Electrical Brain Stimulation
transcranial Direct Current Stimulation (tDCS)
transcranial Alternating Current Stimulation (tACS)

Marom Bikson
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The City College of New York of CUNY, New York
Disclosure (relevant to presentation)

The City University of New York: Patents on brain stimulation.
Soterix Medical: Co-founder, Produces tDCS and High-Definition tDCS.
Boston Scientific: Neuromodulation Scientific Advisory Board
GlaxoSmithKline (GSK) Life Science Scientific Advisory Board
Mecta, Consultant

Support

NIH (NIMH, NINDS, NCI, NIBIB) – BRAIN Initiative, NSF, Harold Shames, CCNY Fund, 21st Century Fund
What defines neuromodulation technologies is how energy is delivered to what target:

- **Implants**
  - Deep Brain Stimulation (DBS)
  - Spinal Cord Stimulation (SCS)

- **In-Hospital**
  - Transcranial Magnetic Stimulation (TMS)
  - Electroconvulsive Therapy

- **Wearable**
  - Transcranial Direct Current Stimulation (tDCS)
  - Transcranial Alternating Current Stimulation (tACS)
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- **Wearable**
  - Transcranial Direct Current Stimulation (tDCS)
  - Transcranial Alternating Current Stimulation (tACS)
tDCS: transcranial Direct Current Stimulation

Cathode (-) Electrode

Anode (+) Electrode

1-2 mA
20 minute session
5x per week

“Anodal” / “Cathodal” refer to proximity of target
"Cathodal" tDCS
Soma hyper-polarized
Apical dendrite depolarized

"Anodal" tDCS
Soma depolarized
Apical dendrite hyper-polarized

tACS: transcranial Alternating Current Stimulation

Electrode

Opposite polarity Electrode

0.5-2 mA_{pp}
20 minute session
5x per week

Typical frequencies 0.1-100 Hz
Scalp

Cortex

Alternating current flow direction / polarization

Given up to 2 mA applied current, where and how much electric field in the brain?
tDCS / tACS (large electrode)  

M1-SO tDCS/tACS montage  

Experimentally-verified Anatomical MRI derived models of current flow  

High Definition tDCS / tACS  

4x1 HD-tDCS/tACS montage  

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Experimentally-verified Anatomical MRI derived models of current flow

4x1 HD-tDCS/tACS montage

~1 V/m Electric Field

tACS current flow: alternating direction
High-Definition tDCS/tACS uses arrays of electrodes to focus current to targets.

Different anatomy → Different brain current flow.

Including for atypical anatomy (neurodegenerative disorders, brain injury), extremes of age…

When applying the same tDSCS / tACS across a population, aggregate response reflect individual variability.

Realistic vOlmetric-Approach-based Simulator for Transcranial electrical stimulation

BRAIN initiative: NIMH 1R01MH111896. Free (Matlab), Open Source, One command line, validated outcomes.

Huang et al. ROAST -- a fully automated open-source pipeline, bioRxiv 217331, Nov 10, 2017
Given ~1 V/m Electric Field, How much neuronal polarization?
tDCS: Sustained weak polarization

Brain slice: Optical Mapping with Voltage Sensitive Dyes

0.1 mV membrane polarization per 1 V/m Electric Field

Bikson et al. Effects of uniform extracellular DC electric fields on excitability in rat hippocampal slices. *J Physiol* 2004
**tDCS: Sustained weak polarization**

Brain slice: Optical Mapping with Voltage Sensitive Dyes

Bikson et al. Effects of uniform extracellular DC electric fields on excitability in rat hippocampal slices. *J Physiol* 2004
Given small (<1 mV) neuronal polarization, what are effects on neurophysiology?

tDCS
Synaptic efficacy is modulated by Direct Current (pathway + polarity specific)

Evoked Response + Cathodal or Anodal Direct Current Stimulation

Synaptic efficacy is modulated by Direct Current (pathway + polarity specific)

- Direct Current stimulation does not generate synaptic activity or neuronal firing (Functional Targeting)

Axon (synapse) terminals are most sensitive to stimulation.

**tDCS:** 0.8 mV membrane polarization per 1 V/m Electric Field

**tACS:** ~1 ms membrane polarization time constant
Theta Burst Stimulation (TBS) generates LTP which is modulated by concurrent Direct Current Stimulation (DCS).
Theta Burst Stimulation (TBS) generates LTP which is modulated by concurrent Direct Current Stimulation (DCS)

- DCS does generate synaptic plasticity de novo \textit{(Functional Targeting)}

Repeated DCS accelerates LTP and boosts the ceiling for synaptic learning

- Hypothesis: Combing Direct Current stimulation with ongoing training of a task may enhance the rate and ceiling learning specifically of that task (Functional Targeting)

Bikson et al. Origin of specificity during tDSC: activity-selective mechanisms. Front Human Neuro 2013
tDCS: **Stimulation** engages brain activity
+ that **Task / Plasticity** produces
How could weights help with so many sports?

It’s a tool to enhance specific training.

How could tDCS (tACS) treat many disorders?

It’s a tool to enhance cognitive training and therapy.
tDCS/tACS

From Anatomical Targeting to Task Targeting

Current flow across entire region

Network of interest (e.g. depression, pain network)

Other networks – not targets for neuromodulation

 Preferential modulation of selected active neurons

Given small (<1 mV) neuronal polarization, what are effects on neurophysiology?

tACS
Mechanism of tACS: Origins of Specificity

- AC Current flow
- AC cell polarization

Enhance of ongoing activity (oscillations)

Alternating Current Stimulation of Network Oscillations

Alternating Current Stimulation of Network Oscillations

- AC stimulation
- Brain oscillations

Graph showing the relationship between increasing AC amplitude and AC frequency, with peaks at 25Hz and 50Hz.

- Entrainment
- Frequency increased
- Subharmonics
- Frequency decreased
- Power modulation
- Spiking resonance

Reato et al., 2010
tACS: **Stimulation** to engages endogenous oscillations + produced by task / training
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