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Editorial: Clinical Neurofeedback

Neurofeedback allows a person to see and regulate the signal from their own brain (Cox et al., 1995; deCharms, 2008). Development and testing of this technique is an ongoing international effort, and targets a wide range of mental and neurological disorders. This special issue provides the latest cutting-edge research into the clinical potential of neurofeedback

1. Clinical Trials

The majority of articles in this special issue involve clinical trials of neurofeedback for psychiatric and neurological disorders, with post-traumatic stress disorder (PTSD) and stroke being the most commonly targeted diseases. In individuals diagnosed with PTSD, neurofeedback training to increase the lateral prefrontal cortex response during reappraisal training was associated with symptom improvement, including less negative affect, relative to reappraisal training without neurofeedback (Zweerings et al., 2020). Interestingly, while participants were theoretically trained to increase frontal activity, the experimental group actually decreased both frontal and amygdala activity, which was associated with clinical improvements. The authors hypothesize that the decreased frontal activity was a result of premature strategy selection resulting in increased baseline activation in preparation for reappraisal training. The reduced amygdala response was expected, and another paper in the special issue reported that training to reduce an EEG signature of the amygdala response during the experience of trauma related stimuli showed promising results in a group of patients with PTSD (Fruchtman-Steinbok et al., 2021). This study did not include a sham control group, however, and conclusions regarding the clinical efficacy of this particular neurofeedback protocol cannot be reached.

Several studies also examined the clinical potential of neurofeedback for stroke rehabilitation. Liang et al., 2020 reported that TMS neurofeedback was effective at increasing corticospinal excitability in affected muscles. Bhagat et al., 2020 found that using a brain-exoskeleton interface to translate motion intent (based on EEG and EMG activity) into actual movement was effective at increasing functional movements in participants who had experienced stroke. Finally, Wang et al., 2020 found that 2 of 3 healthy participants could increase IPS activity, and suggest such training could be a new direction for post-stroke hemispatial neglect interventions. In all the stroke studies included in this issue, it is important to note that none included a control group or a long term follow-up. Therefore, while it is valuable to demonstrate initial proof of concept for neurofeedback interventions in these populations, any evidence of clinical improvement should be interpreted cautiously.

Other studies in this issue show the clinical potential of alpha neurofeedback training in reducing pain (Peng et al., 2020), frontal gamma neurofeedback in improving working memory in schizophrenia (Singh et al., 2020), and training to modulate slow cortical potentials relative to treatment as usual resulted in improvement in core symptoms of autism (Konicar et al., 2021).

While larger well-controlled studies are needed, the articles in this issue demonstrate the clinical potential of neurofeedback for several disorders.

2. Mechanisms

There is an interest in how neurofeedback works and the specificity of its effects. A number of papers in this special issue investigated the mechanisms and extended impacts of neurofeedback. It is increasingly evident that regional NF leads to diffuse changes in network connectivity; the impact extends beyond the region targeted. Criaud et al., 2020 found that neurofeedback training targeting the right inferior frontal cortex resulted in increased activation in left fronto-insular-striatal and premotor regions that have been implicated in self-control and self-monitoring. However, this increase was also observed in a control group that received neurofeedback training targeting parahippocampal gyrus activity, suggesting that the ventral attention network is involved in learning to gain control over a signal more generally, and not related to the specific target regions or clinical effects of the intervention. Similarly, Zotev and Bodurka (2020) performed an eLORETA source analysis on data collected during a combined fMRI/EEG neurofeedback task and found widespreadchanges in hemispheric lateralities in prefrontal regions, supporting that training indeed changed the EEG targeted alpha asymmetry. However, these changes were observed in both the experimental and the control group which received sham feedback not based on neural signals, suggesting that the strategy employed by subjects (positive memory recall) and not the specific neurofeedback paradigm was driving these results, though studies with larger sample sizes are warranted.

