Comparing the focality of TMS and HD-tDCS

Understanding anatomical and functional targeting with tDCS

Marom Bikson

Lucas Parra, Asif Rahman, Niranjan Khadka, Dennis Truong, Abhishek Datta, Davide Reato, Belen Lafon, Gregory Kronberg, Thomas Radman, Ole Seibt, Bhaskar Paneri, Chris Thomas

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

$ NIH (NINDS, NCI), NSF, Epilepsy Foundation, Coulter Foundation, DoD (USAF, AFOSR)

• Moving electrode / coil position changes neurophysiological / behavior outcomes

• Sensitivity of outcomes to (small) displacement of electrode / coil does not imply focality of stimulation
Current flow through head during tDCS determined by anatomy and tissue properties

- High conductivity of skin and CSF diffuses current
- 1 mm resolution preserved through model workflow
- Corrections beyond scan resolution (CSF continuity)
- Standard-1 tissue conductivities

Gyri-precise model of tDCS: Improved spatial focality using a ring versus conventional pad. *Brain Stimulation* 2009

Scans of post-mortem subject detect current polarity specific artifact, concentrated in CSF

Antal et al. Imaging artifacts induced by electrical stimulation during conventional fMRI of the brain. *Neuroimage* 2014
Current flow through head during tDCS determined by anatomy and tissue properties.

From Standard-1 to H-1 adaptive conductivities (explicit consideration of skin polarization by DC).

4x1 montage of High-Definition tDCS
Polarity set by center electrode
Current flow restricted to cortex within 4 electrode ring (insensitive to model parameters).

Conventional tDCS (2 mA)

High-Definition tDCS (2 mA)

• Comparable intensity at target

• Comparable tolerability using HD electrodes*
  • 10 minutes of 2 mA 4x1 HD-tDCS produces >2 hour of after-effects

Kuo et al. Comparing cortical plasticity induced by conventional and HD-tDCS 4x1. *Brain Stimulation* 2013
Transcranial Electrical Stimulation (TES): Short high-intensity pulse that triggers MEPs

4x1 montage used to localize current on or off motor region

Edwards et al. Physiological and modeling evidence for focal transcranial electrical stimulation: HD-tDCS. *Neuroimage* 2013

---

Transcranial Electrical Stimulation (TES): Short high-intensity pulse that triggers MEPs

4x1 montage used to localize current on or off motor region

Edwards et al. Physiological and modeling evidence for focal transcranial electrical stimulation: HD-tDCS. *Neuroimage* 2013
Edwards et al. Physiological and modeling evidence for focal transcranial electrical stimulation: HD-tDCS. *Neuroimage* 2013

**Left:** TES intensity increased to threshold for each subject

**Right:** Fixed TES intensity for each subject

>2x inter-individual difference captured by anatomical models

Supra and sub-threshold electrical stimulation

**High-intensity Pulses**

- Over-driving neurons (axons)
- Neuromodulation (therapy) derives from secondary system changes

**Low-intensity Direct Current**

- Polarize neurons
- Neuro-modulation: Interacting with specific ongoing neuron activity
Anatomical targeting with brain stimulation

Supra-threshold stimulation
- DBS
- Cortical stim
- TMS


Sub-threshold stimulation
- HD-tDCS
- 4x1

Stimulation primary neuromodulation target. Endogenous circuit.

From Anatomical Targeting to Functional Targeting

Network of interest (e.g. depression, math cells)
Other networks – not targets for neuromodulation

Electrode / Coil

Preferential modulation of selected active network (activity dependent)

Current flow across entire region
Biophysical basis of tDCS functional selectivity

① tDCS produces a sustained weak polarization of neuronal membranes

② Weak polarization modulates synaptic efficacy

③ Network activity that is engaged during tDCS will be amplified
tDCS: Sustained weak polarization

Brain slice: Optical Mapping with Voltage Sensitive Dyes


Radman et al. Role of cortical cell type and morphology in subthreshold and suprathreshold uniform electric field stimulation. *Brain Stimulation* 2009

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

Biophysical basis of tDCS functional selectivity

1. tDCS produces a sustained weak polarization of neuronal membranes
2. Weak polarization modulates synaptic efficacy
3. Network activity that is engaged during tDCS will be amplified
Weak polarization modulates synaptic efficacy

The amount of post-synaptic current for given pre-synaptic activity


Modulation of on-going synaptic activity, *not* generation

Excitatory post-synaptic currents (field) in brain slice

Anodal stimulation

Cathodal stimulation

Control

Train of synaptic activity

- Ongoing synaptic activity modulated while tDCS sustained
- Substrate for plasticity
- Modulation of ongoing activity, *not generation*
Biophysical basis of tDCS functional selectivity

① tDCS produces a sustained weak polarization of neuronal membranes

② Weak polarization modulates synaptic efficacy

③ Networks activity that is engaged during tDCS will be amplified

Fritsch 2010: BDNF dependent + activity dependent induction

Specific ongoing synaptic activity (no plasticity)

TDCS induces plasticity

Rahman 2015: Pathways specific + plasticity dependent modulation

Ongoing Plasticity

TDCS modulates plasticity

“None-active” synapse

No tDCS synaptic plasticity

Synaptic Plasticity in brain slice
• (HD) tDCS presents advantages for cost, tolerability, broad deployment
• Sub-threshold neuromodulation. Efficacy and specificity derive from:
  - Anatomical targeting based on current flow physics
  - Functional targeting based on adjunct training