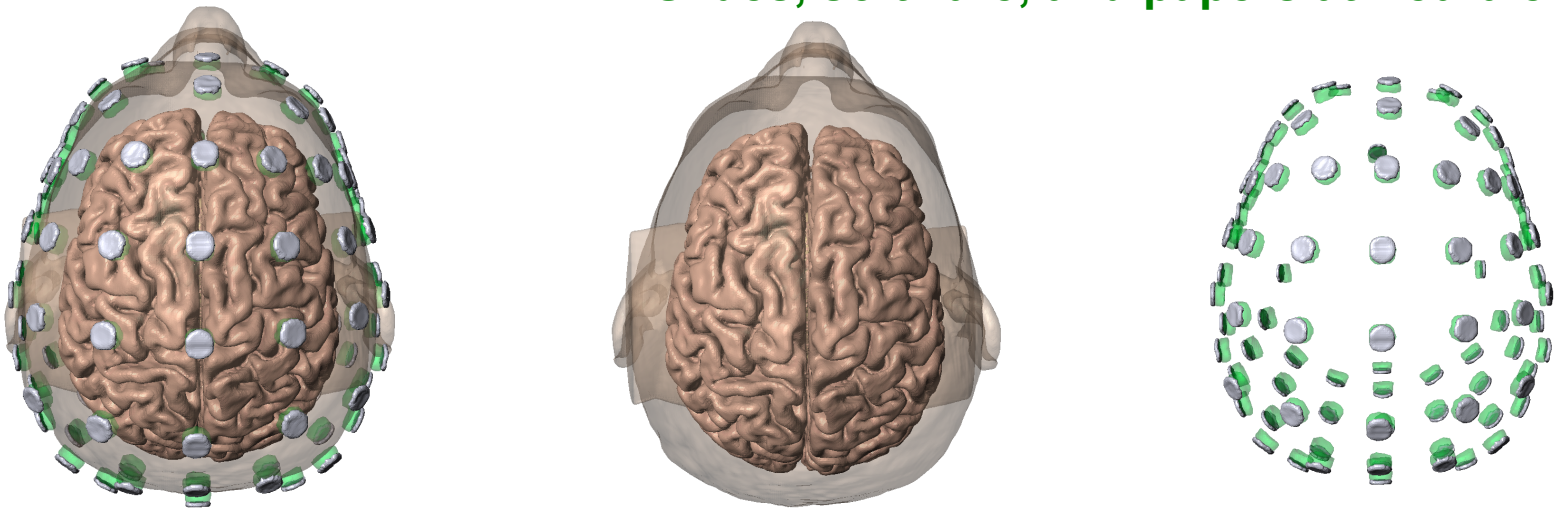
Computational Modeling-assisted Design of tDCS Protocols

Slides, software, and papers at Neuralengr.com



Marom Bikson

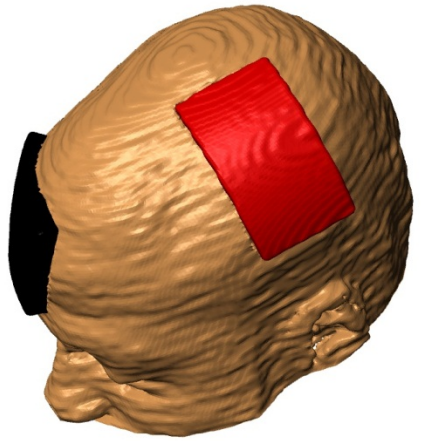
Lucas Parra, Abhishek Datta, Asif Rahman, Jacek Dmochowski, Niranjan Khadka, Dennis Truong, Yu Huang, Mahtab Alam, Asif Rahman, Zeinab Esmaeilpour

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

$ NIH (Brain Initiative), Epilepsy Foundation, Wallace Coulter Foundation, DoD

COI: Soterix Medical Inc., Boston Scientific Inc.

Proposition: Appropriately applied computational models are pivotal for rational tDCS dose selection.



For hypothesis-driven research :

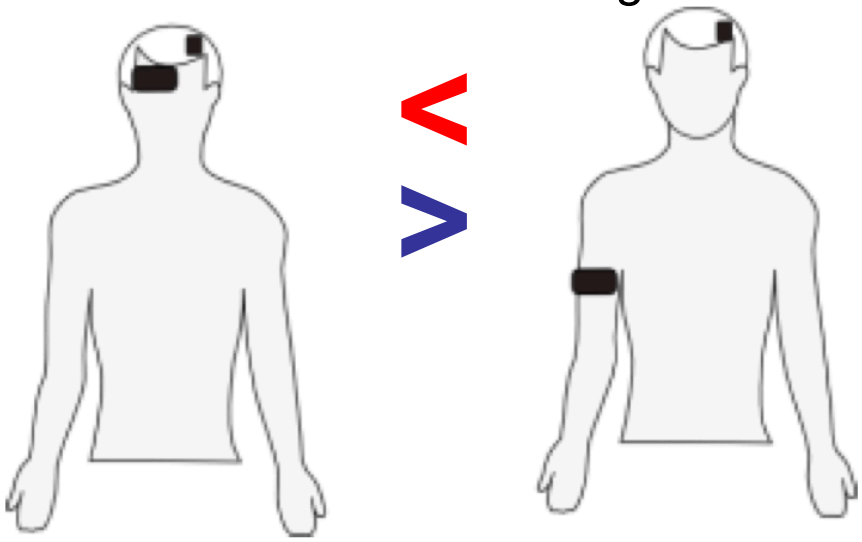
- **How do you leverage computational models in the design of a clinical trial ?**
- **Which modeling tools should you use?**

