GitHub:

Electrode localisation for electrical field (EF) modelling in tDCS studies using magnetic resonance imaging

Daniela Rodriguez-Manrique[1,2], Gülce Lale[2], Begüm Sönmez[3], Kathrin Koch[1,2]

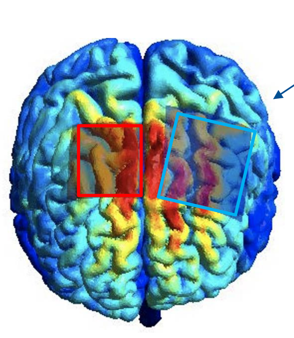
Transcranial direct current stimulation (tDCs):

- Sub-threshold effects (does not elicit an action potential but) modulate the pattern of already active neurons.
- Increased neuroplasticity during use
- Limited studies on tDCS mechanisms of action. Has been associated with Ca2+ and CMP concentrations in mice. Additionally has shown to influence LTP and LFP.

Background

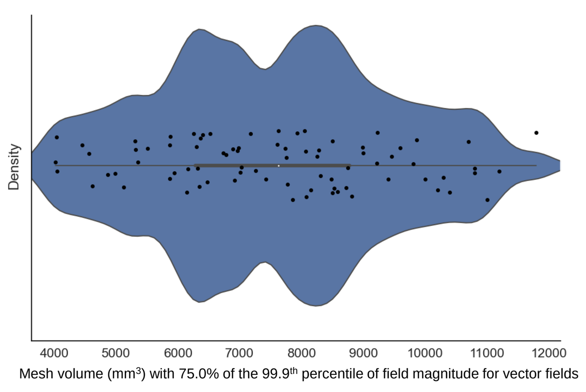
- Distribution of electric field magnitude and focality measured as mesh volume (n=79)
- Electrical field was calculated using T1 and T2 images with SimNIBS[7] for a 2mA current

