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Personalization and Validation of Electric Field Models for Transcranial Electrical Stimulation

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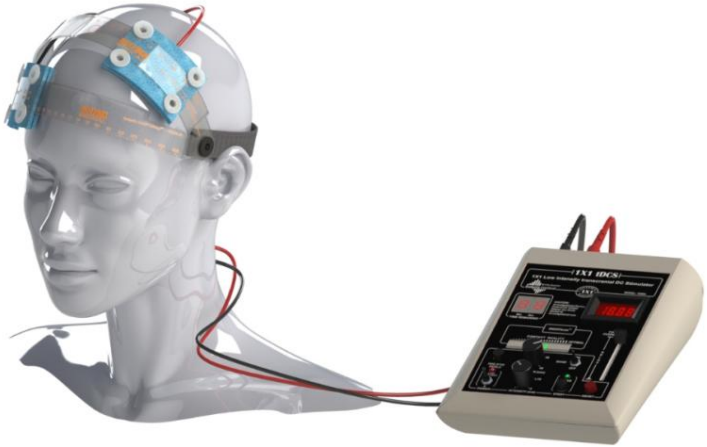
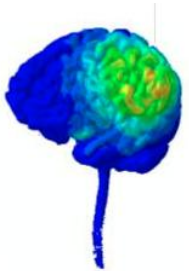
2024 NYC NEUROMODULATION CONFERENCE

Outline

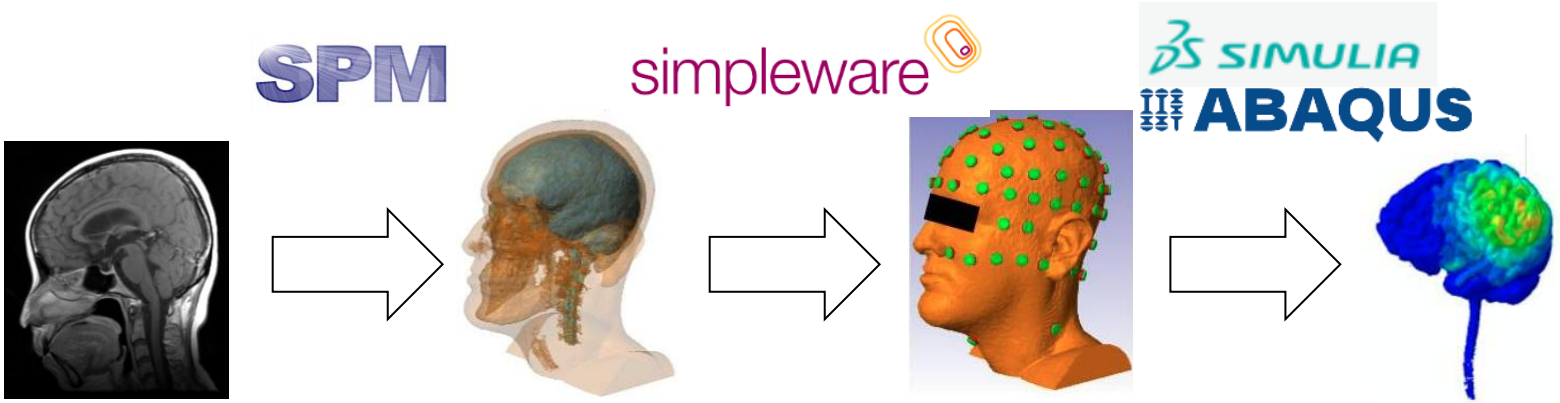
- Modeling workflow
- ROAST software
- Model validation
- Beyond ROAST
- Applications of models: targeting, deep TES, IFS (TI)

Transcranial electrical stimulation (TES)



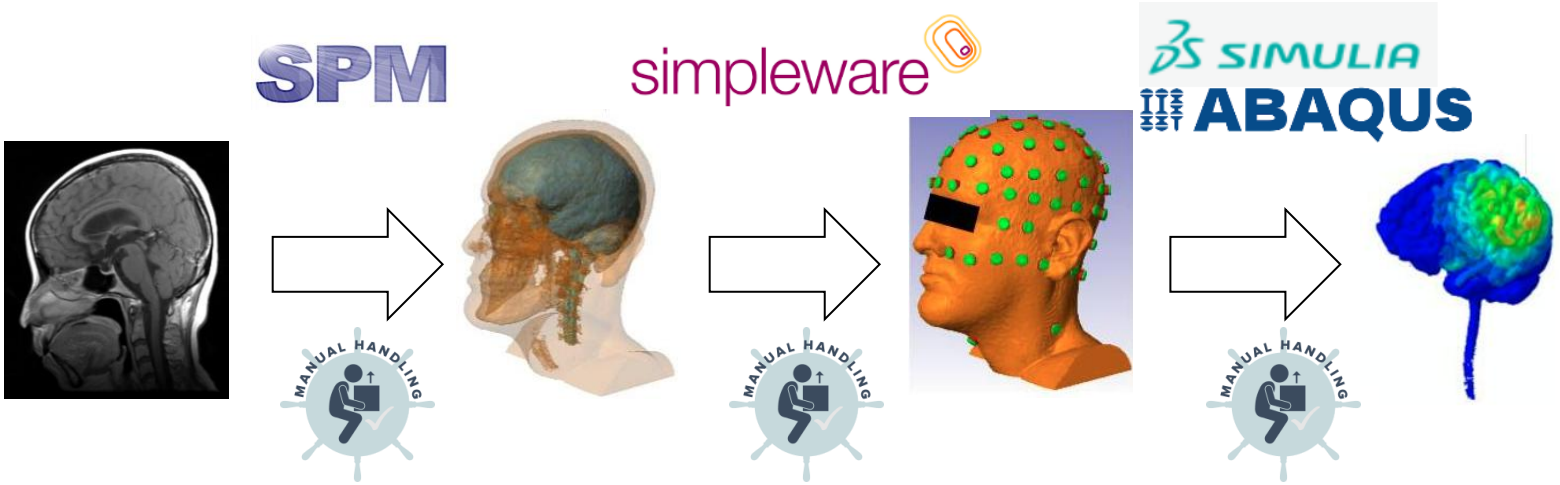


Workflow of image-guided TES modeling (from 2010)



Huang et al., 2013

Workflow of image-guided TES modeling (from 2010)



1~2 weeks

Huang et al., 2013

ROAST (from Nov. 11, 2017)

ROAST

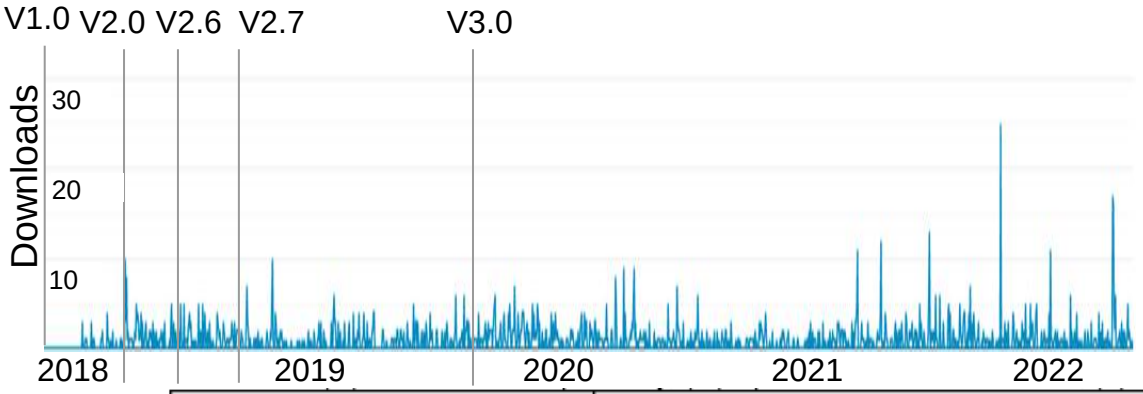
MATLAB

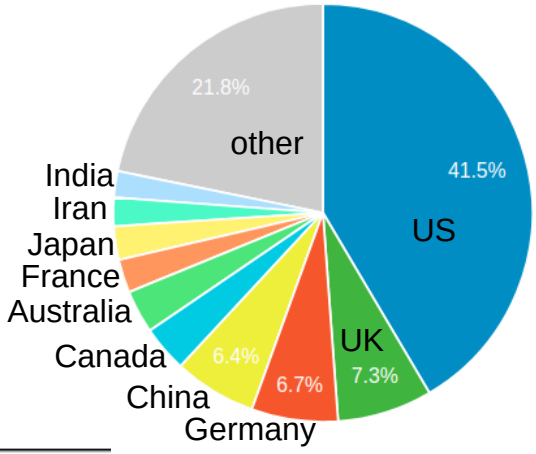
10~20 minutes

https://github.com/andypotatohy/roast

Huang et al., 2019

Adoptions of ROAST





Conditions	Number of subjects modeled (References)
Depression	N = 151 (Argyelan et al[133])
Schizophrenia	N = 89 (Kantrowitz et al[134]); N = 17 (Mondino et al[135])
Dementia	N = 60 (Sanches et al[136])
Cognitive performance in Alzheimer's disease	N = 2 (Im et al[137])
Aging	N = 587 (Indahlastari et al[138])
Cerebellar stimulation	N = 18 (Rezaee et al[139]); N = 10 (Rezaee et al[140]); N = 12 (Solanki et al[141]); N = 25 (Moussa et al[142])
Working memory and attention	N = 52 (Nikolin et al[143])
Functional connectivity	N = 10 (Kar et al[144])
Inter-individual variability	N = 50 (Evans et al[145]); N = 29 (Caulfield et al[146]); N = 57 (Kasten et al[147]); N = 47 (Filmer et al[148])
Total (subset of 200+ citations of our publications[20,111])	**N = 1216**

Nasimova & Huang, *2022*

How to use ROAST?