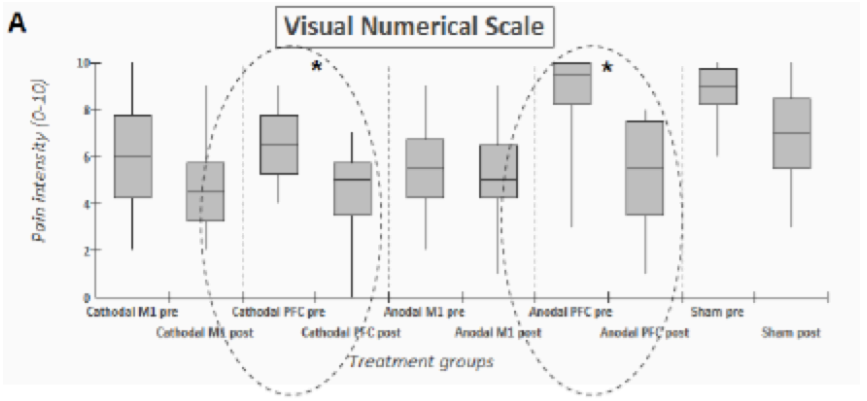
Electrode-distance dependent after-effects of transcranial direct and random noise stimulation with extracephalic electrodes
Clinical Neurophysiology 2010 121:2165-71
Moliadze V, Antal A, Paulus W

Electrode montages for tDCS and weak transcranial electrical stimulation: Role of "return" electrode's position and size
Clinical Neurophysiology 2010 121:1976-8
Datta A, Rahman A, Scaturro J, Bikson M

M1-SO Montage

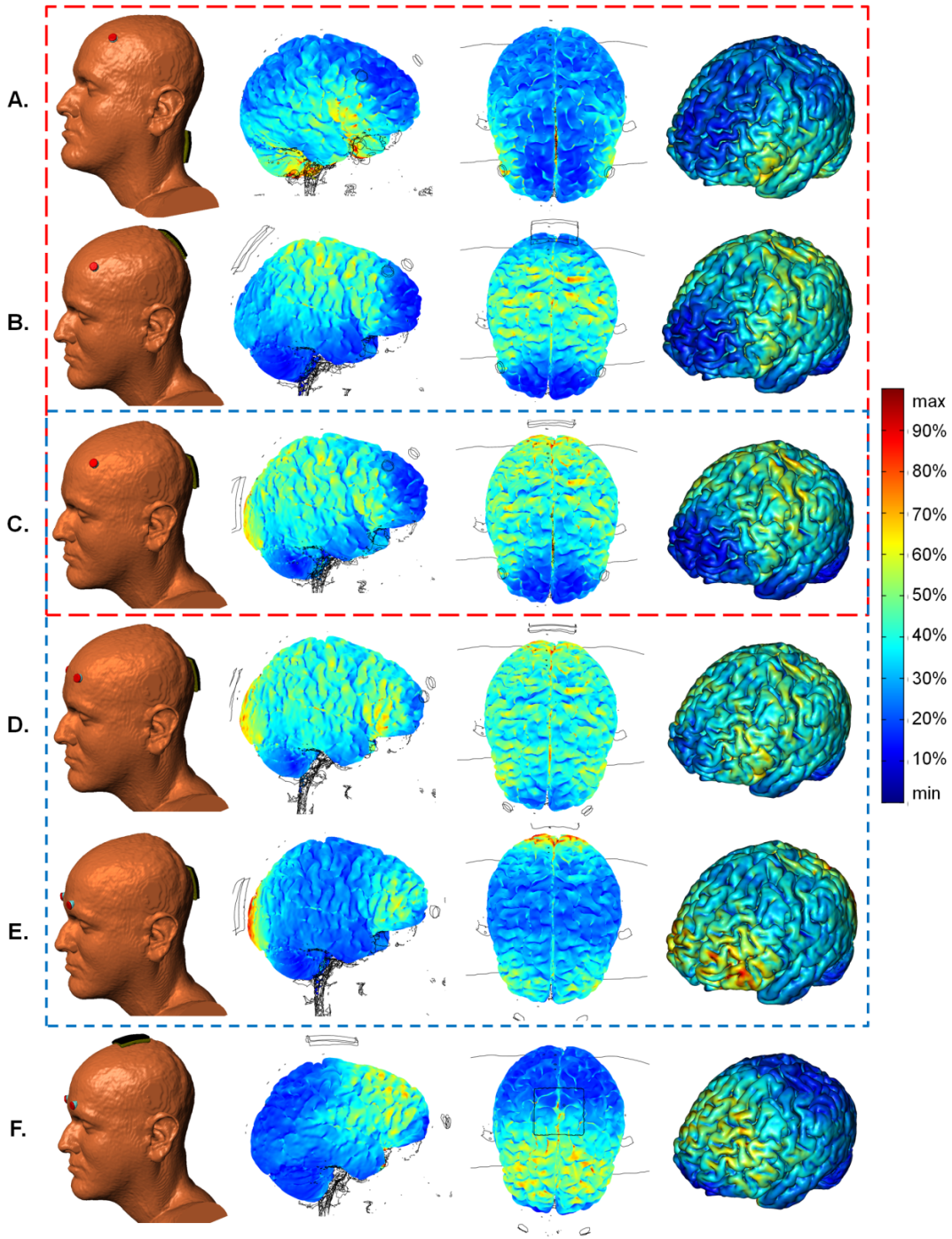
M1-Extracephalic montage





Transcranial DC stimulation in fibromyalgia: optimized cortical target supported by high-resolution computational models
J Pain 2011 12:610-7
Mendonca ME, Santana MB, Baptista AF, Datta A, Bikson M, Fregni F, Araujo CP

< A priori assumption: **Increased** current delivered to brain (decrease scalp shunt)
> Clinical neurophysiological: **Decreased** motor-cortex modulation (TMS-MEP)
> Model prediction: Temporal current "slip"- **reducing** intensity at motor cortex.
> Clinical trial: **Decreased** analgesic effect



A Feasibility Study of Bilateral Anodal Stimulation of the Prefrontal Cortex Using High-Definition Electrodes in Healthy Participants. *Yale Journal of Biol Med* 2015 88: 219-25