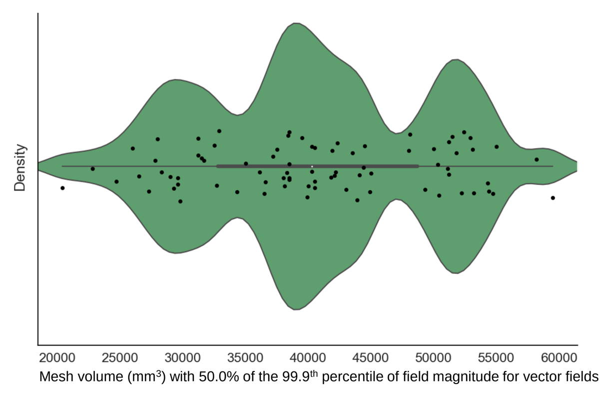
Electrode set-up

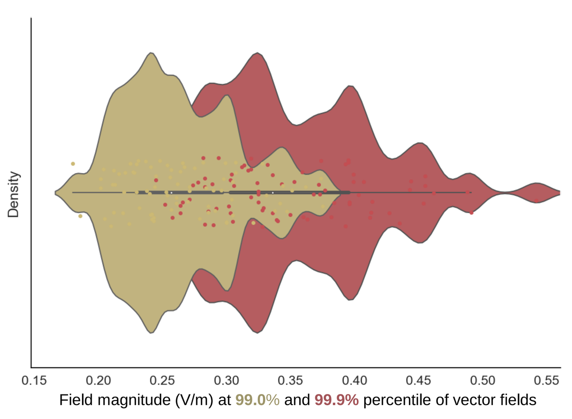


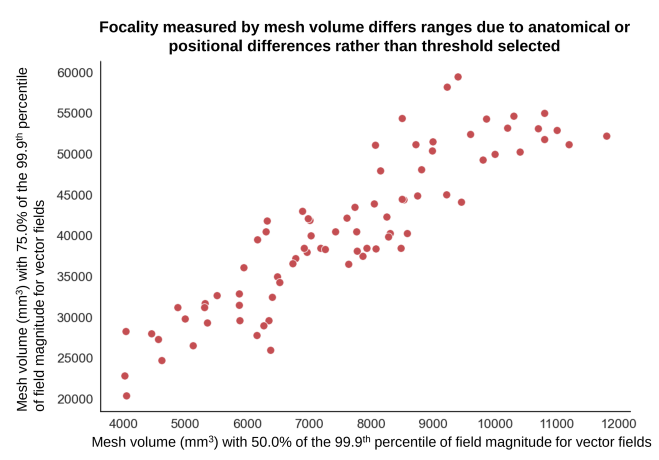
Anode modelled on the FC1 and cathode on the FC2 EEG 10-20 position (shown)

Upon noticing large variability in focality and field magnitude, likely derived from electrode position differences, we saw the need for accurate modelling.

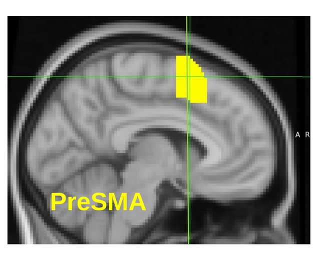


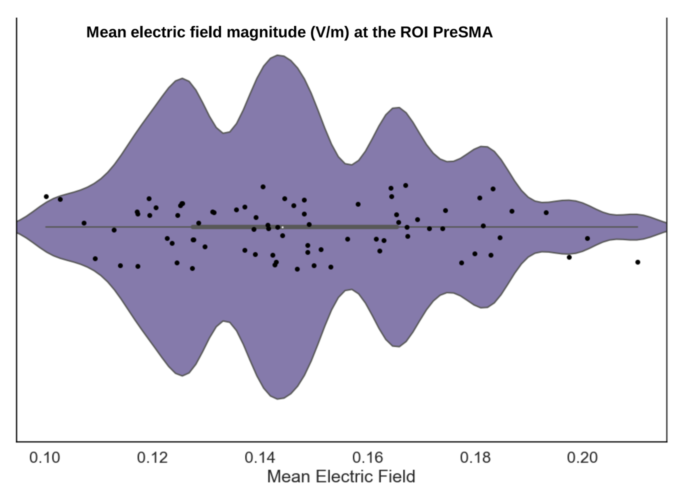






Using SimNIBS we performed a ROI analysis with a 10mm radius of the sphere at MNI coordinates [-3, 6, 53].





Literature shows that tDCS stimualtion effects differ even if the same stimulation protocol is being followed (electrode placement, current, duration) ➡ The variability in our modelling results shown in **background**, demonstrates why the same montage could produce differing results.

An automatic electrode localisation pipeline provides a stricter quality control metric post-hoc. It relies on minimum one structural scan and provides a cheap alternative to using the NeuroNavigator technology.

