Current Amplitude during Trans-cranial Direct Current Stimulation within Brain in Relation to Thickness of Surrounding Matter

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Abstract

As Transcranial Direct Current Stimulation (tDCS) research grows in popularity as a safe method to aid in improving the ability to cope with neural system disorders, to promote rehabilitation after brain trauma and to improve cognitive function in aging adults, it needs to be known how the treatment varies between patients and how this can be standardized. Currently, it is the convention to give recipients a dose determined via educated guess in the range of 1-2 A/m. Due to the uncertainty of the amount of current reaching the brain, there may not be any notable effect on the patient. The goal of this research was to determine how tDCS treatment among adult subjects varies and determine if it can be standardized. To determine this, 4 anatomically correct brains derived from MRI scans of actual people were computationally modeled and subsequently simulated using Finite Element Method modeling (FEM). This facilitated being able to see how the current would behave inside the head during tDCS stimulation. The amount of matter the current passed through to reach the grey matter was measured at 24 locations per model and were compared to the amplitude of the electric field in the grey matter. These results have shown that there is a correlation between the amount of matter between the sponge of the electrode and the cerebral spinal fluid (CSF) of the brain. In order to standardize the current flow, a formula was derived. This formula was found to increase the similarity of results among subjects.

Table of Contents

List of Tables

List of Figures (make section heading)

Introduction

Transcranial Direct Current Stimulation (tDCS) is currently being investigated for its ability to help enhance and repair the human brain. While a large number of trials are being conducted, there is no convention in place to standardize the currents used in tests. This led to discrepancies among subjects. The reason that there is no universal convention is that anatomical makeup can vary greatly between subjects (Giedd, Raznahan, Mills, & Lenroot, 2012).

While the current guideline of not individualizing currents does not seem to pose a risk (Truong et al., 2013), doing so is not a reliable way to get consistent results as the flow of the applied current will vary depending on each individual's anatomy (Datta et al., 2012).

As demonstrated in Truong et al. (2013), there is a correlation between the amount of fat on the head and the current amplitude within the brain. The study found that the resistance of the electrical current increased as the body fat increased. This study tried to normalize the amplitude of the electric field in the brain by taking each individual's body mass index into account, however they were unable to accurately predict the outcome using this method. However, given the correlation found in the study between head thickness and current resistance, there could be a way to normalize the current amplitude within the brain without taking body mass index into account that could be reliable. In order to conduct this research, there needed to be a way to visualize what the amplitude of the electric field was in the brain during simulation along with the path that the current would take. The most widely accepted and accurate process for accomplishing this is using a finite element method (FEM) model generated from anatomically correct MRI scans.

Materials and Methods

Head Model Creation

The models used for simulation were derived from MRI scans of actual people, making them as anatomically correct as possible. These scans were imported into Simpleware ScanIP, a medical image processing software designed for this type of process. The imported scan was positioned in three dimensional space. The images were then processed layer by layer in each of the three directions, adding a mask for each type of matter (skin, bone, CSF, grey matter, white matter, fat and air). These masks will later each be assigned their corresponding electrical properties. This ScanIP file was then opened in ScanCAD, a standalone application from the same developers designed to manipulate CAD (computer aided design) objects and place them in ScanIP files. Two 5cm by 7cm electrode models and two sponge models of the same size were imported into the application. The electrodes were placed on top of the sponges and were then moved as a group into the M1-SO stimulation position. The cathode was placed in the M1 position, above the left ear and over the motor cortex. The anode was placed in super orbital (SO) location, above the right eyebrow. This electrode configuration was chosen due to its common usage and wide application. Once the placement of the electrodes and sponges was completed, the model was exported back to ScanIP. Here the four new masks, one for each electrode and one for each sponge, were Boolean subtracted with the masks of the head. This fits the sponges and electrodes to the contours of the head and eliminates any overlapping of the layers. The masks were then added to a finite element (FE) model in the following order, skull, air, skin, fat, CSF, gray matter, white matter, sponges and electrodes. This order was chosen due to the process in which ScanIP generates FE meshes and subsequently smooths them, it allows for the highest fidelity among the most important areas of the model, allowing for a more accurate model overall.