Xu J, Healy SM, Truong DQ, Datta A, Bikson, M, Potenza MN

Intuition without models is faulty

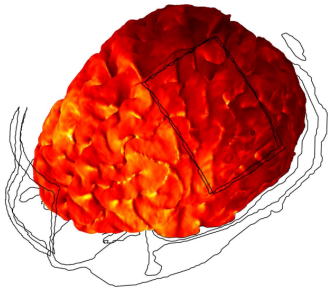
Small changes in montage: change brain current flow between and under both electrodes.

tDCS "Dose" is those parameters controlled by operator

Electrode number, size, current at each electrode

Current flow models only predict the electric field generated in the brain for a specific stimulation configuration/settings

Electrical activity (efficacy and safety) is determined by electric fields at tissue



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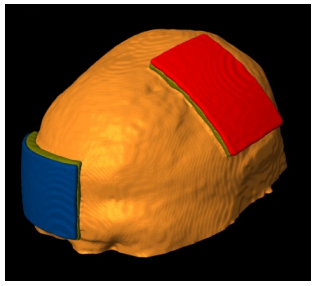
tDCS dose is set by surface application (current, duration, montage)

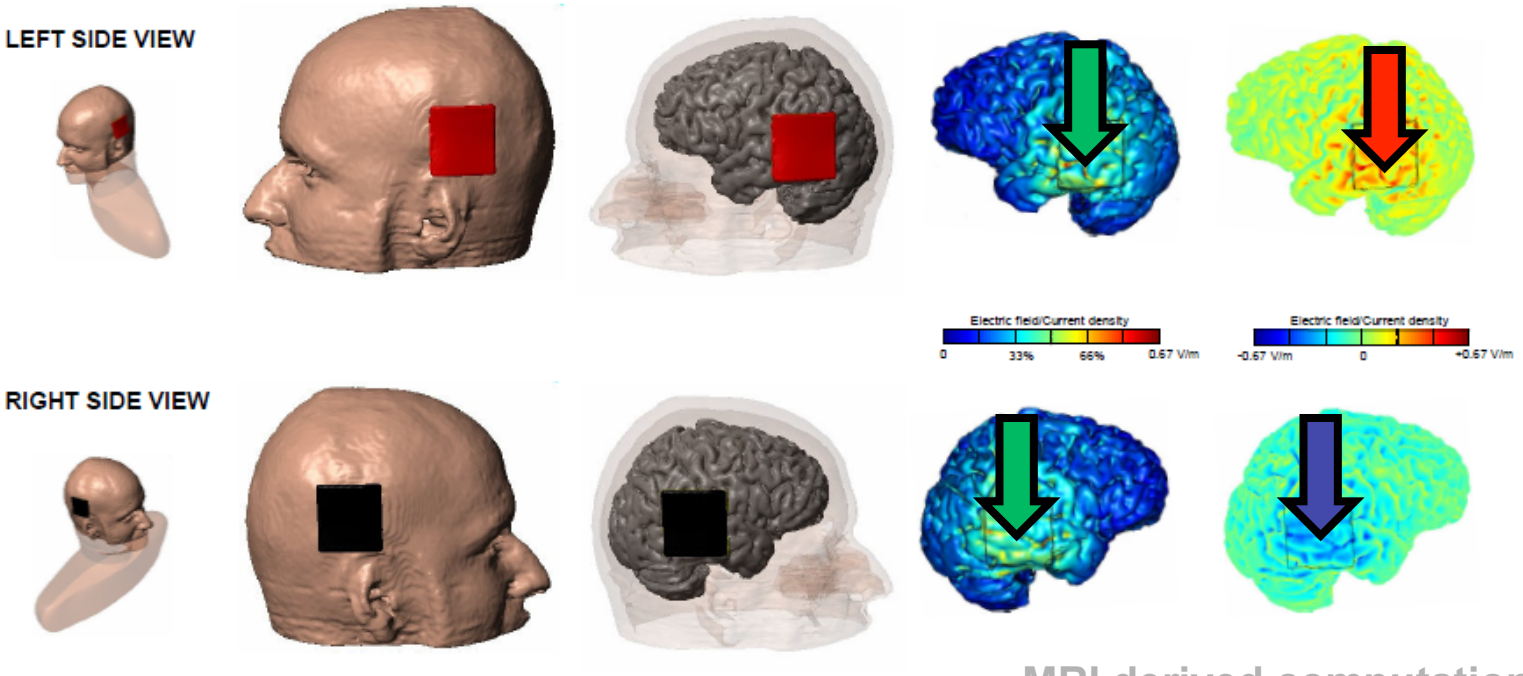


Fundamentals of transcranial electric and magnetic stimulation dose: definition, selection, and reporting practices. *Brain Stimulation* 2012 4: 453-53

Peterchev AV Wagner T, Miranda P, Nitsche M, Paulus W, Lisanby SH, Pascual-Leone A, Bikson M

Transcranial Direct Current Stimulation (tDCS)

- Two pad electrodes placed on head and connected to DC current stimulator.
- Current passed between ANODE(+) and CATHODE(-)
- DC CURRET FLOW across cortex.
- Current is INWARD under ANODE and OUTWARD under CATHODE

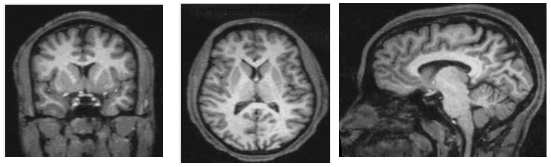


MRI derived computational model

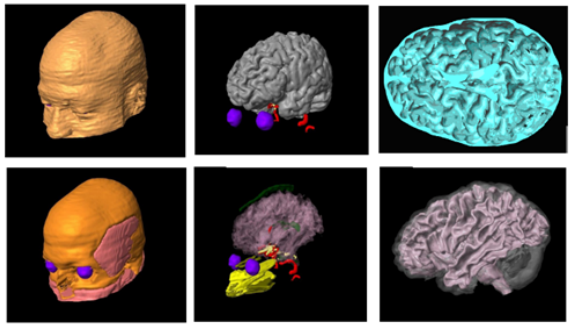
Model predict brain current flow during tDCS

