

Neural Engineering Group

Department of Biomedical Engineering
The City College of New York, CUNY



Measurements and models of electric fields in the *in vivo* human brain during transcranial electric stimulation

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Parra Lab

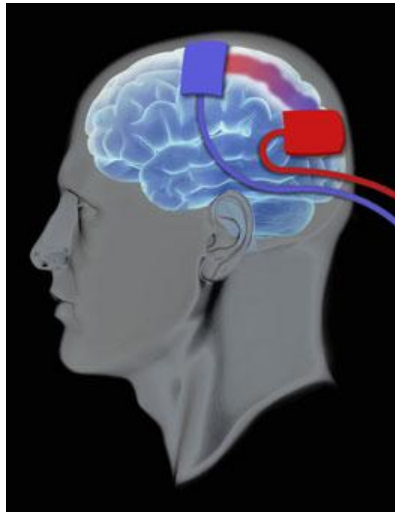
Department of Biomedical Engineering, City College of New York



April 7th, 2017

Background

tDCS; tACS

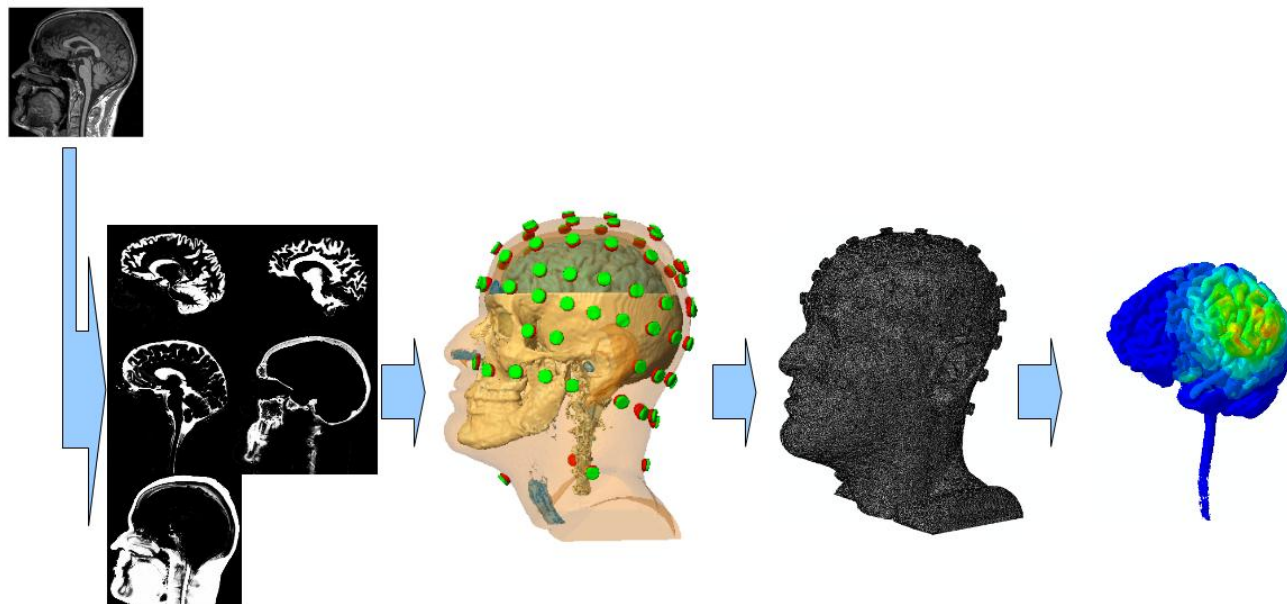


Mechanisms?

How to place electrodes to hit ROI?

Image credit to cognitiveneuroscience.it

Computational models



Huang *et al.*, 2013

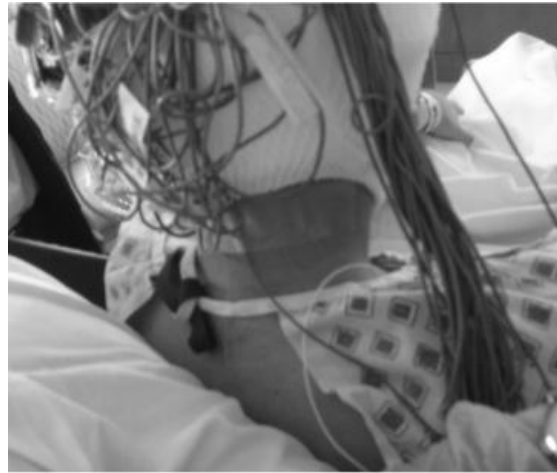
Motivation

- Sophisticated models, but **none of them** validated.
- Previous recording efforts only done in **simians** (Hayes, 1950), **scalp surface** (Burger and van Milaan, 1943; Datta *et al*, 2013), or **ex vivo** (Rush and Driscoll, 1968).
- The **literature-reported tissue conductivities**, which modern models heavily use, are mostly measured **ex vivo**, and under stimulation frequency **higher than 10 Hz**.
- We have **little info** as to the actual electric field in the human brain induced by the stimulation

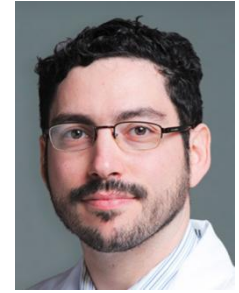
whether the model accurately predicts the **spatial distribution**?

can the actual field magnitude achieve **1 V/m** under 2 mA, as the model predicts?

