Optimized Multi-electrode Transcranial Direct Current Stimulation Targeting of Human Somatosensory Network

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Abstract

Transcranial direct current stimulation (tDCS) is a noninvasive method that delivers current through the scalp to enhance or suppress brain activity. The standard way of applying this methodology is by the use of two large sponge electrodes on the head surface and delivering an electrical current through these electrodes. The resulting electric fields stimulate a broad region of the brain distributed over brain networks. Recently, multi-electrode transcranial direct current stimulation has been used to stimulate a specific brain region of interest (ROI) which requires an acceptable trade-off between focality and intensity of the electrical current. However, the position of the brain target is mainly considered and not the orientation when stimulating with multi-electrode tDCS. Here we particularly emphasize the importance of orientation of the target in effective brain stimulation to achieve significant excitatory or inhibitory effect. We have chosen the generators of the somatosensory network, namely P20/N20 component, located at the Broadman area 3b as our target for stimulation. Each component in the network can be modeled as a single dipole source with a fixed position and orientation. Initial simulation results show that the configuration of optimized electrodes changes for different subjects having different target orientations to achieve an optimum tradeoff between focality and intensity at the target.

Simulated current density and technical parameters of TES applied with a flexible cap

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Conventional transcranial electric stimulation (TES) mostly facilitates rubber electrodes manually attached to the scalp with rubber bands. This procedure is burdensome for participants and staff, lacking reproducibility and limiting montages to a few electrodes.

The aim of this study is twofold: we introduce a flexible cap with 19 fixed electrode positions and provide a framework for determining the distribution of stimulation currents across those electrodes.

We designed a flat knitted cap of flexible fabric with 19 integrated stimulation electrodes of silver-coated polyamide threads with electrolyte reservoirs that are encapsulated by diffusion barriers of silicone. Each electrode is squared with 9 cm² in size, and the positions are distributed according to the international 10-20 system. We compared the novel cap with a conventional rubber band electrode application in 10 volunteers. We monitored position changes of 4 electrodes in each setup for 30 min.

To compute the distribution of the stimulation currents for the novel cap, we used the framework of Helmholtz reciprocity. We targeted dipole triplets at 7 positions in the brain. In a five compartment finite element head model, we evaluated the scalar electric potential. Based on the potential at the stimulation electrodes, we used the maximally activated electrodes (narrow configuration) or considered the spread of the potential (wide configuration). We compared the current density distribution of narrow and wide configurations by means of intensity and orientation relative to the target. Comparing positions of the conventional rubber band and the new cap electrodes, drifts of 7.4 ± 3.8 mm in rubber band

comparing positions of the conventional rubber band and the new cap electrodes, drifts of 7.4 ± 3.8 mm in rubber band and 2.0 ± 0.9 mm in the cap electrodes were found. Stimulation configurations generated mean electric field strength of 0.1 V/m at targets with mean cosines of angles between dipole and electric field of 0.55 (narrow) and 0.7 (wide).

With our present development, we provide a flexible cap and an individualized distribution of stimulation currents for multiple electrodes.

Modeling the origin of TMS motor evoked potentials and their sensitivity to model parameters

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Transcranial magnetic stimulation (TMS) allows for non-invasive stimulation of the human cortex. However, its exact neurophysiological mechanisms remain elusive and it is difficult to predict which neuronal populations are actually stimulated, leading to considerable variation in the observed effects.

It is our goal to localize the stimulated cortical regions and reveal the involvement of radially and tangentially oriented cell compartments including uncertain model data.

TMS stimulation was performed in 15 healthy participants while recording motor evoked potentials (MEPs) for different coil locations and orientations. By increasing the stimulator output, we determined the inputoutput MEP curves. For every condition, the electric field was calculated numerically using the finite element method using high-resolution realistic head models with anisotropic conductivity profiles derived from individual MRI datasets. A congruence measure between the condition wise E-MEP curves is determined in every finite element. For all subjects, the hotspots of the congruence factor are lying in the M1 region and thus confirm anatomic functional expectations. The individual results are mapped to the group template and do confirm the former observations. It was found that the tangential component of the electric field close to the gyral crowns plays a major role in TMS.

The results support the notion that the direct stimulation targets are interneurons rather than pyramidal cells. With the methodology presented, it is possible to improve the localization of stimulated areas during TMS. Moreover, the causal field components leading to a successful stimulation are identified, which enables the possibility for targeted optimization.

Calibrating skull conductivity using combined analysis of EEG and MEG in a sphere model

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The optimization of transcranial brain stimulation and the accuracy of electroencephalography (EEG) source reconstruction strongly depend on the conductive properties of human head tissues, especially on skull conductivity. However, this parameter shows a high variability between and within subjects and is hard to determine in practice. Here, we introduce a new method based on Aydin et al. (doi: 10.1371/journal.pone.0093154) to estimate skull conductivity and test it in a 4-layer sphere model. For a given skull conductivity and set of test dipoles, the analytical and numerical solution of the EEG and magetoencephalography (MEG) forward problem is calculated, with noise added to the numerical solution these are used as a reference. Subsequently, the skull conductivity is reconstructed using an optimization procedure that exploits the advantages of combined EEG and MEG. For the forward calculations in both EEG and MEG, we use the finite element method which is implemented in the software toolbox *duneuro* (http://www.duneuro.org). The results show that, except for deepest sources at eccentricity 0.1, both the Venant and the partial integration source model are able to reliably reconstruct skull conductivity. Additionally, the relative error tends to increase for lower signal-to-noise ratios (SNR), but even for reference data with an SNR of 2 dB, it stays below 0.16 except for the deepest sources. Thus, this method is a promising new procedure to reliably and non-invasively estimate skull conductivity and should further be evaluated in realistic head models and measured EEG and MEG datasets.

Recovering event-related oscillations during concurrent tACS-MEG

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Introduction

Transcranial alternating current stimulation receives growing popularity as a tool to modulate brain oscillations in a frequency specific manner and to study causal relations between these oscillations and cognition. However, so far mechanisms of tACS especially during stimulation are poorly understood as a strong electro-magnetic artifact is introduced to electrophysiological measurements. Recent work demonstrated that the application of LCMV beamforming leads to a strong, yet imperfect suppression of this tACS-artifact in MEG recordings. Such imperfect artifact suppression results in the presence of residual tACS-artifacts, which in turn limits the range of meaningful analyses that can be performed. Here we demonstrate how the careful analysis of event-related oscillatory dynamics during a cognitive task (mental rotation), accompanied by appropriate control analysis can still provide valuable insights to tACS effects during stimulation.

Methods

MEG of twenty-five volunteers was continuously recorded. After 10 minutes of baseline measurement, they received either 20 minutes of tACS at individual alpha frequency or sham stimulation. Another 40 minutes of MEG were acquired thereafter. Data were projected into source space and carefully examined for residual artifacts.

LCMV projected MEG data show a clear presence of residual artifacts, indicating an imperfect suppression of the tACS waveform. Contrasting pre- and post-stimulus intervals, however, recovered stimulus induced alpha suppression during tACS. Results revealed strong facilitation of event-related power modulations in the alpha band during tACS. Data provide first direct evidence, that tACS may not counteract top-down suppression of intrinsic oscillations, but rather enhances pre-existent power modulations within the range of the individual alpha (=stimulation) frequency.

Conclusions

The combination of tACS with MEG can provide important insights into tACS online effects than can help to predict behavioral outcomes of the stimulation. However, experiments require careful design and appropriate control analysis to account for residual artifacts after beamformer projection.