Electrical Properties

Once the FE mesh was generated by ScanIP, it was imported into COMSOL Multiphysics® 4.3 and each mask was assigned its corresponding material properties as shown in Table 1. These values were derived from the study Wagner et al. (2007), which are currently the accepted values for use in simulation.

Simulation

The mesh files were imported into COMSOL Multiphysics's Physics module, using a stationary electric currents solver in three dimensional space. This solver calculates the electric current given a normal current density and a grounding surface given a constant current. Once the mesh was imported and the masks had been assigned their properties, the cathode was assigned as the outermost face on the electrode in the M1 position. The normal inward current density was then calculated. In order to do this, the surface area of the cathode was calculated using a built in function. The result, given in square millimeters, was converted into square meters. The desired current was divided by the surface area in order to obtain the inward current density (A/m^2). The anode was then defined as the outermost face on the electrode in the SO position. Once all of these parameters were defined, the solution would be computed.

Normalization

In order to normalize the current amplitude, the resulting amplitude of the electric field was compared to the amount of matter between both the anode and the cathode and the CSF surrounding the brain in about 24 locations per head. The CSF was chosen as the boundary due to the fact that it is more uniform across the brain than the grey matter which has numerous folds, along with its high electrical conductivity. These thicknesses were plotted against each other (Figure 1) and their averages were computed. This comparison allowed for a formula to be determined that fit the curve, which was developed by analyzing the differences between heads compared to thickness and developing a curve around the data. This formula was then tested in other subjects to determine its validity. The first simulation of each model was computed with a current of 2A/m, these were used as a baseline. The current was then adjusted using the formula and re-computed.

$$a = \frac{t^2 - .2t + 41.45}{100}$$

Figure 2 Current adjustment accounting for thickness *t*

The models' simulation results were then displayed in a three dimensional grid with a rainbow color scheme depicting the intensity of the current amplitude across the grey matter. The grey matter was selected to be shown as it is what this study is interested in normalizing. These normalized results are shown in Figure 4 along with their related thicknesses.

Results

The preliminary results of the computational simulation were in agreement with Truong et al. (2013) and Datta ,Baker, Bikson & Fridriksson (2011) in that there was a definite correlation between thickness of matter between the electrode sponges and the CSF of the heads. This is demonstrated in Figure 3 which shows the baseline simulation using 2mA and the average thicknesses under the electrode sponges in both the M1 position and the SO position. The research also went on to find that the current can be adjusted using the formula in Figure 2 in order to normalize the resulting current amplitude within the brain. The application of this formula was able to bring other simulations to be much more in line with each other, eliminating the extremes of the results. Besides the extremes, models that were initially similar to each other also saw an increase in uniformity

Discussion and Conclusions

The results of this inquiry showed that using a normalization formula would allow for much more consistent current flow through the brain. This is important in helping to eliminate discrepancies between research groups caused by increased impedance by the thickness of the head due to variation among individuals. Although only 4 head models have been tested at this time, since they all showed increased similarity after the formula in Figure 2 was applied, there is justification for further study.

This study did not account for the safety of higher currents necessary to obtain higher current amplitude in subjects that have more matter that the current needs to pass through. Although the resulting current amplitude within the brain is at a safe level and would not cause brain damage, as it is in line with other subjects who receive a 2mA current, it may cause discomfort or pain in the skin to which the electrodes are attached. This aspect of the method investigated in the paper also warrants further investigation.

In conclusion, while this method may allow for a standardization of current amplitude across subjects, it is not clear whether doing so is safe in heads which have a large thickness between the CSF and the electrode sponge. If this is deemed safe, however, this method allows for a way to obtain more consistent results among a wide range of subjects with an increased certainty of correctness.