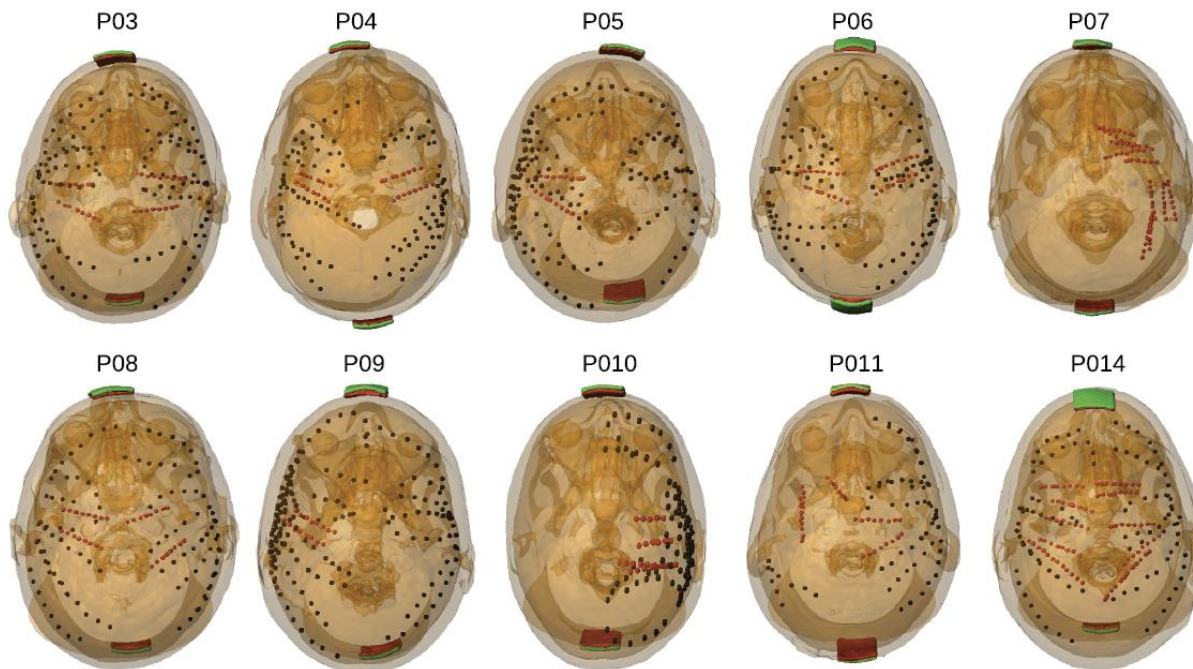
- There are controversy even in models themselves: **skull compartments? white matter anisotropy?**



