Volitional control of basal ganglia activity for the treatment of Parkinson's disease

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Introduction: Parkinson's disease (PD) is characterized by motor deficits due to disrupted transmission in the basal ganglia (BG)-thalamus-cortex circuit [1]. This circuit exhibits enhanced neuronal synchronization in the beta frequency band (13-30 Hz) proportional to motor deficit severity and beta synchronization is decreased during treatment by levodopa or deep brain stimulation (DBS) [2, 3]. Disruption to the pathological synchronization through long-term intrinsic circuit modification may lead to symptom improvement. Brain computer interfaces (BCIs) can be used to induce and guide adaptive plasticity through operant conditioning of disease-related brain signals; it may be possible to use BCI technology to reduce PD symptom-severity through operant conditioning of PD-related brain signals.

Material, Methods and Results: The participants are individuals diagnosed with Parkinson's disease who have been selected to undergo surgical implantation of deep brain stimulation (DBS) electrodes as part of their standard-of-care treatment. The signals from the clinical microelectrode recording system are passed into a separate computer running the experimental software that processes the brain signals and presents the tasks through a virtual reality program. This program coordinates the inputs from the clinical neurophysiology equipment and the optical trackers then displays the results through a consumer-grade head-mounted display that allows the participants to perceive his/her true hand location in the virtual workspace.

The experimental protocol comprises three tasks: one to identify subject-specific brain signals, one to train the participant on the identified signals, and another to test the interaction of volitional brain signal control and motor performance. As of this writing, six participants have each completed at least one of the tasks.

The first task requires the participant to perform cued movements to virtual targets. We quickly calculate the brain signal features that best predict behavioural performance (i.e., reaction time, movement time, initial error). The most relevant features have been the beta power and the phase amplitude coupling (PAC) between the phase of the beta-band signal and the amplitude of the high-frequency signal.

In the second task, the magnitude of the brain signal features identified in task 1 are fed back to the participant as the colour of the effector in the virtual environment. The participant is instructed to change the colour to match the colour of the visual cue by imagining smooth movements for blue colour or parkinsonian movements for orange colour. To date, we have used beta power as the control signal and most participants are able to acquire significant control over BG beta power after 30-40 trials.

Finally, in the third task, the effector colour control task is embedded in the cued movement task. This experiment is underway.

Discussion: This work is still underway. Preliminary results indicate that patients with Parkinson's disease are able to acquire volitional control of disease-relevant brain signals. We are now working toward demonstrating that volitional modulation of these signals affect motor symptoms. The short amount of intraoperative training is unlikely to induce lasting changes in the BG-thalamus-cortex circuit but this work is a precursor to the development of closed-loop DBS devices that make available the ongoing basal ganglia activity for prolonged neurofeedback training.

Significance: This work will motivate the development of technology for a novel BCI-based therapeutic device for the treatment of Parkinson's disease.

References

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