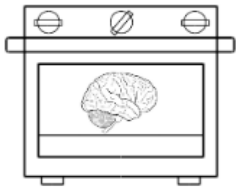
- Documentation: https://github.com/andypotatohy/roast
- Tutorial video: https://www.youtube.com/watch?v=-Yr53o4Sw2Y
- Tutorial slides: https://neuromodec.org/nyc-neuromodulation-online-2020/Neuromod2020_ROASTtutorial.pdf
- Mailing list: roast-users@googlegroups.com

How to use ROAST?

- roast('example/subject1.nii',{'F1',1,'C5',-1})
- Electrode layout, shape, size, resampling, padding, tag
- roast([],'leadField','simulationTag','MNI152leadField')
- roast_target([],'MNI152leadField',[-48 -8 50])

Why ROAST?

ROAST



Realistic vOlumetric Approach to Simulate TES

Why vOlumetric?

SimNIBS
by Axel Thielscher
2011

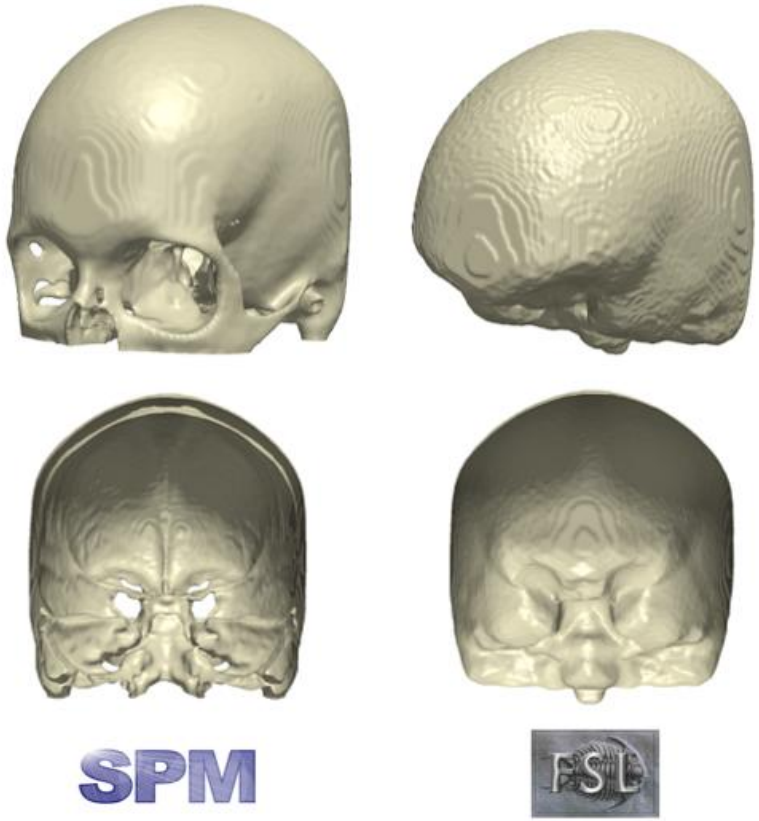
BET

gmsh

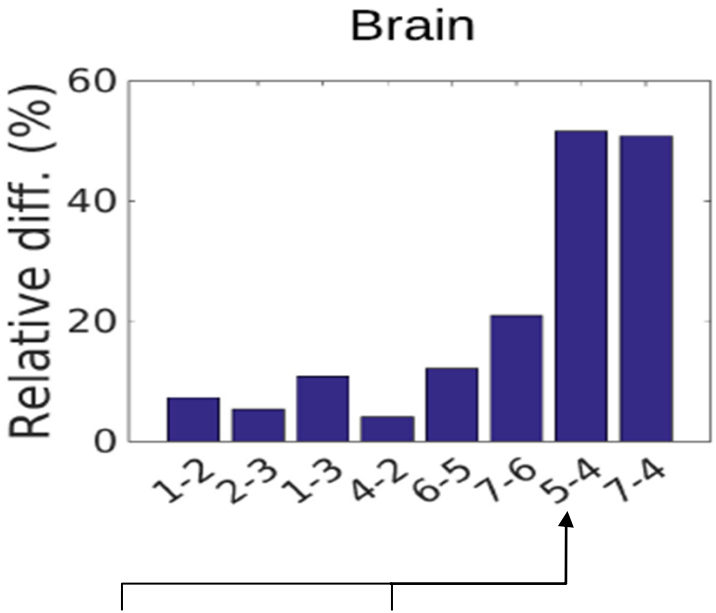
ROAST
2017

getDP

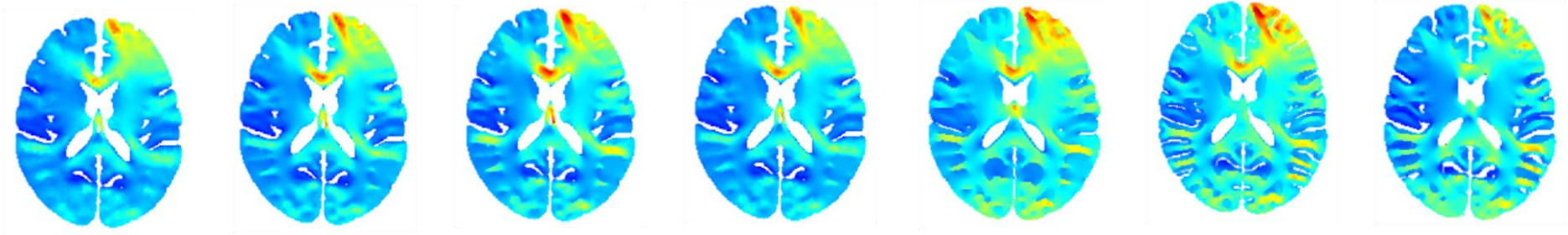
Why Realistic?



Difference from two approaches



(1) ROAST (2) ROAST-sg (3) ROAST-sa (4) ROAST-gg (5) SimNIBS-hr (6) SimNIBS-hrE (7) SimNIBS-mm

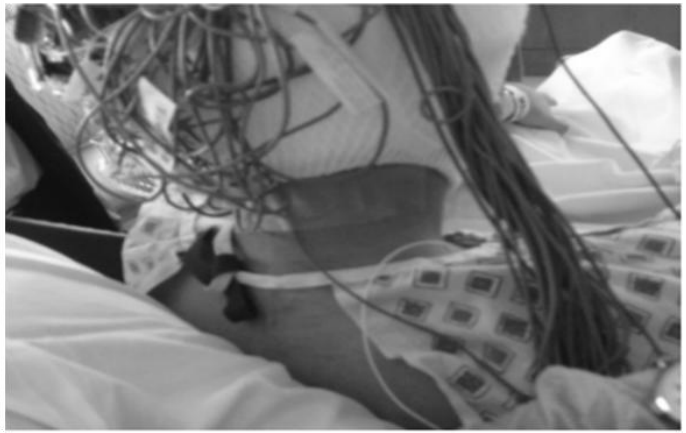


Huang et al., 2019

Can we trust all these models?