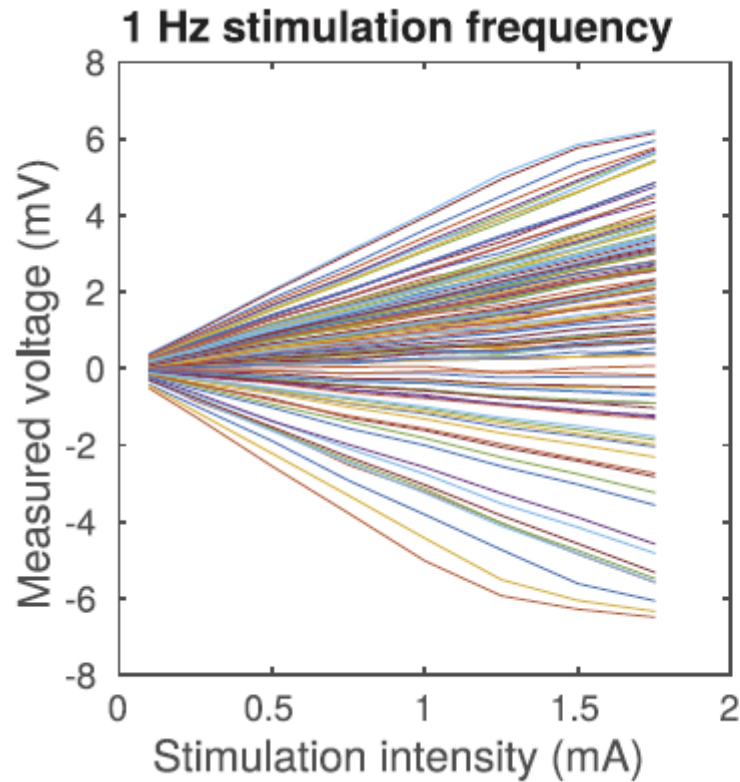
Anli Liu



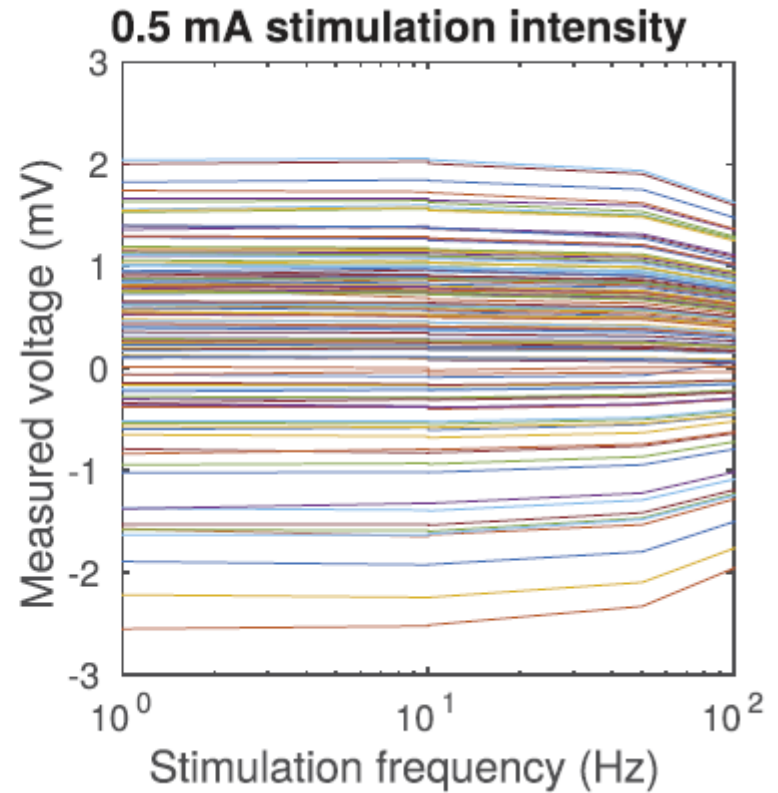
Daniel Friedman



- 10 patients under iEEG
- 1380 recording electrodes
- 1 Hz tACS



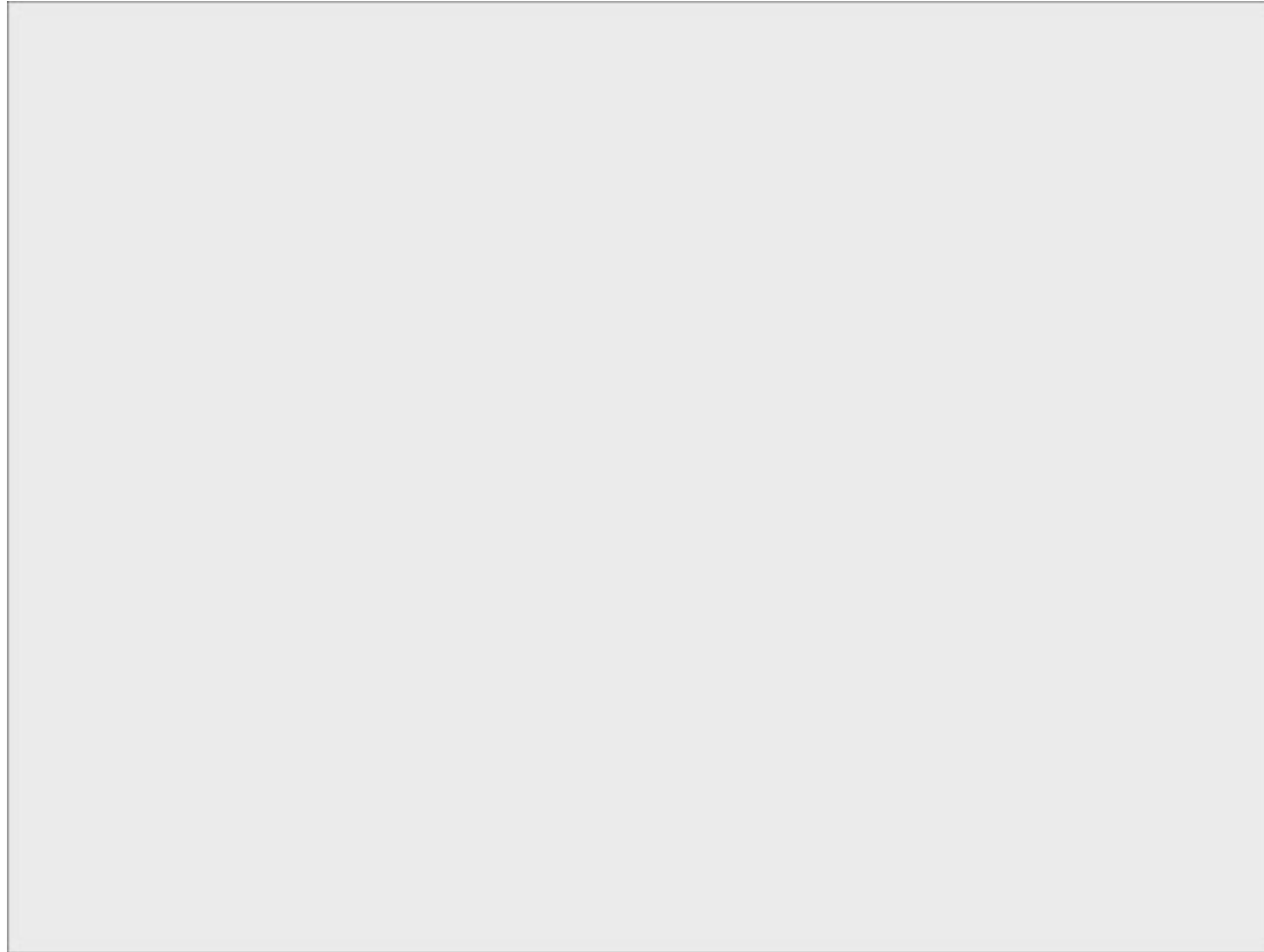
Measured voltages increased linearly with current intensity