The Challenges

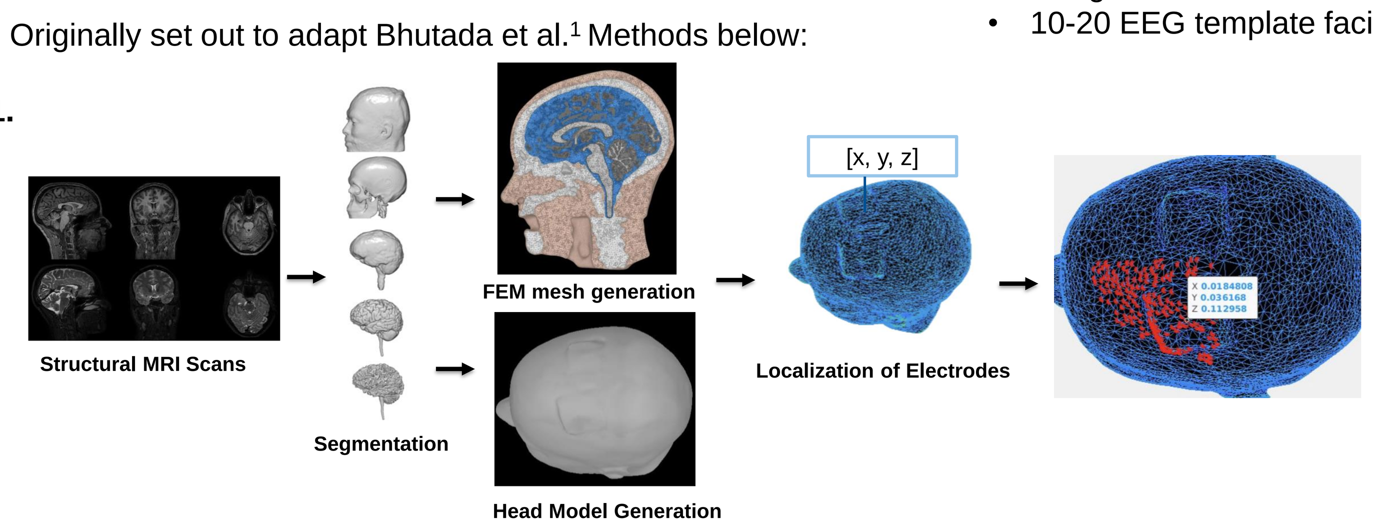
Pipelines developed to identify EEG electrodes from T1 and/or T2 MR images do not work for tDCS electrodes.

They are either based on:

- Curvature values on a T1 derived brain mesh[1].
- Specific imaging techniques so EEG electrodes will portrude (Ultra short Echo Time sequence[2]).
- Hough Transform used to detect spheres in 3D data sets[2].
- 10-20 EEG template facilitating search in MR images[3].

Originally set out to adapt Bhutada et al.[1] Methods below:

1.

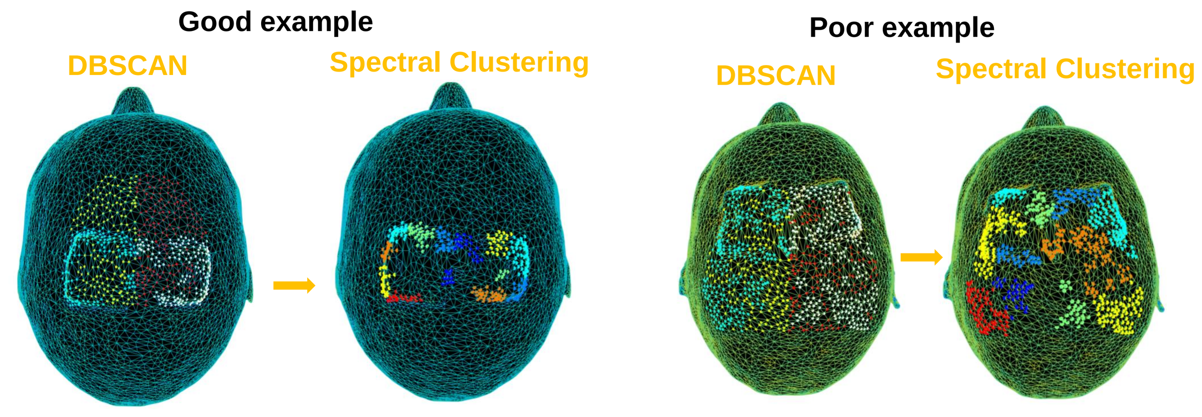


Lack of success due to large variability in curvature values.

T1 picks up the Ten20 electrode paste which we apply a 2mm layer, not the actual electrodes.

Thus, the edges are not perfect and the paste thickness differs throughout the electrode depending on hair thickness and scalp temperature.

2.



DBSCAN reduces noise and marks relevant coordinates in white and light blue. Any other points get excluded from spectral clustering.

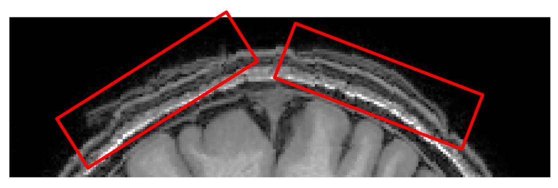
Spectral clustering is used to find a minimum of two corners, from which we can calculate the electrode centre coordinates.

