Why transcranial direct current stimulation (tDCS) models cannot be trusted yet? A simulation study.

M. Grignard[1,2], C. Geuzaine[2], M. Hansenne[3], S. Majerus[1,3], C. Phillips[1,2]

[1]GIGA-CRC In Vivo Imaging ; [2]Department of Electrical Engineering & Computer Science; [3]Psychology & Cognitive Neuroscience Research Unit. All from Liège University, Belgium.

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Poster & Abstract

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Introduction

Transcranial direct current stimulation (tDCS) has gained increased interest over the past decades due to its affordability, ease of use and wide range of applications. Yet, its **lack of consistency and reproducibility** is concerning. A potential solution to improve the method is to tailor the stimulation for each subject based on individual measurements and models. Each **model requires accurate information** about the geometry of the tissues composing the head of the subjects, their electric properties and the electrode montage.

Aim of the study: Exploring the sensitivity of such models with respect to two factors (anode placement & conductivity values) with simulated data

Methods

Model building

- 20 BrainWeb virtual subjects [1]
- reduced to 5 tissue classes (WM, GM, CSF, skull, and soft tissues), to build individual finite element models (FEM)
- Reference conductivity profile for the 5 tissues as "weighted mean" from [2]
- 4 regions of interest (ROIs) as targets: MC, dlPFC, vmPFC, IPS;
- 5x5 cm^2 patch electrodes placed according to the 10-20 EEG system and 4 target regions
- 2 mA current injected at the anode and cathode as a reference (i.e. 0V).

Sources of variability

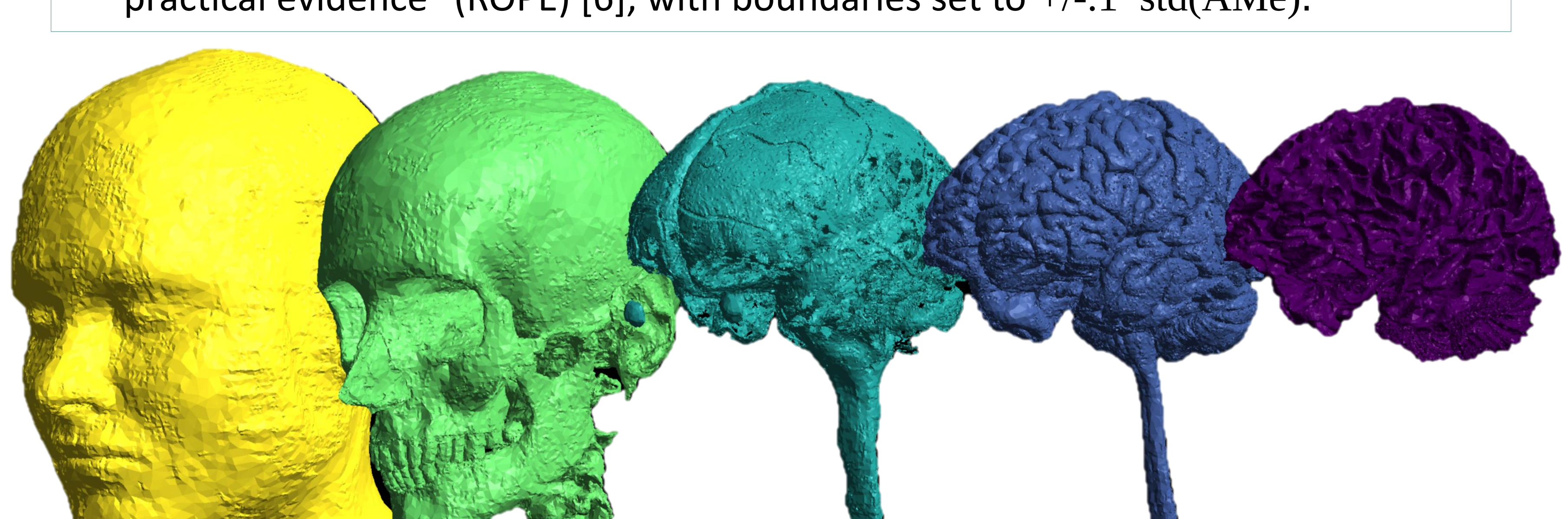
- bipolar or unipolar (only MC and dlPFC) montages → 6 montages
- anode was either correctly centred, or displaced by 1 cm in 4 directions (anterior, posterior, central or lateral) → 5 electrodes setup
- pick 20 random conductivity profiles, sampled [3] from uniform conductivity distribution, Ω_{uni} + reference → 21 profiles