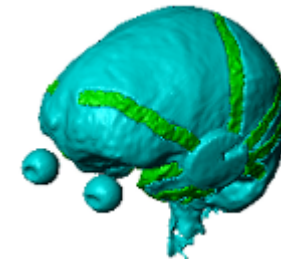
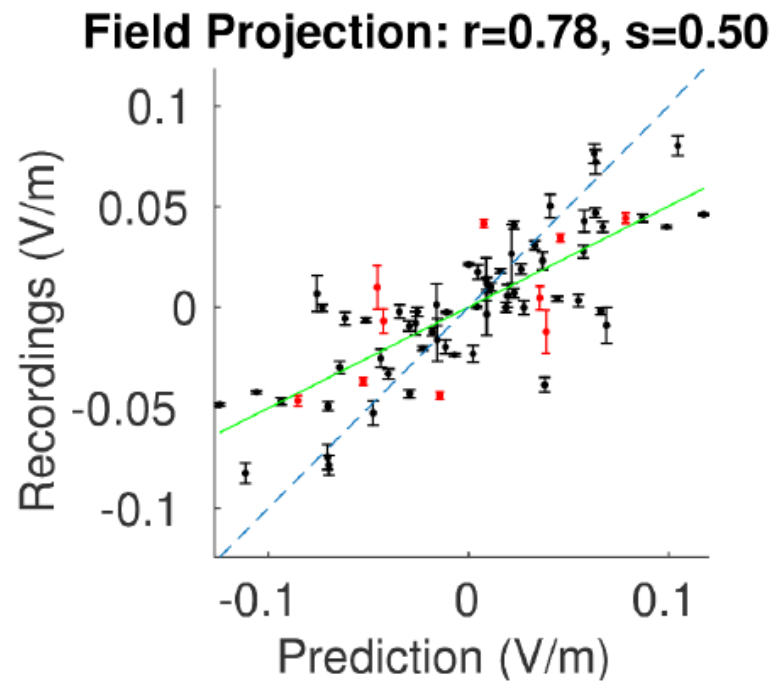
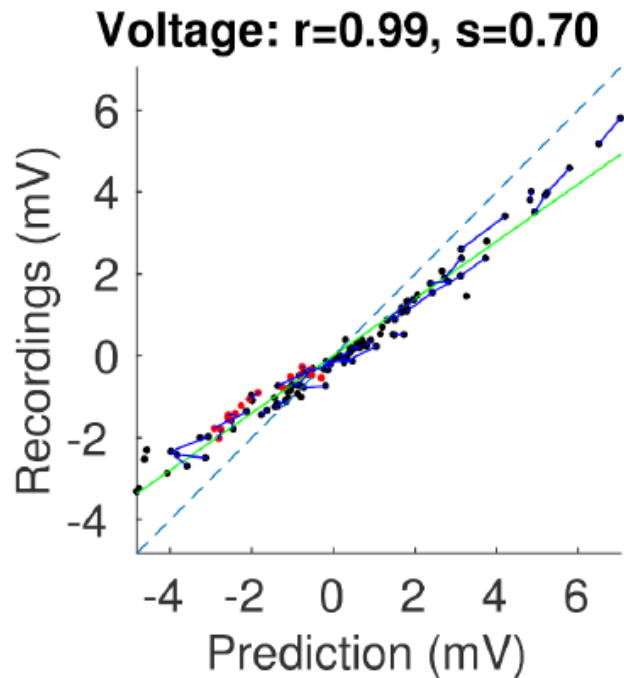


Measured voltages consistent with increased frequency, with drop of 25% at 100 Hz

Are model predictions reliable?

Summary video





Relative patterns well predicted (r);

Absolute magnitudes over-estimated by model (s)

GM: 0.276

WM: 0.126

CSF: 1.65 S/m

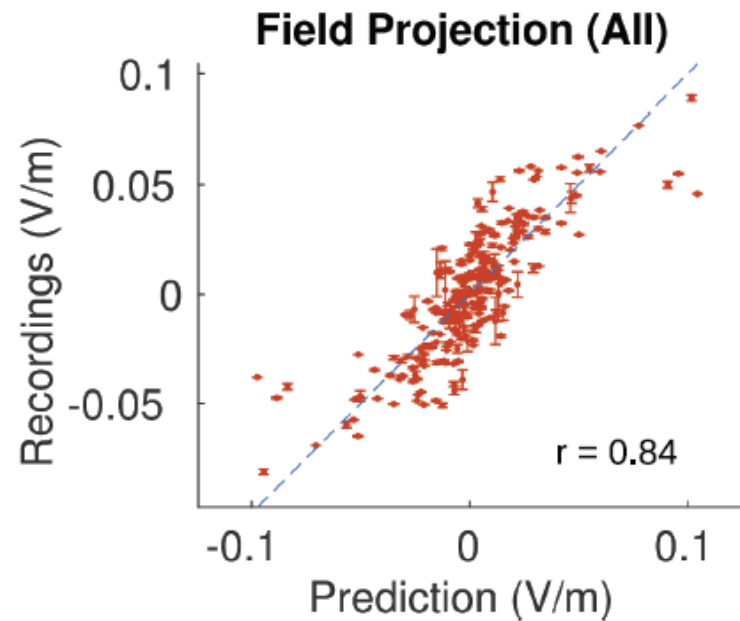
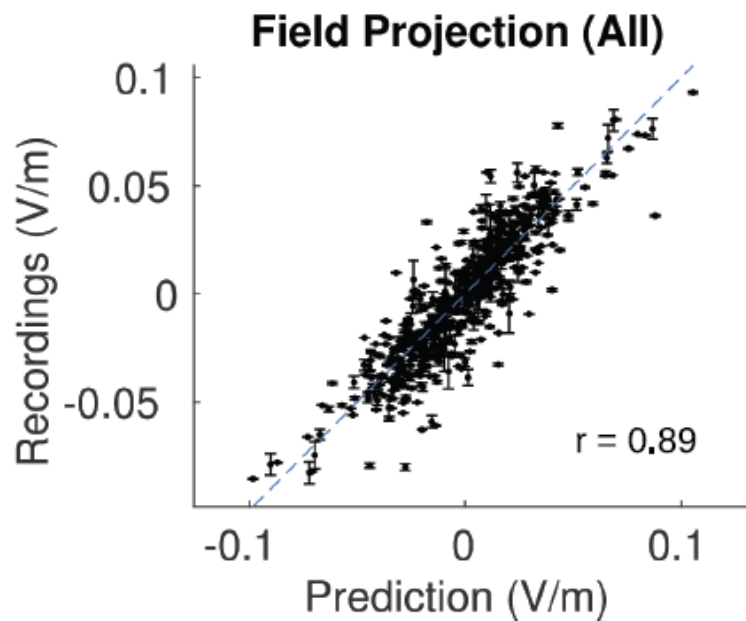
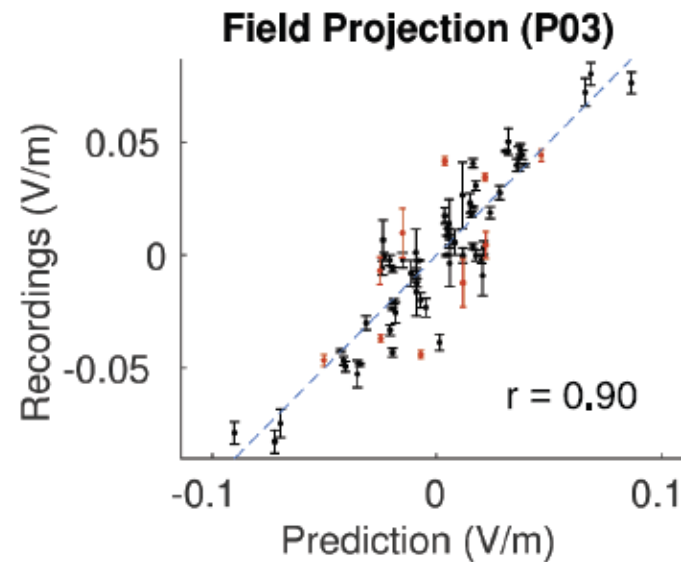
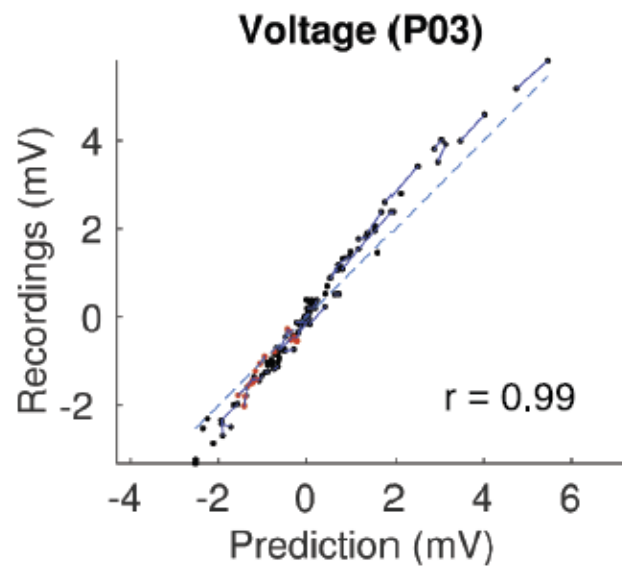
Skull: 0.01

