala and right mid cingulum parcels, respectively. Complete analyses will be available at the time of the conference presentation.

Conclusions

This proof-of-principle study aims to establish whether parcel-wise cortical and subcortical fMRI activity can be predicted from simultaneously acquired fNIRS signals using subject-independent regression models based on a small number of task-relevant fNIRS channels and analysis performed on pilot recordings yielded promising results even with a event-related task design.

Demonstrating reliable prediction and future modulation of deeper brain activity would support the feasibility of portable, neurofeedback with a minimum set of fNIRS channels and provide evidence for the potential of fNIRS neurofeedback to target beyond cortical signals, including deeper brain regions [4]. More broadly, the findings will help define the practical limits and generalizability of fNIRS-based decoding for neurofeedback applications.

References (optional, maximum 6)

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