Practical for transcranial Direct Current Stimulation (tDCS)

Marom Bikson
The City College of New York, CUNY

Adam Woods
University of Florida
Conflicts of Interest

• Marom Bikson, PhD
  – The City University of New York: Patents on brain stimulation.
  – Soterix Medical: Co-founder, Produces noninvasive brain stimulation devices and models.
  – Boston Scientific: Neuromodulation Scientific Advisory Board
  – GlaxoSmithKline (GSK) Life Science Scientific Advisory Board

• Adam J. Woods, PhD – None to report
  – Consultant: Norgine Ventures
• Reproducibility
  — Protocol documentation and methodological rigor

• Professional Standards
  — Organization and certification

• Comprehensive Training
  — Well defined, non-trivial techniques

• Safety
  — Tolerability provided through rigor

• Optimization
  — Selection of dose “target” and subjects

• Ethics and Access
  — Regulations and dissemination
Reproducibility

- Dose control
  - Electrode Shape/Size
  - Electrode Position
  - Current Intensity
  - Current Duration
  - Use of Ramp
  - Use of Sham

- Electrode preparation
  - Electrode Assembly
  - Electrode Placement
  - Electrode Localization
  - Contact Medium
  - Oversaturation
  - Electrode Orientation
  - Electrode Drift
  - Impedance
  - Electrical Bridging
Some questions about tDCS....
What does tDCS look like?
What does tDCS look like?

Here’s an electrode

Here’s another one

Head-gear to hold them in specific places

Two cables to the device
The most fundamental mistake in tDCS is assuming equipment and accessories selection does not matter, electrode preparation does not matter, training does not matter.

Control and documentation of details underpins reproducibility, tolerability, efficacy...

What is the “dose” of tDCS?

- Size, position, and current applied to electrodes
- Example: 5x5 cm² electrodes, C3 Anode, SO Cathode, 2 mA for 20 minutes

Peterchev, Bikson et. al. 
*Brain Stim* 2012
tDCS waveform is easy to describe

Intensity (mA), Duration (minutes)

2 mA
Anode (1 mA, 20 min)
-2 mA
Cathode (-1 mA, 20 min)

30 min
tDCS montage pretty easy to describe

Number, position, and shape.

5x5 cm, M1 (anode), SO (cathode)

“Lateralized” Montage

Extra-cephalic Montage
So: **regular tDCS** uses large sponge based electrodes connected to a 2-channel device (one anode, one cathode)

**Practical training** is just how to prepare these sponge electrodes and set-up 2-channel device.

**Theory** is where you should place them and device settings (dose) along with other intervention design factors (tasks, inclusion/exclusion...)

DaSilva et al. Electrode positioning and montage in transcranial direct current stimulation. *JOVE* 2011
What is the High-Definition tDCS?

- Use of small “HD” gel-electrodes, instead of sponges
- Categorical increase in control on brain targeting
- Useful with EEG

Dmochowski, Bikson et al

*J. Neural Engr.* 2011
What is the 4x1 HD-tDCS?

• Five HD electrodes (one center, four surround)
• Used for focal unidirectional cortical modulation

Datta, Bikson et al
*Brain Stimulation* 2009
So regular tDCS uses large sponge-based electrodes connected to a 2-channel device (one anode, one cathode)

Practical training is just how to prepare these sponge electrodes and set-up 2-channel device.

Theory is where you should place electrodes and device settings (dose) along with other intervention design factors (task, inclusion/exclusion)

Villamar et al. Technique and considerations in the use of 4x1 ring HD-tDCS. JOVE 2013
Is tDCS safe?

- Consensus YES: No serious adverse effect in >30,000 sessions in (diverse) patients or healthy volunteers
- Requires certified equipment and protocols

Safety of Transcranial Direct Current Stimulation: Evidence Based Update 2016

Marom Bikson a,*, Pnina Grossman a, Chris Thomas a, Adantchede Louis Zannou a, Jimmy Jiang a, Tatheer Adnan a, Antonios P. Mourdoukoutas a, Greg Kronberg a, Dennis Truong a, Paulo Boggio b, André R. Brunoni c, Leigh Charvet d, Felipe Fregni e, Brita Fritsch f,g, Bernadette Gillick h, Roy H. Hamilton i,j,k, Benjamin M. Hampstead l,m, Ryan Jankord n, Adam Kirton o, Helena Knotkova p,q, David Liebetanz r, Anli Liu s, Colleen Loo t, Michael A. Nitsche r,u,v, Janine Reis f,g, Jessica D. Richardson e,w,x, Alexander Rotenberg y,z, Peter E. Turkeltaub aa,ab, Adam J. Woods ac
Is tDCS tolerated?

• Consensus YES: but when standard protocols are followed
• Requires certified equipment (devices, electrodes) and training
Can tDCS be done at home?