Model estimations

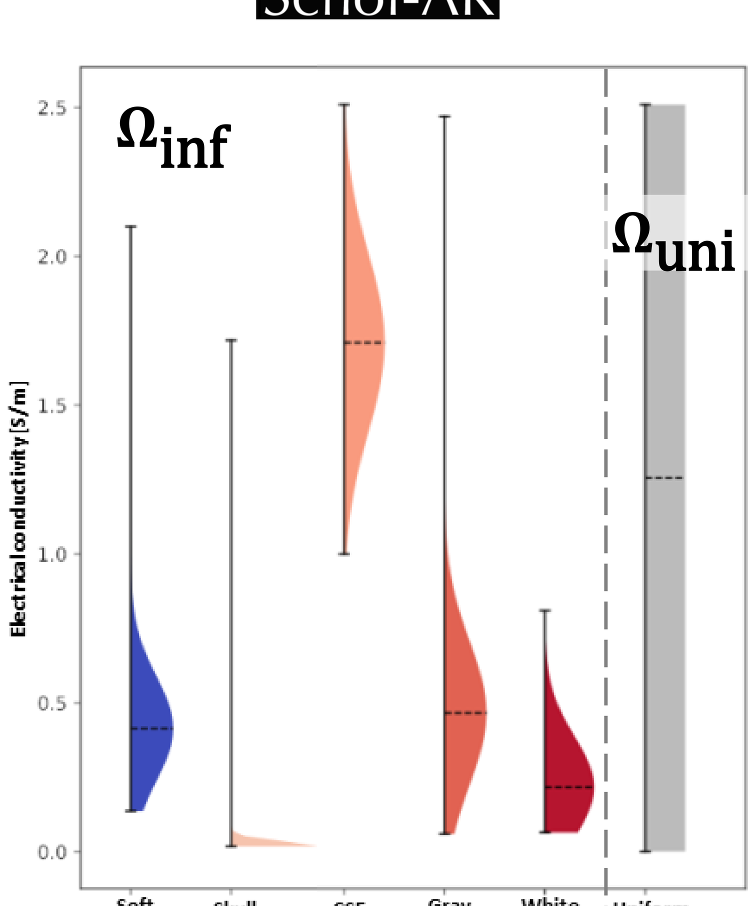
- solve the 12600 (20x5x6x21) FEM simulations with Shamo [4]
- calculate the electric field e (V/m) over the head volume
- each simulation summarized by the "*average magnitude of e*" (AMe) in the ROIs targeted in each model
- interpolate (GPR) results for another 20 "informed" conductivity profiles Ω_{inf}, using a truncated normal distribution [2]

