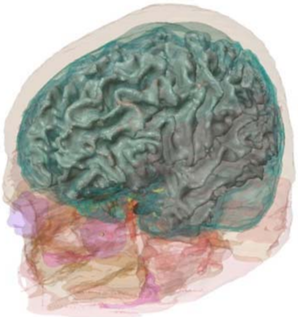
Models for tDCS



Marom Bikson

Lucas Parra, Abhishek Datta, Mathias Hueber

Neural Engineering Laboratory **- Department of Biomedical Engineering**

The City College of New York of CUNY, New York, NY

$ NIH, Wallace Coulter Foundation, DoD

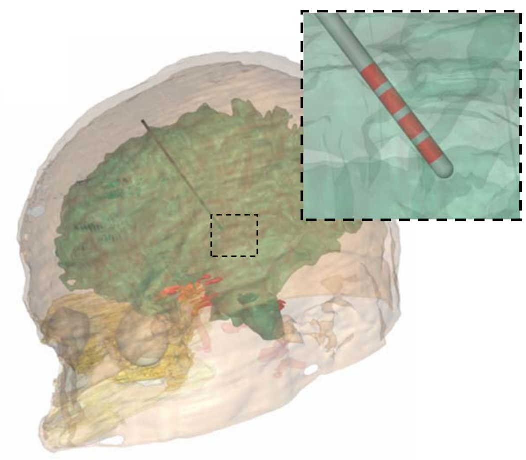
Neuralengr.com

Why Neuromodulation?

(applying electricity to CNS to treat neuropsychiatric disorders and enhance recovery)

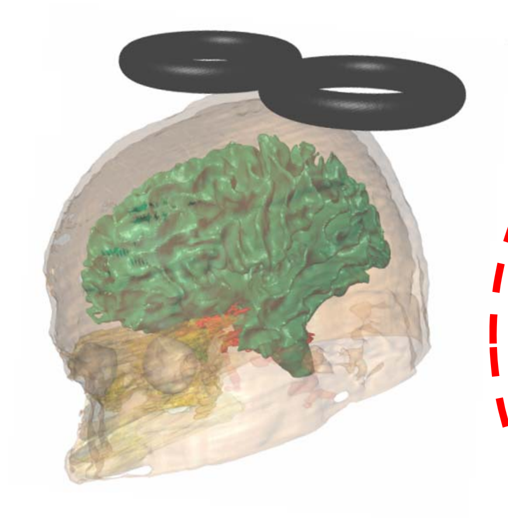
- **Application/outcome specific** (neuropsychiatric, rehabilitation, cognitive performance…)
- **Individualized therapy** (customize, tune-able)
- **Targeted brain modulation** (space + time)
- **Safe** (reversible, no residue, minimal complications + counter-indications)
- **Cost / Access** (multi-use, production, treatment-infrastructure)

Types of Brain Neuromodulation (efficacy and safety)



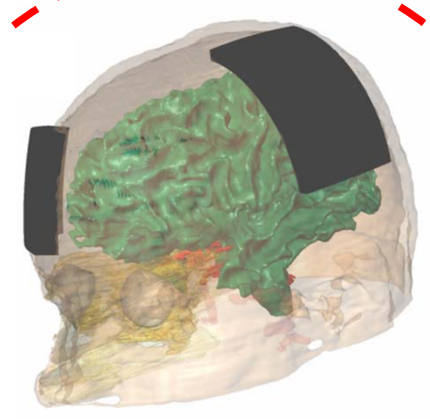
Invasive Leads
(also Vagus, Spinal..)

- Very Targeted
- Safety + Reversibility Concerns
- Supra-threshold dose only
- Costly (resources)



Transcranial Magnetic

- Somewhat Targeted
- Mostly Safe (clinic)
- Supra-threshold dose only
- Not cheap (resource)



Transcranial Electrical

- ~~Not~~ Targeted
- Safe
- Any dose, Supra- or Sub-threshold
- Cheap (home)

Computational models are critical tools for clinicians to understand and improve the outcomes of Neuromodulation

Models are ONLY useful to make predictions

Critical issue of "dose"

Computational models predict the electric field generated in the brain for a *specific* stimulation configuration/settings

---

Electrical activity (efficacy and safety) is determined by electric fields <u>at tissue</u>

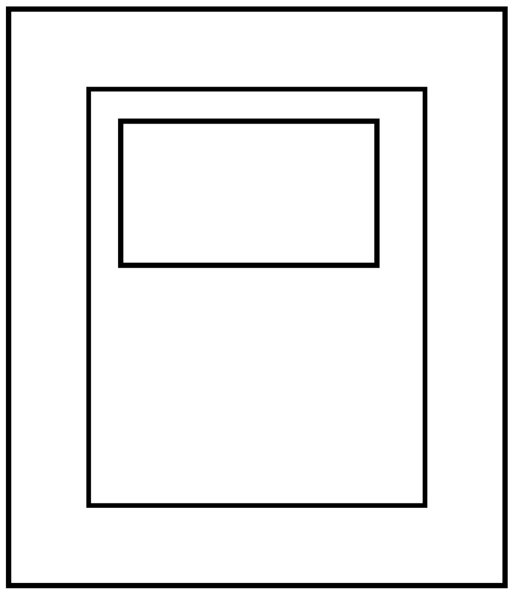
⟺

Clinical dose is set by systemic application (stimulators and pads/coils)

2 steps of "Forward" models

1) Divide the head into compartments
(skin, skull, CSF, brain….)

2) Apply electricity
(the way is it applied clinically)



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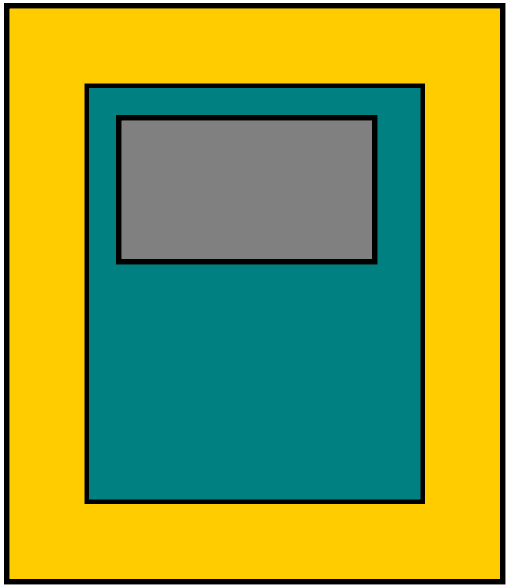

2 steps of "Forward" models

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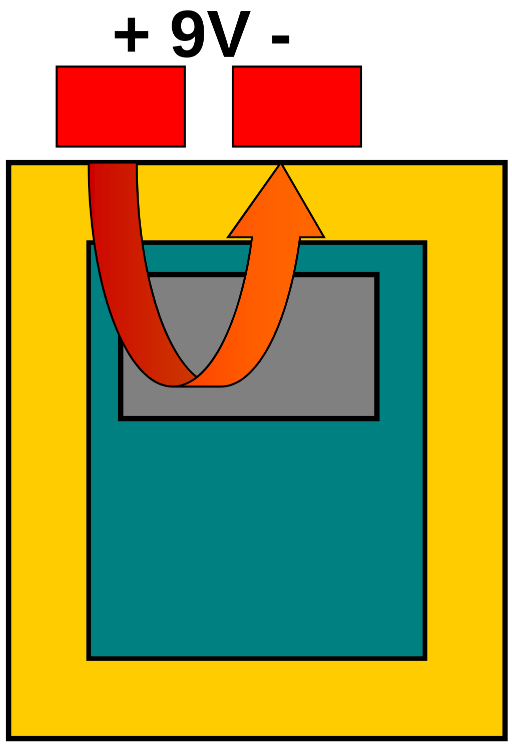
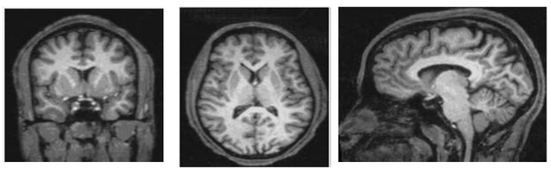


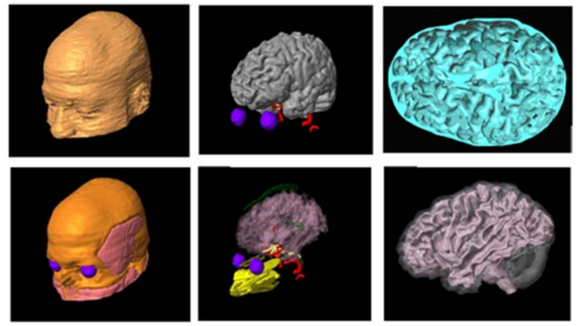
= See where the current goes in the brain !

Workflow (engineering center)

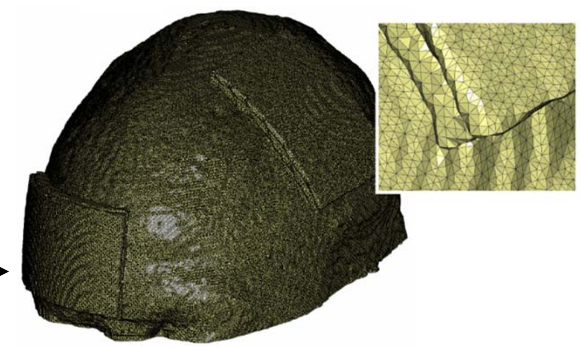
Full work-flow developed to preserve accuracy and resolution



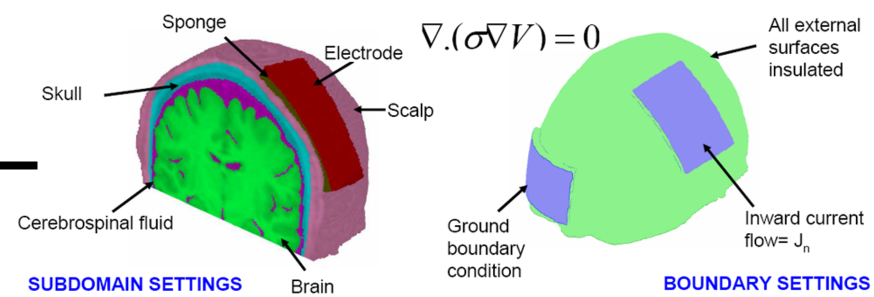
MRI sequences optimized for tDCS modeling (3T at 1x1x1 mm)



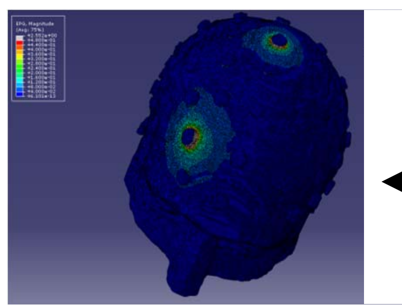
Special segmentation tools perverse resolution in generation of tissue masks



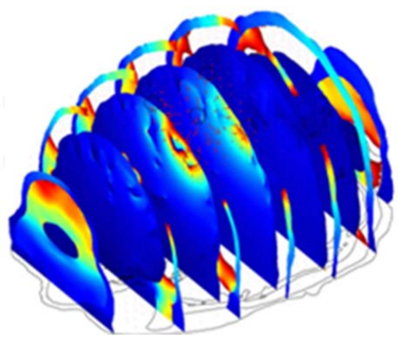
Mesh includes >10 million elements



Model physics/domains include explicit consideration of electrode properties.