Nicholson et al., 2020, however, found network connectivity changes specifically related to their neurofeedback intervention. In patients with PTSD, training to decrease alpha amplitude in the parietal cortex improved symptoms and also normalized default mode and salience network connectivity. This effect on connectivity was not observed in the sham control group.

These studies suggest that targeting network connectivity through neurofeedback may be a promising direction for clinical interventions. Indeed, Misaki et al., 2020 suggest a specific connectivity target for MDD that is based on a data-driven approach using resting state data from a large cohort of individuals with mood and anxiety disorders (n=233). They suggest that functional connectivity between the precuneus and

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right temporo-parietal junction is associated with rumination and that decreasing this connectivity may be an effective intervention to reduce rumination in MDD and other associated disorders.

3. Predictors

Studies have consistently found a high degree of variability in NF response across participants. Research is therefore focusing more on understanding or predicting who will respond to a given type of NF in order that interventions can be targeted at those most likely to respond. Several studies suggest that baseline characteristics of the region to be trained are particularly important for determining regulation success and treatment response. Weber et al., 2020 present a review of studies investigating predictors for the outcome of NF training and conclude that characteristics of the pretraining signal are important for NF learning. For example, several studies found larger volume of grey matter as well as higher activity in the to-be-trained region was associated with better neurofeedback learning. They conclude that a certain level of activity should be available before the start of training. The importance of the baseline signal was also emphasized in Lam et al., 2020, who found that higher connectivity in fronto-striatal cognitive control regions predicted better neurofeedback learning of rIFC neurofeedback in children with ADHD relative to a control group who received parahippocampal feedback.

Fewer studies have reported cognitive/clinical factors associated with neurofeedback learning and remission. Pillette et al., 2020 found that in stroke patients, impaired somatosensory abilities interfered with neurofeedback learning and suggest that this variable be taken into account when designing neurofeedback studies for stroke. Krepel et al., 2020 found that decreased hyperactivity was associated with clinical response to QEEG neurofeedback training in ADHD. Weber et al., 2020 conclude that there were no effects of demographic characteristics such as age and intelligence on general NF learning. With respect to biological predictors, Tsuchiyagaito et al., 2021 found that a higher KynA/QA ratio predicted better neurofeedback performance in depressed individuals trained to increase their amygdala response during positive autobiographical memory recall. Further research into predicting on an individual basis whether a participant will likely be able to regulate their brain activity from NF and benefit from the training will be critical for tailoring neurofeedback protocols and increasing their clinical efficacy.

4. Reviews

Review papers have become an important tool for synthesizing the numerous NF studies that have been published. Soekadar et al., 2021 provide an overview of studies using fNIRS and multimodal (fMRIS/MEG) neurofeedback in clinical populations, and suggest that hybrid neurofeedback combining a number of bio-signals is of particular interest and need of further study. Additional reviews in the current issue support the clinical utility of neurofeedback for treatment of addiction (Martz et al., 2020), particularly smoking cessation (Pandria et al., 2020), and more generally in psychiatric conditions (Tursic et al., 2020). All reviews come to the same conclusion; namely that clinical trials using large samples, appropriate controls, and reproducible methods are strongly needed to move the field of clinical neurofeedback forward.

Abstract

Increasing evidence suggests neurofeedback is an effective method of treating a wide range of clinical disorders, including ADHD, PTSD, depression, stroke, autism and schizophrenia. The papers in this issue demonstrate the wide variety of potential uses for neurofeedback, explore the mechanisms underlying its effects, and examine potential predictors of response to neurofeedback. We hope this special issue provides not only an overview of the state of the field but directions for future development of this promising technique.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Kymberly Young[a,*], Heidi Johansen-Berg[b]

[a] *Department of Psychiatry, University of Pittsburgh, School of Medicine, United States*

[b] *Department of Clinical Neuroscience, University of Oxford, United States*

[*] Corresponding author.
E-mail address: youngk@pitt.edu (K. Young).