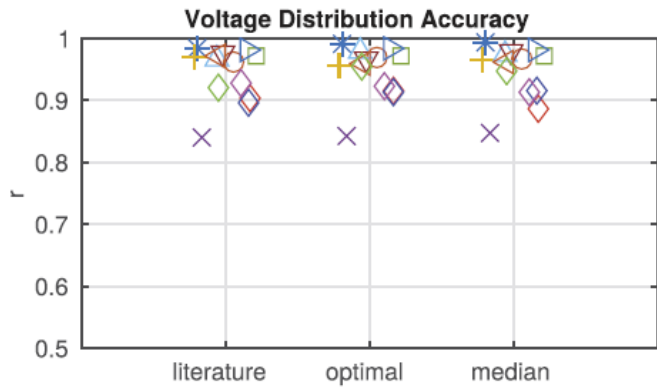
Scalp: 0.465

at frequency > 10 Hz

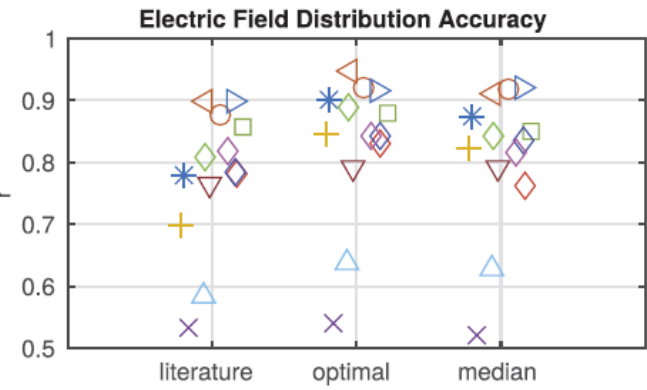
Wagner *et al.*, 2004

$$\sigma^* = \operatorname{argmin}_{\sigma} f(\sigma), \text{ where } f(\sigma) = \frac{1}{M} \sum_{i=1}^M [E_i - \hat{E}_i(\sigma)]^2.$$

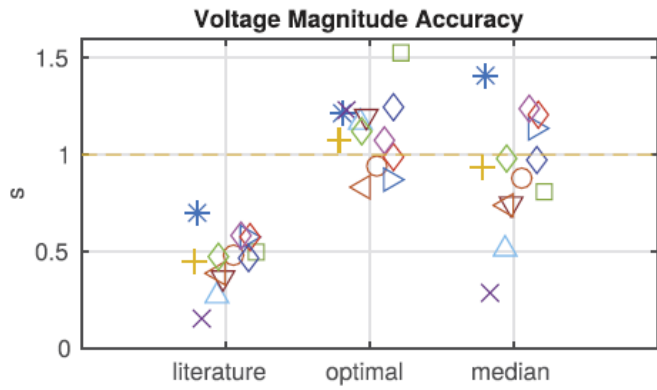




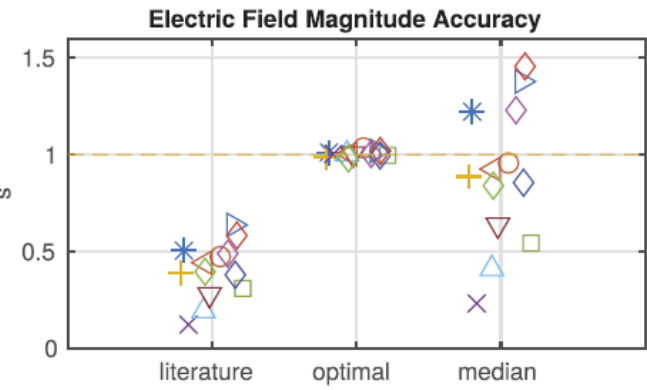
(A)



(B)