Predictions as precise as (MRI derived) models

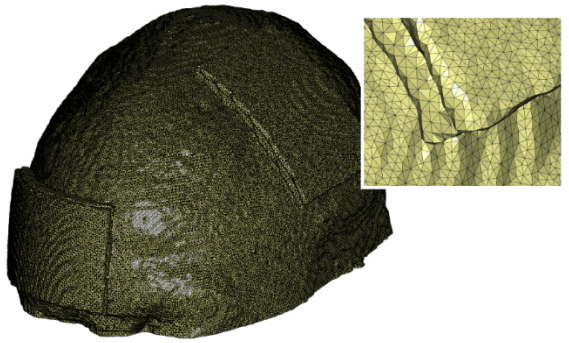
Full work-flow developed to preserve accuracy and resolution



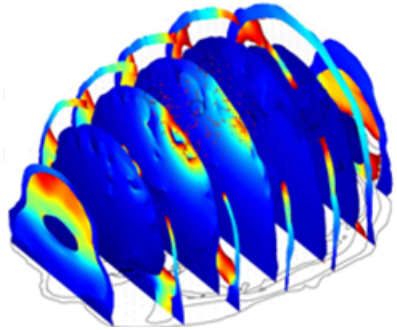
MRI sequences optimized for tDCS modeling (3T at 1x1x1 mm)



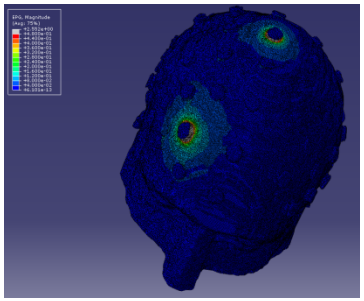
Special segmentation tools perverse resolution in generation of tissue masks



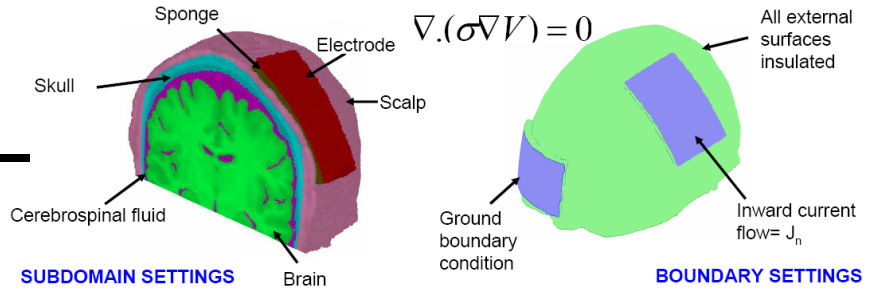
Mesh includes >10 million elements



Solution provides detail insight into brain modulation



Conjugate gradient solver with <1E-8 tolerance



Model physics/domains include explicit consideration of electrode properties.

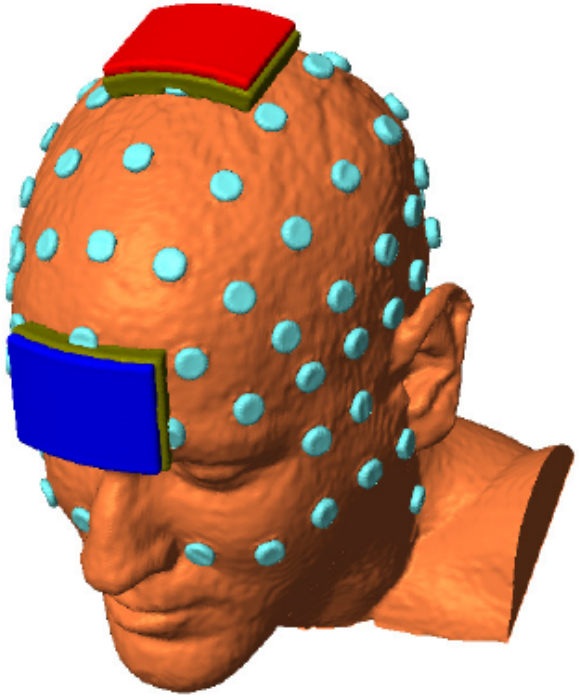
Gyri-precise head model of transcranial direct current stimulation: improved spatial focality using a ring electrode versus conventional rectangular pad.

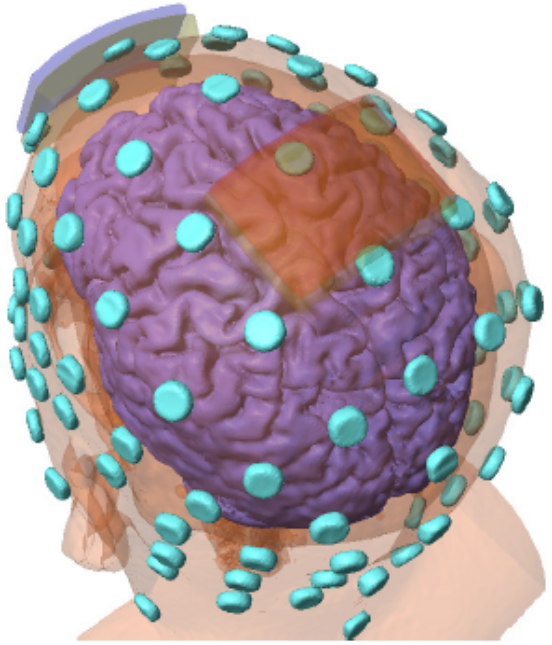
Brain Stimulation 2009 Datta A, Bansal V, Diaz J, Patel J, Reato D, Bikson M.