Works Cited

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Tables

Table 1

Electrical Conductivities and Relative Permittivities

Material	Electrical Conductivity (S/m)	Relative Permittivity (F/m)
Air	$1x10^{-15}$	$1x10^{-15}$
Skin	0.465	$1.2 x10^{-7}$
Fat	0.025	$1.2 x10^{-7}$
Skull	.01	$0.8 x10^{-7}$
CSF	1.65	$0.6 x10^{-7}$
Grey Matter	0.276	$1.2 x10^{-7}$
White Matter	0.126	$1.2 x10^{-7}$
Electrode	$5.99x10^{7}$	5.99x107
Saline-soaked Sponge	1.4	$0.6 x10^{-7}$

Note. Electrical Conductivities and relative permittivities used in this study were derived from Wagner et al., 2007.

Figures

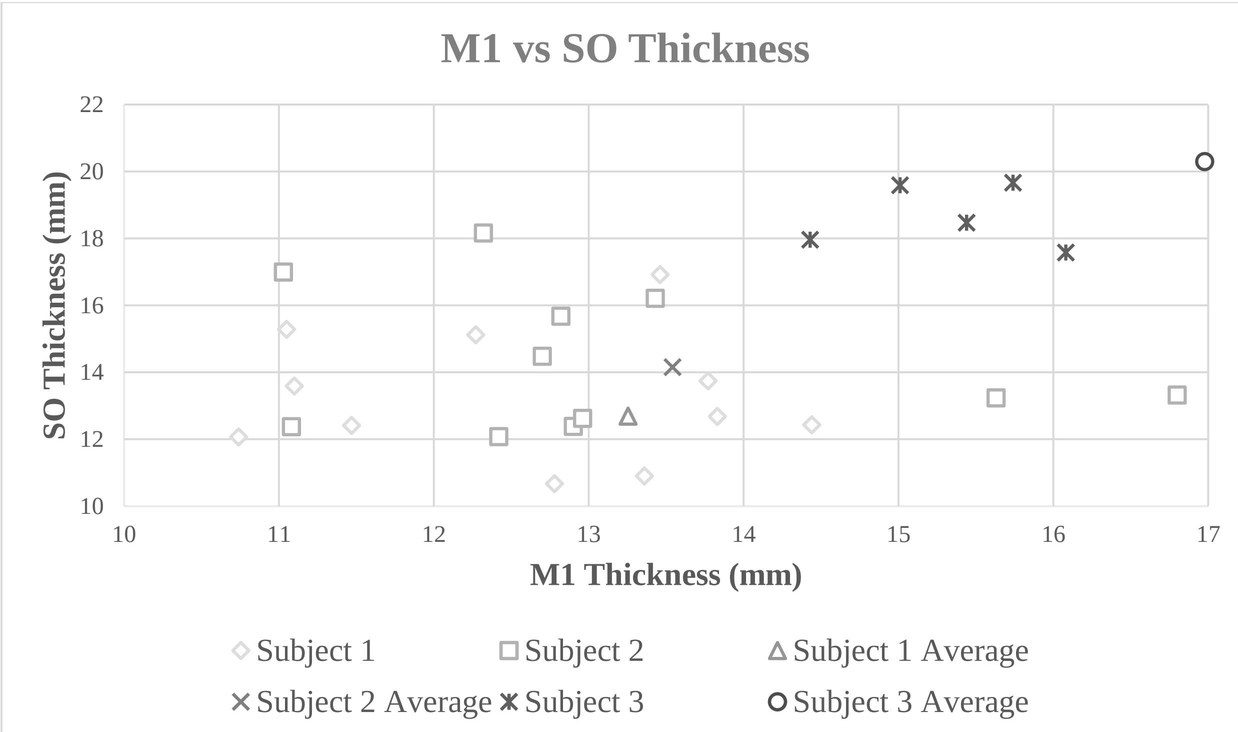

Figure 1. Scatterplot of thickness of matter under the M1 electrode sponge and the SO electrode sponge plotted against each other including averages of the data from each head.