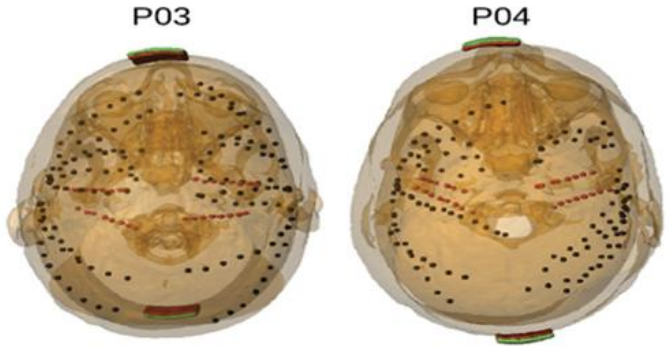
Model validation

NYU School of Medicine
NYU LANGONE MEDICAL CENTER



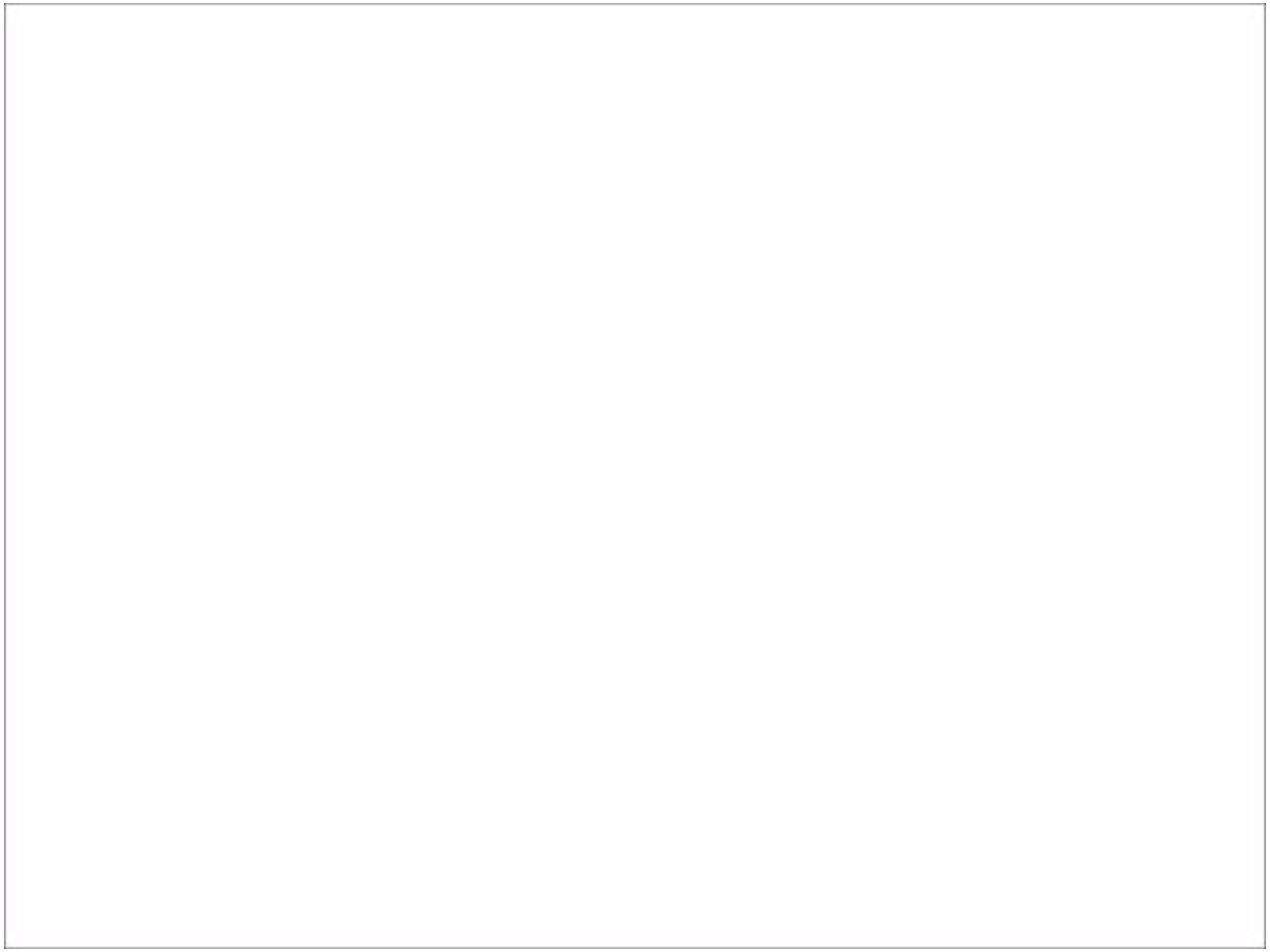
Anli Liu

Daniel Friedman



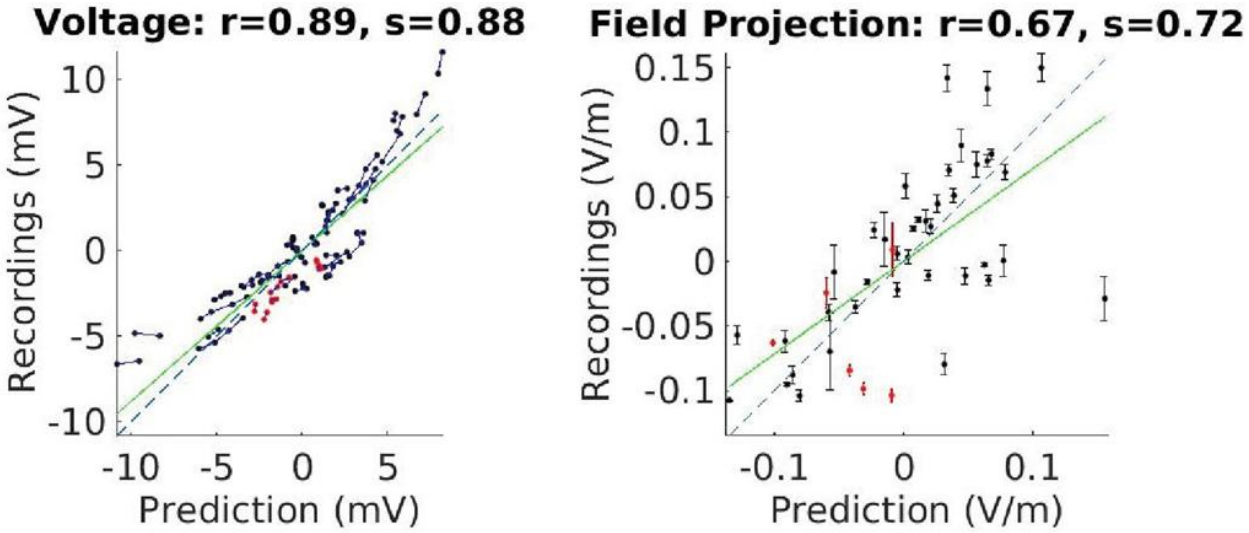
- 10 patients under iEEG
- ~130 recording electrodes per patient