High-Definition tDCS (HD-tDCS)

- tDCS pads replaced with array of small High-Definiton (HD) electrodes.
- Catagorical change in brain current flow control.
- Optimization problem “solved” given a MRI + head model

10/20 position coordinates

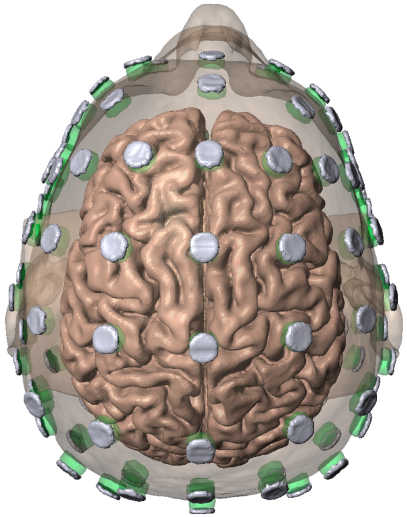


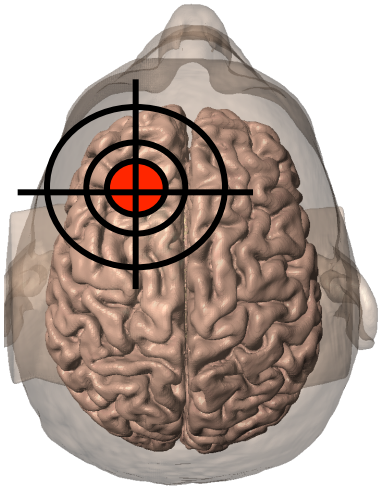


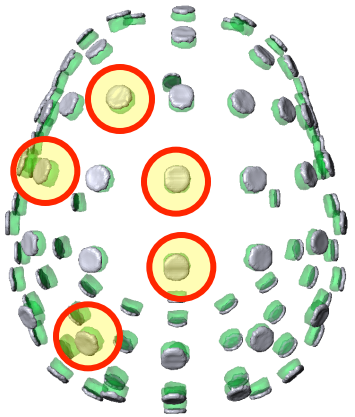
Optimized multi-electrode stimulation increases focality and intensity at target.
J Neural Engineering 2011 Dmochowski JP, Datta A, Bikson M, Su Y, Parra LC.

Given a brain region of interest, which tDCS or HD-tDCS electrodes should be activated?

- Target brain region is selected.
- Current is applied to select HD electrodes to optimize current flow to target.
- Need to specify "what" is optimized since no perfect solution







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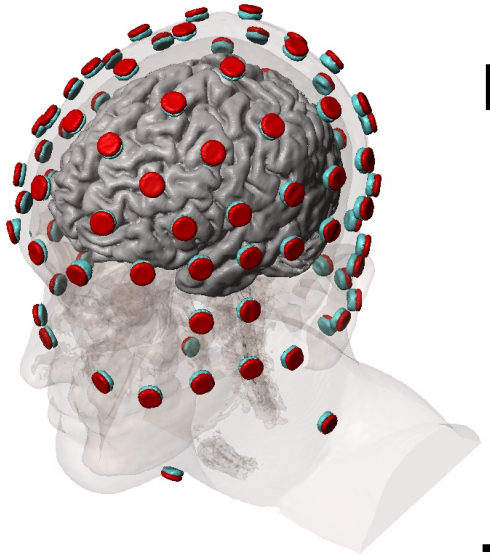
"Best" solution depends on trial objectives / criterion

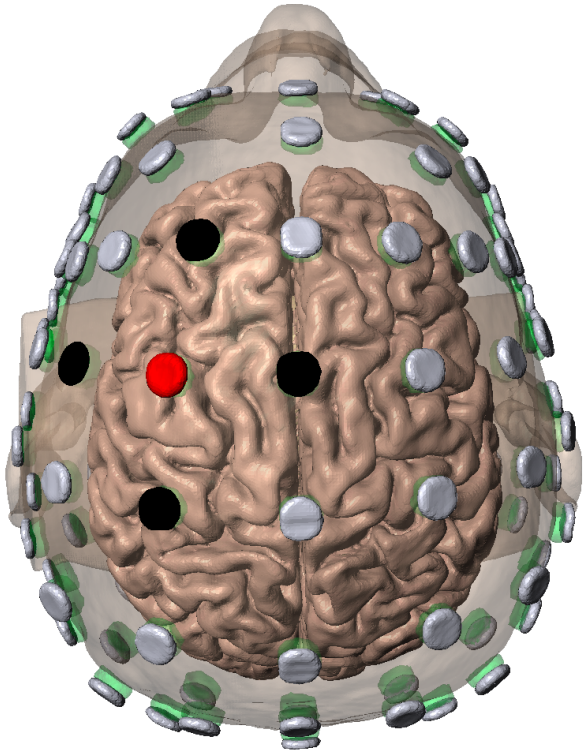


Efficacy: Focality at target (s)
Size of target
Superficial or deep target location
Maximize intensity at target
Direction of current (modulation).

Tolerability: Minimize total current
Minimize total current per electrode
Limit intensity at brain

Optimized multi-electrode stimulation increases focality and intensity at target.
J Neural Engineering 2011 Dmochowski JP, Datta A, Bikson M, Su Y, Parra LC.

Goal: target a single cortical brain region, with single direction of current (exctiability change) while maintaining all intensity parameters (total current, maximum intensity at brain) within convetional norms.