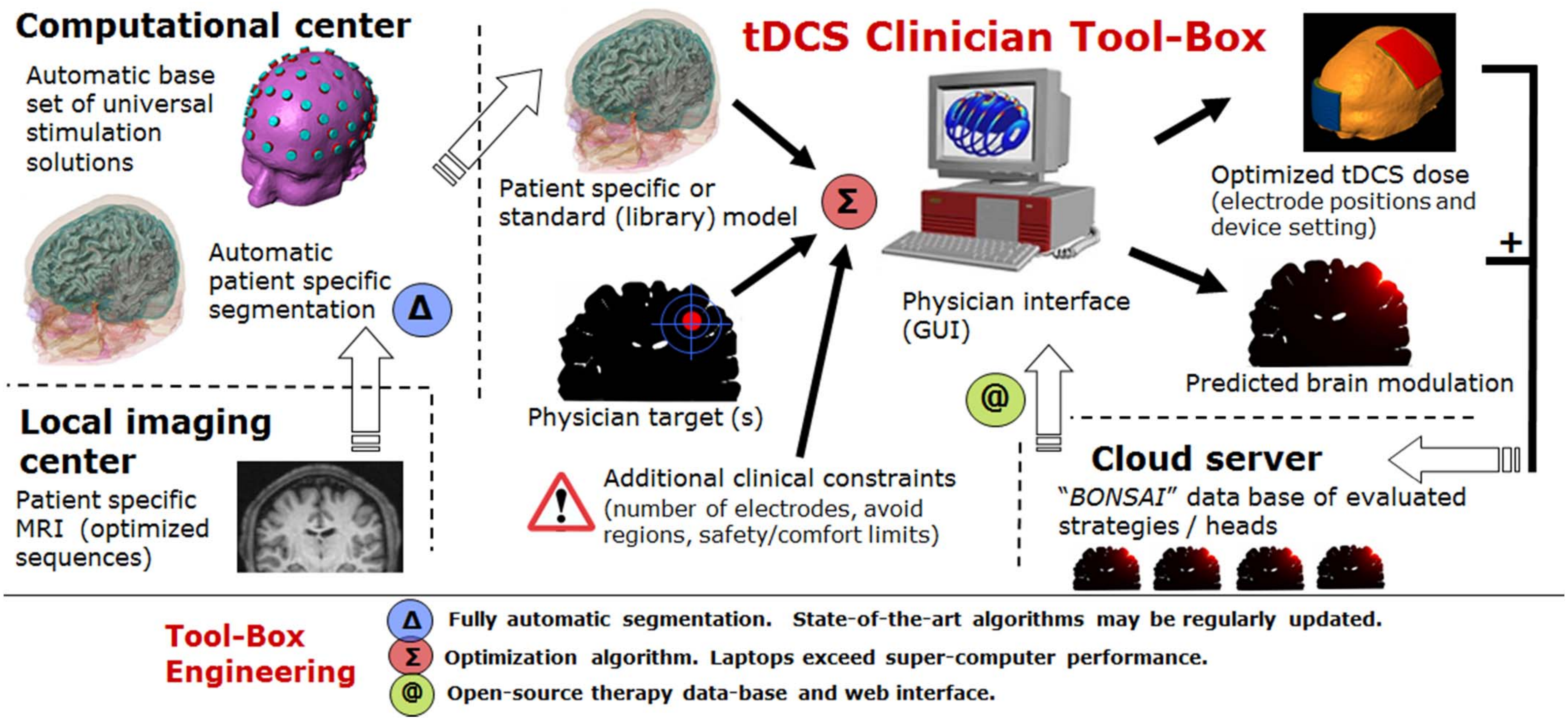


Conjugate gradient solver with <1E-8 tolerance

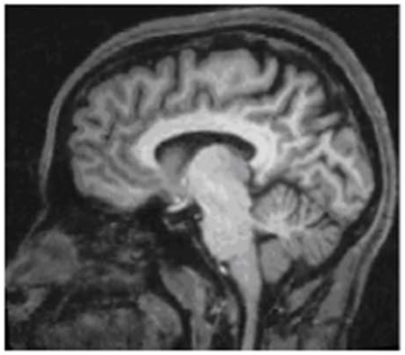


Solution provides detail insight into brain modulation

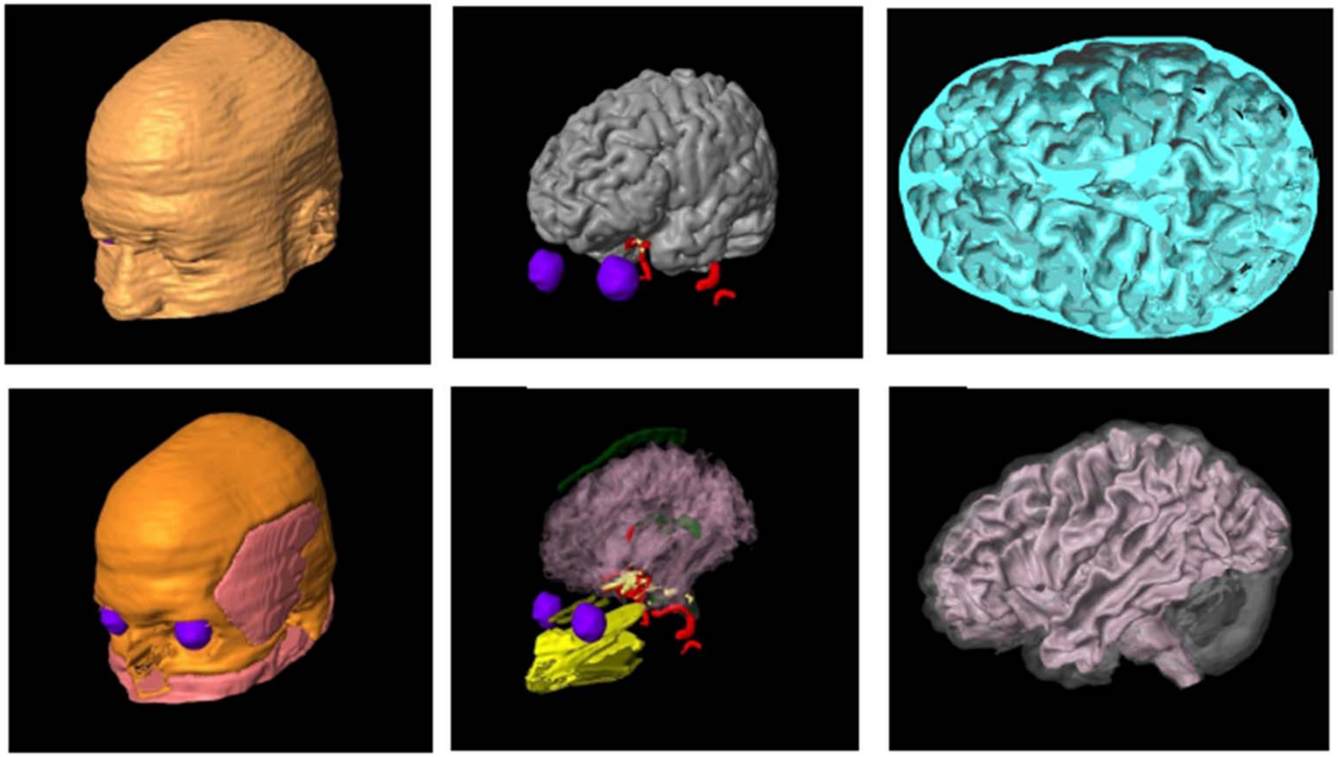
Tool-Box Workflow (clinic)



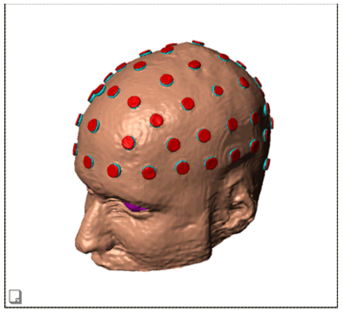
Individualized high-resolution models



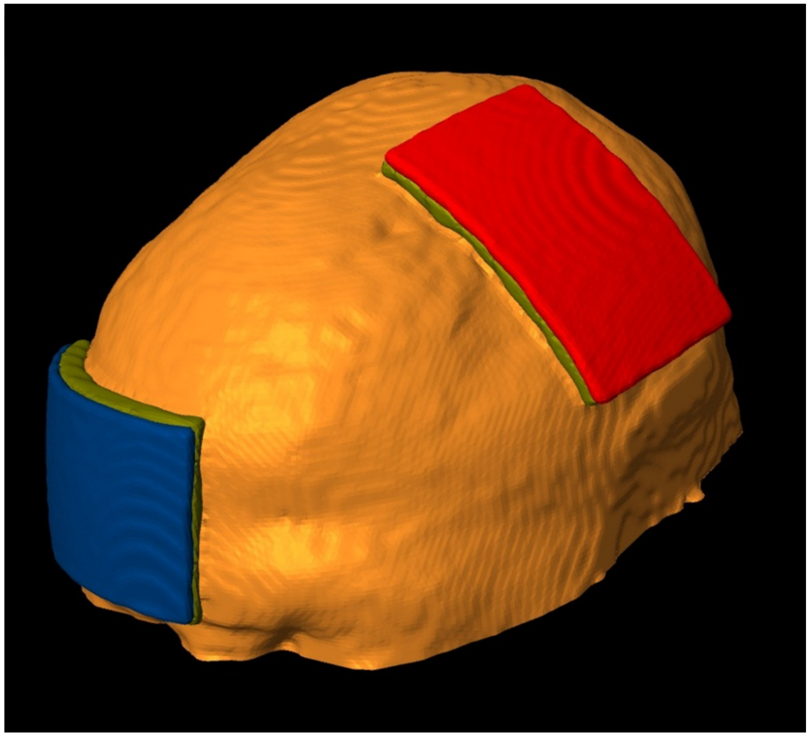
High-resolution 3T MRI scans at 1 mm X 1 mm X 1 mm pixel spacing



1) Anatomical targeting
2) Customized therapy

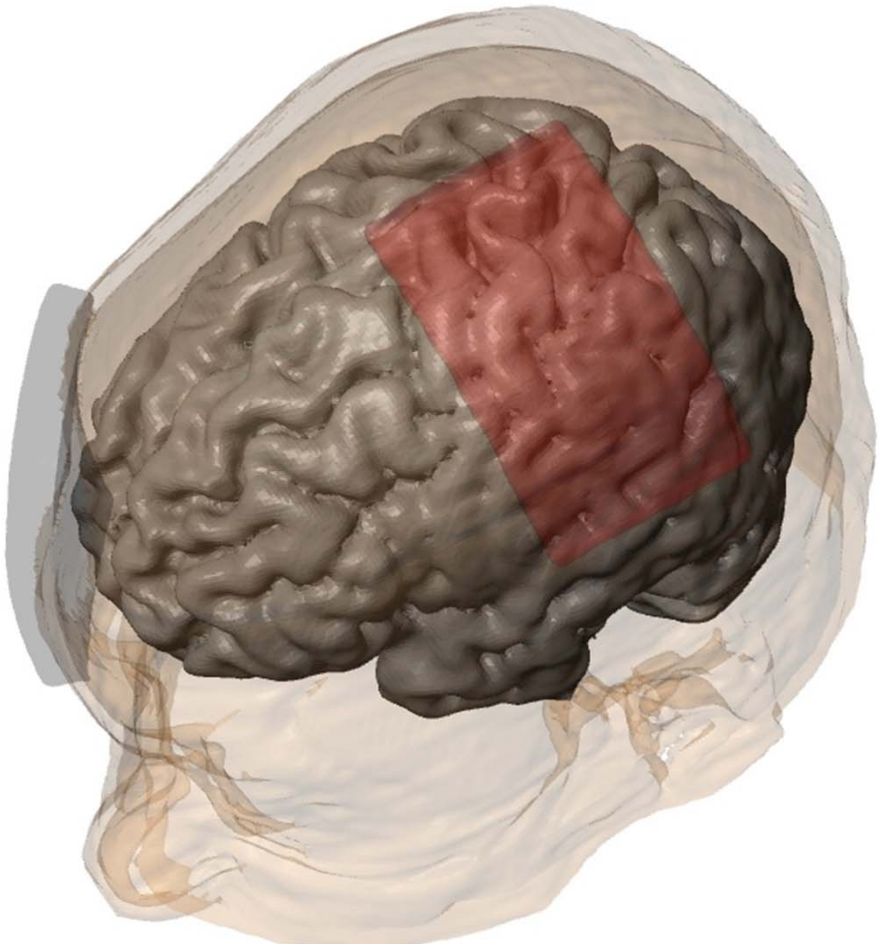


tDCS using existing and *new* electrode montages



1) Rapid screening and computer aided optimization
2) Mechanistic insight (can "look inside")
3) No risk