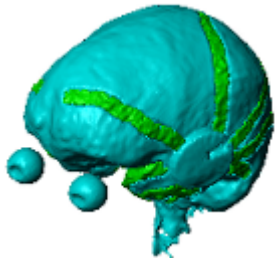
Huang, Liu, et al, *eLife*, 2017



https://www.youtube.com/watch?v=jg9HVpaROoI

Validation results

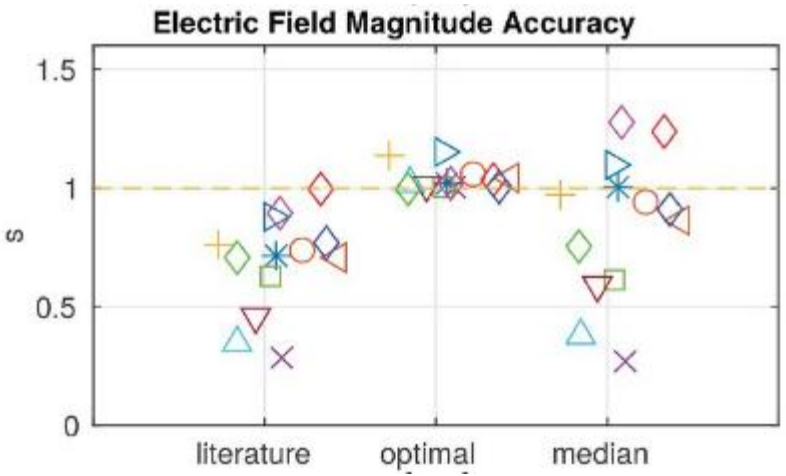


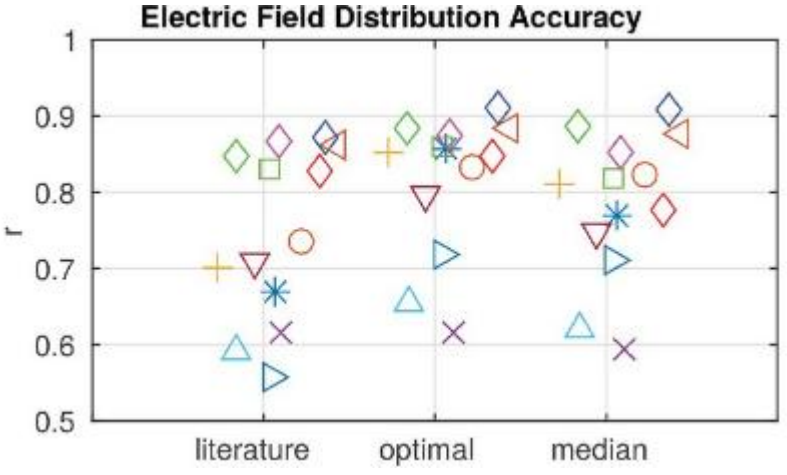


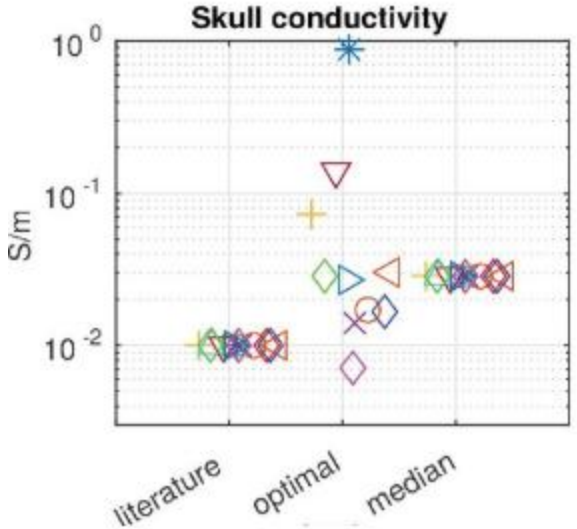
Relative distribution patterns well predicted (correlation “r”);
Absolute magnitudes roughly estimated by model (slope “s”)

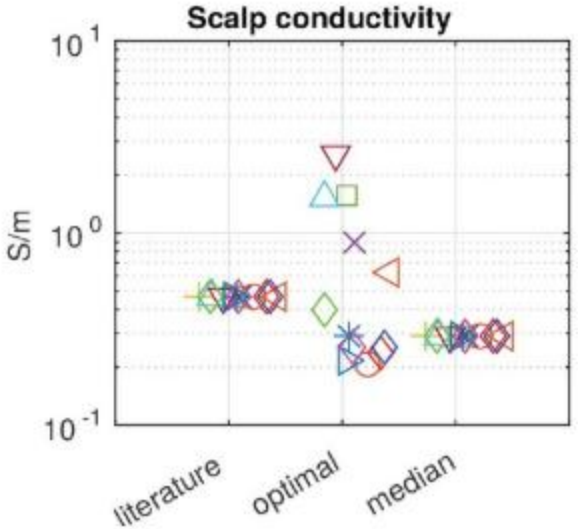
First-time validation of TES models!

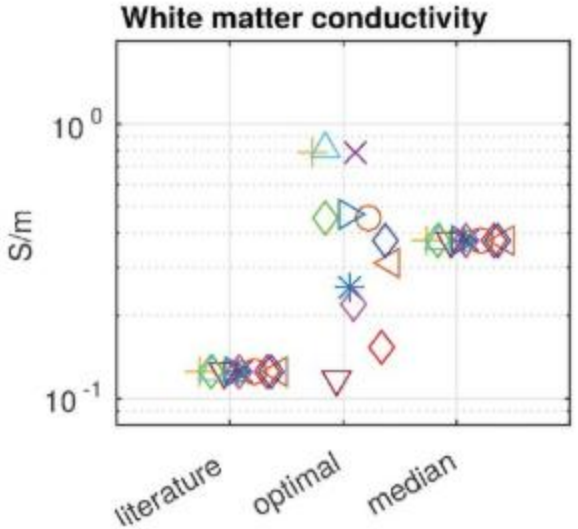
Huang, Liu, *et al*, eLife, 2017





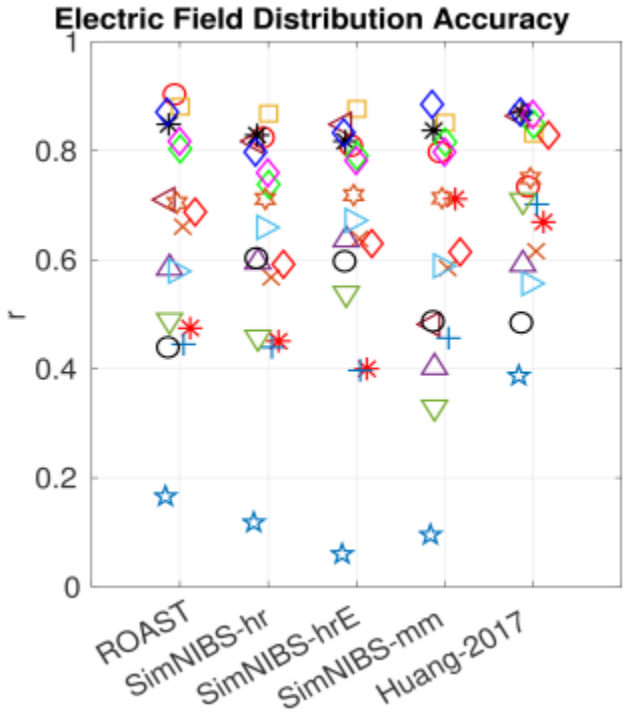


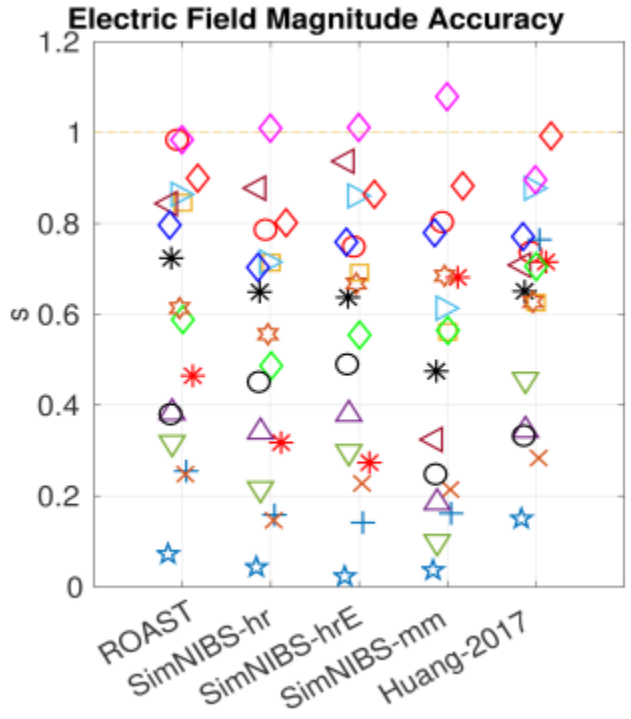




Huang, Liu, *et al*, eLife, 2017

ROAST vs. SimNIBS



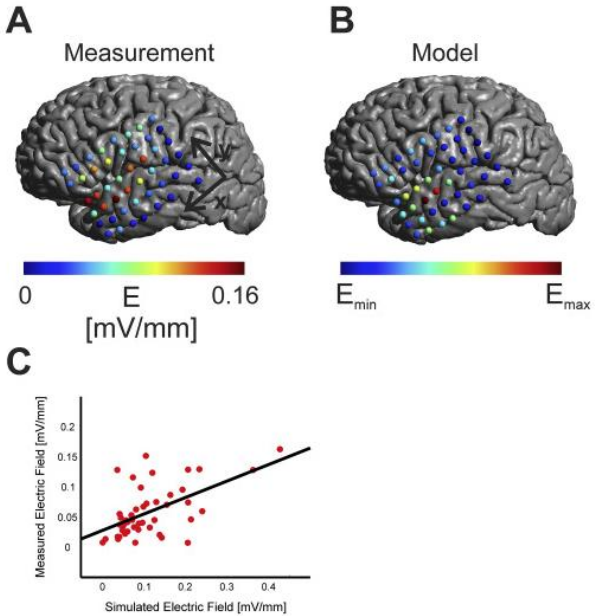


Huang et al., 2019

Further validation

On the importance of precise electrode placement for targeted transcranial electric stimulation

Alexander Opitz [a b c], Erin Yeagle [d], Axel Thielscher [e f], Charles Schroeder [b g], Ashesh D. Mehta [d], Michael P. Milham [b c]



- Opitz et al., 2018: on 2 patients, ECoG / sEEG electrodes vs. SimNIBS, similar results

