

# In-vivo Mapping of transcranial Direct Current Stimulation(tDCS) of Human Brain using MRI

Mayank V Jog<sup>1</sup>, Robert Smith<sup>2</sup>, Kay Jann<sup>2</sup>, Walter Dunn<sup>3</sup>, Allan Wu<sup>2</sup>, and Danny JJ Wang<sup>2</sup>

<sup>1</sup>Biomedical Engineering, University of California Los Angeles, Los Angeles, California, United States, <sup>2</sup>Neurology, University of California Los Angeles, Los Angeles, California, United States, <sup>3</sup>Psychiatry, University of California Los Angeles, Los Angeles, California, United States

**TARGET AUDIENCE:** Neuroimaging scientists and clinicians interested in tDCS

**PURPOSE:** Transcranial Direct Current Stimulation (tDCS) is a neuromodulation technique. Hypothesized to affect cortical excitability, tDCS has been found to facilitate clinical treatments (e.g., stroke<sup>[1]</sup>, depression<sup>[2]</sup>, pain relief<sup>[3]</sup>) and enhance cognition (e.g., math<sup>[4]</sup>, verbal working memory<sup>[5]</sup>). A typical tDCS setup involves placing electrodes over the scalp and driving a constant, low (~1mA) electric current. To date, however, the in-vivo distribution of the current density remains an open question, with most of the research focused on mathematical modeling. Visualizing the current density distribution through imaging would enable us to improve the efficacy and targeting of tDCS on an individual basis.

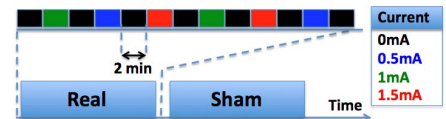


Fig 1. Concurrent tDCS-MRI Protocol

**THEORY and METHODS:** Two sponge electrodes (5cmX10cm) wetted with conductive gel were secured bilaterally over the primary motor cortex areas. Electrical current through tDCS was applied in two blocks (single blinded) –Real and Sham (Fig 1). Ampere's law states that these electrical currents should induce a linearly dependent magnetic field, a component of which along the B<sub>0</sub> direction can be measured as a phase change using MRI. tDCS stimulation was applied concurrently with MRI data acquisition. (Quadrature volume coil, field mapping TE1/TE2=4.92/14.76 msec, TR=1.15 sec, FA = 25°, 65 slices, 2x2x3mm<sup>3</sup> Voxel, Matrix: 128 x128, BW=750 Hz/pix ). The order of applied electrical currents was counterbalanced. Sham involved 20 sec. of tDCS stimulation at each step before imaging.

Statistical Analysis: We modeled our measured phase ( $\Phi_{\text{meas}}$ ) as

$$\Phi_{\text{Meas}} = \Phi_0 + \Phi_{\text{Current}} + \Phi_{\text{Non-Current}} + \Phi_{\text{Drift}} + \Phi_{\text{Motion}} + \Phi_{\text{Noise}}$$

Here,  $\Phi_0$  is the initial phase post RF excitation,  $\Phi_{\text{Current}}$  is the induced phase linearly dependent on applied electrical current,  $\Phi_{\text{Non-Current}}$  is TE dependent, applied-current independent phase gain (flow, chemical shift),  $\Phi_{\text{Drift}}$  accounts for inter-scan drift of the main magnetic field (B<sub>0</sub>) and  $\Phi_{\text{Motion}}$  is the phase induced by inter-scan subject motion.

Acquired data was smoothed to a final resolution of 6x6x3mm<sup>3</sup>. Phase gained between two echoes was used, eliminating the possible confound of  $\Phi_0$ . A voxelwise linear regression analysis was performed with applied current as the predictor variable. Drift and motion were covariates modeled as a linear function of time and change in Euclidean distance between successive timepoints respectively (based on rigid motion correction). The results of the regression analyses were thresholded by the following in addition to p<0.05 by linear regression model:

1. Noise floor constraint: Phase gained due to largest applied current should be at least twice the standard deviation of the model error residuals.
2. Directionality constraint: Differences between mean phases due to successively applied currents should be of the same sign.