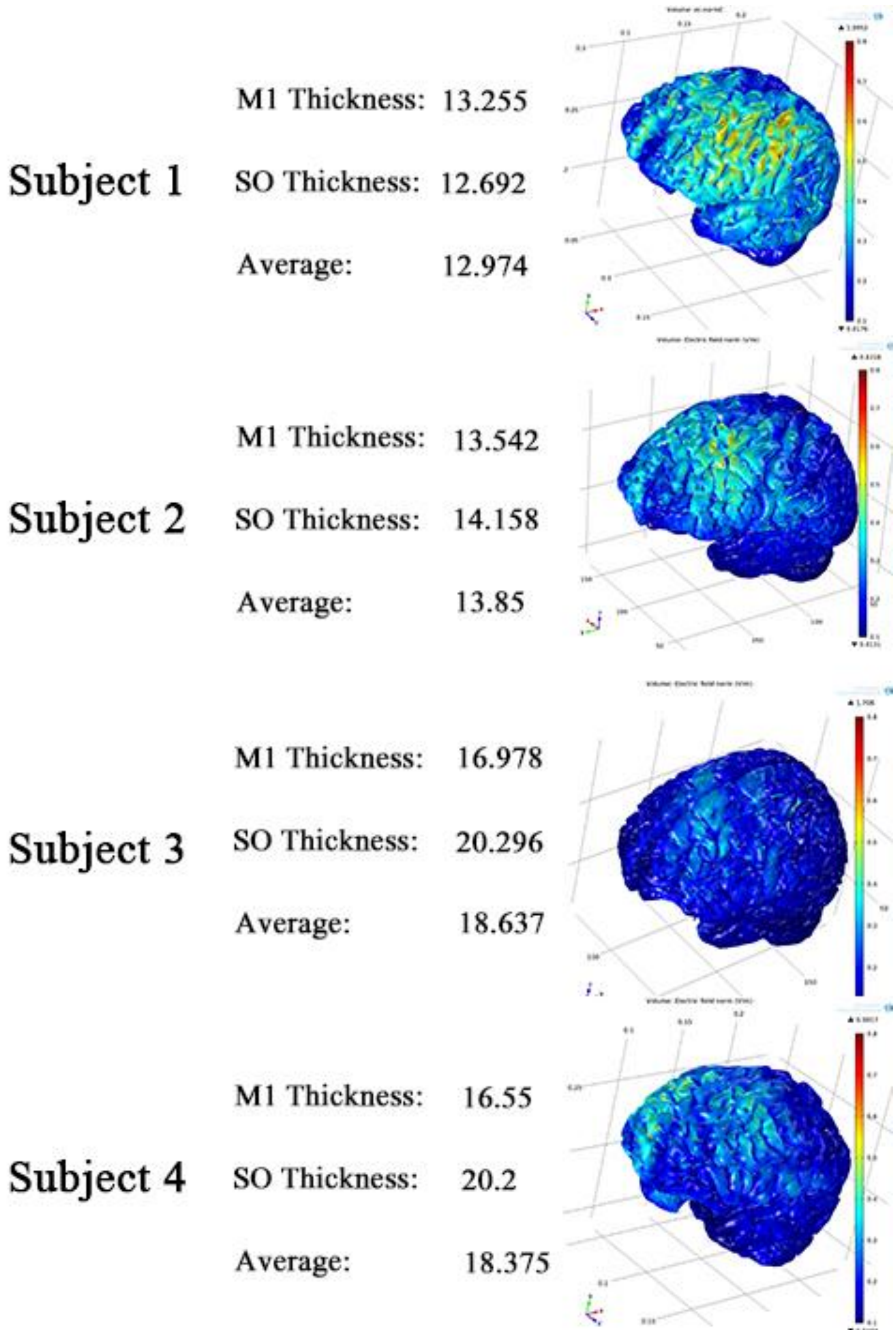

Figure 3. This figure depicts the results of the head simulations and their corresponding thicknesses which were deemed as the baseline. These were all simulated using a current of 2A/m with a scale of .1V/m to .8V/m.