Conventional tDCS – large pad



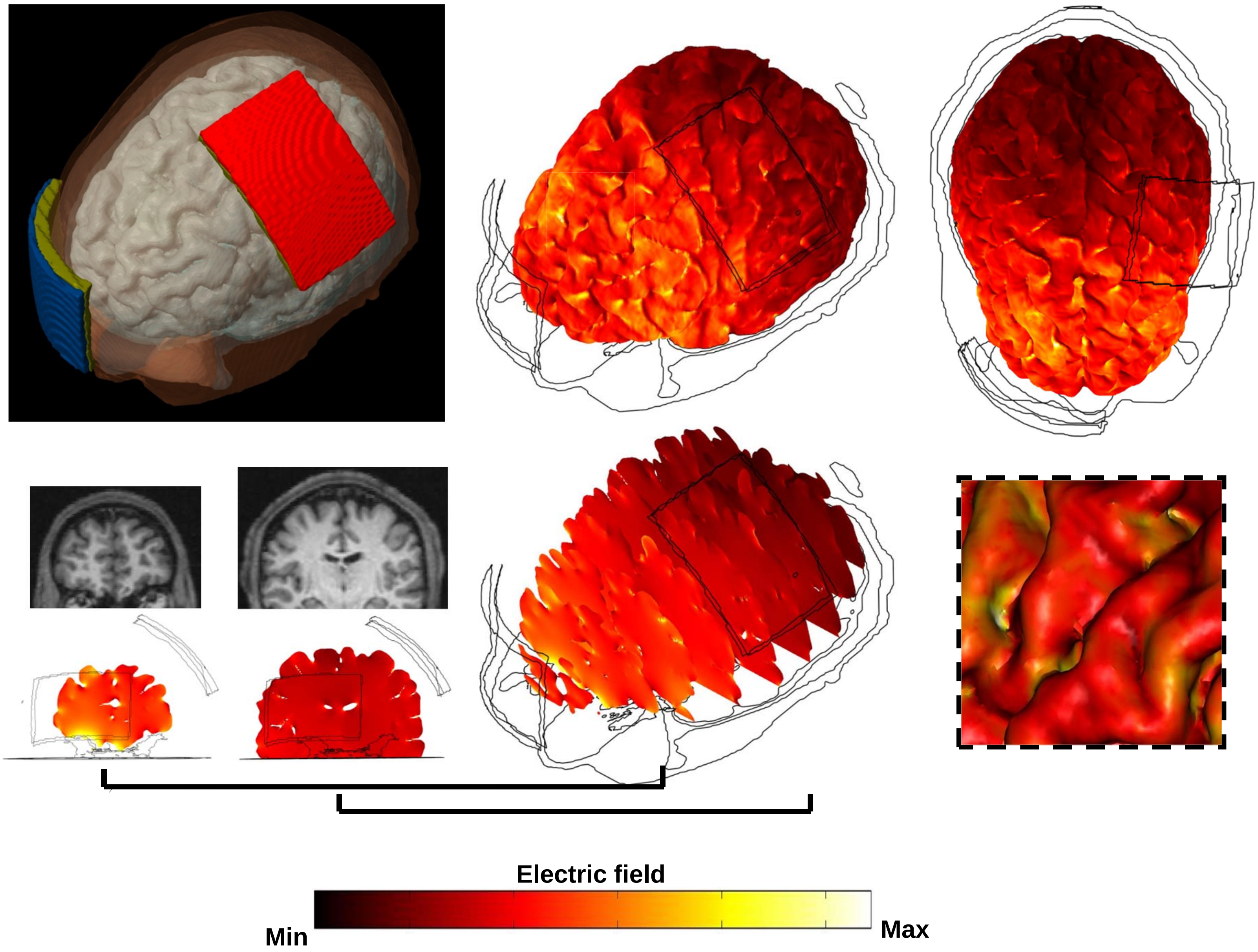
Brain Activation

Maximum

Moderate

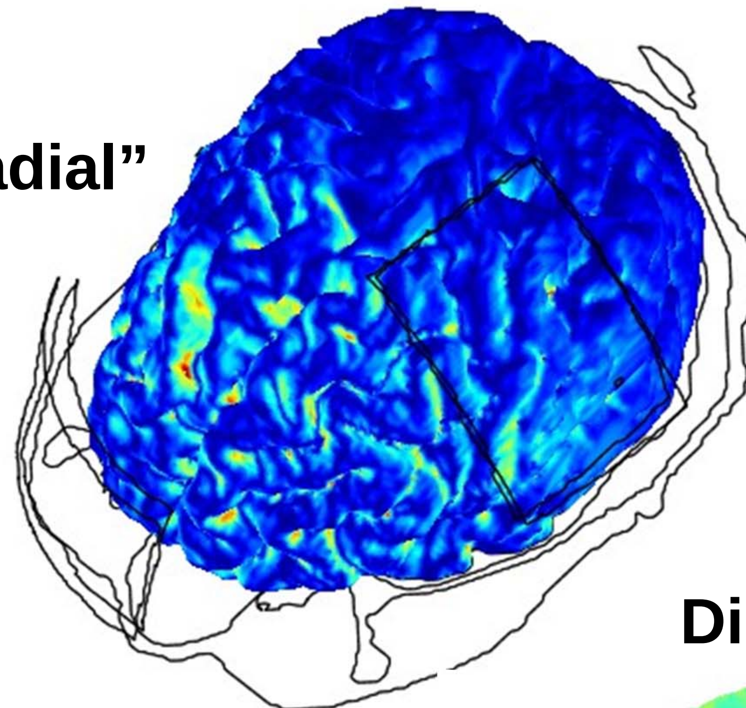
Minimum

Conventional tDCS – large pad

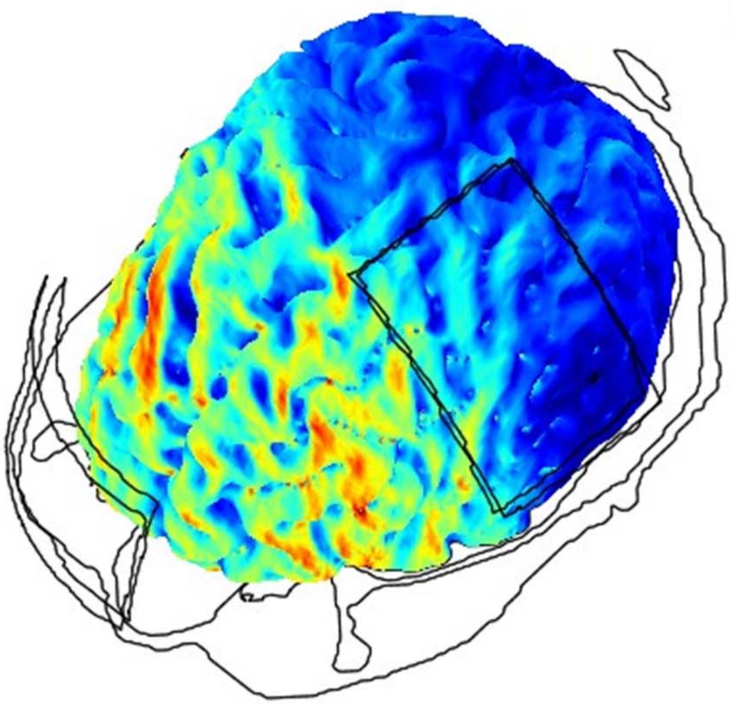


Conventional tDCS – large pad

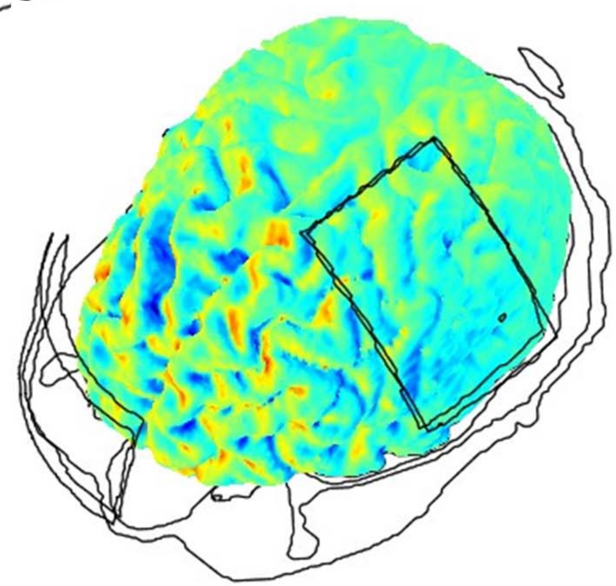
“Radial”



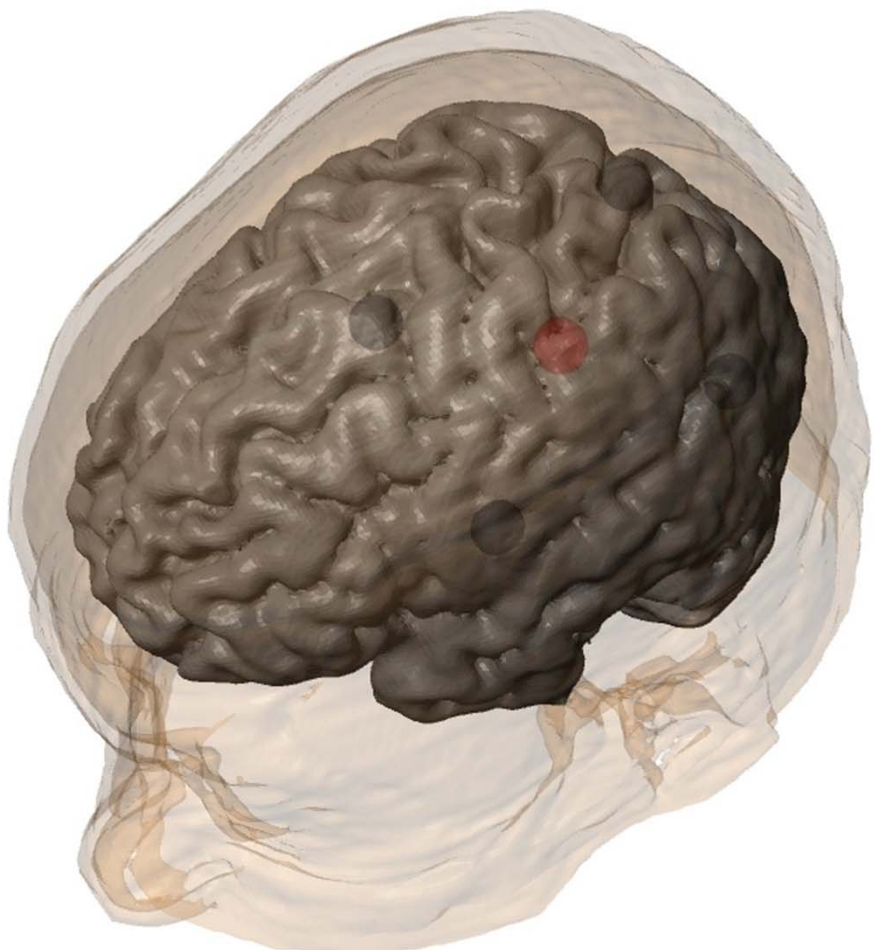
“Tangential”



“Radial Directional”



