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The role of agency in neurofeedback performance

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Introduction: Neurofeedback (NF) aims to elicit voluntary modulation of neural activity by providing online feedback (FB). In Motor Imagery (MI) NF, participants reduce sensorimotor activity by imagining movements. Providing FB improves modulation relative to simple MI [1]. Yet, a lot of NF participants fail to learn to modulate targeted activity [2]. Most studies feature abstract FB obscuring the causal link between the MI task and the FB. This may reduce the sense of agency, which is rooted in the consistency between predicted and actual sensory outcomes [3]. FB transparency could increase this consistency, yielding better sense of agency and in turn better NF performance. In this study, we tested this hypothesis in a MI-NF EEG-based protocol with different FB conditions.

Material, Methods, and Results: 23 participants performed right-hand MI with EEG recording (32 active electrodes). They received online FB through three conditions: a pendulum, a virtual hand, a virtual hand and vibrotactile stimulation inducing motor illusion. The amplitude of the pendulum and virtual hand movement was proportional to online β power (8-30Hz) reduction over C3 (above left motor cortex), relative to β reference level at rest. There were 10 NF trials of each condition. We included control conditions of MI alone (without FB) and passive observation of FB stimuli (without MI).

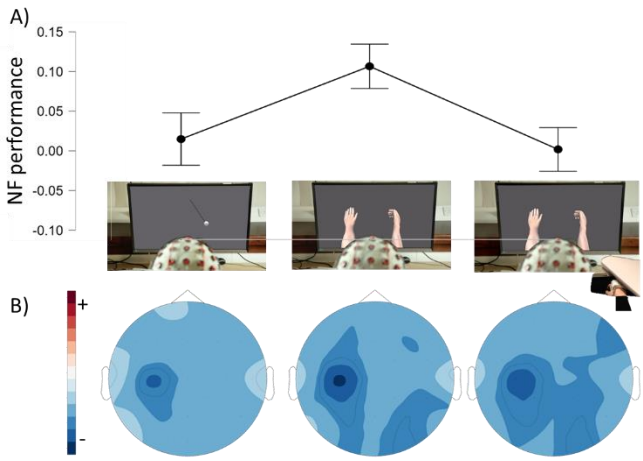

Figure 1. A) NF performance as a function of FB condition (pendulum / virtual hand / virtual hand plus vibration). *Plot of the overall mean NF performance across subjects. Vertical bars = standard error of the mean.*
B) Topographical maps of the ERD in the β band for the 3 FB conditions. *Overall mean of the 23 subjects.*

Participants showed best NF performance with the virtual hand (**Fig 1**). This translated into a stable β reduction pattern during and across trials for this condition. In contrast, the other conditions yielded lower performance that rapidly degraded across trials. Agency was highest in the virtual hand condition. Mediation analysis showed that agency fully mediated the effect of FB transparency on NF performance. In addition, time-frequency analysis showed that event-related desynchronization (ERD) was more focal with the virtual hand than the pendulum and the virtual hand plus vibration conditions, peaking on C3 in the 12-15 Hz SMR frequency band. Control condition analyses showed that this effect was not merely due to the visuo-tactile stimuli used as FB and that MI alone was not sufficient to reduce online β power.

Discussion/significance: Our results suggest that feedback transparency allows better NF performance mediated by agency. Spatio-frequential patterns suggest that practicing with virtual hand FB allows to selectively downregulate SMR activity over motor cortex. These results have important implications for the development of MI NF protocols that foster learning.

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