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Influences on the beneficial effect of neurostimulation

Kevin T. Jones\textsuperscript{a,b}, Filiz Gözenman\textsuperscript{a} & Marian E. Berryhill\textsuperscript{a}

\textsuperscript{a} Department of Psychology, Program in Cognitive and Brain Sciences, University of Nevada, Reno, NV, USA
\textsuperscript{b} Department of Neurology, Center for Aphasia Research and Rehabilitation, Georgetown University Medical Center, Washington, DC, USA

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Influences on the beneficial effect of neurostimulation

Kevin T. Jones1,2, Filiz Gözenman1, and Marian E. Berryhill1

1Department of Psychology, Program in Cognitive and Brain Sciences, University of Nevada, Reno, NV, USA
2Department of Neurology, Center for Aphasia Research and Rehabilitation, Georgetown University Medical Center, Washington, DC, USA

Neurostimulation, such as transcranial direct current stimulation (tDCS) shows promise in improving and maintaining cognition in both neurotypical and patient populations. This technique administers small amounts of electric current through the cortex to modulate the excitability of underlying neurons (Nitsche & Paulus, 2000, 2001). tDCS has some advantages over other neuroimaging and neurostimulation techniques because it is safe, well tolerated, and more affordable. However, recent findings suggest that tDCS may not work equally well across all individuals. First, we administered anodal tDCS to the prefrontal cortex (PFC) in healthy older adults prior to performing a WM task. Interestingly, we found that only the more educated half of our participants showed a WM benefit following tDCS (Berryhill & Jones,2012). Second, in young adults, we found that right posterior parietal cortex (PPC) tDCS prior to a visual WM recognition task benefited participants with a high WMC (WMC) only (Jones & Berryhill,2012). The question emerged as to why group differences would predict WM benefits following tDCS. We hypothesize that these findings demonstrated differences in strategy and motivation level in WM tasks across our participants.

Previous research implicates differential WM strategy use between participants with a high and low WMC. Those with lower WM capacities are more distractible (Unsworth, 2007), and have fewer attentional resources. Furthermore, high WMC participants are more likely to adopt efficient strategies.
However, when provided effective instruction regarding strategy use, low WMC participants had rescued performance. These findings suggest that in low WMC participants there can be a failure to spontaneously apply effective WM strategies. This suggests that providing effective strategy-related instructions may lead to greater WM benefits following in low WMC participants.

One alternative possibility is that low WMC participants were also under motivated participants. When motivated by monetary incentives, neuroimaging studies demonstrate differential processing in the PFC. Behavioural performance on WM trials significantly improve when monetary gains are higher and modulated late-trial processes in the electroencephalogram (EEG) signals (Sanada, Ikeda, Kimura, & Hasegawa, 2013). Regions in the PFC and visual association cortex are differentially activated based on motivation levels (Krawczyk & D’Esposito, 2013). In addition, differential processing in the ventromedial PFC is observed based on the perceived value of a stimulus (Kringelbach & Rolls, 2004). However, other research has demonstrated that financial motivation cannot expand WMC (Zhang & Luck, 2011).

Here we predicted that raising motivation level might extend tDCS-linked WM benefits to those who previously demonstrated no benefit, the low WMC participants, by countering disengagement. The following experiments address two questions. First, can instruction in WM strategy extend tDCS-linked WM benefits to low WMC participants? Second, can increasing motivation by monetary gains extend tDCS linked WM benefits to low WMC participants? We hypothesized that in both cases we would find significant tDCS-linked improvement in WM performance for low WMC participants. We also predicted an increased cortical response at the stimulated PFC site, as measured by functional near-infrared spectroscopy (fNIRS), which would correlate with behavioural benefits.

There were two counterbalanced sessions of tDCS: anodal (active) and sham (control). Neurovascular recordings used a continuous wave fNIRS system, which measured neural activity at two wavelengths (690, 830 nm; 50 Hz sampling). We used a simple array of a single emitting source with three detectors spaced around the source (spaced 2.6 cm from the emitter) to measure the haemodynamic response in the PFC. WMC was determined by performance on the Operation Span task. Participants then completed a preliminary WM task prior to tDCS. The task required participants to view four novel geometric stimuli (3° visual angle, 1000 ms), which were followed by a 5000 ms delay period. Next, a single probe item appeared in one of the four locations from the initial stimulus presentation and participants made a button press judgement on whether the item was old or new (2000 ms). After the preliminary task, the fNIRS system was removed from the left PFC and tDCS (anodal or sham) was applied to the same location. Following tDCS, the fNIRS headband was reapplied to the left PFC and participants completed the strategy (Experiment 1)
Figure 1. The functional near-infrared spectroscopy difference scores. The difference scores for HbO levels between the preliminary task and each of the tDCS and motivation conditions for the high and low WMC groups at Channel 1, 2, and 3. The high WMC group showed little to no change in HbO levels from preliminary across both tDCS and motivation conditions. The low WMC group showed an increase across both tDCS and motivation conditions at each of the three channels. Bottom left: The raw HbO levels during the preliminary task. The high and low WMC group had significantly different HbO levels at Channel 1 during the preliminary task, \( t_0 = 2.23, p = .05, r^2 = .36 \), although not at Channels 2 (\( p = .20 \)) and 3 (\( p = .17 \)). To view this figure in colour, please see the online issue of the Journal.
or motivation (Experiment 2) task. The strategy task was the same as the preliminary task, with new strategy instructions. Participants were instructed to internally rehearse and name the objects during the delay period of the active strategy blocks. During passive blocks, participants were instructed to refrain from verbal rehearsal. The experimental design in Experiment 2 was the same as in Experiment 1, with the following modifications. First, the blocks varied by financial reward rather than strategy blocks. Participants completed blocks of trials with low ($0.01 per correct trial) and high ($0.25 per correct trial) incentive. Participants were not penalized for incorrect trials.

Experiment 1 revealed that supplying an effective verbal rehearsal WM strategy only improved performance in the high WMC participants, replicating our previous findings. Questionnaires after each session confirmed that the participants complied with the strategy instructions. Furthermore, changes in cortical blood flow before and after tDCS followed a similar pattern: Only the high WMC participants showed an increase in oxygenated blood (HbO) following anodal tDCS (Figure 1).

Experiment 2 showed that financial incentives sufficiently raised WM performance. Following anodal tDCS, the low and high WMC groups had improved performance in the high motivation condition. While the fNIRS data demonstrated little to no change in HbO levels from the preliminary task in the high WMC group, the low WMC group showed a significant increase in HbO levels across both motivation and tDCS conditions. This finding demonstrated that introducing incentives to low WMC participants could provide a tDCS-linked WM benefit to the low WMC participants equal as that garnered by the high WMC participants. These findings give hope to the notion that tDCS may be effective for inducing broad cognitive improvements; however, careful attention to participant strategy and motivation level are important in order to avoid negative or null findings. Further research is required to predict the ideal parameters for each task and population tested in tDCS paradigms.

REFERENCES