4x1-Ring HD-tDCS Montage

(total 5 electrodes)

- Center active electrode (2 mA) over cortical target
- Four surround return electrodes (0.5 mA each)
- Ring radius circumscribes underlying cortical region of interest

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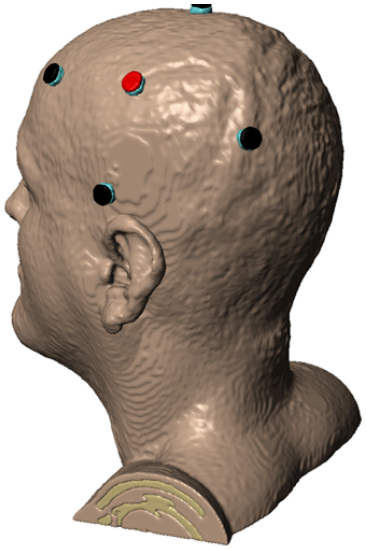
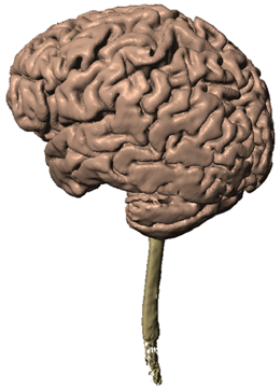
Brain Stimulation 2009 Datta A, Bansal V, Diaz J, Patel J, Reato D, Bikson M.

High-Definition tDCS 4x1-Ring Montage

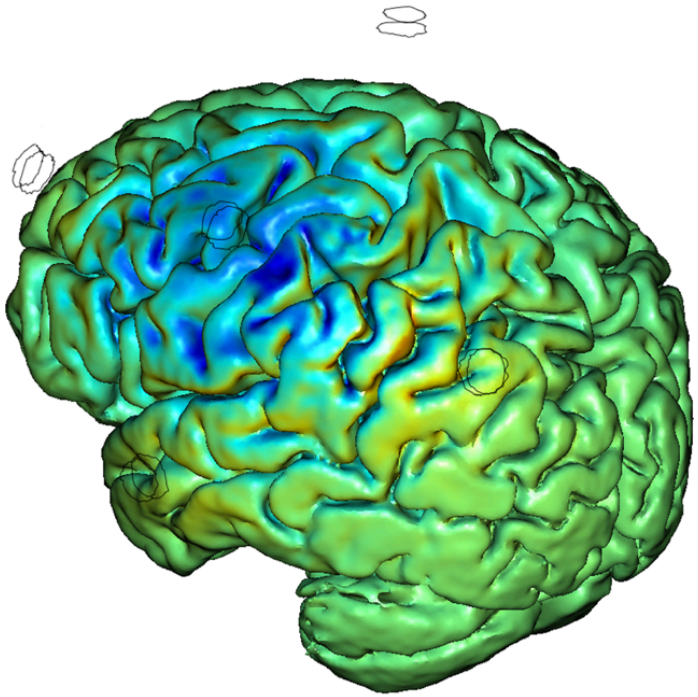
- Center electrode determines polarity (anode, cathode)
- Ring radius determines modulation area

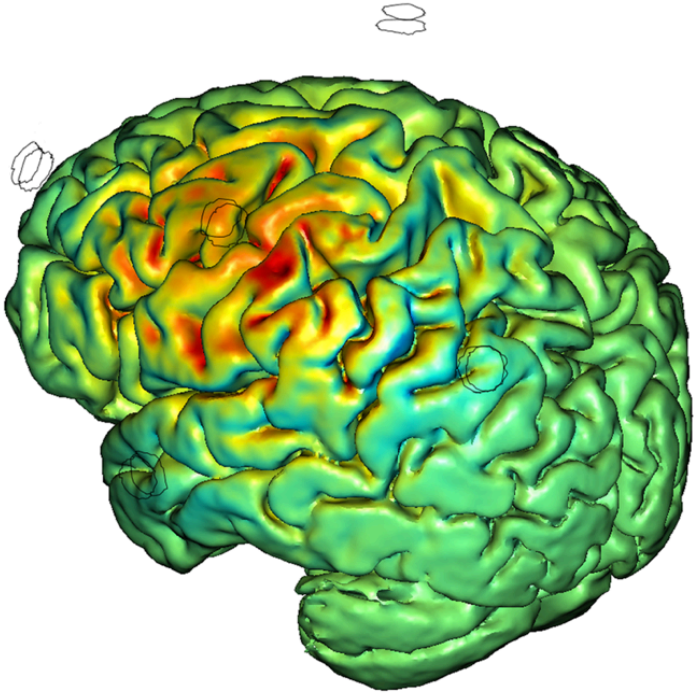


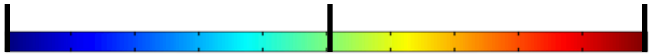


Center electrode: CATHODE

Center electrode: ANODE







Outward current direction (inhibitory)

Outward current direction (excitatory)

Reasons NOT to use models

- The increased control over current flow (e.g. great targeting, great intensity) is not what I wanted all along.

  Diffuse current flow is good.

- Models are just models. Rather use my intuition then rely on math.

- I don't have access to models.

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Clinician accessible tools for GUI computational models of transcranial electrical stimulation: BONSAI and SPHERES. *Brain Stimulation* 2014
Truong, Huber, Xie, Datta, Rahman, Parra, Dmochowski, Bikson.

