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Exploring fNIRS-guided neurofeedback to alleviate motor symptoms: A proof-of-concept study in Parkinson‘s disease and healthy older adults

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Introduction: Parkinson's disease (PD) is the second most common neurodegenerative disorder and affects up to 3% of people over 80 years, with its prevalence and societal costs expected to rise by 2030 [1]. Motor symptoms such as tremor, bradykinesia and rigidity are due to neuropathological causes, including degeneration of the substantia nigra and the supplementary motor area (SMA) [2]. Current therapies, including medications, exercise and deep brain stimulation, often face challenges such as side effects and varying effectiveness. Neurofeedback (NFB) in combination with motor imagery (MI) offers a promising complementary therapy [2]. Initial findings from fMRI show that NFB can increase SMA activation in PD [3]. After confirming with fMRI that fNIRS reliably measures SMA activity [4], here we test an NFB system with healthy older adults and PD patients to investigate its potential for motor neurorehabilitation [5]. This study is the first to use fNIRS to guide NFB based on changes in deoxygenated hemoglobin (Δ[HbR]) concentration during MI tasks in PD.

Material, Methods and Results: 19 early-stage PD patients (**PD-NFB** group, 63.95 ± 8.41 years, 7F/12M) and 38 healthy older adults participated in the study. Healthy adults were divided into an **NFB** group (63.63 ± 9.04 years) and a **noNFB** control group (63.68 ± 7.75 years), both age- and gender-matched to the PD-NFB group. The NFB groups performed MI of whole-body movements with real-time NFB based on SMA activity (Δ[HbR]), while the noNFB group performed MI without NFB. All participants completed 4 training sessions (S1–S4), with SMA activation assessed before and after training (PRE & POST) using MI without NFB. SMA activation was quantified with GLM-based analyses, incorporating nuisance regressors from short-distance channels and EMG of all limbs to account for voluntary movements.

As shown in Fig. 1, the NFB group had significantly higher SMA activation than the noNFB group during training sessions (S1–S4), especially for Δ[HbR]. SMA activation in the NFB group increased significantly from PRE to S1 ($p < 0.05$), while the noNFB group showed minimal changes. Between-group comparisons revealed significantly higher activation for the NFB group during S1 and S3 ($p < 0.05$). The PD-NFB group showed moderate but non-significant increases in SMA activation during training, remaining lower than the NFB group. Both NFB groups reported positive perceptions of NFB controllability.

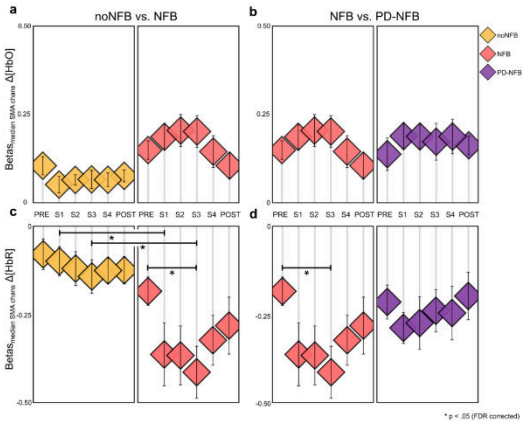

Figure 1 Mean beta values across all runs (PRE, S1–S4, POST) for Δ[HbO] (a, b) and Δ[HbR] (c, d). Panels (a) and (c) compare noNFB and NFB groups, while panels (b) and (d) compare PD-NFB and NFB.

Conclusion: This study demonstrated the feasibility of an fNIRS-guided NFB system targeting the SMA during MI in healthy older adults and PD patients. Results showed that combining MI with NFB significantly enhanced SMA activation in healthy adults, with good perceived controllability reported across sessions. The PD-NFB group exhibited lower and more variable SMA activation, reflecting potential challenges related to disease pathology and individual differences. These findings highlight the potential of fNIRS-based NFB for motor rehabilitation while emphasizing the need for protocol refinements, optimized channel selection, motor improvement assessments, and further testing with a PD-noNFB control group.

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