Intracranial measurement of electric fields in monkeys and humans reveal spatiotemporal structure of transcranial electric stimulation

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Introduction

Transcranial electric stimulation (TES) is an emerging technique to non-invasively modulate brain function. However the spatiotemporal distribution of electric fields during TES remains poorly understood, and some question how much current actually reaches the brain. In this study we perform intracranial measurements of the electric field generated by each of two common TES modalities (transcranial direct current stimulation [tDCS], transcranial alternating current stimulation [tACS]) in epilepsy patients and a cebus monkey to investigate its spatial and temporal characteristics.

Methods

Patient recordings

Four presurgical refractory epilepsy patients, with intracranially implanted electrodes participated in a single TES session. Two sponge electrodes (25cm2) were attached over the left and right temporal and a current of 1mA was applied for 2 min. We measured electric fields of tDCS and tACS with frequencies of 1Hz, 5Hz and 10Hz.

Monkey recordings

Three electrodes, with a total of 32 contacts (5mm apart) were permanently implanted through a skull incision over the left occipital cortex with posterior-anterior orientation. In multiple sessions intracranial EEG was recorded during TES. Small round stimulation electrodes (3.14 cm2, Ag/AgCl with conductive gel) were used in all sessions. We systematically varied the current strength to test for linearity of the conducting medium. To investigate the temporal course of electric fields during tACS and to test for possible frequency dependent effects on field strength or phase shifts, we parametrically varied the frequency of stimulation from 1 Hz to 150 Hz.

Results

We found a linear relationship between the input current and the recorded intracranial voltage, thus indicating a linear resistive medium. Analysis of the frequency response indicated that power magnitude slightly decreased with stimulation frequency . We observed only very small phase differences up to 3 degrees. We found measured potentials to be in accordance with predictions from computational models with spatially continuous varying potentials from the anode to the cathode for each montage.

Discussion

We conducted a comprehensive evaluation of the intracranial electric field during TES in both human patients and monkeys. Our results indicate that TES currents spread in a linear ohmic manner. Capacitive effects are if present very small. We observed small frequency dependent attenuation of recorded signals. Our measurements can be useful for optimizing stimulation protocols and to understand physiological or behavioral effects from TES experiments.