Westfälische Wilhelms-Universität Münster

Cells in Motion Cluster of Excellence

IBB Institute for Biomagnetism and Biosignalanalysis

Volume conduction and optimized stimulation protocols in transcranial current stimulation

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Introduction

It has been shown in standard tCS approaches that a widespread current density activation pattern with often strongest current densities in non-target brain regions is induced [1,2] and Fig. 2. Consequently, the aim of sensor optimization approaches is to optimize the focality, orientation and intensity of current density at the target location, while minimizing current density in the remaining brain.

Methods

➢ The current density $J = \sigma \nabla \Phi$ is calculated using a Laplace equation $\nabla \cdot \sigma \nabla \Phi = 0$ with inhomogeneous Neumann boundary conditions at the electrode surface [1,2].

➢ A six compartment (skin, skull compacta, skull spongiosa, CSF, gray and white matter) geometry-adapted hexahedral finite element head model with white matter anisotropy (6CA) was generated and two sponge-like tCS electrodes (7x5 cm²; 4mm thickness) were placed on the head surface.

➢ We also use a low-parametric three compartment (skin, skull, brain) version (3CI) of the (6CA) head model to show tCS volume conduction effects.

➢ For sensor optimization, we fix 74 electrode locations (locations of a 10/10 EEG system) on the head surface.

➢ We use the alternating direction method of multipliers [3] to calculate an optimized stimulation protocol at the fixed surface electrodes by minimizing an L1 norm subject to appropriate constraints (which ensure patient safety and focused stimulation in the pre-defined target region).

➢ Direct validation of our approach is given by tCS forward calculation using the optimized stimulation protocol and visual inspection of the results, i.e., current density in the brain.

