Contribution of Far Field Effects of Cortical tDCS in the Cerebellum to Learning in an Object Detection Paradigm

Aaron P. Jones1, Michael C. Trumboo2, Brian A. Coffman3, Michael A. Hunter4, Charles S.H. Robinson5, Angela Combes6, Mohamed Abouseria7, Kinsey Steuterman8, Vickey Musser8, Alexander David9, Marom Bikson10, & Vincent P. Clarke11

1Psychology Clinical Neuroscience Center, The University of New Mexico, Albuquerque, NM, USA 2Department of Psychology, The University of New Mexico, Albuquerque, NM, USA 3University of Pittsburgh School of Medicine, Department of Psychiatry 4Department of Biomedical Engineering, The City College of New York, New York, NY, USA

Background/Previous Studies

We have previously used tDCS guided by neuroimaging to examine the brain basis of learning to detect objects hidden in a complex visual environment (Figure 1). Training resulted in an increased difference between object present and object absent images in right frontal and parietal cortices, and reduced activity in occipital-temporal regions bilaterally, among other regions (Figure 2). 2.0 mA anodal stimulation over right parietal (P4) or right inferior-lateral frontal cortex (F10) or cathodal stimulation over left lateral temporal cortex (T5), all vs. a non-scarifier return electrode, increased participants’ ability to detect hidden objects, with effect sizes (Cohen’s d) ranging from 1.10 to 1.83 for F10, 0.79 for P4, and 1.28 for T5 (Clark et al., 2012; Coffman et al. 2012; Clark et al., 2013) at UNM, and for a replication at another university (GMU, Fatoune et al. 2012). Pilot studies using F10 vs. T5 or F10 vs. left lateral frontal cortex (F9) have shown smaller effects so far, with effect sizes of 0.19 and 0.21, respectively.

Finite element modeling (FEM) simulations were performed to investigate the predicted electrical field effect under these various montages (Figure 3). Modeling simulations showed that the less effective protocols did not stimulate the cerebellum, among other regions. The cerebellum was targeted here with tDCS to examine if it effects contributed to our prior findings on learning this task using electrodes placed over other brain regions, but which FEM modelling predicted would also produce effects in the cerebellum.

Finite element modeling (FEM) simulations were performed to investigate the predicted electrical field effect under these various montages (Figure 3). Modeling simulations showed that the less effective protocols did not stimulate the cerebellum, among other regions. The cerebellum was targeted here with tDCS to examine if it effects contributed to our prior findings on learning this task using electrodes placed over other brain regions, but which FEM modelling predicted would also produce effects in the cerebellum.

Results

Figure 1: Example stimuli for the object detection paradigm. Top: No concealed objects present. Bottom: Concealed objects present.

Figure 2: fMRI results showing object present–absent across learning stages. Red/yellow = increased activation. Blue/green = decreased activation.

Figure 3: Finite element modeling of the more effective 2.0mA anode F10, P4 and 2.0mA cathode T5 vs. contralateral arm montages predicts large effects in the cerebellum, whereas only small effects are seen with the F10 anode vs. T5 cathode placements that were less effective. 2.0mA over the cerebellum vs. left arm predicts a field effect in the cerebellum similar to that found for the more effective compared to less effective montages.

Table 1: Summary of experimental design.

<table>
<thead>
<tr>
<th>Group</th>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sham</td>
<td>Sham</td>
<td>No stimulation</td>
</tr>
<tr>
<td>Anode</td>
<td>Anodal</td>
<td>2.0mA anodal</td>
</tr>
<tr>
<td>Cathode</td>
<td>Cathodal</td>
<td>2.0mA cathodal</td>
</tr>
</tbody>
</table>

Table 2: Summary of experimental design.

<table>
<thead>
<tr>
<th>Group</th>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sham</td>
<td>Sham</td>
<td>No stimulation</td>
</tr>
<tr>
<td>Anode</td>
<td>Anodal</td>
<td>2.0mA anodal</td>
</tr>
<tr>
<td>Cathode</td>
<td>Cathodal</td>
<td>2.0mA cathodal</td>
</tr>
</tbody>
</table>

Figure 4: Upper panel: An increase in performance rates observed across groups from baseline for both immediate (mean difference = 0.180, p < 0.0001) and delayed (mean difference = 0.153, p = 0.0001) tests. A decrease was observed across groups between the immediate and delayed tests (mean difference = -0.027, p = 0.011). A significant time by group interaction was observed as well (F(2,21) = 3.371, p = 0.035), where performance was significantly reduced from immediate to delayed tests for the cathode and sham groups, but not the anode group. Other than this, no significant effect of tDCS condition was observed.

Lower panel: Immediate and delayed learning scores. No significant group differences were found between active and sham groups.

Discussion

We have previously found that different tDCS montages produce different magnitudes of effect sizes on learning to detect objects hidden in complex visual environments. Some of these differences suggest that brain areas far from electrode sites might be involved. Finite element modeling of effective vs. ineffective tDCS electrode placements suggested that differences in the level of cerebellar stimulation might contribute to the behavioral differences previously observed.

However, here we found that stimulation targeting the medial cerebellum directly did not produce a significant improvement in performance or learning compared to sham (Figure 4), with effect sizes (Cohen’s d) for immediate and delayed learning of 0.027 and 0.017 for the anode group, and 0.027 for the cathode group, respectively. This suggests that the cerebellum might contribute a small amount to the overall effects, but not to a significant degree. Anodal stimulation over the cerebellum did increase retention after an hour break compared to the cathode and sham groups.

To our knowledge, this is one of the first studies to systematically compare models of the anatomic locations of electric fields among montages producing different behavioral effects in order to infer which brain regions are involved in a behavioral response to tDCS, and using this information to guide additional studies in order to confirm these predictions.

Other regions, including the inferior temporal lobes, are suggested by FEMs to have greater field effects in effective vs. ineffective protocols, which could be tested in additional studies.

Participants

- 30 total subjects (21 female, mean age = 21.22 years, 5.29 SD) participated in the study.
- Group assignment was as follows: 12 active (2.0mA) anode, 12 active (2.0mA) cathode, and 12 sham (0.1mA).
- tDCS was delivered for 30 minutes during the first two of four training blocks.
- Double blinding was achieved via a custom made 6-switch box.