High-Definition tDCS – 4x1



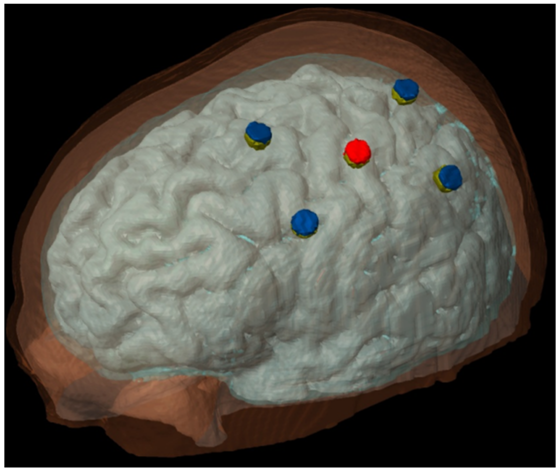
Brain Activation

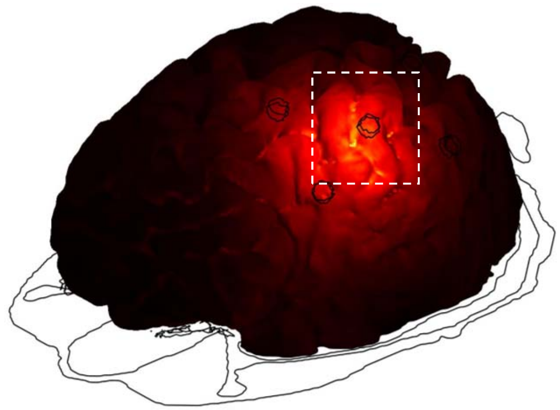
Maximum

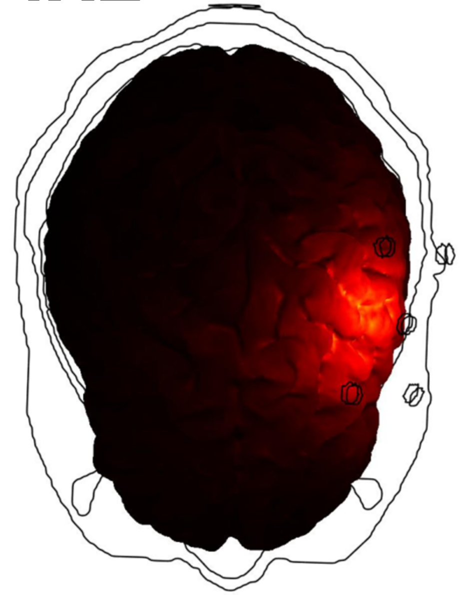
Moderate

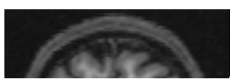
Minimum

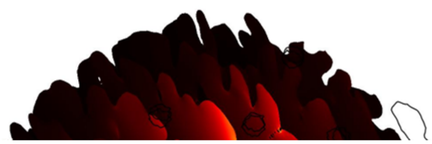
High-Definition tDCS – 4x1

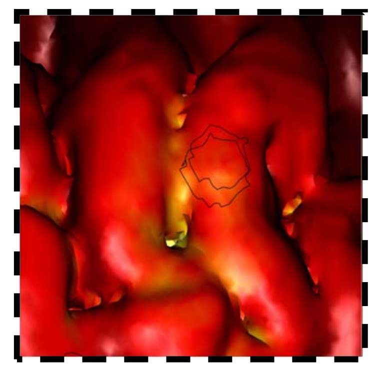












Brain Stimulation (2009) 2, 201 7

ELSEVIER

BRAIN
STIMULATION

www.brainstimjrnl.com

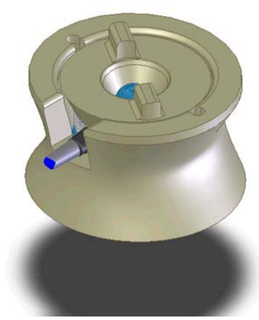
Gyri-precise head model of transcranial direct current stimulation: Improved spatial focality using a ring electrode versus conventional rectangular pad

Abhishek Datta, MS, Varun Bansal, BS, Julian Diaz, BS, Jinal Patel, MS,
Davide Reato, MS, Marom Bikson, PhD

High-Definition tDCS – 4x1

Hardware Development

Soterix Medical



Clinical Trials

NIH-NINDS
Eric Wassermann, Egas Caparelli Dáquer

MUSC
Mark George
Jeff Borckardt

Burke Rehabilitation
Dylan Edwards
Mar Cortes

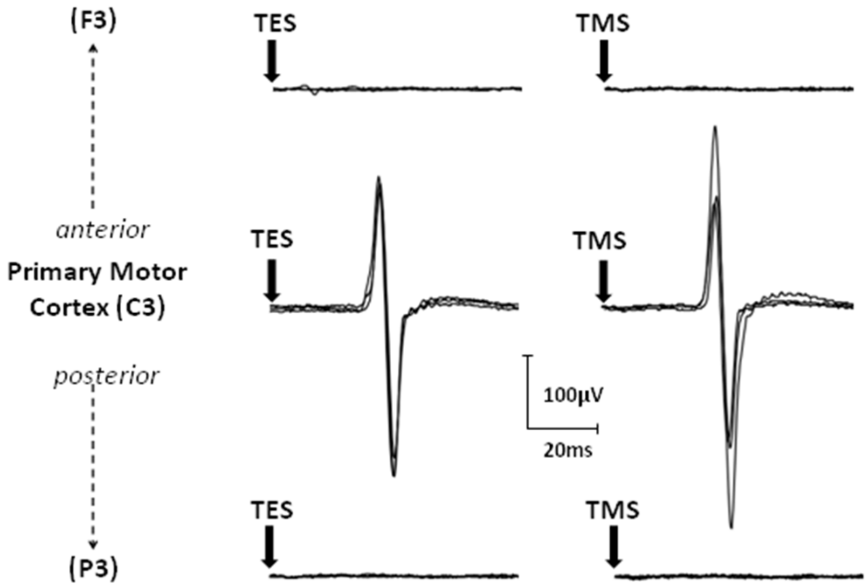
Harvard (Spaulding)
Felipe Fregni

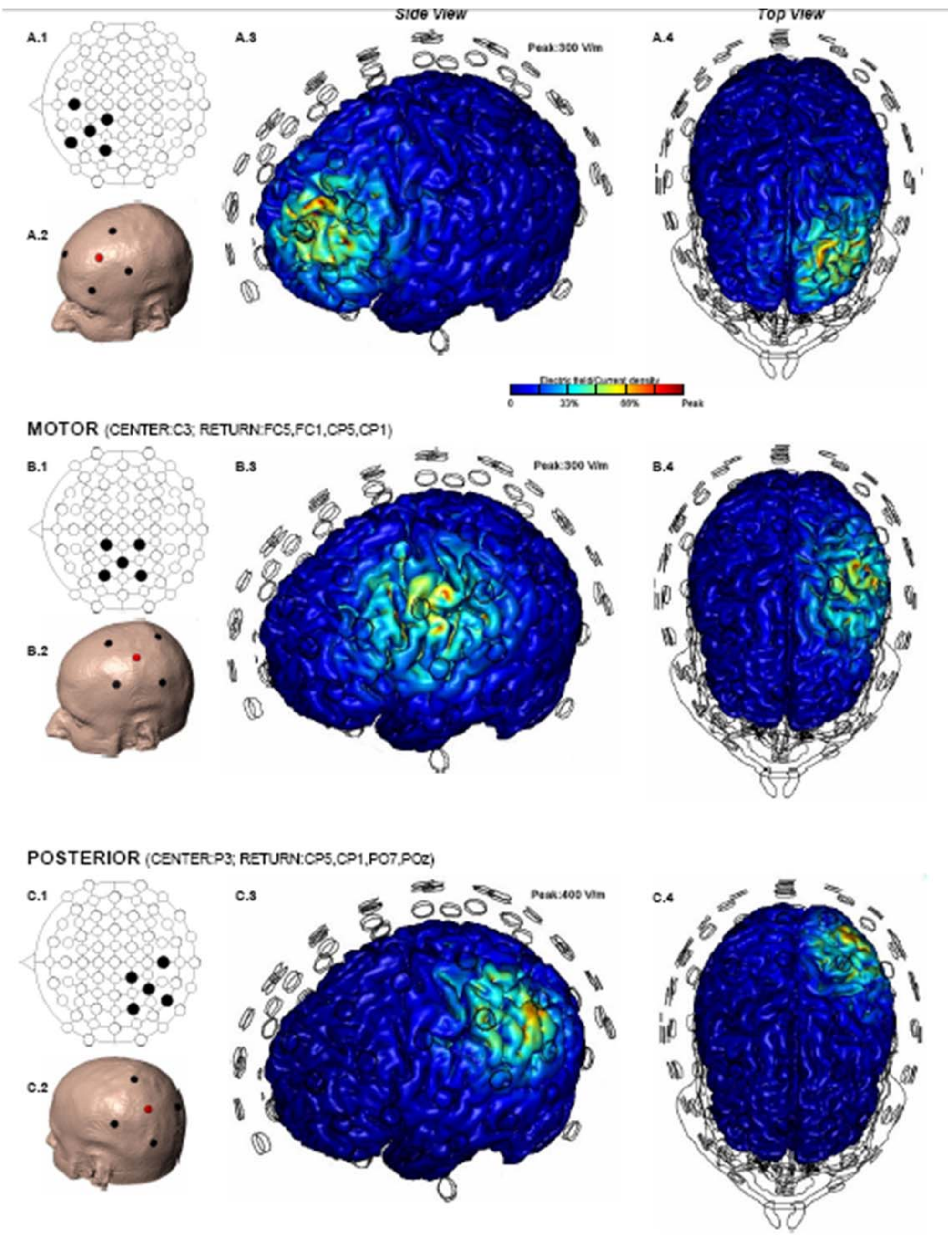
....

High-Definition tDCS – 4x1

Phase 1 Clinical Trials
Burke Rehabilitation, Harvard Medical School
Dylan Edwards, Mar Cortes

Transcranial Electrical Stimulation (TES) – short high-intensity pulse that triggers motor response (MEP)





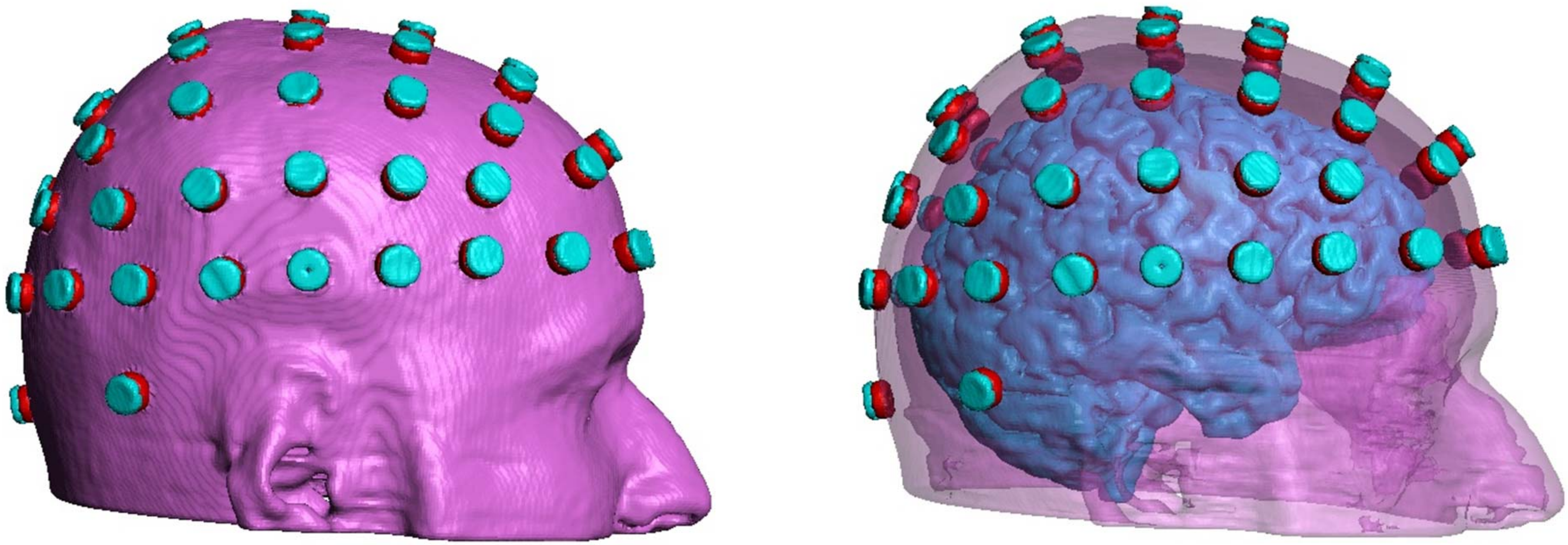
High-Definition tDCS – 4x1

Better Outcomes

Design feed-back and design from clinical trials

Models as a tool for developing better electrotherapies

High-Definition transcranial Electrical Stimulation (HD-tES)



4x1 HD-tDCS, 6x6 HD-tES, Deep HD-TES….