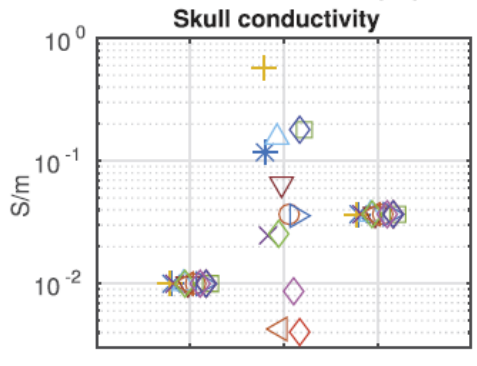
(C)



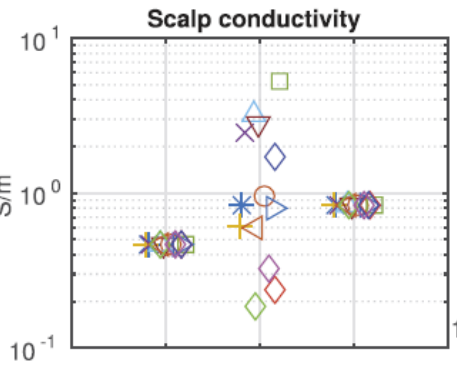
(D)

Median:
 Bone: 0.04 S/m
 Skin: 0.84 S/m
 White matter: 0.52 S/m

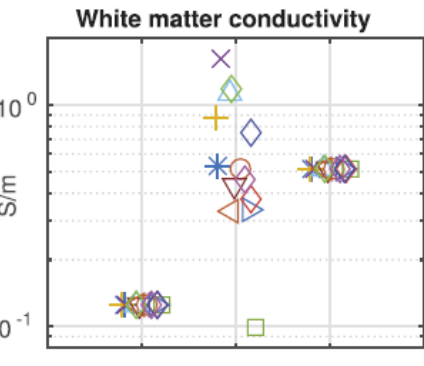
Gives significantly better predictions than literature values



(E)



(F)



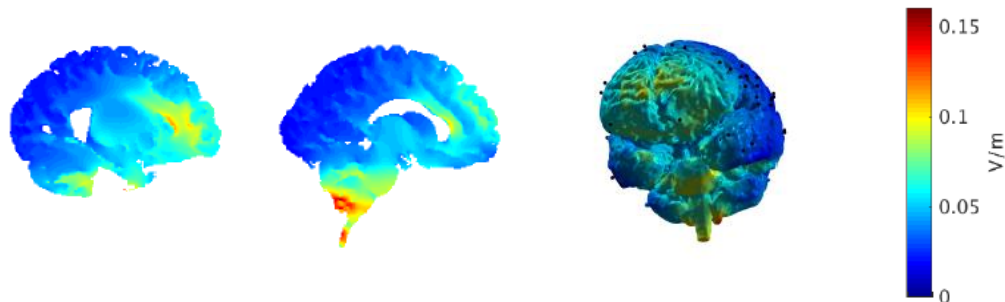
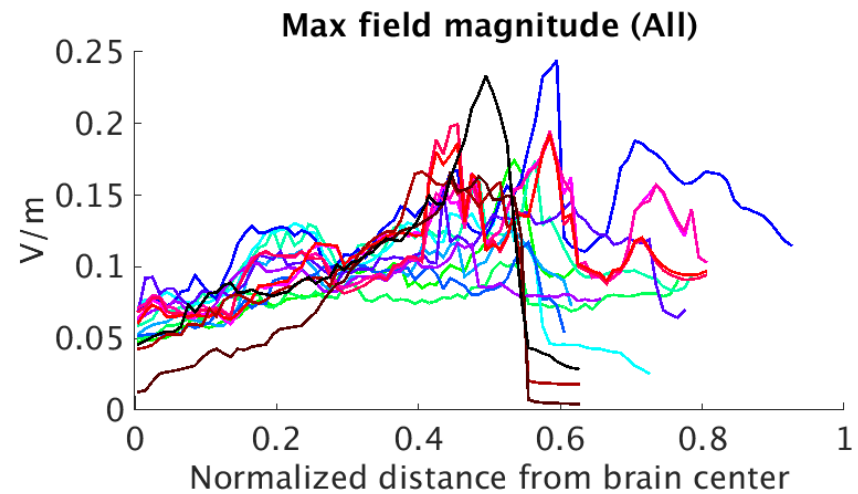
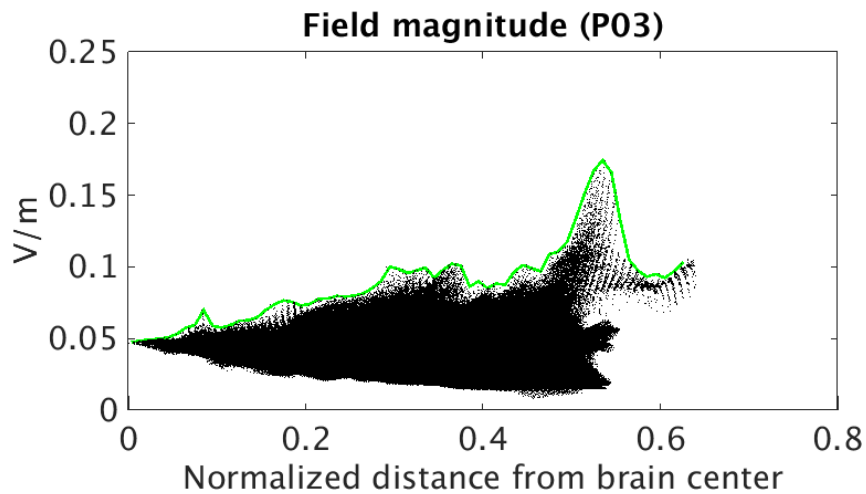
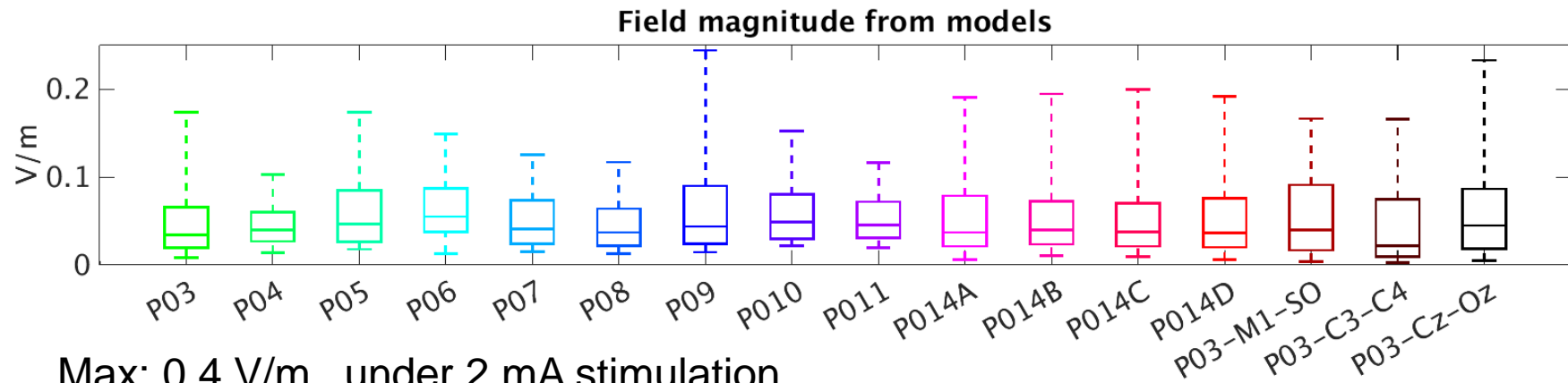
(G)