- Only with specially designed equipment
- Consensus telemedicine protocols: “Remote-Supervised tDCS”

Remotely-supervised transcranial direct current stimulation (tDCS) for clinical trials: guidelines for technology and protocols

Leigh E. Charvet¹ *, Margaret Kasschau¹, Abhishek Datta², Helena Knotkova³, Michael C. Stevens⁴, Angelo Alonzo⁵, Colleen Loo⁵, Kevin R. Krull⁶ and Marom Bikson⁷
Practical Guide to Transcranial Direct Current Stimulation

Contains:
- 21 Chapters
- Contributions from 40+ field leading authors
- Covers content ranging from neural mechanisms to clinical trials and ethics.
Is more dose, more?
Is more dose, more?

Intensity (mA), Duration (minutes)

Outcome (behavior)

Linear dose-response

Is more dose, more?

Intensity (mA), Duration (minutes)

Non-linear dose-reponse (none-monotonic)

Nitche et. al. J Physiol. 2013
Lets talk montage...

(and all the mistakes people make and all the potential people don’t leverage)
Transcranial Direct Current Stimulation (tDCS)

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

Current flow

outward  inward

Radman et al.  
*Brain Stim.* 2009
Transcranial Direct Current Stimulation (tDCS)

Radman et al.
*Brain Stim.* 2009
Transcranial Direct Current Stimulation (tDCS)

Current flow
inward
outward

Head Surface

Anode (+)

Hyperpolarized cell compartments

Depolarized cell compartments

Increased Excitability / Plasticity

Radman et al.
Brain Stim. 2009
Transcranial Direct Current Stimulation (tDCS)

Current flow

outward  inward

Head Surface

Cathode (-)

Current Flow

Hyper-polarized cell compartments

Depolarized cell compartments

Decreased Excitability / Plasticity

Radman et al.

Brain Stim. 2009
Central assumption: Inward/Outward current flow produces Excitation/Inhibition

Then, classic tDCS design:

- “Active” electrode placed over the target and polarity selected to Excite (Anode) or Inhibit (Cathode)
- “Return” (“reference”) electrode placed somewhere else, and ignored

Physics of current flow does not support this approach
Montovani Montage (tested for OCD)

“Active” electrode over the pre-Supplementary Motor Area

“Return” on the right shoulder
Physics

• Current goes from anode to cathode
• All current that enters the cortex must exit

**tDCS design implications**

• Must consider both electrodes
• No such thing “anodal” or “cathodal” tDCS

Datta et al. *Clinical Neurophys.* 2010
Current does not stop at cortex

Physics

• Hot-spots around deep structures
• Cellular morphology is varied

tDCS design implications

• Difficult to predict “increase” or “decrease” in deep structures
• Details idiosyncratic
4x1 High-Definition tDCS

High-Definition electrodes in “4x1” configuration

Conventional bipolar large electrodes
4x1 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

**Center electrode:** CATHODE

**Center electrode:** ANODE

**Outward current (inhibitory)**

**Inward current (excitatory)**
Conclusions: Current flow design in tDCS

- tDCS is rationalized based on increasing / decreasing cortical excitability with inward / outward current flow
- Conventional tDCS uses two large electrodes (one anode, one cathode) producing diffuse and deep brain current flow, with peak brain intensity somewhere between electrodes
- 4x1 High-Definition tDCS (HD-tDCS) allows targeting of just cortex with a largely uni-directional pattern

Datta et. al. Brain Stim 2009

- Other High-Definition montages can be designed and optimized

Dmochowski Neural Engr. 2011
Conventional tDCCS
Conventional (1x1) tDCS
The Electrode Assembly

Conventional 1x1 tDCS
Electrode Assembly

• Biocarbon Electrodes

• Electrode Sponges
  – Soterix: one use
  – NeuroConn: multi-use

• Electrode Wires
Electrode Size

• A variety of sizes
  – 5x5 cm
  – 5x7 cm
  – 5x10 cm
  – 10x10 cm
  – Other sizes available

• Why different sizes?
  – Control of current concentration/intensity
  – Method for altering the focality of current delivery
Sponge/Electrode Integrity

• Biocarbon Electrodes and Sponges

• 1x1
  – Rubber electrodes
  – Sponge pads
    • Soterix – one use
    • Neuroconn – multi-use
  – Replace electrodes with any sign of cracking or moderate to severe wear
  – Replace sponges with signs of wear
Wire Integrity

• Electrode wires wear over time
  – Disconnection in the connection terminal
    • Not visible
    • Impacts impedance

  – Visible wire fraying
    • Burn/shock should saline make contact
    • Never use

  – Visibly worn or stretched wires are best replaced
    • When in doubt, take no chances

• Avoid pulling on electrode wires or removing electrodes by grasping the wire
Contact Medium

Conventional 1x1 tDCS
Saline: 0.9% Solution

– Proper saturation of sponge
  • Plastic syringe gives best control over delivery (e.g., ~4 mL/side for 5 x 7 cm Soterix Sponge)
– Do **NOT** over saturate
– Do **NOT** apply stimulation to a dry sponge
– Do **NOT** use water
Electrode Paste