Preliminary Results

Most accuracy over many subjects was show using the T1 image directly instead of the brain mesh created by Brainstorm & SimNIBS.

The automatic segmentation would be composed out of a combination of techniques

1. **Regionprops** on T1 images
2. the **Hugh Transform** targetting slices.



1.

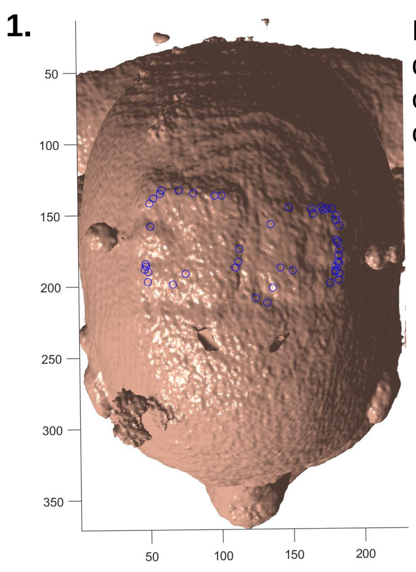


Image shows centroids detected by **regionprops** overlayed on the T1 image of a subject.

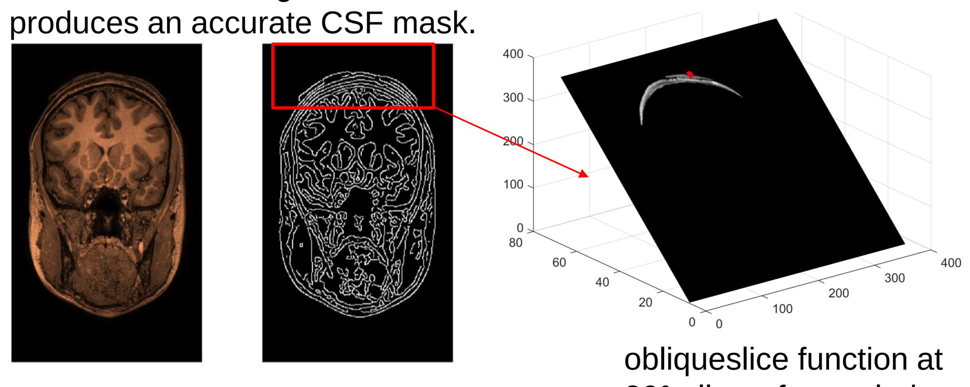
To reduce low-intesity noise that could be detected, the lowest 10% intensities are removed from the T1 image.

Regionprops varies in resolution. We are working on combining it with DBSCAN and other noise reduction techniques.

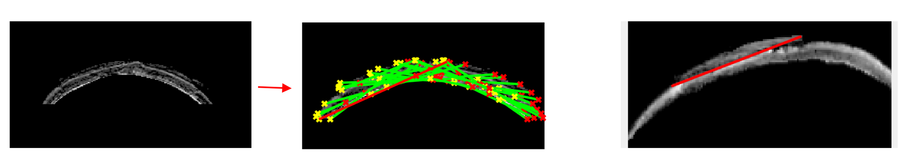
2.

SimNIBS *charm* segmentation produces an accurate CSF mask.