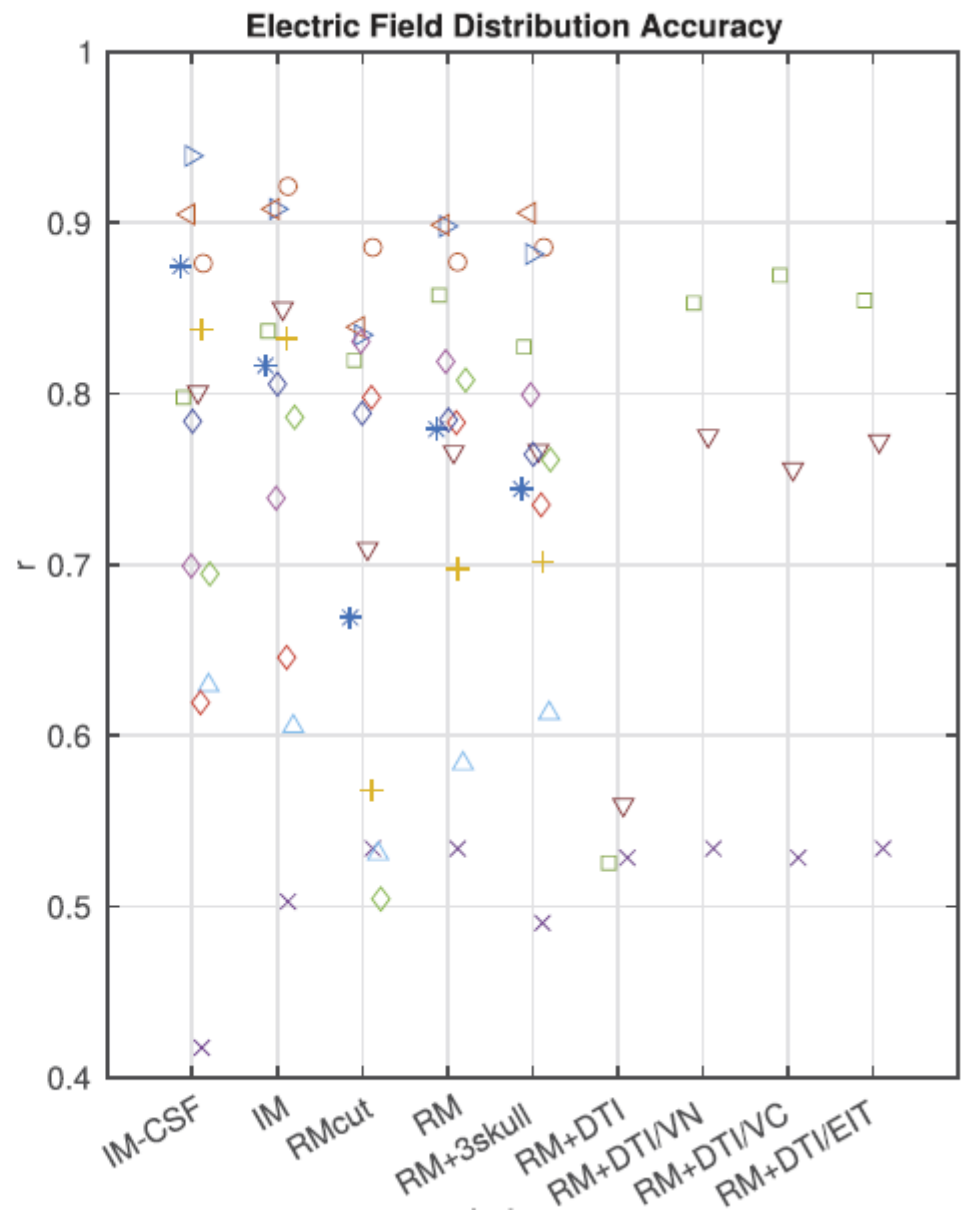
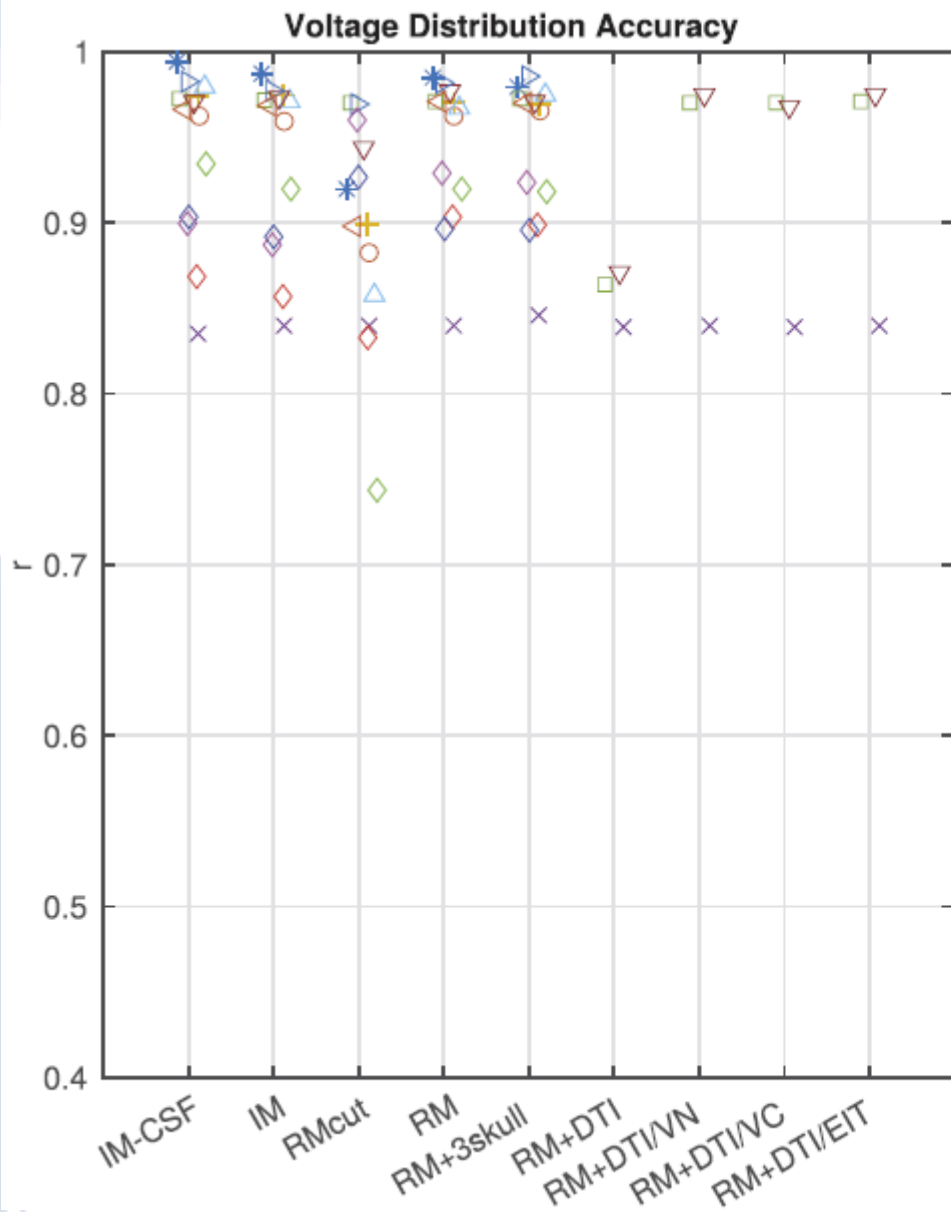
Huang, Liu, *et al*,
 eLife, 2017