Clin Neurophysiol. 2010 Dec;121(12):2165-71. Epub 2010 Jun 15.

Electrode-distance dependent after-effects of transcranial dir and random noise stimulation with extracephalic reference electrodes.

Moliadze V, Antal A, Paulus W.

Department of Clinical Neurophysiology, Georg-August University, Robert-Koch- Strasse 40, 37 Göttingen, Germany.

Clinical Neurophysiology 121 (2010) 1976–1978

Contents lists available at ScienceDirect

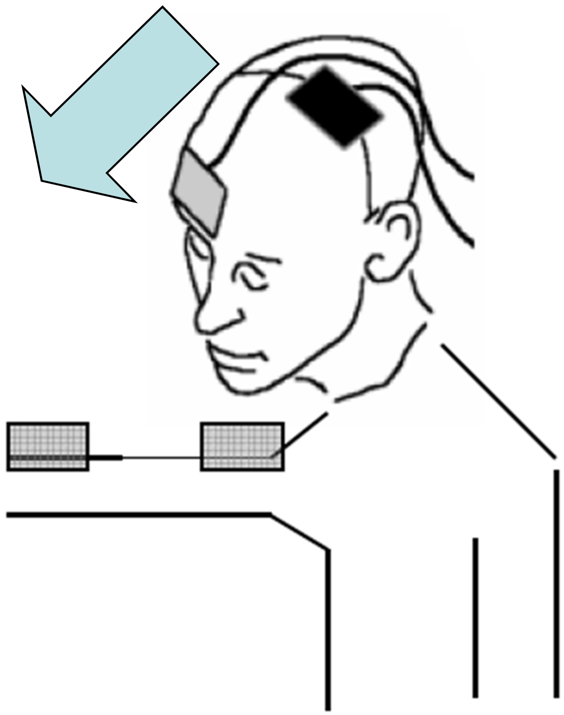
Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

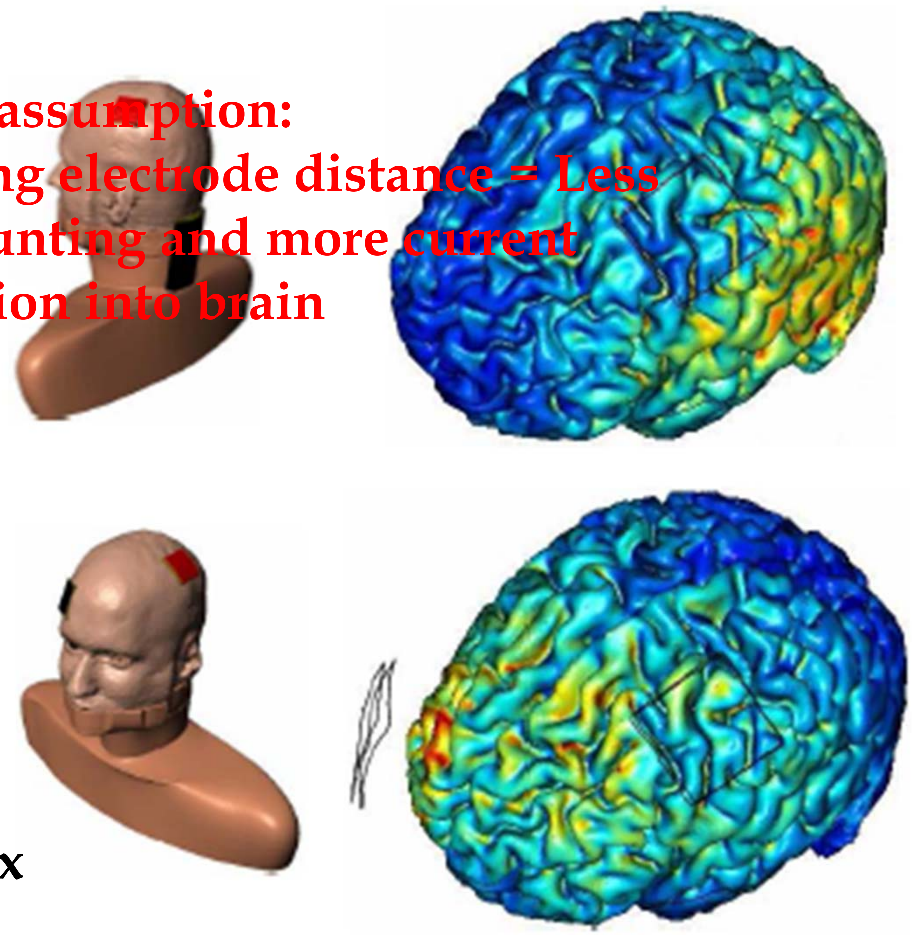
ELSEVIER

Editorial

Electrode montages for tDCS and weak transcranial electrical stimulation: Role of "return" electrode's position and size



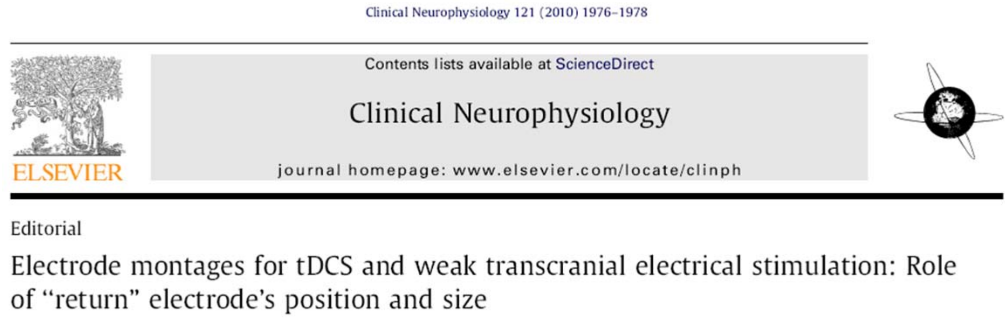
Clinical assumption:
Increasing electrode distance = Less scalp shunting and more current penetration into brain



?? Distance between electrode correlates *negatively* with motor cortex modulation under active electrode

tDCS therapy design - Extracephalic electrodes in treating Fibromyalgia

Bahaina School of Medicine, Brazil
Spaulding Rehabilitation Hospital, Harvard Medical School


Clinical Neurophysiology 121 (2010) 1976–1978
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journal homepage: www.elsevier.com/locate/clinph
ELSEVIER
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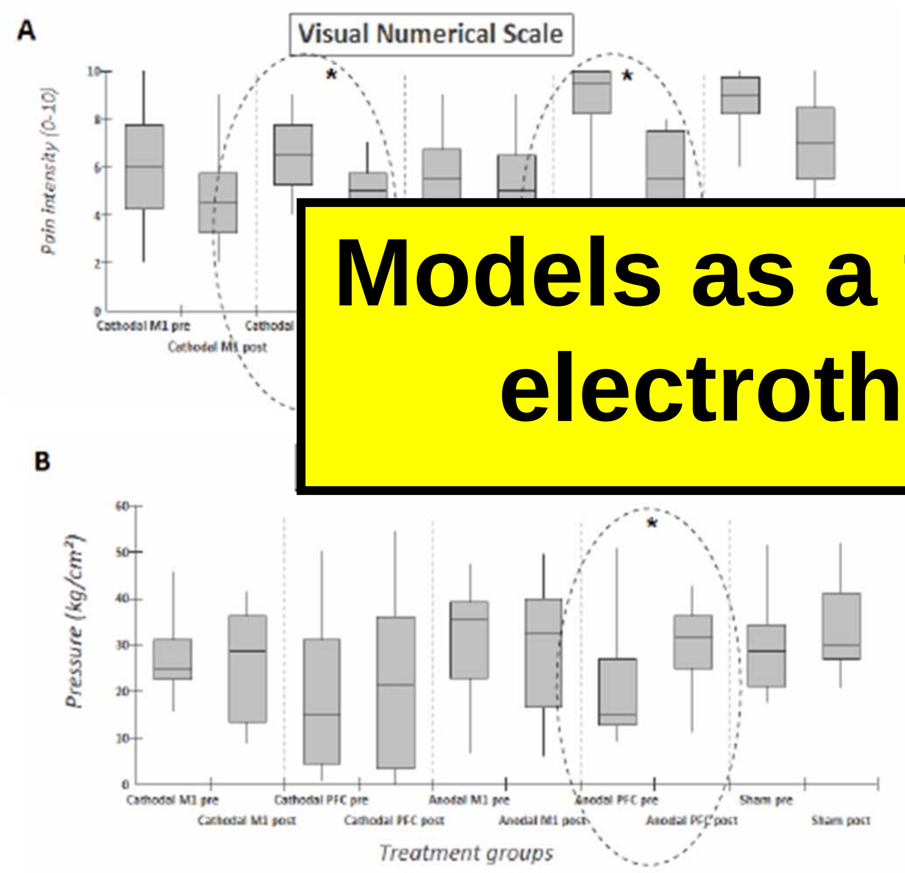
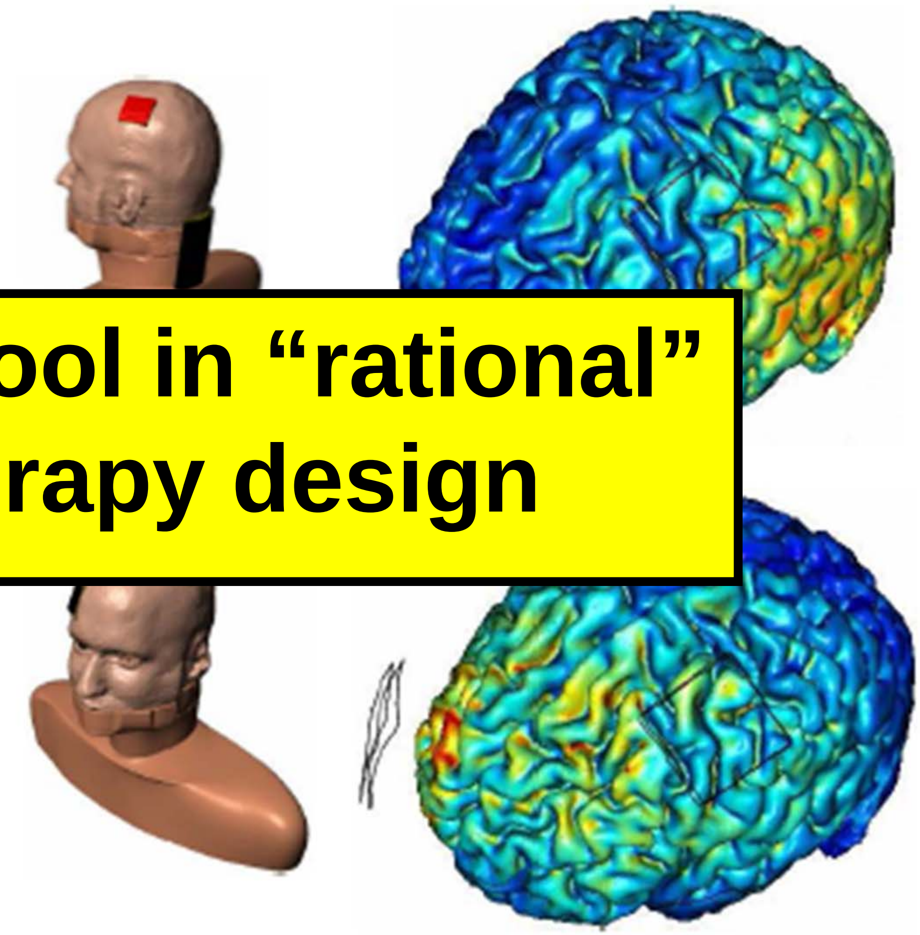
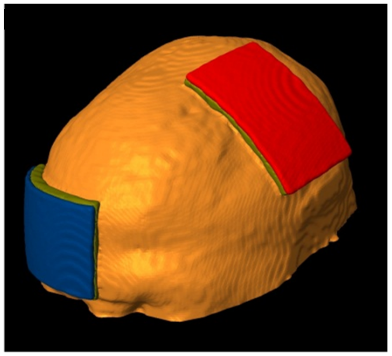
Electrode montages for tDCS and weak transcranial electrical stimulation: Role of "return" electrode's position and size

