Targeting transcranial Electrical Stimulation using EEG: The scalp space approach

July 11, 2015, BrainSTIM 2015 Conference

Marom Bikson, The City College of New York

Modeling: Lucas Parra, Asif Rahman, Dennis Truong, Jacek Dmochowski, Abhi Datta, Mahtab Alam, Alexander David, Asif Rahman, Maged Elwassif, Salman Shahid, Mohammed Aboseria, Ole Seibt, Andoni Mourdoukoutas

Electrode Design: Preet Minhas, Johnson Ho, Abhi Datta, Chris Thomas, Varun Bansal, Jinal Patel, Justin Rice, Niranjan Khadka, Vaishali Patel

Scalp-Space EEG inversion: Franca Tecchio, Andrea Cancelli, Carlo Cottone

“The problem with EEG + TES”: Emily Kappenman, Vladimir Miskovic, Karl Kuntzelman

Disclosure:

Soterix Medical Inc. produces tDCS and High-Definition tDCS. Marom Bikson is founder and has shares in Soterix Medical. Some of the clinical data presented may be supported by Soterix Medical Marom Bikson serves on the scientific advisory board of Boston Scientific Inc.

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Transcranial Direct Current Stimulation (tDCS)

• Non-invasive, portable, well-tolerated neuromodulation.
• Low-intensity (mA) current passed between scalp electrodes.
• Tested for cognitive neuroscience and neuropsychiatric treatment.

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Depression, Pain, Migraine, Epilepsy, PTSD, Schizophrenia, Tinnitus, Neglect, Rehabilitation (motor, aphasia), TBI, OCD, Attention / Vigilance, Accelerated learning (reading, motor skills, math, threat detection), Memory, Creativity, Sleep (SW, Lucid dreaming, Threat detection, Impulsivity, Compassion, Jealousy, Reality Filtering, IQ, Prejudice...
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How do we optimize tDCS for a specific indication and individual

Current flows from one electrode to the other

Truong et al. Clinician accessible tools for GUI computational models. “BONSAI” and “SPHERES”. Brain Stimulation 2014

Extra-cephalic electrode won’t solve the issue of diffuse bi-directional flow

Datta et al. Electrode montage for tDCS: Role of return electrode. Clinical Neurophysiology 2010

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“4x1” montage of High-Definition tDCS

- Allows targeting of selected cortical regions

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

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“4x1” montage of High-Definition tDCS

- Total of 5 small “HD” electrodes (4+1)
- Center electrode over target determines polarity
- 4 return electrodes - Ring radius determines modulation area

Minhas et al. Electrodes for High-Definition transcutaneous DC. *J Neuroscience Methods* 2010

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It won’t work because:

- The skull is resistive
- Current is diffused in the skin and CSF, not skull, and can be controlled inside ring
- Prior efforts limited by use of large pads, not by physics

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“4x1” montage of High-Definition tDCS

- 2006-2008 Gyri-precise brain models
- 2008 3rd International Brain Stimulation Conference
- 2008-09 Publications on Theory
- 2008-10 Safety (Wassermann et al.)
- 2012: Experimental Pain (George et al.)
- 2012 Fibromyalgia (Fregni et al.)
- 2013 Neuro-plasticity (Nitsche et al.)
- 2013 Focality Physiology (Edwards et al.)
- 2015 Cognitive Performance (Loo et al.)

Minhas et al. Electrodes for High-Definition transcutaneous DC. *J Neuroscience Methods* 2010
It won’t work because:

- **The skull is resistive**
  - Current is diffused in the skin and CSF, not skull, and can be controlled inside ring
  - Prior efforts limited by use of large pads, not by physics
- **DC can’t be applied through little electrodes**
  - 2008-10 design of **High-Definition Electrodes**
  - 3cm$^2$ electrode-electrolyte contact area, Ag/AgCl electrodes, high-capacity gel (e.g. Signa), rated 2 mA + 22 minutes

Minhas et al. Electrodes for High-Definition transcutaneous DC. *J Neuroscience Methods* 2010

High-Definition tDCS uses arrays of electrodes to focus current to targets

- Without need for “search” there is a single solution given a target (2009-11)


Use EEG to guide HD-tDCS targeting (~1978)

- **Easy** – HD easily integrated with any EEG
- **Individualized** – Sure
- **Automatic** – But how? Still Easy?
- **Real time** – Beware
Model driven EEG to HD-tDCS. Easy?
1) Get and process high resolution MRI
2) Conduct high-density EEG
3) Localize sources (assumptions)
4) Run full HD-tDCS optimization using all electrodes

Scalp Space EEG to HD-tDCS. Easy.
1) Conduct EEG
2) Scalp Space Inversion with no scans, no source assumptions, easy math
3) HD-tDCS with minimal electrodes
Single dipole – Laplacian inversion

Current source density at each electrode, apply that current (exclude borders)

<table>
<thead>
<tr>
<th>Number electrodes</th>
<th>256</th>
<th>128</th>
<th>64</th>
<th>32</th>
<th>16</th>
<th>8</th>
</tr>
</thead>
</table>

Voltage to current

Laplacian

Single dipole – Two HD electrodes

Scalp Potential (v)

Brain Electric Field (v/m)

Local dipole

Source

Ad hoc position

At laplacian peaks

2 Electrode: Ad-Hoc / Model-Based Placement

Close Electrodes

Distant Electrodes

Off-angle Electrodes

Targeted (focused current flow) but low intensity in brain

Diffuse across brain but high intensity

Current flow orientation along target key

Scalp-Space EEG to HD-tDCS

**Method**
1) Collect EEG
2) Laplacian at all channels
3) 2 HD electrodes at MAX and MIN

**Outcome**
1) Direction of current flow at source matched
2) Balance between targeting and intensity
3) Simple

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The problem with concurrent tDCS and EEG

- **No stimulation source is perfect.** Noise limits signal change size detectable. Must be reported.
- **Stimulation alters tissue conductivity,** most evident in scalp erythema. Will alter detection of EEG in a montage + time specific fashion.
- **Stimulation effects amplifiers.** Volts can drive non-linear performance (e.g. filtering) in a montage + time specific fashion. Active head-stages, DRL…
- **Physiologic artifacts.** Eye-blink artifact, retinal sensitivity, EKG…
- **Electrode distortion.** Electrochemical change in impedance. When same one used.

Not systematically addressing all these issues, in a trial specific fashion, leads to meaningless data.
Take home messages

1) tDCS can be focal at cortex using 4x1 (2008).
2) HD electrodes needed for tolerability (2008).
4) Simple inversion of EEG to HD-tDCS fails.
5) Scalp Space-Inversion provides simple targeting without need for MRI.
6) Limited EEG and only few HD electrodes needed: Bipolar or 4x1 montage.
7) Concurrent EEG + tDCS problematic.

“Functional Sets” of HD electrodes

- Set of HD electrodes that share a total current
- Bain current flow does not depend on the relative current split of between electrode within function set
- Skin current density is reduced

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