

Spatial Specificity in fNIRS-Based Neurofeedback: An Investigation of dlPFC Regulation and Non-target Brain Activity

Gon Richman ¹, Michael Nevat ³, Tali Bitan ^{1,2},

¹ *Psychology Department, University of Haifa, Haifa, Israel*

² *Speech Pathology Department, University of Toronto, Toronto, Canada*

Introduction

Previous fMRI and fNIRS neurofeedback studies have reported successful upregulation of the dorsolateral prefrontal cortex (dlPFC). However, little is known about the spatial specificity of this effect, namely, whether neural modulation is limited to the target region or expands to other brain areas. Investigating spatial specificity may provide important insights into the neural mechanisms underlying neurofeedback, the design of control conditions, and its clinical application. We examined this issue by conducting a single-session fNIRS neurofeedback training targeting bilateral dlPFC upregulation, while also measuring activation in non-target regions. As the dlPFC and posterior parietal regions are both part of the frontoparietal network and have been shown to coactivate during executive function and working memory tasks, we hypothesized that our training would be associated with increased activity both in the targeted bilateral dlPFC and the functionally connected bilateral posterior parietal cortex. In contrast we did not expect changes in neighboring areas namely bilateral inferior frontal and temporo-parietal areas.

Methods

Sixty-five university students with no history of neurological or psychiatric disorders participated in the study and were randomly assigned to either an experimental group (N = 33) or a control group (N = 32). Participants completed a single 16.5-minute-long fNIRS-based dlPFC neurofeedback training session consisting of alternating 30-second rest and regulation conditions. Both groups were asked to upregulate their brain activity by using a strategy of mental arithmetic, but only the experimental group received real-time feedback reflecting dlPFC activity in the form of a thermometer, while the control group did not receive any feedback. Neural activity was measured in four bilateral regions: bilateral dlPFC, bilateral posterior parietal cortex (PPC), bilateral inferior frontal gyrus (IFG), and bilateral temporoparietal cortex (TPC). The IFG and TPC are not part of the

frontoparietal network and served as non-target comparison regions. The primary outcome measure was task-related HbO activity, quantified using GLM-derived beta values.

Results

In the dlPFC, a trend-level Group $\times$ Condition $\times$ Hemisphere interaction ($p = .054$, $\eta^2p = .06$) was found. Contrary to our hypothesis, follow-up analyses revealed increased left dlPFC activity during regulation compared to rest only in the control group ($p = .034$, $\eta^2p = .137$), and no effects in the experimental group. However, consistent with our hypothesis, the bilateral PPC showed a main effect of condition in the experimental group ($p < .001$, $\eta^2p = .383$), reflecting increased activation during regulation compared to rest, and no significant effects in the control group. In the left IFG, activation was significantly higher during regulation in the control group ($p = .030$, $\eta^2p = .147$), with a similar trend in the experimental group ($p = .064$, $\eta^2p = .110$). No significant effects were observed in the temporoparietal cortex.

Conclusions

Contrary to our hypothesis and to previous studies, the experimental group failed to upregulate dlPFC activity. However, the control group did upregulate activation in left dlPFC and left IFG by merely using a mental strategy, without receiving any feedback. These unexpected findings may reflect methodological differences from previous studies, including the use of a no-feedback rather than sham-feedback control condition and short-separation regression to reduce physiological noise. Despite this, and consistent with our hypothesis, only the experimental group showed increased activity in the bilateral PPC, a key component of the frontoparietal network. These findings suggest that fNIRS neurofeedback engages broader networks rather than region-specific effects. A possible limitation of the study is the lack of control for working memory load and motivation. Altogether, our findings highlight the need to further investigate neurofeedback spatial specificity, the design of the control-group, and physiological-noise correction methods, and may contribute to the understanding of neural mechanisms involved in neurofeedback.