Drawn to the rhythm

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The research presented in this doctoral thesis explored the role of neural oscillations during attention and learning. The obtained results have theoretical as well as potential clinical implications, which will be discussed hereafter.

The studies of part 1 showcased the causal or functional role of neural oscillations in attention performance and the ability of electrical brain stimulation to modulate it. Our research indicated that the electrical brain stimulation affected voluntary but not reflexive attention processes through modulation of neural oscillations and that these effects are specific to stimulation of a certain brain area. These findings enhanced the research field and broadened our understanding of the functional role of neuronal oscillations in attention. Beyond these fundamental theoretical advancements, the research also shed light on the functional properties of the electrical brain stimulation intervention itself, such as the relevance of an individualized stimulation protocol for the magnitude of the stimulation effects. In chapter 3, we demonstrated that the effects of electrical brain stimulation on attention performance and neural oscillations are most pronounced if the stimulation protocol is individually tailored to the participant's brain. By indicating advancements in the choice of stimulation parameters, this research is immediately relevant for future applications of electrical brain stimulation.

Electrical brain stimulation does not only represent an elegant research tool to explore the causal or functional role of neural oscillations but might also be relevant for clinical applications in patients with neurological disorders. Hemineglect is a disorder of attention, which can arise after brain damage and is marked by a deficit in attending to or being conscious of one side of the surroundings. In part 1 of this thesis, we showcased the general capability of manipulating the focus of attention in space through electrical brain stimulation. The electrical brain stimulation might therefore serve as a potential treatment for hemineglect patients, which focuses on shifting the attention towards the 'ignored' side by directly modulating brain functioning. Future research should test whether the stimulation protocol, as applied here in healthy participants, leads to similar attention effects in hemineglect patients. Our research could serve as a guiding principle for these clinical trials by providing information about the choice of stimulation parameters such as electrode montage and stimulation frequency. Generally, the capability of modulating attention performance through electrical brain stimulation might not only be relevant for the treatment of hemineglect but also other attentional disorders such as ADHD or general attentional impairments following brain damage. Yet it must be noted that our research also hints at shortcomings of potential clinical electrical brain stimulation interventions. We only found a stimulation effect on the neuronal oscillations for the first minute after termination of the stimulation. One could argue that this implies that also the effect on attention performance might fade away rapidly after turning off the stimulation device. Our findings could serve as a starting point for further research that aims at prolonging the after-effects through further individualizing the stimulation protocol and/or through a repeated or extended application of the brain stimulation.

Similar to the studies of part 1, the electrical deep brain stimulation and recording study of part 2 have theoretical as well as potential clinical implications. We showcased that a certain deep structure in the brain, the anterior thalamus, is causally or functionally relevant for visual attention performance and our data support neural oscillations as the underlying mechanism for this process. The results of this unique data set broaden the fundamental knowledge in the research field but are also relevant in the framework of deep brain stimulation treatments. Our results showed a slowing of response times during the stimulation, which might be indicative for potential cognitive adverse effects of a stimulation protocol, similar to the one used for the treatment of epilepsy (Halpern et al., 2008; Schaper et al., 2020). This might have implications for potential contraindications of this treatment and might inspire further research to further explore the cognitive impairments that may accompany the stimulation.

In the study of part 3, we shed light on the oscillatory mechanisms underlying perceptual learning and elucidated the link and potential parallels between attention and perceptual learning. This study crucially enhances the research field and will inform future experiments on this topic. As perceptual learning is fundamental to the rehabilitation of perceptual skills after sensory damage, the theoretical advancements of the presented study might also have indirect clinical implications. Building upon our findings, a brain stimulation study could focus on enhancing the oscillatory mechanisms underlying perceptual learning to boost perceptual performance in patients with perceptual deficits.

To summarize, the research presented in this thesis highlights the role of neural oscillations during attention and learning. This advances the theoretical knowledge in the field and will guide future research on this topic. Additionally, our findings highlight practical issues of electrical brain stimulation techniques, such as the relevance of individually tailoring the stimulation protocol. By showcasing the possibility of modulating attention through electrical brain stimulation, our findings hint at a potential treatment for patients with attentional disorders. Furthermore, we revealed a slowing of response times during a deep brain stimulation protocol, similar to the one used for the treatment of epilepsy, which indicates a potential cognitive adverse effect of the treatment. The research reported in this thesis has been presented at local and international conferences and workshops. The results of the deep brain stimulation project (part 2) were also shown to local medical doctors, who are involved in the surgical implantation and administration of the brain stimulation in epilepsy patients. To share the research findings outside of the scientific community, we presented the results to a broader audience during a local TEDx pitch and regularly communicated the research findings with colleagues, participants, friends, and family.