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Transcranial Direct Current Stimulation to Boost Working Memory

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Summary and conclusion

In the current thesis, I set out to determine (i) the potential use of tDCS to induce lasting and transferable enhancements in WM functioning, and (ii) investigate the possible role of cortical excitability in determining tDCS-induced effects on WM. Excitingly, we found preliminary evidence that if effective, left prefrontal anodal tDCS combined with practice on a challenging WM updating task may induce WM improvements that appear to reflect domain-general learning improvements. Yet, we also observed great variability in tDCS response across individuals. In fact, tDCS may have impaired WM function in some individuals. Moreover, our findings also indicate that the effects of multiple sessions of tDCS are not linearly additive, and spill over effects from previous days may interact with the effects of additional tDCS in daily stimulation.

In this thesis, I also investigated the role of cortical excitability in determining individual tDCS response, and used MRS to quantify cortical excitability based on GABA and Glutamate levels in the prefrontal cortex. However, we found no evidence that baseline prefrontal cortical excitability levels (i.e., 3T-MRS measured Glutamate/GABA ratios) predicted the effects of anodal and cathodal prefrontal tDCS on WM performance. Yet, we also found that current 3T-MRS practices may be insensitive to successfully pick up individual differences in neurotransmitter concentrations that are relevant for behaviour, possibly due to the large brain area over which concentrations are averaged: in contrast to our expectations, prefrontal GABA and Glutamate concentrations did not predict individual differences in WM performance, nor did occipital neurotransmitter levels predict visual discrimination performance.

Increasing the spatial accuracy of both tDCS and MRS methods (e.g., by reverting to HD-tDCS and 7T-MRS) is a crucial step for future studies that aim to examine the neurochemical mechanisms that underlie the effects of prefrontal tDCS on WM functioning. Moreover, a systematic investigation of the optimal parameter setting for tDCS to induce lasting WM improvements is essential if tDCS is ever to be used to enhance WM functioning in everyday life or clinical settings in the future.

Furthermore, while developing this ‘best recipe for success’, it will be crucial to keep an eye on individual differences in tDCS response. In particular, potential interactions of tDCS stimulation with the baseline situation should be taken into account. For this, it is important to concurrently advance our understanding of the mechanisms underlying the effects of tDCS on synaptic-dependent learning mechanisms and behaviour. Only if we succeed to develop tDCS protocols that optimize WM functioning in everyone, may tDCS transcend from a scientific research method to a safe and effective method to counter impaired cognitive functioning in clinical populations.

In the introduction of this thesis, I illustrated the importance of WM in our daily life by describing its role in a situation where you need to make a decision about where to buy a cup of coffee at the train station before you board your train. In making this decision, it is crucial to simultaneously keep all the available options in mind (both the ones that may be visible to you, as well as the ones that you remember) and relate this information to your internal goals and desires at that particular moment. Our WM plays a pivotal role in everyday situations like this, providing us with a mental whiteboard to temporarily store and manipulate information on until we have found the best and most satisfactory solution.

The non-invasive brain stimulation method of tDCS may be a promising method to improve WM in people in which poor WM functioning may affect their everyday lives. However, at the moment, we are still very much in the initial stages of understanding how we may use tDCS to consistently and safely enhance WM functioning in everyone. Eventually, an ethical discussion will also be necessary to determine whether it is desirable to introduce methods such as tDCS into the world to optimize an already well functioning (i.e., healthy) brain, or whether these methods should be reserved for clinical populations in which brain functioning is impaired.

In any case, in the end, application should adhere to strong regulatory standards and presently care should be taken with uncontrolled commercial uses of tDCS devices (Steenbergen et al., 2015). Little is currently known about the potential negative side effects of improving functioning in one brain region or network. Considering the delicate balance of activation of different brain regions both within and between brain networks, tDCS- induced excitation in one network (improving its functioning) may actually be accompanied by inhibition of a different network (possibly resulting in decreased functioning (Wokke et al., 2015)). More research is necessary to gain a better idea of the possible costs or side effects of enhancing functioning of one brain area on functioning of other cortical networks and related functional capacities.

As of yet, for these reasons, I would not recommend widespread application of low-current tDCS stimulation to enhance WM outside of research contexts. However, ultimately, protocols in which prefrontal tDCS is paired with WM training may become a helpful tool to lastingly and generally enhance WM functioning in clinical populations with WM problems.