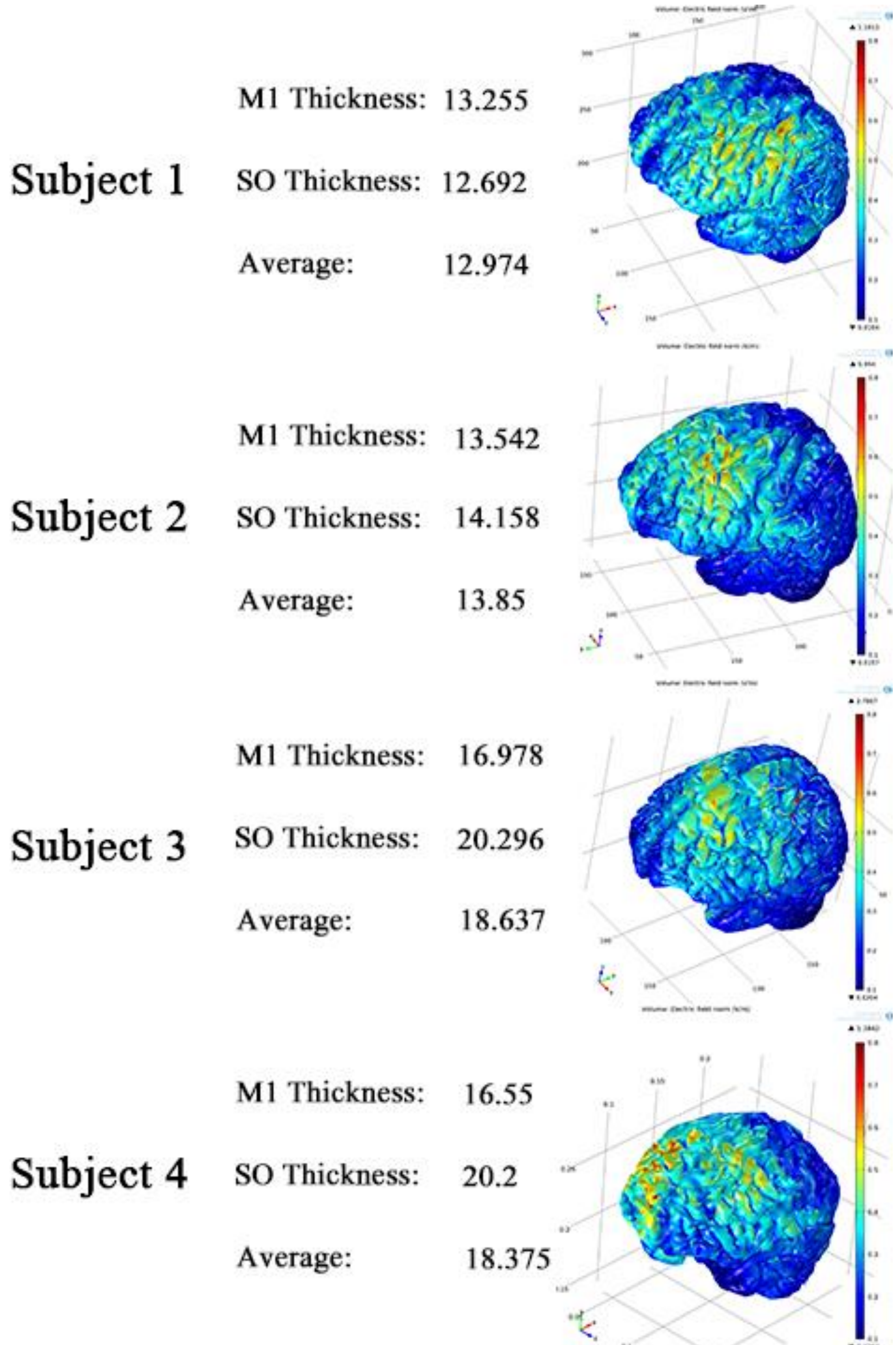

Figure 4. Current amplitude in brains after applying normalization formula. The scale is from .1 to .8 V/m