Engineering the Brain with Non-invasive Electrical Stimulation: Applications in cognition and treatment

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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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What is Neuromodulation?

- Application of electricity to change brain function
- **Often therapeutic**
- Many techniques: Name of each method is defined by how electricity is delivered
  (some letters ending with “s”).

Deep Brain Stimulation (DBS)
Transcranial Magnetic Stimulation (TMS)
Transcranial Direct Current Stimulation (tDCS)
Why Neuromodulation?

- To probe the brain for science
- To treat the brain: neurological, psychiatric, rehabilitation
- To enhance mental performance (neuro-enhancement)

Deep Brain Stimulation (DBS)
Transcranial Magnetic Stimulation (TMS)
Transcranial Direct Current Stimulation (tDCS)
What is tDCS?

transcranial Direct Current Stimulation
Electro-doping
Electroceuticals: Brain healing
What is all the hype about?

Can You Download Knowledge Into Your Brain With Electricity?

tDCS Brain Hacking Tech Boosts Stroke Recovery

Study tests electrical stimulation to treat depression in pregnancy

A Spark of Genius

Jumper Cables for the Mind

HELP YOU LOSE WEIGHT

DIY Brain-Shock Kits Jump Start Users' Day

Have you tried to zap fibromyalgia pain away?
Transcranial Direct Current Stimulation (tDCS)

- Non-invasive, portable (9V), well-tolerated neuromodulation.
- Low-intensity (mA) current passed between scalp electrodes.
- Tested for cognitive neuroscience and neuropsychiatric treatment.

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...
Transcranial Direct Current Stimulation (tDCS)

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Ø How can a 9V battery affect the complex brain?
Ø How is specificity of action achieved?

tDCS Publications

Depression, pain, migraine, epilepsy, PTSD, schizophrenia, (motor, aphasemia), TBI, OCD, addiction, accelerated learning (reading, motor skills, math, threat detection), memory, creativity, lucid dreaming...

How can a 9V battery affect the complex brain?
How is specificity of action achieved?
How can a 9V battery do anything for the complex brain?

How is specificity of action achieved?
How could Pharmaceuticals treat so many disorders?
It’s not one thing. Many formulations.

How could tDCS treat many disorders?
It’s not one thing. Many “formulations”.
tDCS electrode position on the head determines which regions are stimulated.

Specific brain regions are associated with specific functions / disease.

Truong et al. Clinician accessible tools for GUI computational models. “BONSAI” and “SPHERES”. *Brain Stimulation* 2014
High-Definition tDCS uses arrays of electrodes to focus current to targets.

Software allows you to generate subject and target specific (HD) tDCS “formulation”.

“4x1” montage of High-Definition tDCS

✓ Allows targeting of selected cortical regions

High Definition tDCS for Stroke Rehabilitation

Dmochowski et al. Targeted transcranial direct current stimulation for rehabilitation after stroke. Neuroimage 2013
tDCS montages for treatment of Depression

- **Brunoni et al.**
  - SELECT / ELECT
  - target: DPLPC
  - 2.0 mA
  - Double blind RCT

- **Loo et al.**
  - Multi-Center Trial
  - target: DPLPC
  - 2.5 mA
  - Double blind RCT

- **Seibt al.** The pursuit of DLPFC. *Brain Stimulation* 2015

  - Target stimulated but not specifically
Transcranial Direct Current Stimulation (tDCS)

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…

Majority of trials use diffuse tDCS

➢ How can a 9V battery do anything for the complex brain?
➢ How is specificity of action achieved?
How could weights help with so many sports?
It’s a tool to enhance specific training.

How could tDCS treat many disorders?
It’s a tool to enhance cognitive training and therapy.
tDCS combined with training (tasks)
How does tDCS just enhance the trained task?

Cellular mechanism: Functional Targeting

Bikson et al. Origins of specificity during tDCS: anatomical, activity-selectivity, and input-bias mechanisms. *Front Human Neuro 2013*
What makes tDCS so special?

Deep Brain Stimulation (DBS)

Transcranial Magnetic Stimulation (TMS)

tDCS
What makes tDCS so special?
What makes tDCS so special?

High-intensity Pulses

Low-intensity Direct Current

TMS
Invasive cortical
DBS
What makes tDCS so special?

High-intensity Pulses

Low-intensity Direct Current
What makes tDCS so special?

High-intensity Pulses

Low-intensity Direct Current
What makes tDCS so special?

High-intensity Pulses

Low-intensity Direct Current

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

Intracellular recording and morphology

Radman, Bikson et al. Role of cortical morphology in uniform electric field stimulation. *Brain Stimulation* 2009
From Anatomical Targeting to Task Targeting
From Anatomical Targeting to Task Targeting

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

Current flow across entire region

Preferential modulation of selected active neurons

tDCS
**Biophysical basis of tDCS task selectivity**

**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**

DC + Theta burst synaptic activity
Biophysical basis of tDCS task selectivity

① tDCS produces a sustained weak polarization of neuronal membranes

② Weak polarization modulates cortical processing related to active tasks, and can promote plasticity (learning)
tDCS is a tool for the mind that enhances activity and plasticity from cognitive training and therapy

- Human trials with tDCS use brain stimulation as adjunct to the brain training (e.g. math, game)
- Changes in mood that facilitate training (vigilance, relaxation)
- Boosting placebo – real and specific physiological response associated with expectation
How can a 9V battery do anything for the brain?
How is specificity of action achieved?

- tDSCS generates weak current across specific parts of the brain. Neurons in those parts are polarized.
  - Tasks applied at same time.
  
  = tDSCS changes how those specific parts process this activity boosting training and learning.
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Weak polarization modulates synaptic efficacy

Excitatory post-synaptic currents (field) in brain slice

Train of synaptic ongoing activity

- Ongoing synaptic activity modulated while tDCCS sustained
- Substrate for plasticity
- Modulation of ongoing activity, not generation
Weak polarization modulates synaptic efficacy


- Polarity of modulation depends on many factors
Direct Current stimulation of ACTIVE networks

Reato et al. Transcranial electrical stimulation accelerates human sleep homeostasis. PLOS Computation Biology 2013