Can tDCS achieve max of 1 V/m in the brain?

After calibration...



Do we need to model skull compartments and white matter anisotropy?



Whole-head model, CSF: important
 Skull compartments, WM anisotropy: not important

Conclusions

- First-time validation of current-flow models under tES using *in vivo* intracranial recordings from human brain
- Models predict electric field distribution well ($r = 0.89$), but over-estimate the magnitude if using literature conductivity
- Calibrated models show 0.4 V/m max field on the cortex under 2 mA stimulation, half of that reported by modeling studies
- Modeling of WM anisotropy & skull compartments does not significantly improve accuracy, but individual model including CSF and covering the whole head is important
- Data made available online at <http://dx.doi.org/10.6080/K0XW4GQ1>

Acknowledgements

NYU School of Medicine:

Anli A. Liu, MD, MA

Daniel Friedman, MD

Xiuyuan (Hugh) Wang, MS

Werner K. Doyle, MD

Orrin Devinsky, MD

Preet Minhas, MS

The City College of New York:

Belen Lafon, PhD

Lucas C. Parra, PhD

Marom Bikson, PhD

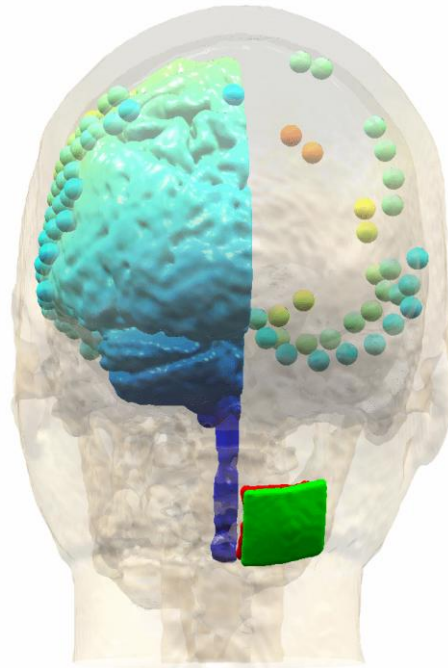
Hetince Zhao

Mayo Clinic:

Michael Dayan, PhD

Funding sources:

R44NS092144, R01MH092926, R41NS076123, R01MH107396



www.parralab.org/tesValidate/

Thank you!
Q & A