**RESULTS:** Fig 2. shows R-value map for Sham and Real blocks, thresholded as discussed above. No significant voxel clusters showed up in the Sham session. In contrast, during Real stimulation session we observed significant phase changes highly correlated with applied current in widespread frontal and parietal regions (Fig 2). Fig 3a shows raw data for one such significant voxel from the Real block. Fig 3b, 3c and 3d show scatter plots of motion, drift and applied current respectively against data corrected for all other model variables for the same voxel.

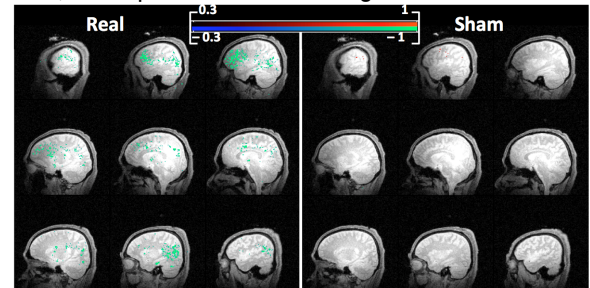


Fig 2. Thresholded R(Pearson correlation coefficient) map

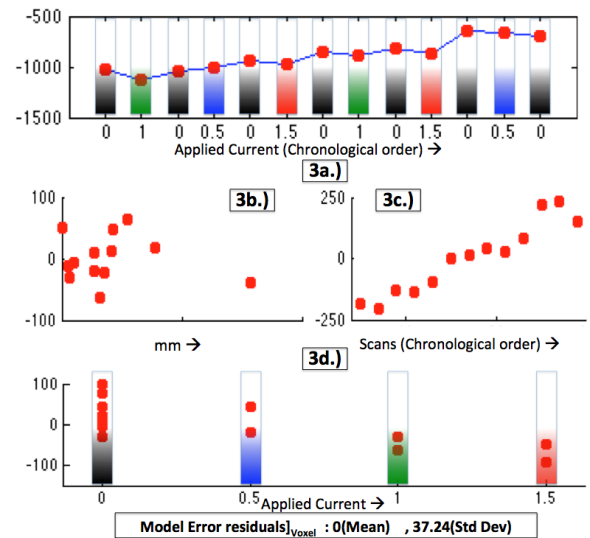


Fig 3. (a) RawData from a significant voxel. Data regressed with all other model variables v/s Control Variable(CV), CV = Motion (b), Drift (c), Current (d)

**DISCUSSION and CONCLUSION:** Our findings provide direct imaging evidence that current passes through the brain parenchyma under tDCS stimulation (instead of shunting through the scalp). Furthermore, the scatter plots (3b,c) provide support to our inclusion of drift and motion as covariates in our model. For a reasonable SNR<sub>Magnitude</sub>, the phase noise is Gaussian. Consequently, enforcement of the Noise floor and directionality constraint, to a certain degree, account for potential false positives (Fig 2). To date, we have collected data from 3 participants with some inter-subject variability. Visualizing current through the scalp may be challenging using our method due to unreliable phase data arising from partial volume effects. Nevertheless, simulation using a Biot Savart law based model of a current flowing through a line-conductor predicts the decay of this effect over 10mm (5voxels). In contrast, the clusters we observe are widespread and located deeper in the brain parenchyma. This gives us confidence that we may have observed, for the first time, direct electric current flowing through the human brain using concurrent tDCS and MRI.

## REFERENCES:

- [1] Fregni F, et. al., Neuroreport. 2005; 16(14):1551-5 [2] Fregni F, et. al., Bipolar Disord. 2006; 8(2):203-4 [3] Fregni F, et. al., Pain. 2006;122(1-2):197-209. Epub 2006 Mar 27 [4] Cohen K. R. et. al., Curr Biol. 2010; 20(22):2016-20 [5] Boehringer A et. al., Brain Stimul. 2013; 6(4):649-53