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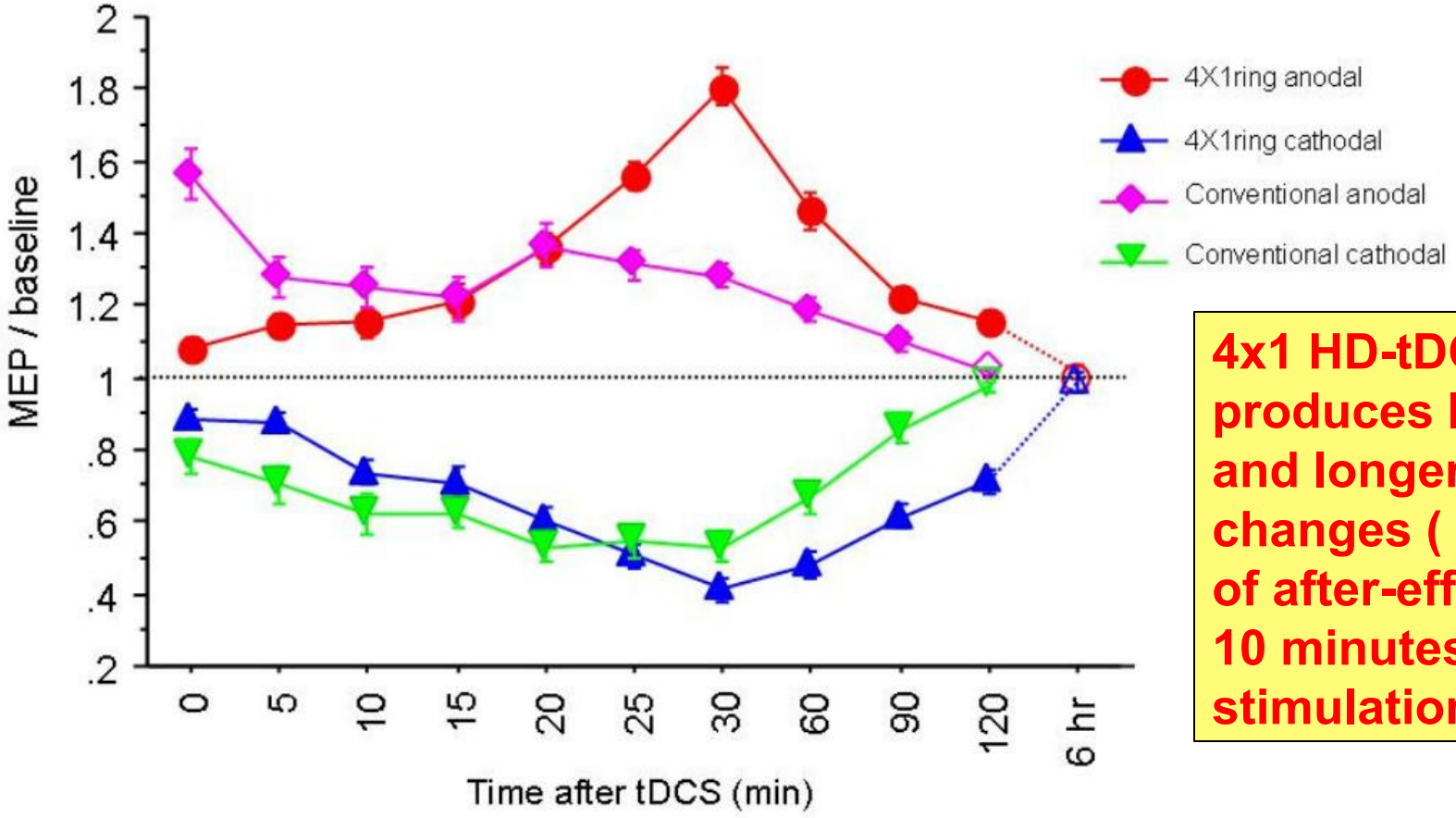
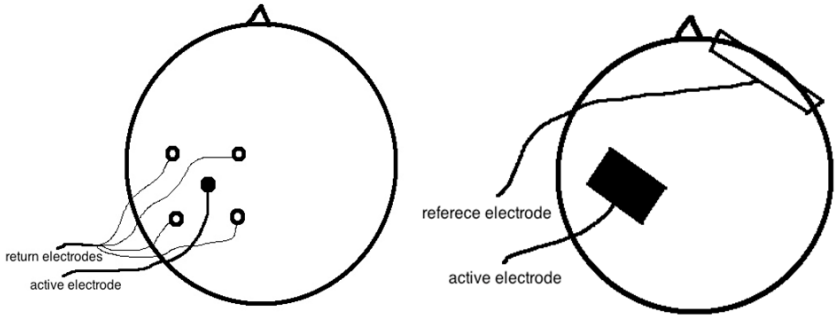
High-Definition tDCS 4x1-Ring Montage



4x1 HD-tDCS produces larger and longer lasting changes (>2 hour of after-effects for 10 minutes of stimulation)

Comparing cortical plasticity induced by conventional and high-definition 4 × 1 ring tDCS: a neurophysiological study. *Brain Stimulation* 2013 Kuo HI, Bikson M, Datta A, Minhas P, Paulus W, Kuo MF, Nitsche MA