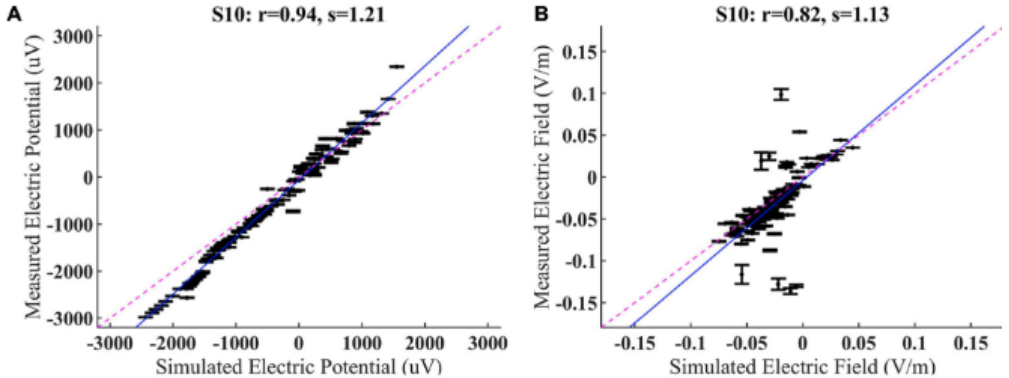
Further validation

In vivo Measurements of Electric Fields During Cranial Electrical Stimulation in the Human Brain


Minmin Wang[1] Tao Feng[1] Hongjie Jiang[2] Junming Zhu[2] Wuwei Feng[3]


Pratik Y. Chhatbar[3]

Jianmin Zhang[2*] Shaomin Zhang[1,4*]



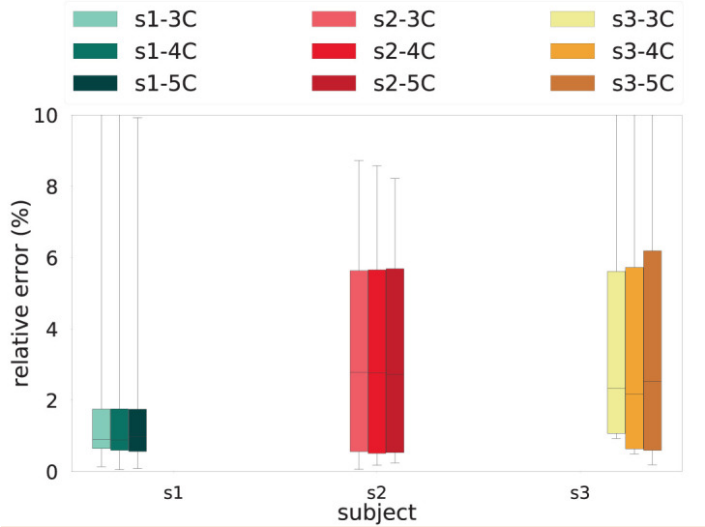
- Wang et al., 2022:
  on 21 patients, sEEG electrodes vs. ROAST, similar results

Further validation

Front Hum Neurosci. 2024; 18: 1279183.
Published online 2024 Feb 12. doi: 10.3389/fnhum.2024.1279183
PMCID: PMC10894995
PMID: 38410258

How to assess the accuracy of volume conduction models? A validation study with stereotactic EEG data

Maria Carla Piastra,[1,2,*] Robert Oostenveld,[3,4] Simon Homölle,[3] Biao Han,[5] Qi Chen,[5] and Thom Oostendorp[2]



- Piastra et al., 2024:
  on 3 patients, sEEG electrodes vs. DUNEuro, ~10% relative difference

Outline

- Modeling workflow
- ROAST software
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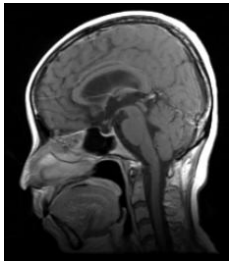
- Beyond ROAST
- Applications of models: targeting, deep TES, IFS (TI)

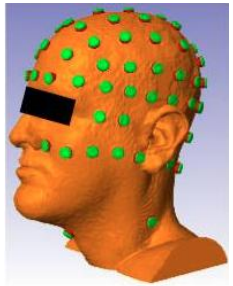
Beyond ROAST: smarter segmentation

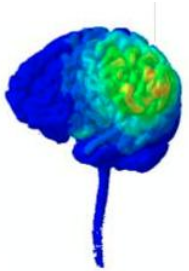
SPM

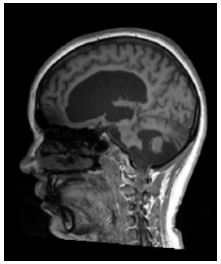
ISO2MESH

getDP

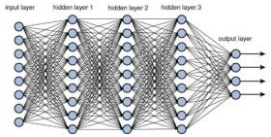








MultiPriors



ROAST

V3.5

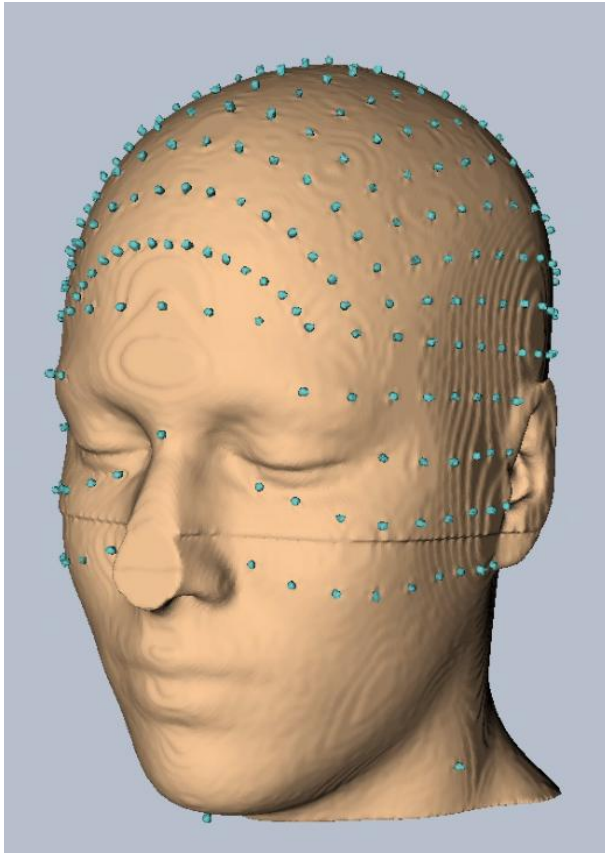
roast('example/subject1.nii',[],'multipriors','on')

