Westfälische Wilhelms-Universität Münster

Cells in Motion Cluster of Excellence

IBB Institute for Biomagnetism and Biosignalanalysis

An optimization approach for well-targeted transcranial direct current stimulation

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Introduction

Standard bipolar electrode montages for transcranial current stimulation (tCS) induce a very widespread current flow field with the strongest intensities often located in the non-target brain regions [1,2]. 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

➢We use the alternating direction method of multipliers [3] to calculate optimized stimulation protocols at the fixed electrodes by minimizing

$$- \int_{\Omega_t} \langle AI, e \rangle \, \mathrm{d}x \; + \alpha \int_\Gamma I^2 \, \mathrm{d}x + \beta \, \|I\|_{\mathcal{M}(\Gamma)} \to \min_{I \in \mathcal{D}(\Gamma)}$$

$$\text{subject to} \quad \omega |AI| \leq \epsilon$$

$$\int_\Gamma |I| \, \mathrm{d}x \leq 4$$

with A being the tCS influence matrix, I being the applied current pattern at the fixed electrodes, e being the target vector, Ω_t being the target area and Γ being the boundary of the volume conductor model.

➢We call the minimization problem with $\alpha = 0$ and $\beta > 0$ and $\alpha > 0$ and $\beta = 0$ to be the L1R and the L2R discretized optimization problem, respectively. Moreover, the M2E approach stimulates only the main positive and the main negative electrode of the L1R stimulation protocol with 1 mA.

➢In a recent work [4], the existence of a unique solution to the tCS optimization problem and objective and residual convergence results were proven for the considered optimization problem.

➢For optimization, a six compartment (skin, skull compacta, skull spongiosa, CSF, gray and white matter) geometry-adapted hexahedral FE head model with white matter anisotropy is used and 74 electrodes are positioned on the locations of an extended 10-10 EEG system.

Results and Discussion

➢The optimized current flow fields show substantially higher focality and slightly greater directional agreement to the target vector in comparison to standard bipolar electrode montages (Figure 1 and Table 1).

➢The optimized stimulation protocol for a tangential target vector is mainly comprised of two electrodes, while weaker compensating currents are injected at the neighbouring electrodes.

➢For a radial target vector, the optimized stimulation protocol consists of one anode directly placed above the target region surrounded by four cathodes located on the neighboring electrodes.

➢The M2E approach provides an optimized bipolar electrode montage for tangential target vectors.