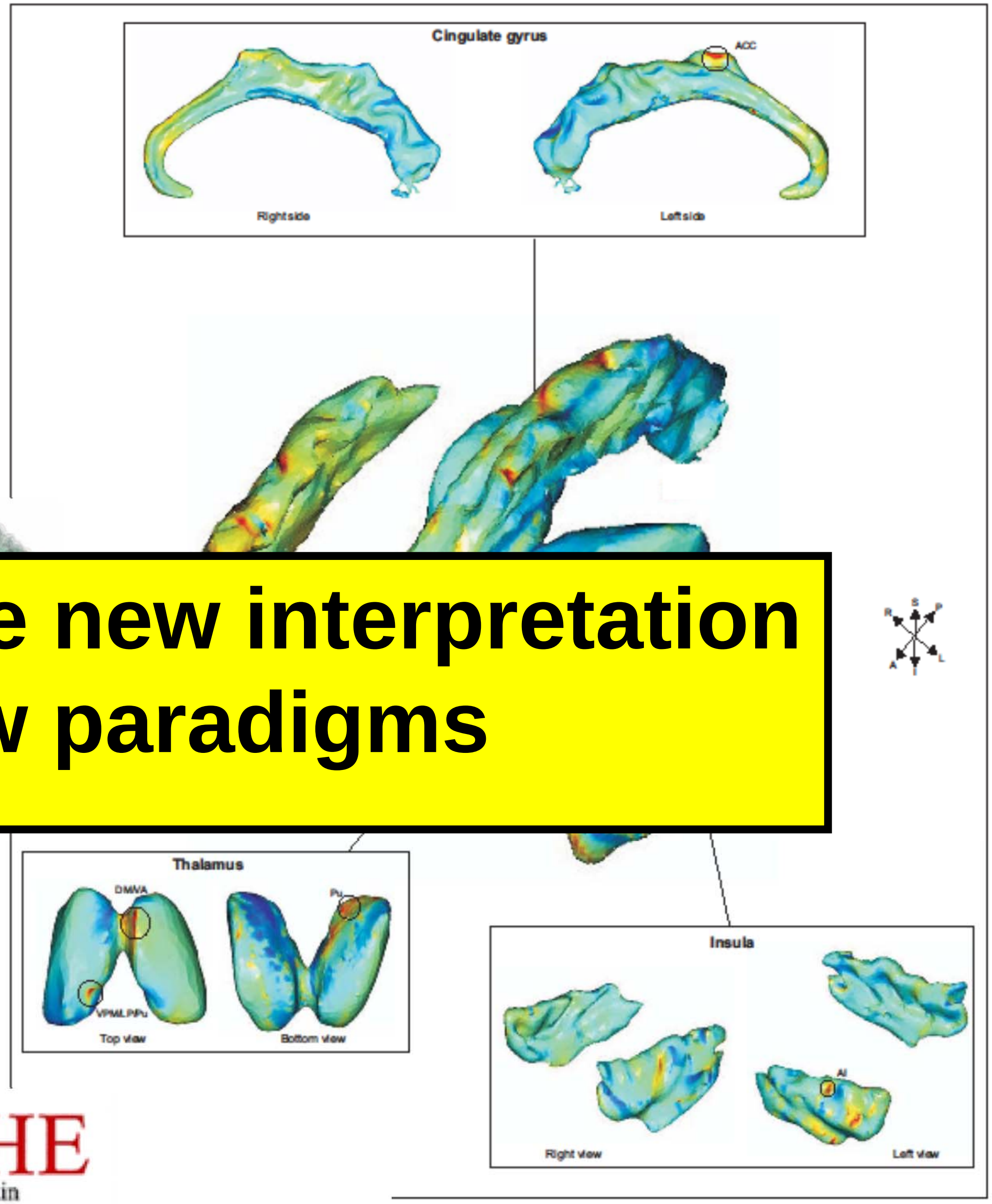




Models as a tool in "rational" electrotherapy design

Deep tDCS?





Models drive new interpretation / new paradigms

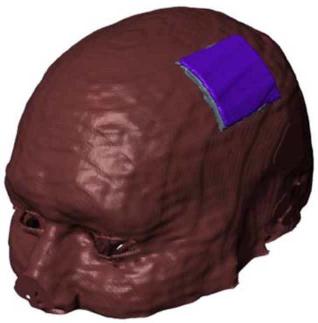
Alex DaSilva (U Michigan)
Felipe Fregni (Harvard)

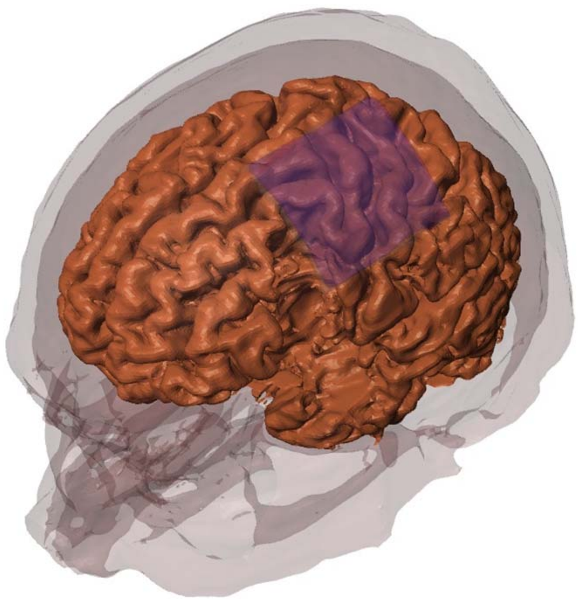
HEADACHE
The Journal of Head and Face Pain

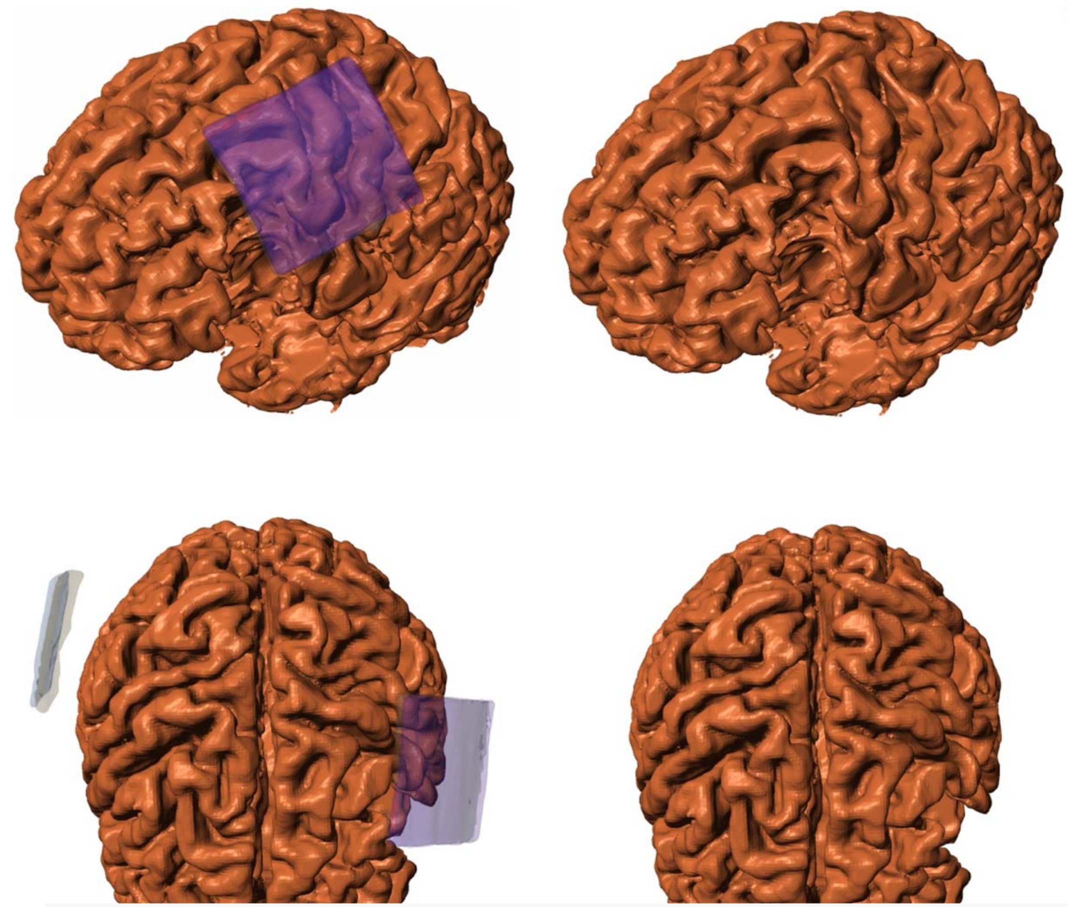
Delayed Analgesic Effects of tDCS in Chronic Migraine

tDCS for stroke rehabilitation

Julius Fridriksson
Julie Baker (USC)





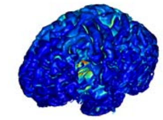


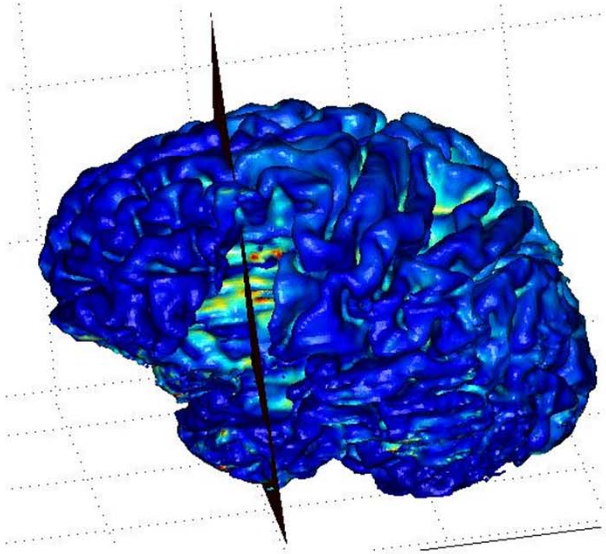
Subject X: Aphasia
Positive tDCS outcome

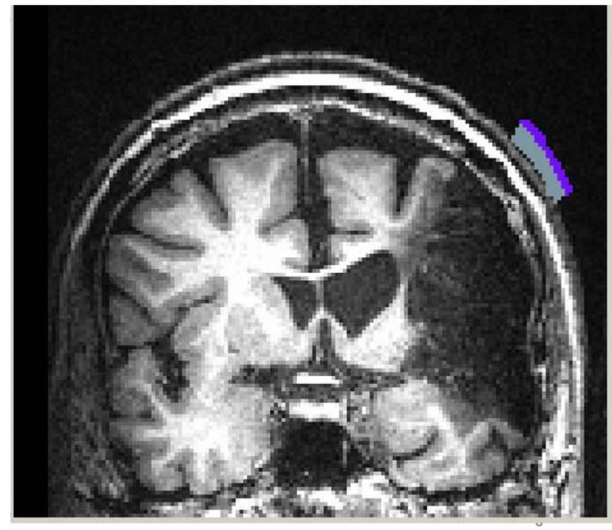
Using transcranial direct current stimulation (tDCS) to treat stroke patients with aphasia

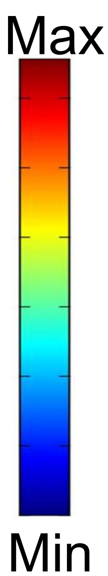
Julie Baker, Ph.D., Chris Rorden, Ph.D., and Julius Fridriksson, Ph.D.