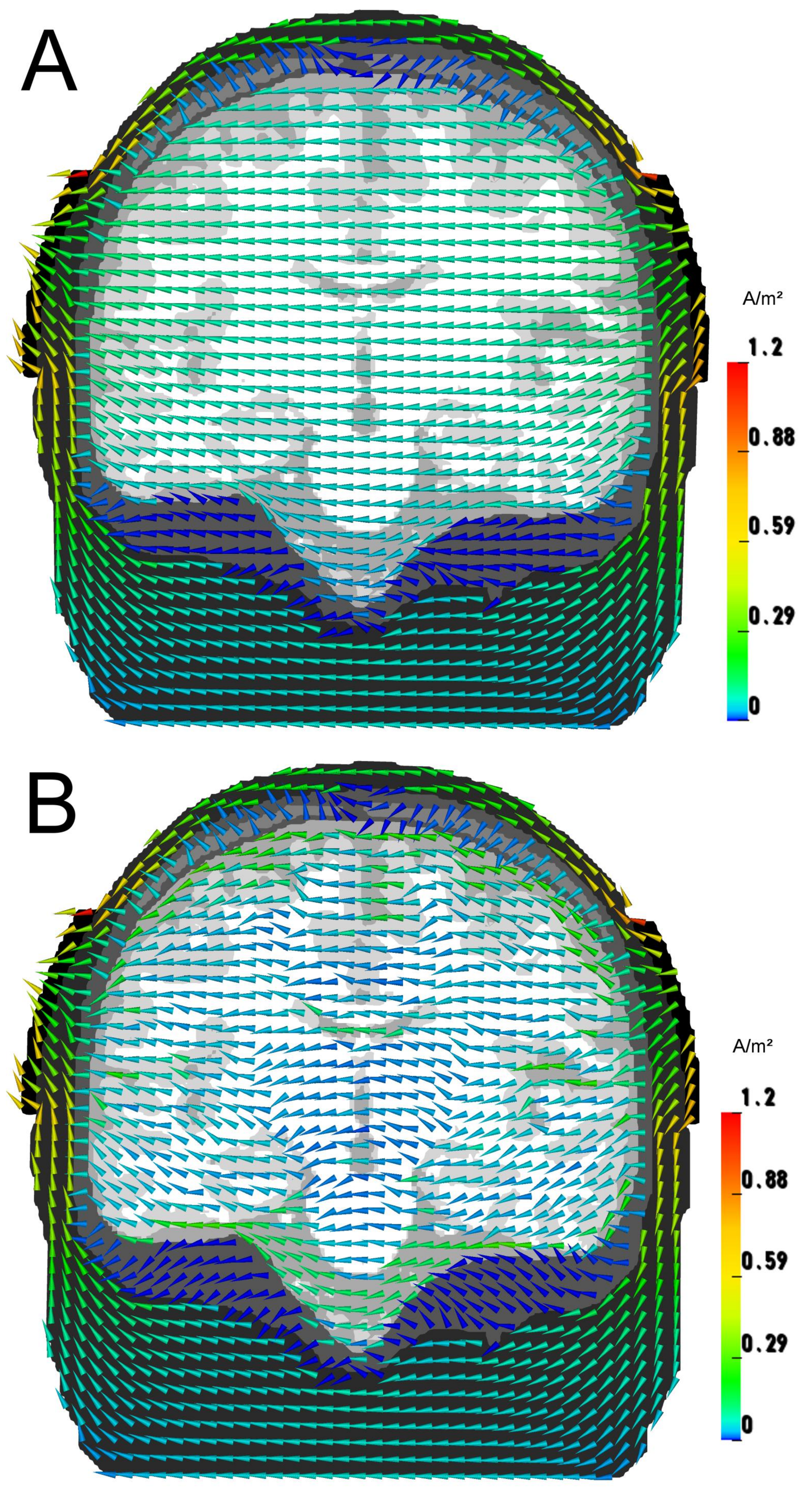

Figure 1.
Current density (A/m²) as a vector field for the 3CI (A) and 6CA (B) head model on a slice through the auditory cortex. We use size-normalized cones to represent vector orientations and color-coded the cones to represent amplitudes (on a 4x4 FE block).