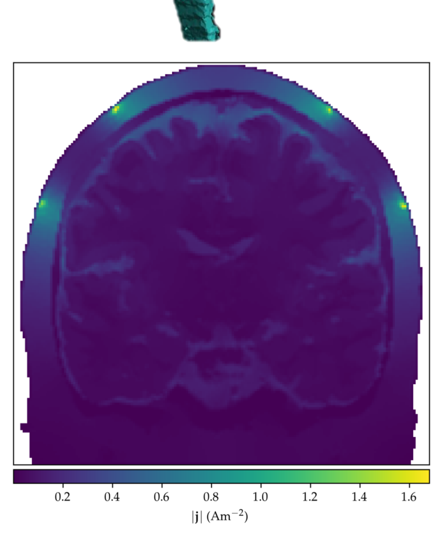
Statistics

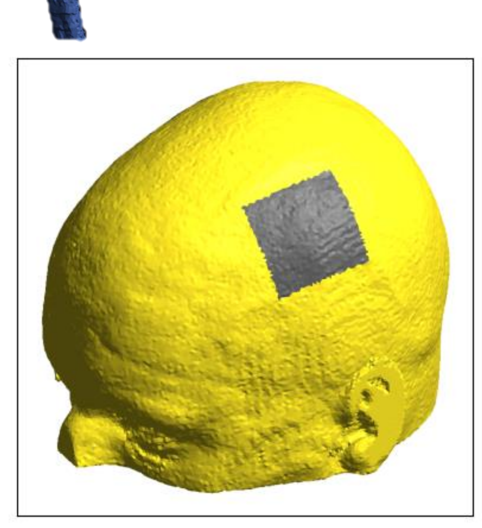
- Bayesian generalized linear mixed effects models [5] to assess the effect of the 2 factors of interest: anode placement and conductivity profile
- Check 95% overlap of "highest density interval" (HDI) and the "region of practical evidence" (ROPE) [6], with boundaries set to $+/-.1*\mathrm{std}(\mathrm{AMe})$.