https://github.com/andypotatohy/roast/releases/tag/v3.5

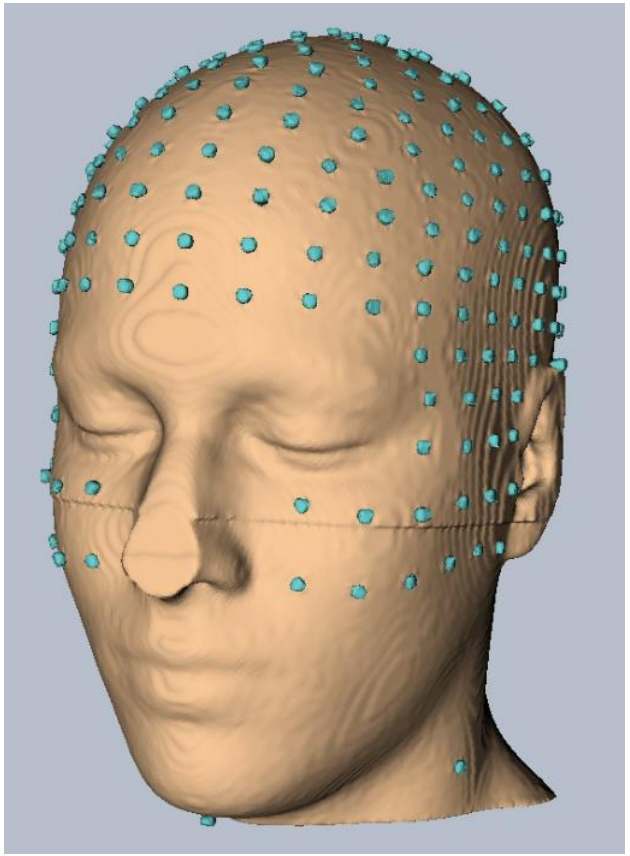
Lukas Hirsch

Andrew Birnbaum

Beyond ROAST: more electrodes



394 electrodes



336 electrodes

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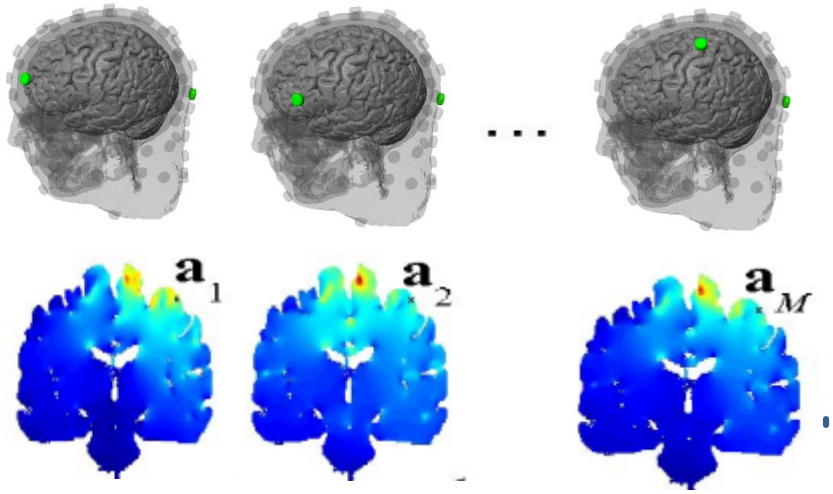
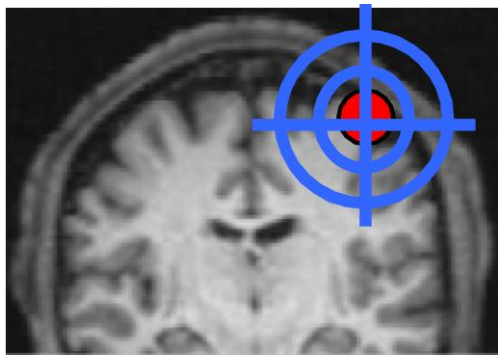
contact@soterixmedical.com

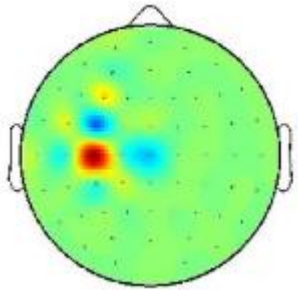
How do we use these models?

Targeted stimulation



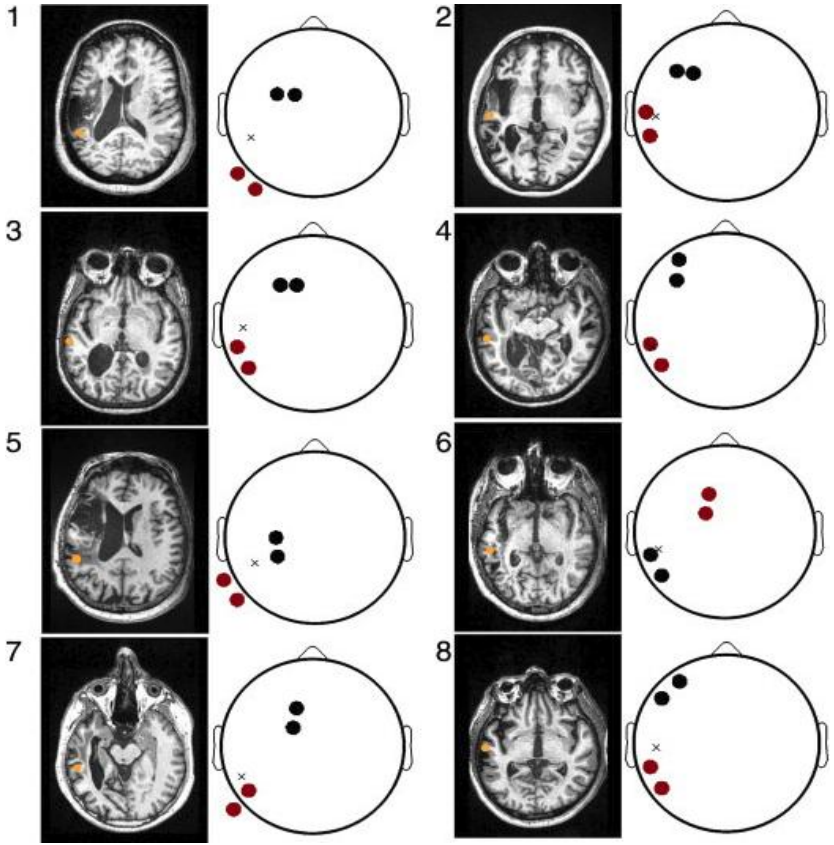


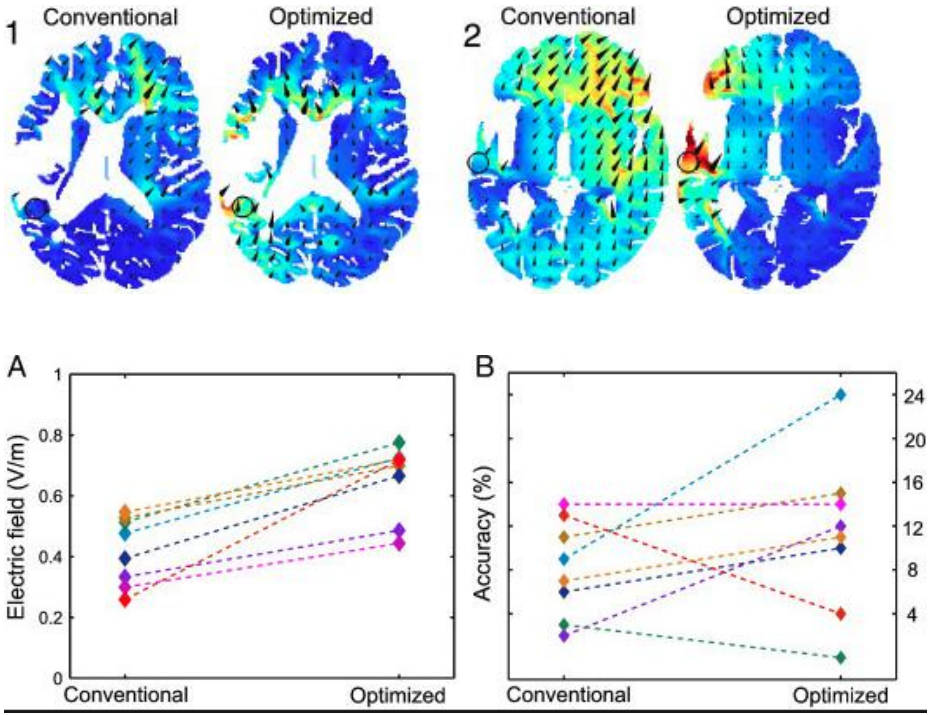
Targeting algorithm



Dmochowski, et al, 2011

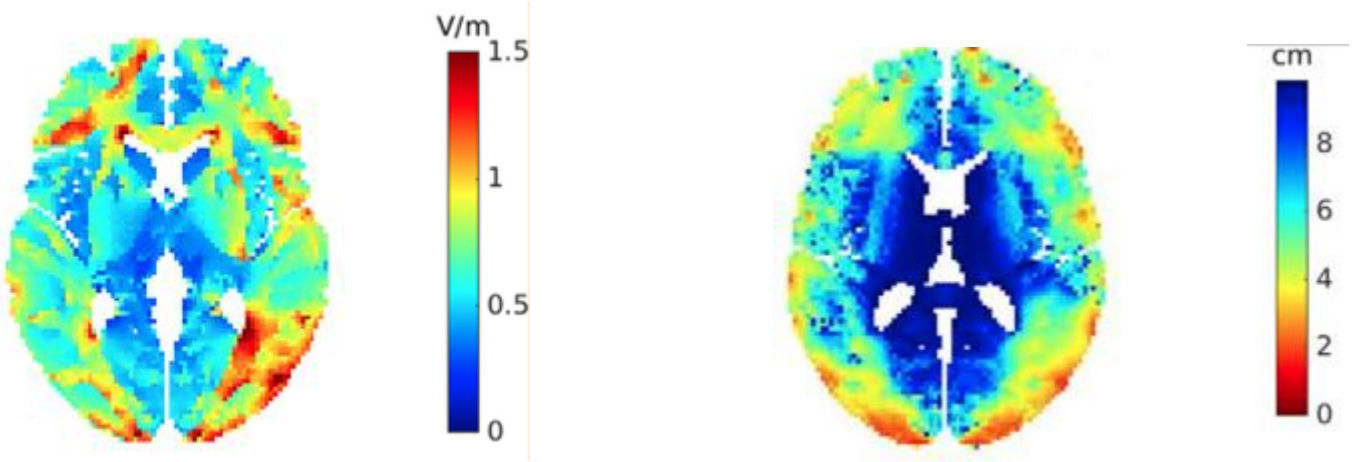
Application of modeling in a clinical trial