• Alternative to Saline
  – Pros
    • Stability over time
    • Less likely to “drip”
  
– Cons
  • Some report increased sensation
  • More difficult to obtain low impedance levels in hair
  • Thick (~3mm) coating of paste must be maintained to minimize skin sensation
    – Easy to press electrode such that paste thickness in decreased
Electrode Localization and Placement

Conventional 1x1 tDCS
Electrode Placement

International 10 – 20 Measurement System

A

B

C
Electrode Placement

- **Elastic Straps:**
  - Adjustable size and configuration

- **EasyStraps:**
  - Montage and head-size specific straps
Electrode to Scalp Contact

• Electrodes should contour to the surface where current is being delivered

• Never allow electrodes to make only partial contact with the head/skin.
  – Delivery of current over a small surface area using a sponge covered electrode could result in burns.
Sponge to Metal Contact

• Shock/Burn Risk
  – Hair clips
  – Jewelry
    • Eyebrow rings, Earrings, beads, etc.
  – Hair pieces
  – Etc.
Electrode Orientation

• Orient electrodes consistently
  – Differences in orientation can alter where on the scalp current is being initially delivered
  – Do not use a variable orientation
    • Much more difficult to replicate
  – Specify wire direction relative to for consistency
Electrode Drift

- When using straps to secure electrodes
  - Straps may drift over time if not properly secured
  - Fine or oily hair have higher rate of drift
  - Use the heads anatomy to your advantage
  - Use cross-straps and chin straps if needed on a particular montage
  - Keep securing strategy consistent across all subjects

Woods et al., 2015
Initiating Stimulation

Conventional 1x1 tDCS
Soterix 1x1 Device
Neuroconn 1x1
Impedance

• Greatest impediment to impedance:
  – Hair

• Do not over-soak sponges with saline

• Use all plastic hair clips to secure hair if needed

• Attempt to provide as much contact with the skin as possible

• Be careful not to stray from the intended electrode site
• Neuroconn Device
  – Aim for <15 kOhm before start of stimulation
  – Impedance will improve during stimulation
  – Good to record impedance at beginning, middle, and end of stimulation period

• Soterix Device
  – Quality measure, not
  – Within ‘<10 bars’ of optimal
  – Rapid improvement with stim
Electrical Bridging

• Consequence of over-saturation of electrodes and/or electrode sites too close to one another.

• If saline from electrodes make contact, can result in electrical shunting through the skin — Not brain stimulation
During Stimulation
Early Removal of Sponge Under Current

• Current ramp is intended to prevent sudden changes in current delivery

• Removing electrodes under stimulation can lead to small electrical shock

• ALWAYS ramp down current to zero before removing electrodes
Typical Side Effects of tDCS

• Itching

• Tingling

• Warming of the skin and slight reddening under the electrode

• Headache

• Nausea
Side effects during stimulation

• In the event of common side effects and participant report of significant discomfort:
  – Itching, prickling, headache, etc.

  • Devices with Ramp Function
    – Decrease current and slowly increase to full current
    – Continued discomfort: discontinue stimulation

  • Devices without Ramp Function
    – Discontinue should participant find sensation significant
Safety?

- 9-volt current source
- No more than 2 mA of current
- Why worry?
HD-tDCS
High-Definition Electrode

① Plastic Holder for positioning of electrode
   - Fits within standard elastic cap
② Gel
③ Electrode (Ag/AgCl sintered)

Minhas, Bikson Electrodes for high-definition transcutaneous DC stimulation. *Journal of Neuroscience Methods*. 2010
HD Plastic Holder

• Ensures minimum distance between electrode and skin
• Sets skin contact area of gel
• Sets gel volume
Conductance Gel

• Conductance gel (e.g. HD-Gel, Signa gel) forms a bridge between electrode and skin
  – Time: gel settles
  – As the gel saturates the skin, impedance improves

• Careful not to under or overfill holder
  – Shunting -such that gel escapes bottom of holder
  – Lack of complete contact
HD-tDCS Stimulators

- Generic (MxN)
- Montage specific (4x1 HD-tDCS)
4x1 Electrode Integrity

• Do not use electrodes to failure

• Ag/AgCl electrodes must be replaced after certain number of uses
  – Excessive corrosion/blackening of electrodes should cue replacement
  – Rated (e.g. 2 mA, 20 min, 5x)

• When in doubt, take no chances
• Mark electrode locations on scalp
  – 10-20 system
  – Cz and Center Electrode Site

• Load cap electrode sites with plastic electrode holders prior to subject arrival
  – This assumes you have enough electrode holders to fill 5 locations in each of your cap sizes
• Using “Scan” setting

• Greatest impediment to impedance:
  – Hair
  – Expose scalp using end of wooden cotton swab

• Attempt to minimize air pockets in gel
  – Fill holder with gel up to electrode location
  – Place electrode in holder
  – Fill gel to cover the electrode in the holder
  – Lock holder
Question and Answer Session