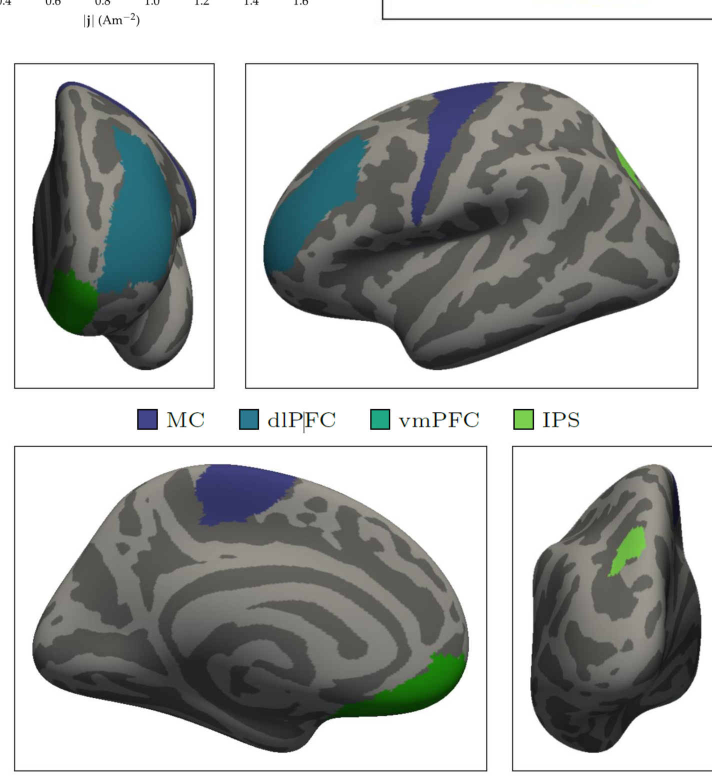


View Data With Schol-AR



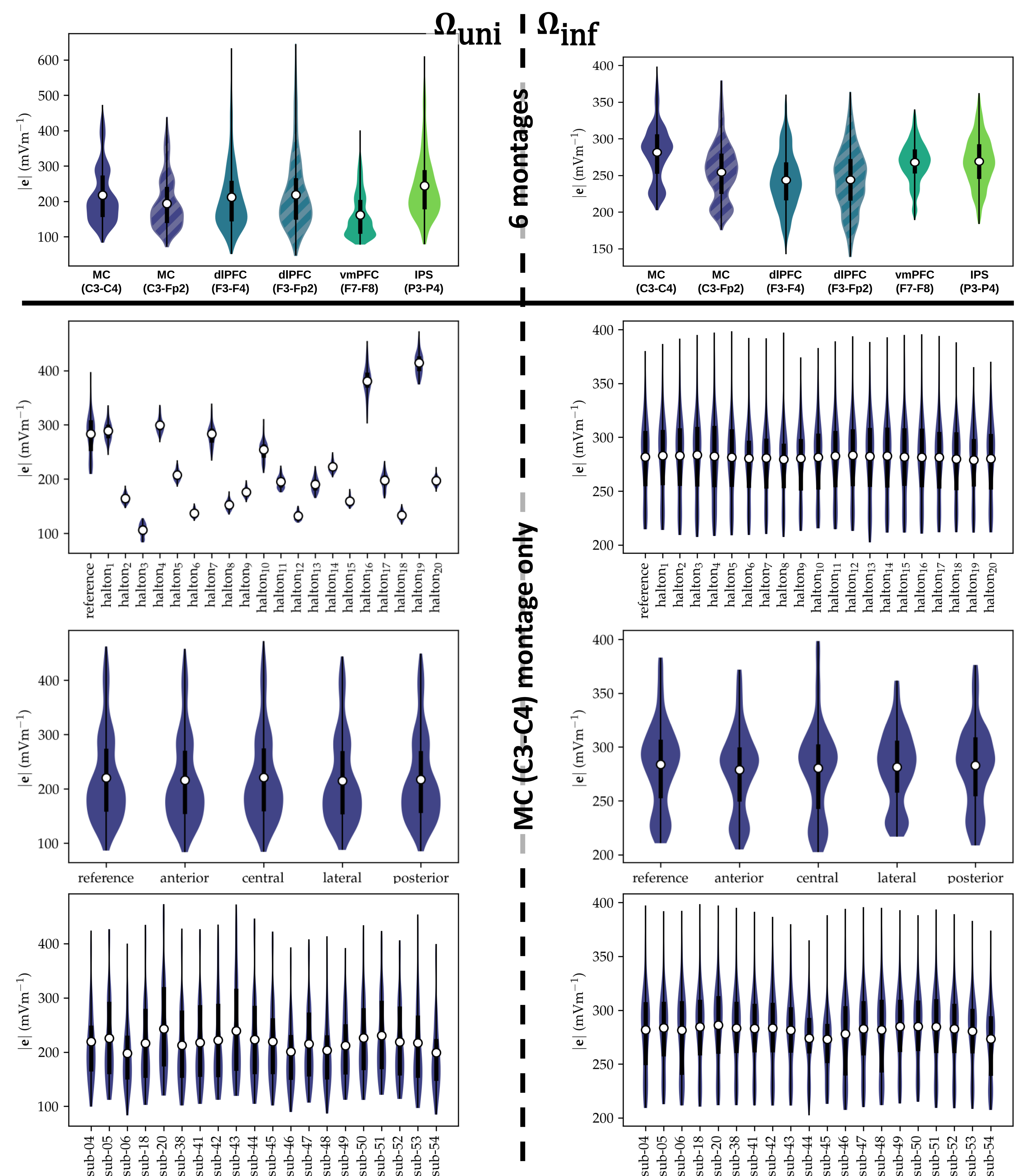






Results

- Overall very weak current flow/electric field throughout the head volume
- AMe distribution all target regions & montage, with conductivity random sampling, ranges from 47.2 to 644.2 mV/m and from 139.2 to 398.5 mV/m, for Ω_{uni} and Ω_{inf}
- effect of a 1cm placement error, according to conductivity profile, on AMe in the ROIs
  - ✓ with Ω_{uni}, HDI and ROPE do overlap to some extent → no decision can be made
  - ✓ with Ω_{inf}, little overlap → significant effect of electrode placement
- effect of conductivity profiles on AMe in the ROIs
  - ✓ with Ω_{uni}, majority of the 95 % HDI completely outside the ROPE → significant influence of uncertainty on the conductivity of the tissues
  - ✓ with Ω_{inf}, mainly overlap → no or undecided effect.



Distribution of the AMe, estimated with 20 Ω_{uni} (left column) and Ω_{inf} (right column) conductivity profiles: for the 6 ROIs & montages (1st row); then for the "MC (C3-C4)" set up only across 21 conductivity profiles (2nd row), 5 anode positions (3rd row), and 20 subjects (4th row).

Conclusion

tDCS is expected to generate an induced transmembrane potential of around 0.5 mV in the neurons of the ROI [7] but

- the values we obtain, considering r=1mm, are at most of the same order of magnitude but can be up to 20 times smaller.
- the uncertainty on the electrical conductivity makes it practically impossible to assess the stimulation effect in the ROI + using any standard values could potentially yield biased results.

More results and code are available in [8].

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