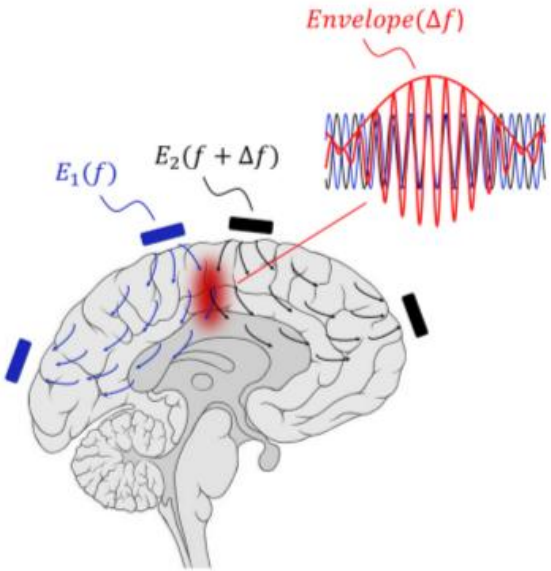
Dmochowski et al, 2013

HD-TES can go to the deep brain



Huang & Parra, 2019

IFS Background

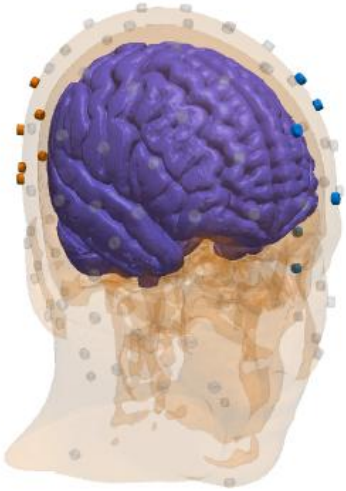


<

in terms of modulation depth; Huang & Parra 2019

>

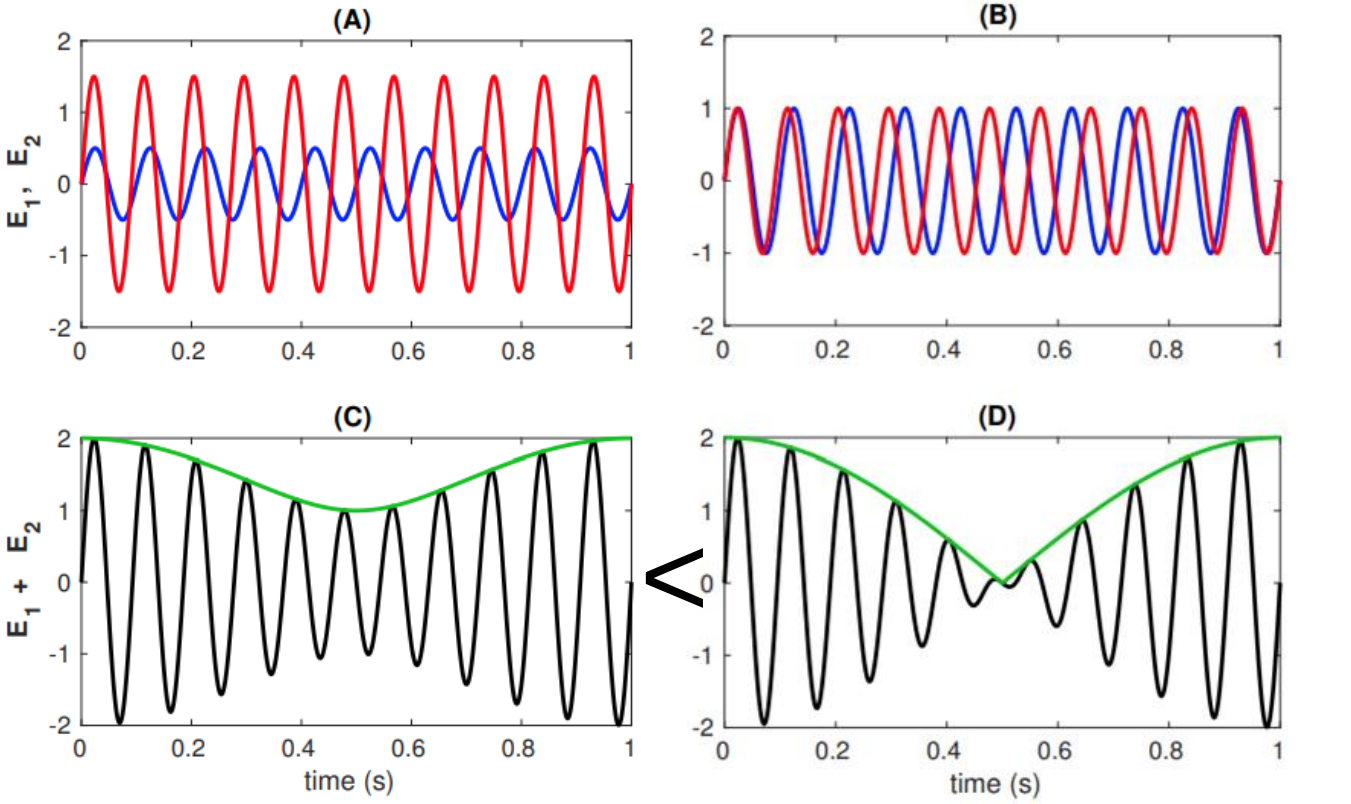
in terms of focality, if optimized; Huang et al., 2020

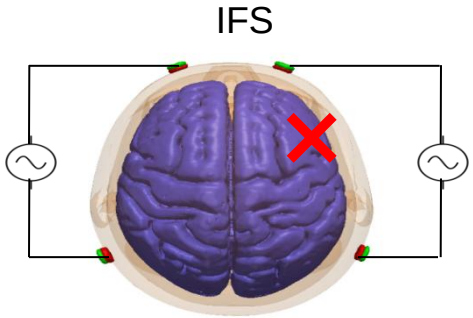


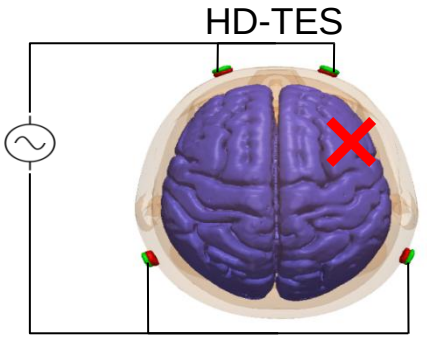
Interferential stimulation (IFS), Grossman et al., 2017

HD-TES, Dmochowski et al., 2011

Some physics:







Huang et al., 2020

Optimizing Interferential Stimulation (focality)

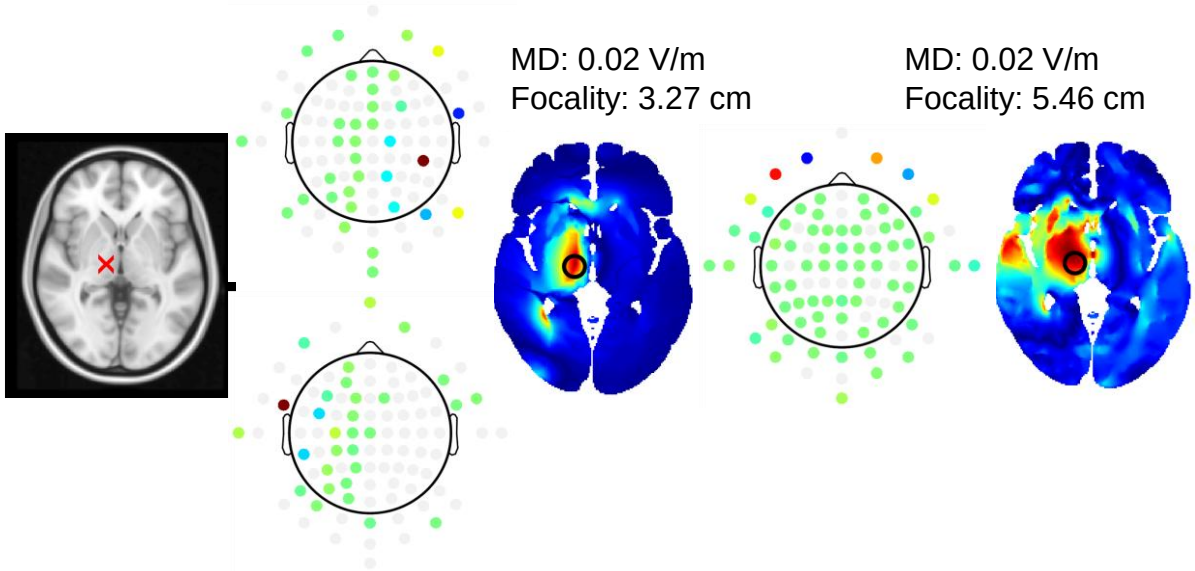
$$\arg\max_{\mathbf{s}_1, \mathbf{s}_2} \quad 2\min(|\mathbf{e}^T\mathbf{A}\mathbf{s}_1|, |\mathbf{e}^T\mathbf{A}\mathbf{s}_2|)$$