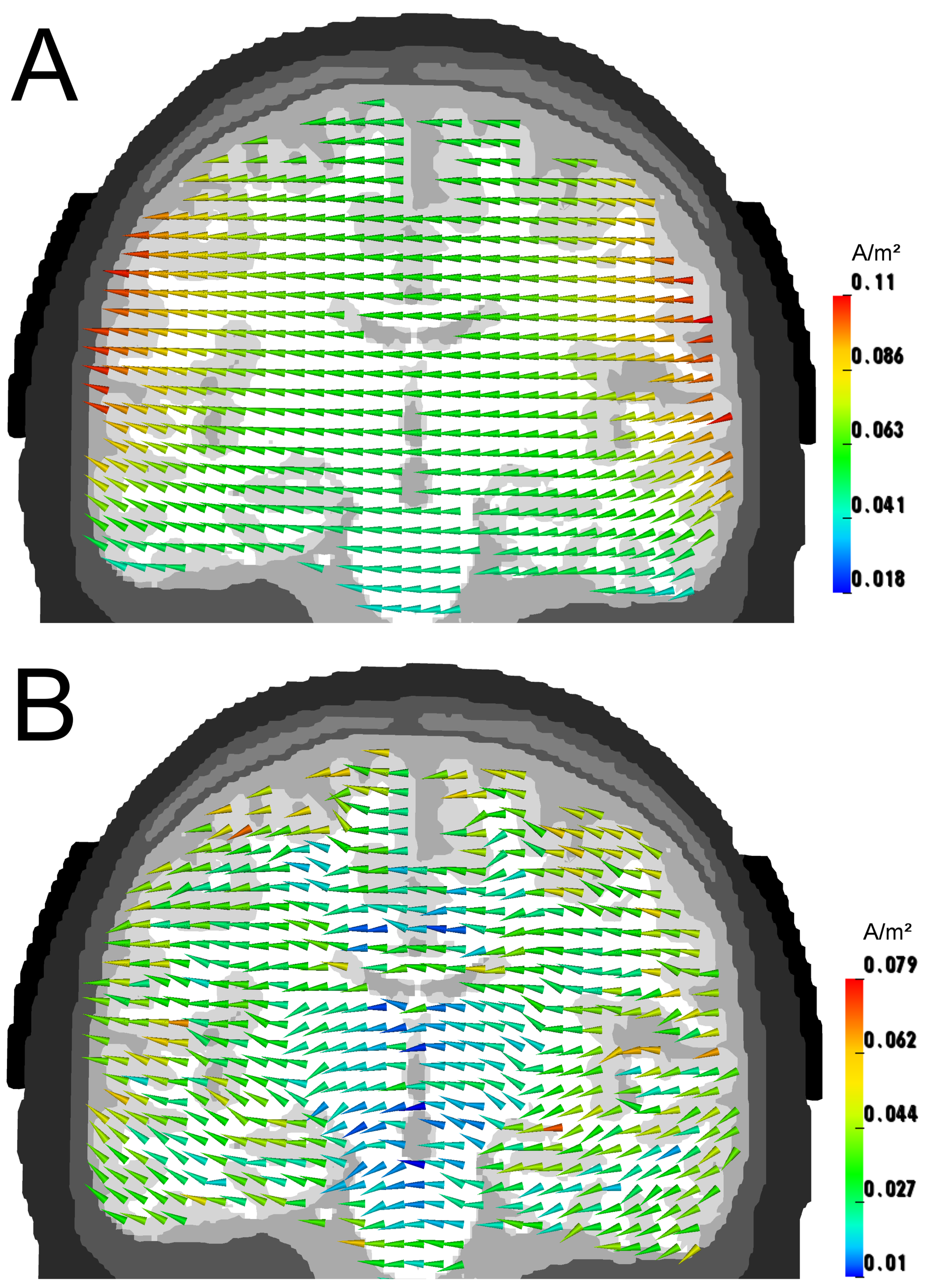

Figure 2.
Current density in the brain compartments. See caption of Fig. 1 for further explanation.

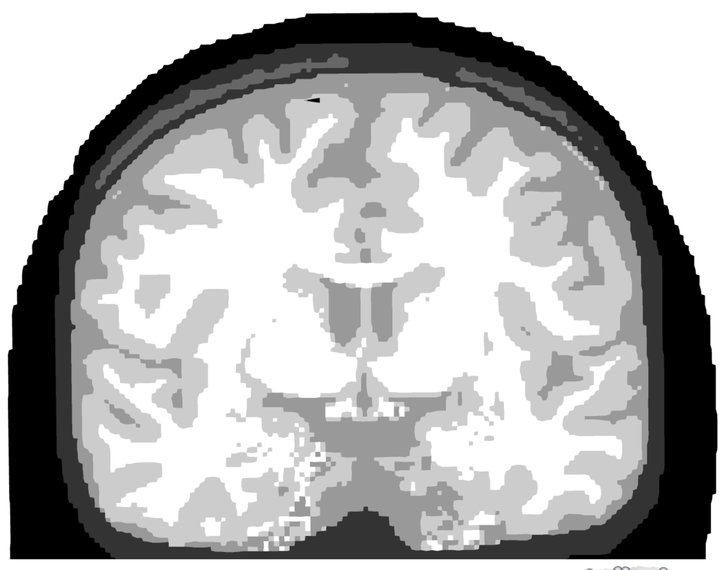

Figure 3.
Location and orientation of the target vector (black cone).