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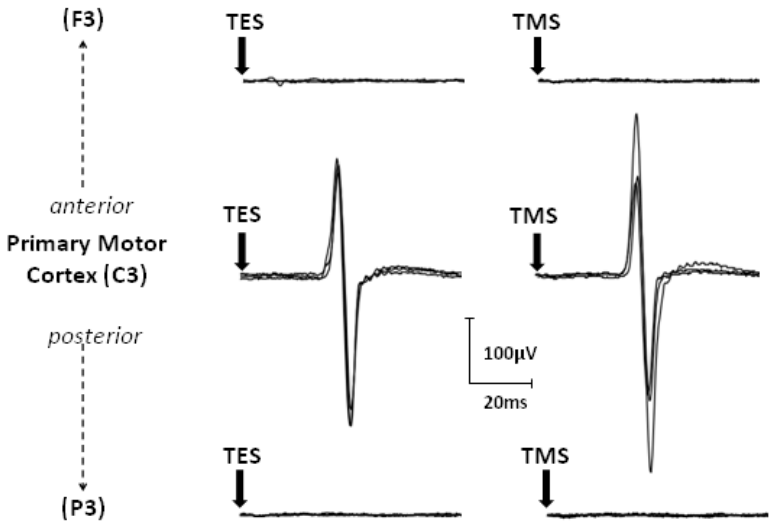
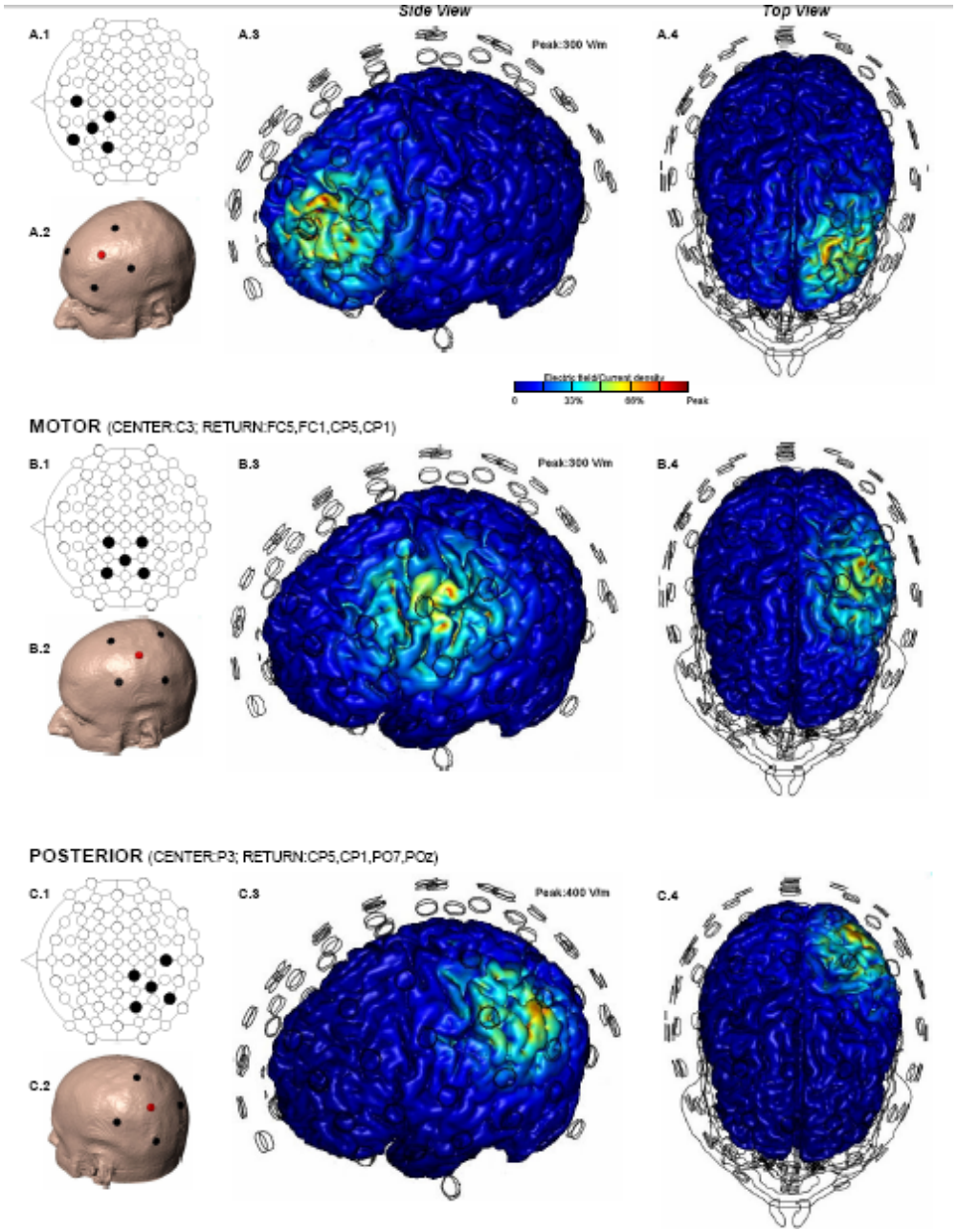
High-Definition tDCS 4x1-Ring Montage

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



Comparable focality to TMS



Physiological and modeling evidence for focal transcranial electrical brain stimulation in humans: a basis for high-definition tDCS. *Neuroimage* 2013 Kuo HI, Edwards D, Cortes M, Datta A, Minhas P, Wassermann EM, Bikson M

Some more reasons to use models

- Can account for inter-individual difference in head anatomy. Including susceptible populations (children, stroke…) to normalize dose.
- Can be correlated with imaging data to test hypothesis.
- Consider novel targets (e.g. deep brain, white matter)
- Current flow models can be coupled with biophysical models of oscillations, information processing, synaptic plasticity to rationally interpret and optimize (HD) tDCS.

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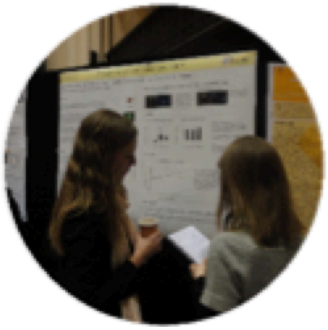
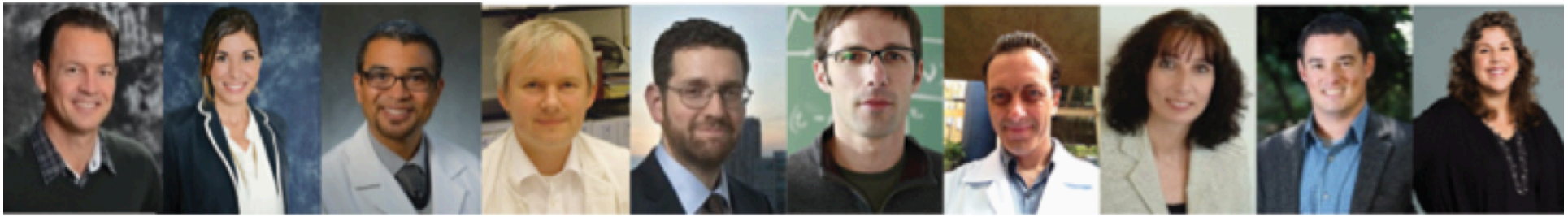


Scientific Conference Committee



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Mar Cortes | Michael Nitsche | Lucas Parra | Helena Knotkova | Leigh Charvet