Transcranial Direct Current Stimulation (tDCS): Predicted Current Densities in a Realistic Head Model

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Abstract

ICDs has been used increasingly for clinical and research purposes. It has been assumed that the most significant current densities occur in brain regions underneath the stimulating electrodes and that these regions are physiologically most relevant. We simulated current densities achieved in the entire cerebrum with a commonly used electrode pattern ("stimulation" electrode at F3, "reference" electrode in the right supraorbital region). Although current densities achieved near these electrode locations. The other major factor was the existence of an anisotropy, arising from examining aspects of working memory and language that have used precisely these locations (Fregni et al. 2005, Iyer et al. 2005).

Methods

Our model was based on the Zubal phantom (Zubal et al. 1994). This three-dimensional representation of an adult human head comprised 62 manually segmented compartments. Data inputs for the Zubal phantom were obtained from a 1.5-T MRI scan of a normal subject. Slices spanned the head from its apex to the roof of the mouth. The overall model had 120 axial slices containing tissue, each slice having 256 × 256 voxels. The overall dimensions of the model were 282.2 cm × 282.2 cm in each transverse plane and 16.8 cm axially. The total volume of tissue in the model was 365.8 ml. Each voxel had dimensions of 1.1 mm × 1.1 mm in the transverse plane and a thickness of 1.4 mm. We defined white matter, striatum, cortex, tetal, fat, subcutaneous fat, muscle, connective tissue, bone, blood, and skin. The surface was assigned to the brain compartments, skull, or muscle. Instead, a composite value derived from longitudinal and transverse conductivities was applied to white matter and muscle tissue. We also compared the results from this composite value with an intermediate white matter value replaced with literature values measured transversely or longitudinal to white matter fibers to determine the sensitivity of results to the conductivities chosen.

We chose these locations to simulate based upon a number of factors. One was the clear anatomical and presumed functional distinction between the structures that might be activated by these electrode locations. The other major factor was the existence of an anisotropy, arising from examining aspects of working memory and language that have used precisely these locations (Fregni et al. 2005, Iyer et al. 2005).

Results

Maximal current densities observed within the head were of the order of 0.8 mA/cm². Figure 2 shows log-scaled current densities in cerebral tissue resulting from the F3-RS electrode placement, and with skin, skull, and fat tissues masked out. Large current densities were evident in both left and right areas adjacent to the anode and cathode. Larger current densities are apparent in the right frontal area than in the left frontal areas. This can be clearly discerned in images of slices 56, 58, 60, and 62. As expected, the median current densities were much higher in the white matter than in the gray matter. Current densities in other tissues near electrodes such as fat and bone were comparatively low because of their lower conductivity. Regions generally considered more relevant to language, learning, and memory (Figure 3) experienced moderate current densities, with those in IFG and DLPFC having the largest densities of these regions. Less current was present in the occipital lobes than in more frontal areas (Figure 4).

Discussion and Conclusions

Both the F3-RS and F4-LS montages produced large current densities near both stimulation and reference electrodes, as expected. While the F3-RS montage produced large current densities in both the left IFG and left DLPFC, those formed by the F4-LS montage were larger in the left DLPFC and overall current densities in both structures were higher using the F4-LS montage. The F3-RS and F4-LS montages were not symmetric as expected, which most likely reflects the effects of variability of conductivity distribution as well as electrode size and shape. It remains to be determined whether such variations distribute current differently and whether in different anatomic situations, and whether the functional-neuroanatomical conclusions of such studies need to be altered. The F3-RS simulation together with the increased current density in left target areas found using the F4-LS montage does suggest that attempts to target the left inferior frontal gyrus may not be achieved by the application of current to F4 and to the left supratemporal, rather than to F3 and the right supratemporal region, as has been supposed. In addition, use of a F4-LS montage might be better employed to target the DLPFC. Current densities in DLPFC and IFG were as a result of the F3-RS montage were higher, although of the same order of magnitude as those in other brain structures considered.

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