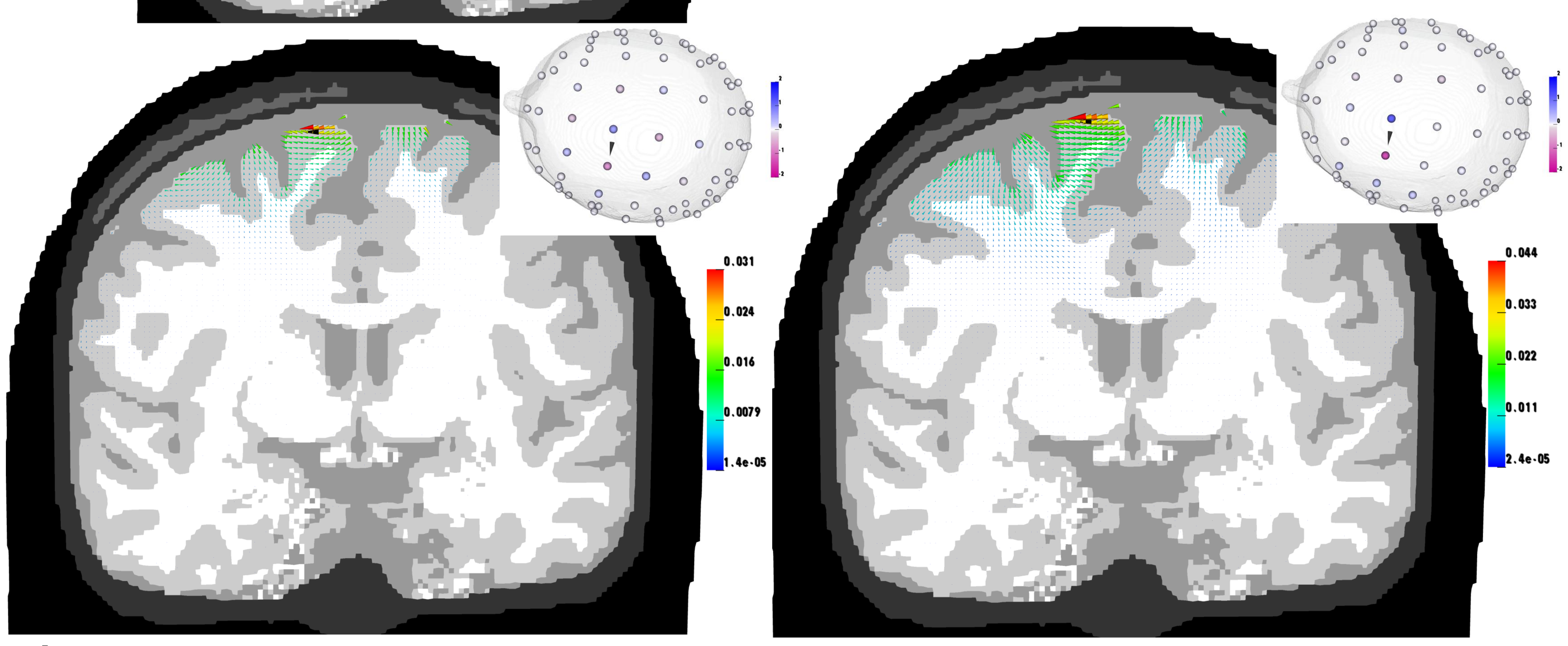

Figure 4.
Optimized current density distribution for a mainly tangential target vector (see Fig. 3) using an L2-regularized (left) and L1-regularized (right) approach. A total current of 2 mA is injected to the surface electrodes as can be seen in the corresponding stimulation protocols (right top). We use cones to represent vector orientations (cone sizes correlate with amplitudes) and color-coded the cones to represent amplitudes.

Results

Volume conduction effects:

➢ Channeling effects of the skin, the skull spongiosa and the CSF compartments, see Figs. 1 and 2.

➢ Highest cortical current magnitudes are not only found close to the stimulation sites, see Fig. 2.

➢ Current vectors tend to be oriented towards the closest higher conducting region, see Figs. 1 and 2.

Sensor optimization:

➢ When compared to standard tCS approaches (Fig. 1), our optimization approach has shown to induce a very focal current density activation pattern, see Fig. 4.

➢ Current density in the remaining brain has been demonstrated to be significantly smaller as compared to the current density in the target.

➢ The orientation component of tangential target vectors can be well approximated using our optimized stimulation protocols.

➢ Our approach allows well targeted stimulation and accounts for patient safety.

References

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