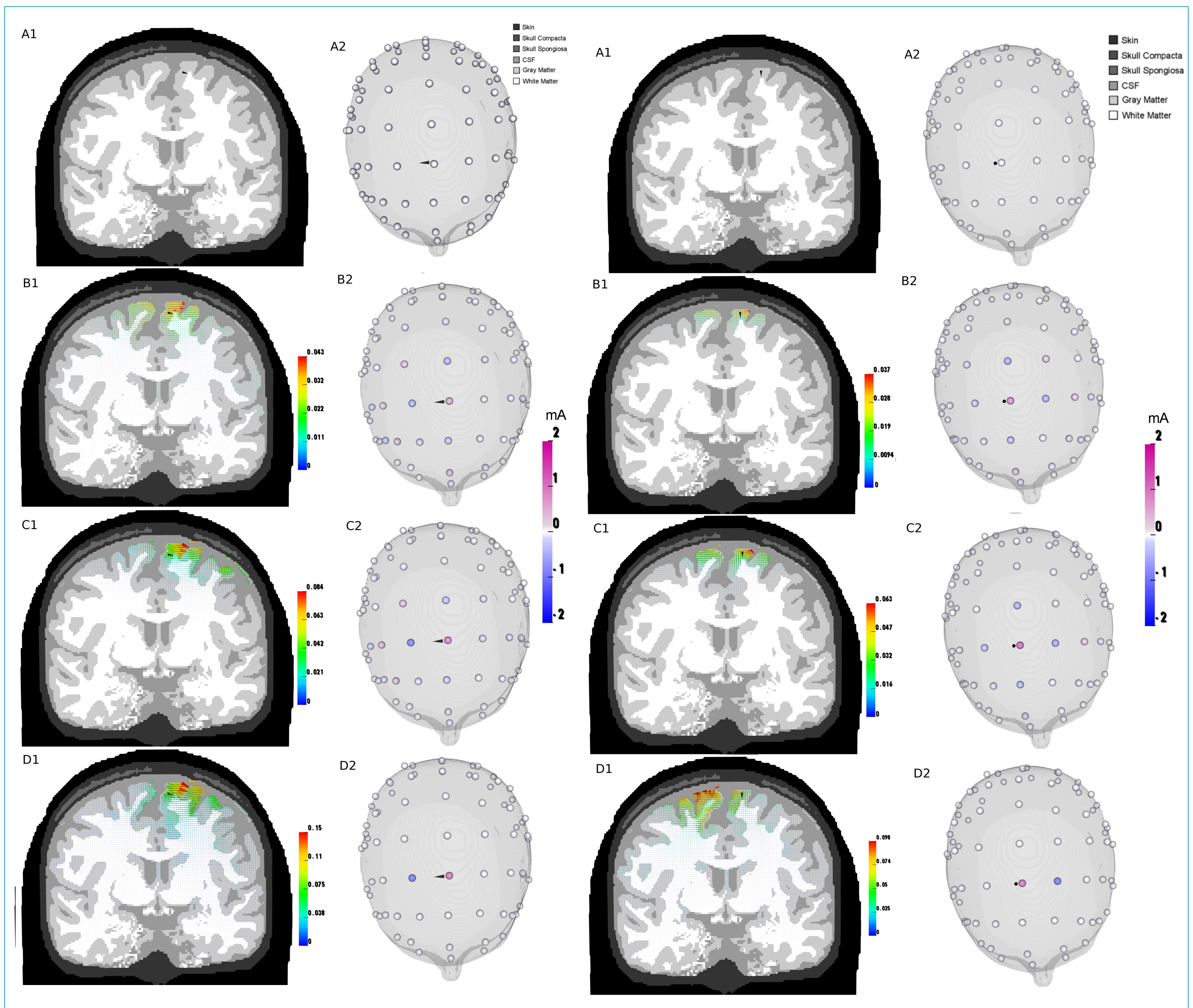

Figure 1
Optimized current density for a mainly tangential (first column) and a mainly radial target vector (third column), respectively. The optimized stimulation protocols are depicted in Columns 2 and 4. Figures –B, -C and –D show optimization results for the L2R, L1R and M2E optimization approaches, respectively.

Target	$\frac{\int_{\Omega_t} \lvert AI \rvert \, \mathrm{d}x}{\lvert \Omega_t \rvert}$	$[Am^{-2}]$ $\frac{\int_{\Omega \setminus \Omega_t} \lvert AI \rvert \, \mathrm{d}x}{\lvert \Omega \setminus \Omega_t \rvert}$	$\frac{\int_{\Omega} \langle AI, e \rangle \, \mathrm{d}x}{\lvert \Omega_t \rvert}$	[%] $PAR = \frac{CD_t}{CD_a}$
tangential L2R	0.022	0.00144	0.019	86.4
tangential L1R	0.038	0.00151	0.033	86.8
tangential M2E	0.071	0.0080	0.061	85.9
radial L2R	0.026	0.00064	0.025	96.1
radial L1R	0.045	0.00071	0.043	95.5
radial M2E	0.063	0.0074	0.048	76.2

Table 1.
Quantification of optimized current density. The averaged current density in the target area (CDa, second column), the averaged current density in non-target regions (third column), the inner product of current density and target vector (CDt, fourth column) and the percentage of current density that is oriented parallel to the target vector (PAR, ftfth column) is displayed for different target vectors (first column).

References

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