

Comparing Real-Time fMRI Connectivity Neurofeedback of M1–Thalamus and M1–SMA Pathways during Motor Imagery

Frank Pollick ¹, Yahia Madkhali ², Yingying Huang ¹, Salim Al-Wasity ³

¹ [School of Psychology and Neuroscience], [University of Glasgow], [Glasgow], [UK]

² [Department of Diagnostic Radiography Technology], [College of Applied Medical Sciences], [Jazan University], [Saudi Arabia]

³ [Department of Electrical Engineering], [College of Engineering], [University of Wasit], [City], [Iraq]

Introduction

Real-time fMRI-based neurofeedback enables participants to voluntarily modulate activity within specific brain regions. In the present study, we investigated whether participants could learn to modulate *functional connectivity* between brain regions during a motor imagery task. Specifically, we compared two connectivity targets: primary motor cortex (M1)–thalamus and primary motor cortex (M1)–supplementary motor area (SMA). Although all three regions — M1, thalamus, and SMA — form part of a broader motor network, these two connectivity pathways (M1–thalamus, M1–SMA) represent distinct neural mechanisms. The M1–thalamus pathway primarily reflects cortical–subcortical communication, whereas the M1–SMA pathway reflects cortical–cortical communication. These pathways may differ not only in their functional roles within motor processing, but also in their accessibility to neurofeedback training and their potential utility for motor rehabilitation following neurological injury.

Methods

Twenty healthy right-handed participants were recruited for this study. Neurofeedback training was conducted using a Siemens 3T MRI scanner in combination with Turbo-BrainVoyager software. Prior to neurofeedback training, participants completed the Vividness of Movement Imagery Questionnaire-2 (VMIQ-2), a task-switching paradigm, and a Go/No-Go task. Participants were then randomly assigned to one of two groups ($n = 10$ per group). One group received connectivity-based feedback targeting functional connectivity between M1 and the thalamus, whereas the other group received feedback targeting connectivity between M1 and the supplementary motor area (SMA). Following neurofeedback training across two sessions of 10 runs each, participants repeated both the task-switching and Go/No-Go tasks to assess whether training produced measurable behavioural changes associated with neurofeedback learning.

Results

Both neurofeedback groups showed significant learning-related increases in the targeted connectivity pathway across 20 training runs. The M1–thalamus neurofeedback group showed increased M1–thalamus connectivity, whereas the M1–SMA group showed increased M1–SMA connectivity. A mixed-design ANOVA examining connectivity strength across pathway (M1–thalamus vs. M1–SMA), time (first vs. final run), and neurofeedback group revealed a significant three-way interaction, confirming that connectivity changes differed according to the trained pathway. Follow-up analyses demonstrated selective target-specific modulation, with each group showing significant increases only in the trained connection and no significant change in the untrained pathway. These findings demonstrate the feasibility of selectively modulating distinct cortical–cortical and cortical–subcortical motor circuits using real-time fMRI connectivity neurofeedback. Preliminary analyses of the behavioural data further suggest that targeting different motor pathways may differentially influence motor function.

Conclusions

Participants successfully learned to selectively modulate distinct motor network connections using real-time fMRI connectivity neurofeedback. The findings demonstrate that both cortical–cortical and cortical–subcortical pathways can be independently targeted, highlighting the potential for pathway-specific neurofeedback interventions and supporting future development of personalised approaches to motor rehabilitation.