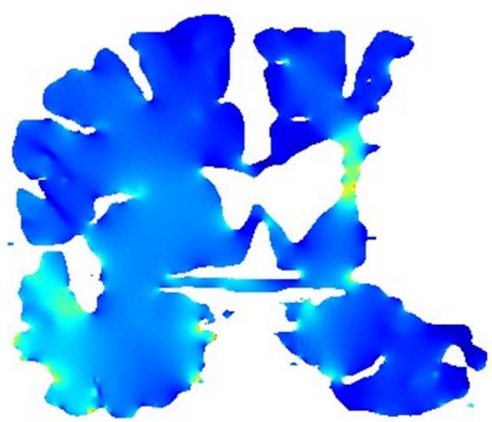
tDCS for stroke rehabilitation



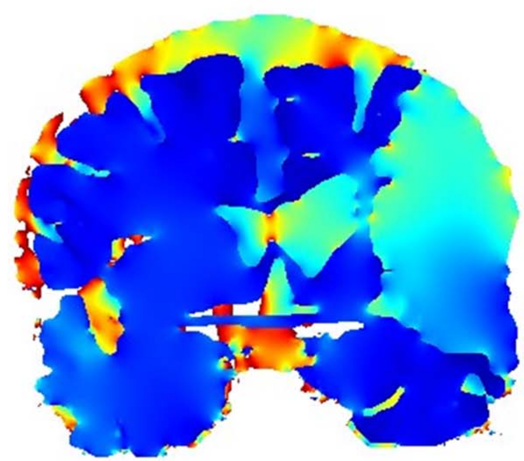






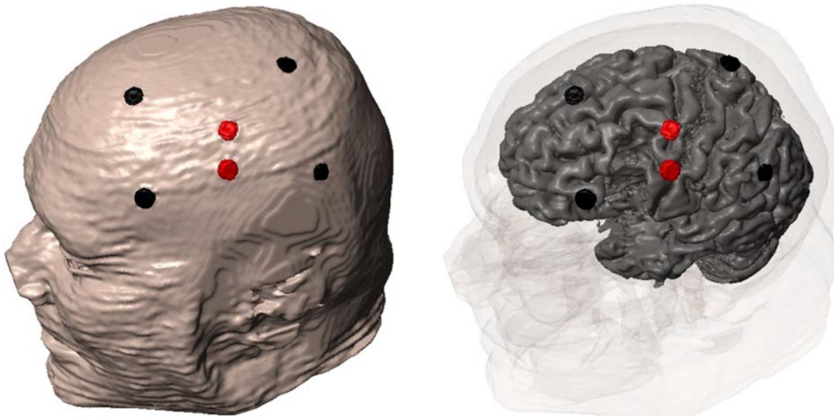


Brain Electric Field

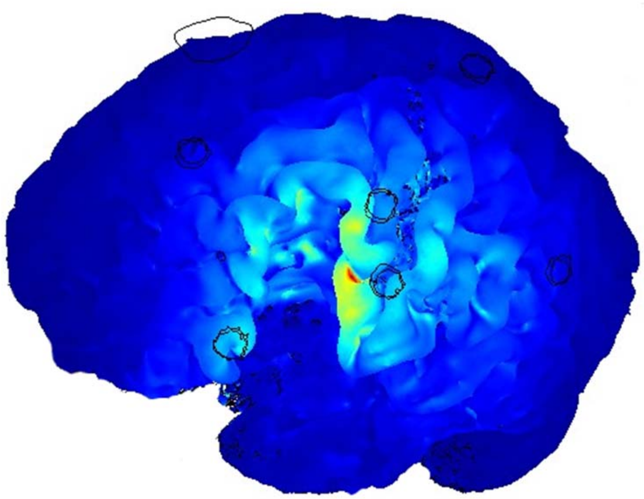


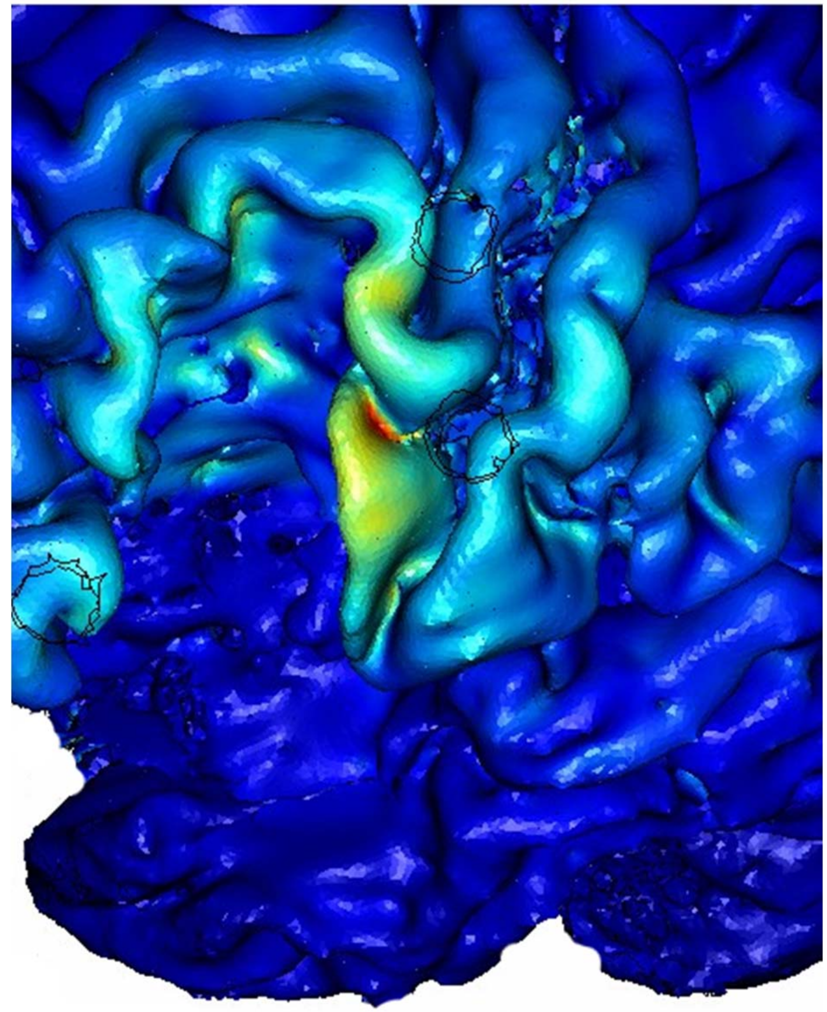
Brain and CSF Current Density

HD-tDCS for stroke rehabilitation



4x2 *HD-tDCS*





"Susceptible" Populations

Young adults, Children…

(dose)

Phil Defina (IBRF)

Alex Rotenberg (Boston Children's)

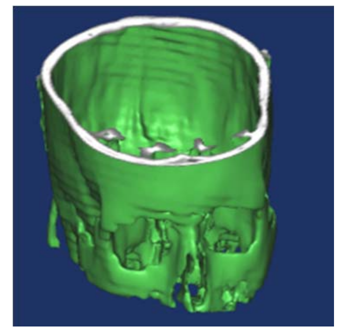
Aging….

Procedures, implants…

(safety)

Ziad Nahas

Mark George (MUSC)



Skull Defects / TBI

(safety, targeting)

Felipe Fregni (Harvard)

NeuroImage 52 (2010) 1268–1278

Contents lists available at ScienceDirect

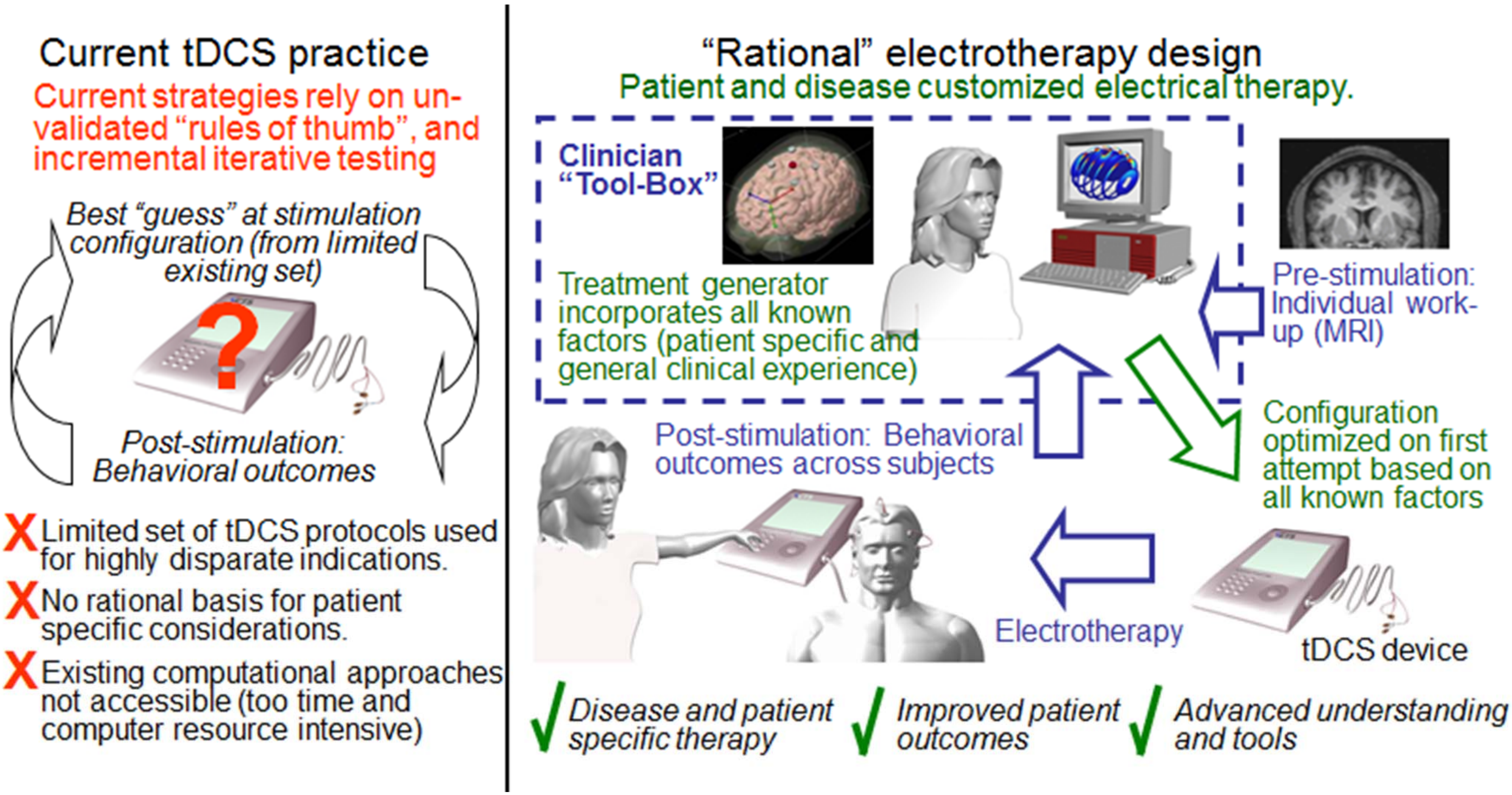
NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Transcranial direct current stimulation in patients with skull defects and skull plates: High-resolution computational FEM study of factors altering cortical current flow

Abhishek Datta [a,*], Marom Bikson [a], Felipe Fregni [b,c,*]

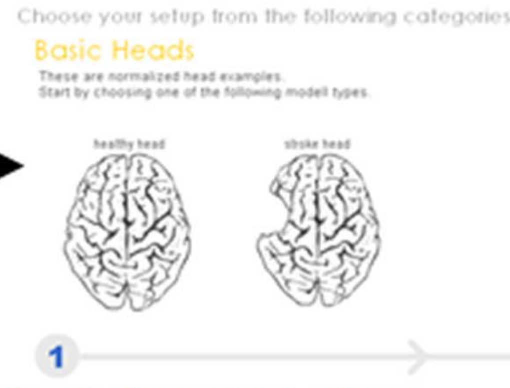
Engineering and modeling driving "rational" electrotherapy



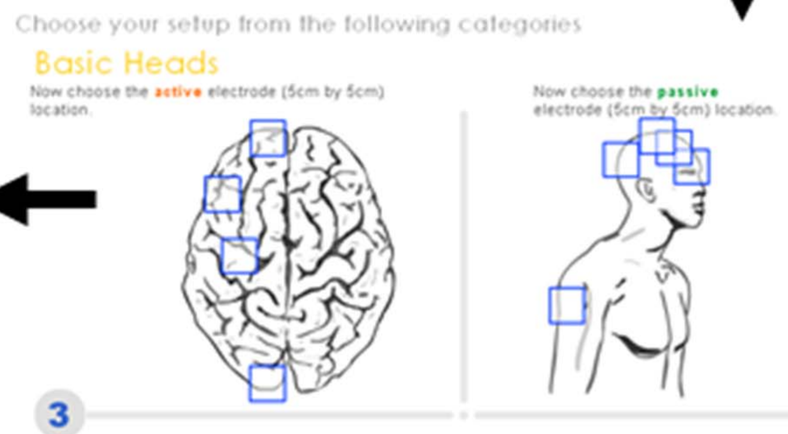
If computational models can help why are they not "popular"?