We extract only the scalp by masking the CSF, so that our T1 image now only featues the outer areas.



obliqueslice function at 30° allows for angled cuts at a coordinate identified by region props. This cleans the data prior to submitting it to the Hough Transform.



without oblique slicing

with oblique slicing

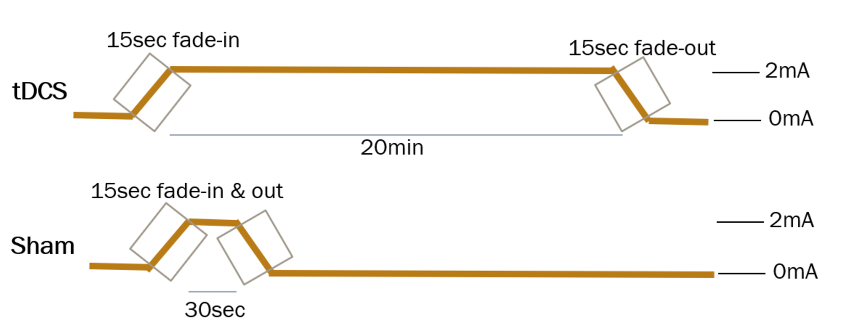
Experimental Design

tDCS while performing two inhibition tasks in MRI:

- Allowing insight into the immediate and postponed blood oxygen dependent (BOLD) changes in brain regions and networks.
- Both tasks are inhibition tasks, which **involve pre-supplementary motor area (preSMA)** activation and increased connectivity.
- OCD patients have shown performance deficiencies in both tasks.

	Anode	Cathode
Locus	FC2	FC1
Electrode Size	4 x 4 cm	5 x 5 cm
Conductor	Ten20 paste	Ten20 paste

tDCS and sham conditions:



Patients undergo both conditions during their **two scans** >1 week apart, they are **randomly** assigned the order of the conditions.

Future Perspectives

- Testing pipeline for accuracy with other electrode montages → looking for other centres to share data.
- A freely accessible tool for investigating effect of **electrode location** and electric field magnitdue in **tDCS** and **tACS** research.
- An increased reliability of our results and relevant insights into the central mechanisms of tDCS stimulation. Do differences in electric field strength have a significant influence on BOLD acitvation and connectivity changes.
- Investigation of inter-individual differences in **gyrification** and **skull thickness** of the preSMA and areas with greates electric field focality. Gyrification strongly determines neuronal orientation, which has been shown particular importance in *in vivo* studies for the polarizing effect of tCDS[6]. Are we able to reproduce this in humans?
- *Investigating whether tDCS efficacy can be explained by target specificity, as certain targets are able to achieve higher electrical density due to their anatomical location. What are the preferred anatomical locations for administering tDCS?*

Associations:
[1]Department of Neuroradiology, School of Medicine, Klinikum Rechts der Isar, Technical University of Munich, Munich, Germany.
[2]Graduate School of Systemic Neurosciences, Ludwig-Maximilians-Universität München, Munich Germany.
[3]Elite Master Program Neuro-Engineering, Department of Electrical Engineering, Technical University

Deutsche Forschungsgemeinschaft

References:

1. Bhutada, A.S. (2020), 'Semi-automated and direct localization and labelling of EEG electrodes using MR structural images for simultaneous fMRI-EEG', *Frontiers in Neuroscience*, **vol. 14**, Article 338981.
2. Fleury, M. (2019), 'Automated Electrodes Detection During Simultaneous EEG/fMRI', *Frontiers in ICT*, **vol. 13**, Article 31.
3. Marino, M., (2016) 'Automated detection and labelling of high-density EEG electrodes from structural MR images', *Journal of Neural Engineering*, **vol. 13**, Article 056003
4. Ekhtiari, H. (2022) 'A checklist for assessing the methodological quality of concurrent tES-fMRI studies: a consensus study and statement', *Nature Protocols*, ISSN: 1754-2189.
5. Monai, H., (2016). Calcium imaging reveals glial involvement in transcranial direct current stimulation-induced plasticity in mouse brain. Nature communications, 7. 2019, PMID: 31725247.
6. Opitz A., (2015) 'Determinants of the electrical field during transcranial direct current stimulation', Neuroimage, **vol. 109**, pp. 104-105.
7. Saturnino, G.B. (2018) 'SimNIBS 2.1: A Comprehensive Pipeline for Individualized Electric Field Modelling for Transcranial Brain Stimulation', Brain and Human Body Modelling, Springer 2019, PMID: 31725247.