$$\text{s.t. } \mathbf{1}\mathbf{s}_1 = 0, \mathbf{1}\mathbf{s}_2 = 0,$$

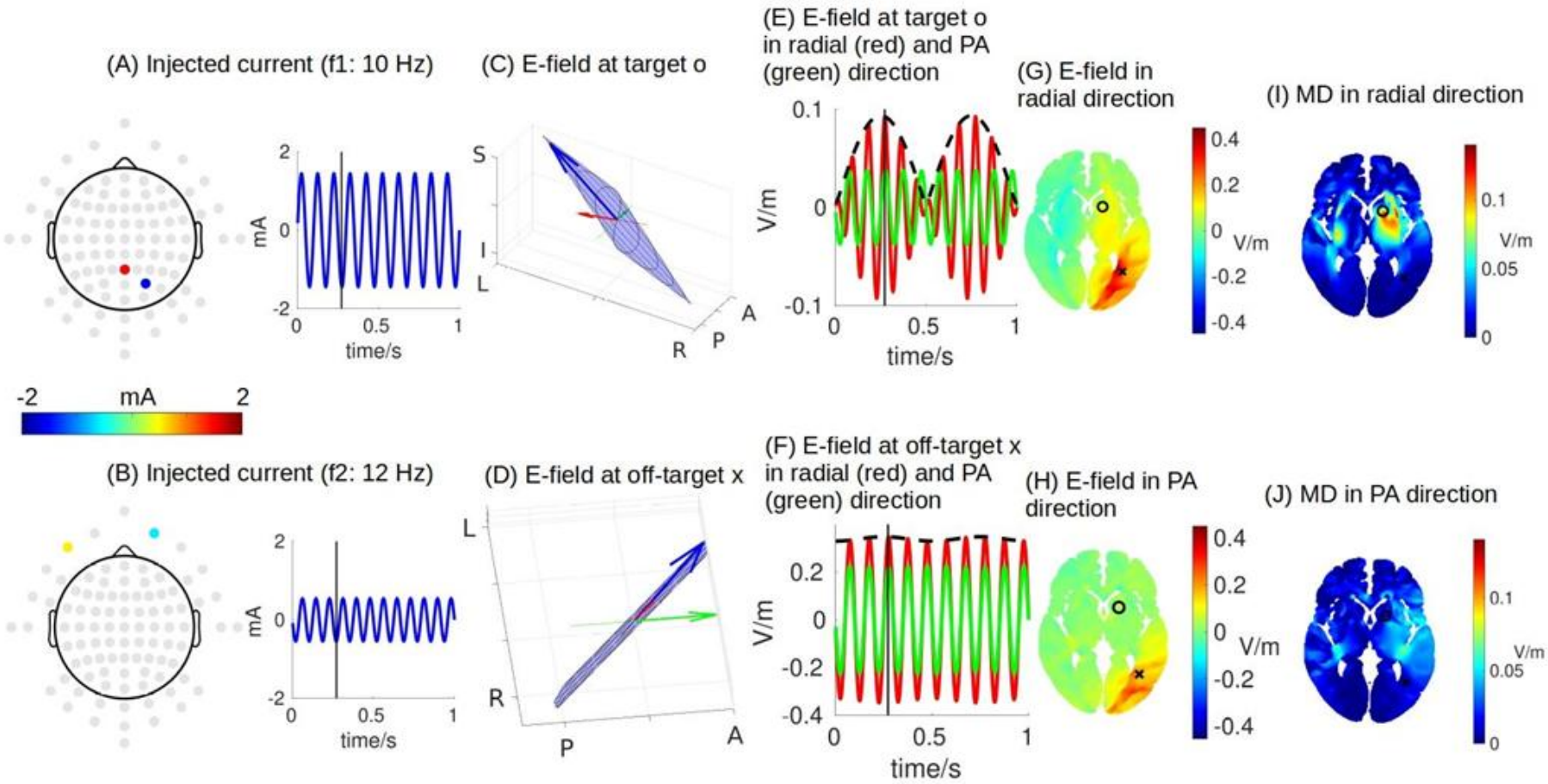
$$\|2\min(|\mathbf{\Gamma}\mathbf{A}\mathbf{s}_1|, |\mathbf{\Gamma}\mathbf{A}\mathbf{s}_2|)\|^2 \leq P_{max},$$

$$\mathbf{1}\mathbf{s}_1^+ + \mathbf{1}\mathbf{s}_1^- \leq I_{max}, \mathbf{1}\mathbf{s}_2^+ + \mathbf{1}\mathbf{s}_2^- \leq I_{max},$$

$$0 \leq \mathbf{s}_1^+, 0 \leq \mathbf{s}_1^-, 0 \leq \mathbf{s}_2^+, 0 \leq \mathbf{s}_2^-.$$



Huang et al., 2020


(A) Injected current (f1: 10 Hz)
(C) E-field at target o
(E) E-field at target o in radial (red) and PA (green) direction
(G) E-field in radial direction
(I) MD in radial direction
-2
mA
2
(B) Injected current (f2: 12 Hz)
(D) E-field at off-target x
(F) E-field at off-target x in radial (red) and PA (green) direction
(H) E-field in PA direction
(J) MD in PA direction
mA
time/s
V/m
S
I
L
A
P
R

Huang 2023

S1A S1C S1E S1G S1J

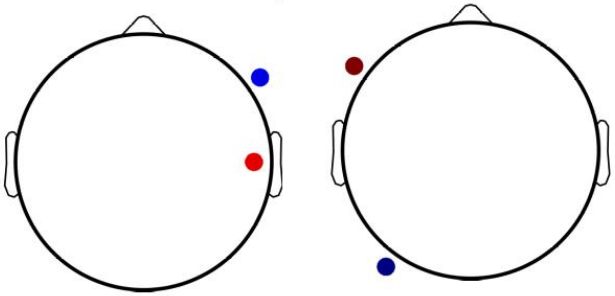
S1B S1D S1F S1H S1I

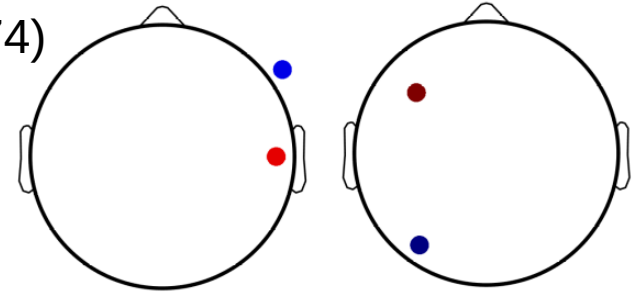
https://www.youtube.com/watch?v=k6BFu28OmLs

Huang 2023

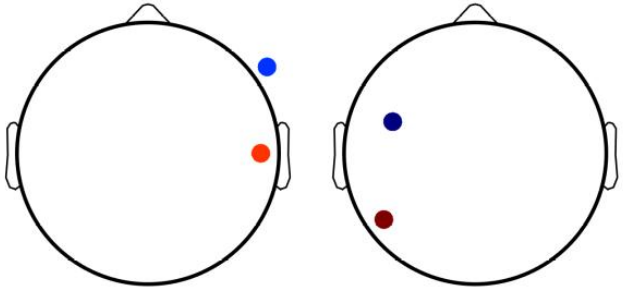
IFS sensitivity (Saturday poster B74)

Original target

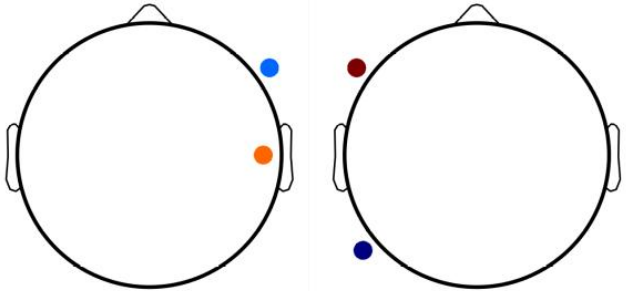




Target shifted 1mm



Target shifted 1.7mm



Target shifted 1.4mm

Brahma, et al.,
manuscript in preparation

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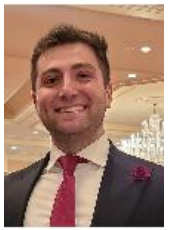
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