Limited access to simple and <u>cheap</u> modeling

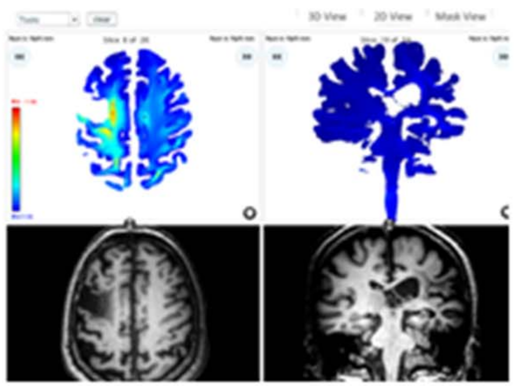
Web-interface sufficient simple to use so that first-time users will not require instructions



Simple flow-chart allows selection of "standard" heads or user-uploaded case studies



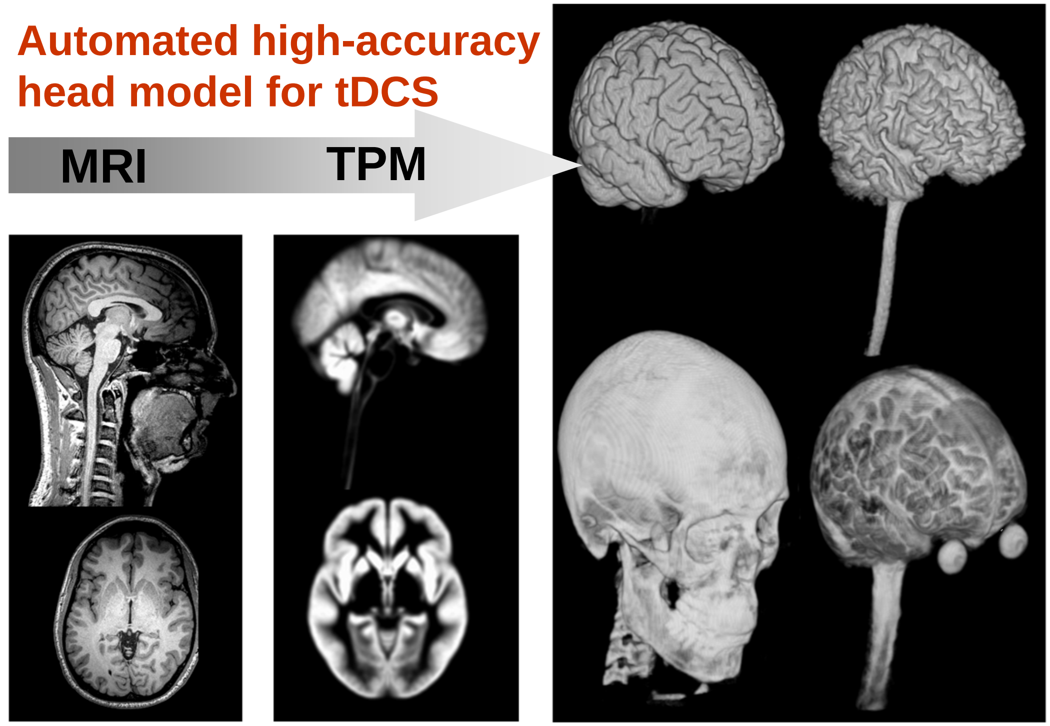
Electrode placement also entirely graphics driven

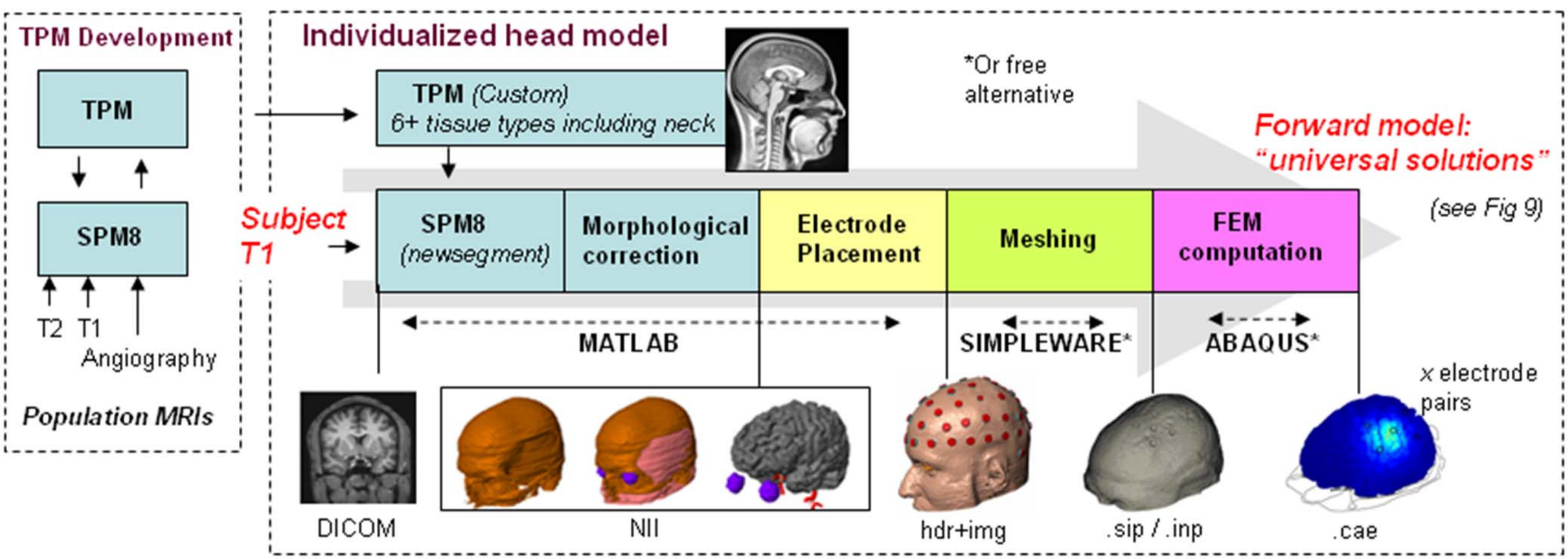


Simple navigation of resulting brain modulation in 2-D or 3-D space

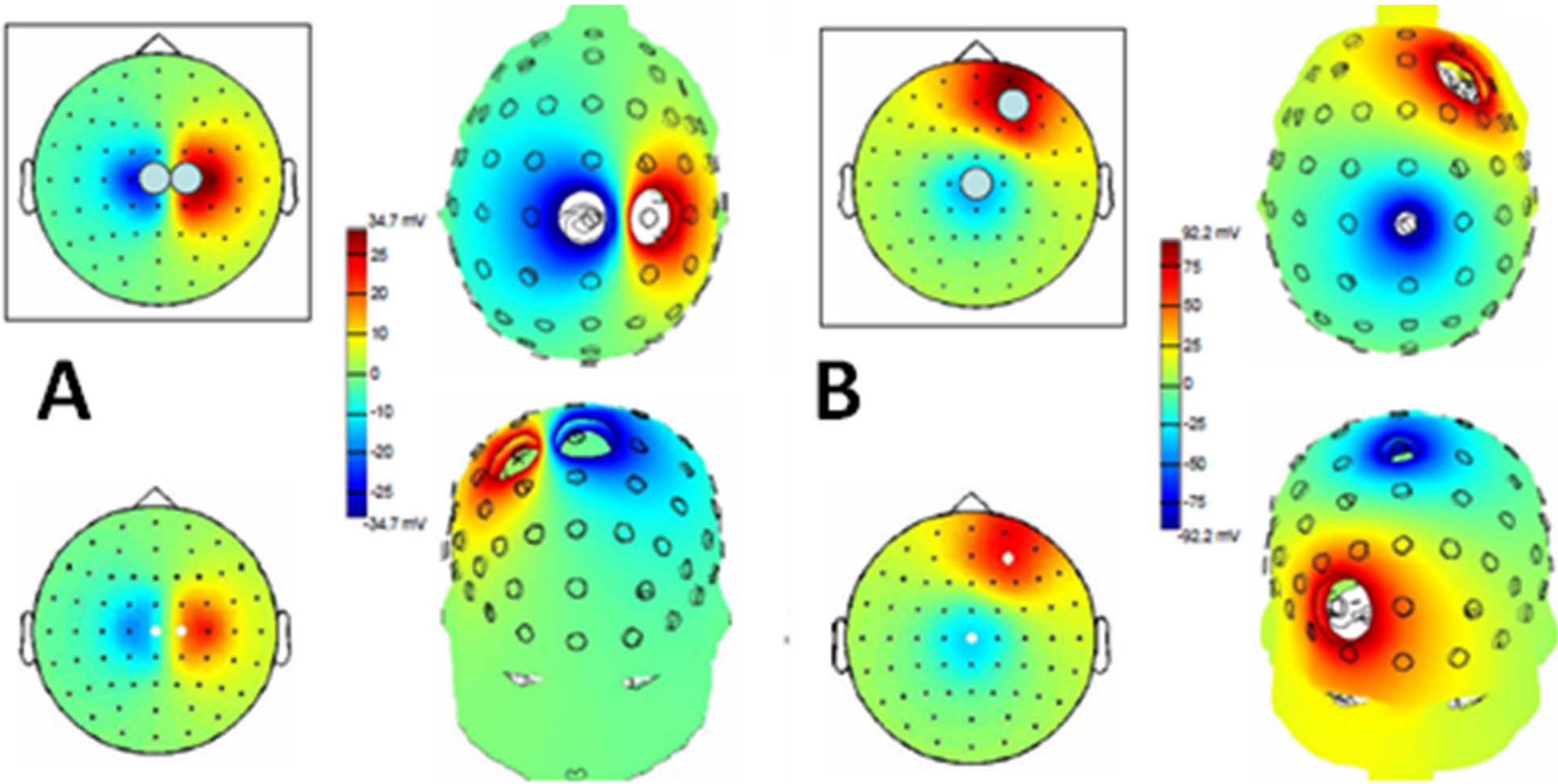
Neuralengr.com/Bonsai

Automated Work-Flow for Clinician Tool-Box





Model Validation



Neuromodulation

- **Application specific** (neuropsychiatric, rehabilitation, cognitive performance…)
- **Individualized therapy** (customize, tune-able)
- **Targeted brain modulation** (space + time)
- **Safe** (reversible, minimal complications + counter-indications)
- **Cost / Access** (multi-use, production, treatment-infrastructure)