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The Dorsolateral Prefrontal Cortex, a Dynamic Cortical Area to Enhance Top-Down Attentional Control

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Review of Gbadeyan et al.

The dorsolateral prefrontal cortex (DLPFC) is part of a domain-general network of frontal, parietal, and insular brain regions activated in response to a wide range of demanding task conditions (Duncan, 2013). Both animal electrophysiology and human neuroimaging suggest that, within the DLPFC, flexible neuronal tuning supports top-down modulation of task-relevant processes (Freedman et al., 2001; Duncan, 2013; Erez and Duncan, 2015). Neuroimaging work has demonstrated that the DLPFC implements cognitive control adjustments, contingent on the detection of conflict (Egner and Hirsch, 2005). In complement with these correlational findings, Gbadeyan et al. (2016) assessed whether exogenously increasing the neuronal excitability of the DLPFC using tDCS was associated with an increase in cognitive control.

The authors used a double-blind, sham-controlled approach to investigate the effects of high-definition (HD) transcranial direct current stimulation (tDCS). A total of 120 healthy young participants received HD tDCS over right DLPFC, left DLPFC, or right or left primary motor cortex (M1). The aims were to ascribe a causal role of the DLPFC to cognitive control and to assess hemispheric differences in this function. Participants performed a visual flanker task, in which they had to respond to a centrally presented target (arrow) surrounded by distractor stimuli that were associated with either the same (congruent, arrow pointing in the same direction) or a different (incongruent, arrow pointing in the opposite direction) response to the target stimulus. In this task, slower response times (RTs) are observed for incongruent compared with congruent trials (Eriksen and Eriksen, 1974). A measure of cognitive control in this task is the magnitude of the "conflict adaptation effect" (Botvinick et al., 2001), according to which the flanker effect is markedly reduced after incongruent trials and increased after congruent trials.

Gbadeyan et al., 2016 found both a robust flanker effect (faster RTs for congruent trials than for incongruent trials) and a conflict adaptation effect (a larger flanker effect after congruent trials than after incongruent trials). Crucially, the conflict adaptation effect was enhanced when activity in the DLPFC was exogenously increased using tDCS. There were no differences in the effect of right and left DLPFC stimulation on the conflict adaptation effect, and stimulation of M1 over either hemisphere did not alter this measure of cognitive control.

These findings corroborate previous fMRI work, which has shown increased DLPFC activity during cognitive control (MacDonald et al., 2000; Egner and Hirsch, 2005), and they provide novel evidence suggesting that the prefrontal cortex plays a causal role in enhancing conflict adaptation. One caveat to the study, however, is that participants who received tDCS over right DLPFC had significantly slower RTs than those who received tDCS over left DLPFC. tDCS is known to interact with already active neuronal populations (Fertonani and Miniussi, 2016). Baseline differences in task performance are therefore of potential importance, calling into question the interpretation that lateralization of the DLPFC did not play a role in cognitive control processes in the present study. This is of particular relevance given discrepancies in the neuroimaging literature regarding lateralization of the DLPFC in cognitive control (MacDonald et al., 2000). One aspect contributing to the diversity of findings might be differences in the type of stimulus material and tasks used in the studies. Paradigms that are sensitive to lateralization of cognitive functions, such as tasks with laterally presented stimuli often used in the assessment of visual processes (Habekost and Rostrup, 2007), might be better suited to detect potential hemispheric asymmetries in cognitive control.

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An important question arising from the causal role that the DLPFC plays in cognitive control adjustments, as demonstrated in the present study, regards the neural mechanisms behind this effect. Previous neuroimaging work (Egner and Hirsch, 2005) has suggested that cognitive control adjustments are associated with an increase in DLPFC activity in concert with enhanced activation in target-specific processing regions in higher-order visual areas. We suggest that the enhanced conflict adaptation effect during stimulation of the DLPFC observed in the present visual flanker task is likely achieved via increased top-down attentional modulation over early visual processes, thus facilitating the deployment of attentional resources to the relevant change in the presented stimulus (i.e., to the target following incongruent trials and the distractor following congruent trials). Anatomical and functional connections among frontal, parietal, and occipital regions exist (Chechlacz et al., 2015; Marshall et al., 2015), and increased activity in visual occipital areas are often observed concurrently with enhanced prefrontal activity (Erez and Duncan, 2015). Furthermore, evidence from correlational neuroimaging studies suggests that the DLPFC exerts top-down modulatory control over early visual attention processes (Zanto et al., 2011). Specifically regarding conflict adaptation, previous imaging work (Egner and Hirsch, 2005) has identified increased functional coupling between a subregion of the DLPFC and extrastriate visual regions during processing of the target stimulus (i.e., activity in the fusiform face area during the processing of target face stimuli). However, whether stimulation of the DLPFC indeed increases the conflict adaptation effect via the modulation of visual attention processes remains to be explored. Future work combing HD tDCS with neurophysiological techniques such as simultaneous tDCS-EEG recordings will shed light on this issue, for example by assessing whether stimulation of the DLPFC is associated with enhanced visual evoked potentials to the task-relevant stimuli.

Gbadeyan et al. (2016) have demonstrated the feasibility of HD tDCS to effectively upregulate the DLPFC in cognitively healthy younger adults. Whether this technique could be used to enhance the excitability of prefrontal regions in individuals with suboptimal cognitive capacities to remediate performance is an exciting avenue for future research. The DLPFC is a flexible cortical region, which makes it an attractive target region for neurorehabilitation of cognitive function. The cortical region has a capacity for adaptive compensation following unilateral stroke (Voytek et al., 2010). Similarly, enhanced recruitment of the DLPFC in older adults is considered an adaptive response to age-related declines in early sensory regions to process visual information (Davis et al., 2008). Of significance, the DLPFC plays a crucial role in the speed at which visual information is processed (Habekost and Rostrup, 2007; Chechlacz et al., 2015). Visual processing speed is impaired in many clinical populations (Habekost, 2015) and is increasingly considered a biomarker of cognitive aging (Ritchie et al., 2014). Future studies should extend the work presented by Gbadeyan et al. (2016) and assess whether prefrontal tDCS can ameliorate cognitive deficits occurring in both healthy and pathological aging.

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