Cognitive Enhancement with tCS

Emiliano Santarnecchi

- Berenson-Allen Center for Non-invasive Brain Stimulation, Department of Cognitive Neurology | Beth Israel Deaconess Medical Center Harvard Medical School, Boston, MA, USA

- Center for Complex System study, Engineering and Mathematics Department, University of Siena, Italy

esantarn@bidmc.harvard.edu

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DIY cognitive enhancement..

Zap Yourself Smarter With This DIY tDCS Brain Stimulator

Kannon Yamada

On 14th November, 2014

Oxford Martin Policy Paper

Mind Machines
The Regulation of Cognitive Enhancement Devices

The Atlantic
Prepare to Be Shocked
Four predictions about how brain stimulation will make us smarter
Outline

• tCS effects: theories and models (n=2)
• tCS as a stand-alone intervention?
• Trait – Dependency of tCS effects
• Polarity specific effects
Why-What-Where-How Neuroenhancement

**Physical activity**
- unspecific effects on metabolism and nutrients
- Requires commitment and time (elderly..)

**Drugs** (modafinil, memantine)
- Side effects
- unspecific effects *(all brain)*

**Brain training**
- Effect on specific functions
- Effect size is usually small..

**Dietary regimen**
- Same as physical activity

**Transcranial Current Stimulation (tCS)**
- Cheap
- Less commitment
- Wearable
- Easy to use
- Stand-alone intervention OR add-on (enhancer)
- More focal (→ modeling)

*Special issue in Current Opinion in Behavioural Sciences 2015/6*
Cognitive Enhancement with tDCS

Reviewed ~ 100 studies
- tDCS (anodal, cathodal)
- healthy participants
- age 18-55
- Sham-controlled

(Coffman et al., 2014; Horvath et al., 2015)

Santarnecchi et al. 2015, Curr. opin. in Behav. Sc.
Non-specific effects?

**COGNITIVE FUNCTIONS**
- Language 19%
- WM 30%
- STM 14%
- LTM 16%
- Problem solving
- Attention
- Creativity
- Implicit learning/memory
- Aritmetical reasoning
- Verbal learning
- Cognitive control

**STIMULATION SITE**
- Left DLPFC 56%
- CP5 13%
- CP6 2%
- C3 2%
- F5 6%
- F4 7%
- F3 3%

**Modeling**

**Montages..?**
Procedural/Motor

- **Anodal** tDCS of the left primary motor cortex enhances motor learning of the contralateral hand (Nitsche et al., 2003)

- **Cathodal** tDCS of the primary motor cortex decreases motor learning of the contralateral hand (Vines et al., 2006)
Procedural/Motor

• Learning occurs in 3 stages
  – Acquisition ➞ Consolidation ➞ Retention

• tDCS improves motor learning by enhancing consolidation (Reis et al., 2009)

• Others have shown additional improvements in retention (Galea & Celnik, 2009)
Enhancement of explicit learning consolidation during sleep (Marshall et al., 2004)

- List of words presented to subjects during the day
- Anodal tDCS of bilateral DLPFC during slow wave sleep
- Enhanced recall of word list

Anodal tDCS of right temporoparietal area enhances memory of object locations after a 1 week delay (Flöel et al., 2011)
  - However, no difference in immediate acquisition
The N-back working memory task (Fregni et al., 2005)

Enhancement of Working Memory

Key region: dorsolateral prefrontal cortex
Enhancement of Working Memory

- Anodal tDCS of left DLPFC enhances performance on 3-back working memory task (Fregni et al., 2005)

- Anodal tDCS of the left DLPFC, combined with N-back working memory task, enhances digit span (Andrews et al., 2011)
  - Neither tDCS nor N-back testing alone was sufficient
Enhancement of Attention

• Visual **Attention** Task: Air Traffic Control (Nelson et al., 2014)
With sham tDCS, attention decreases over time (Nelson et al., 2014)
- Lower target detection rate
- Slower reaction times
- Reduction in cerebral blood flow velocity

Anodal tDCS of the DLPFC (left or right) enhances attention
- Higher target detection rate
- Maintained blood flow velocity
- Increased cerebral oxygenation
• Anodal tDCS of Broca’s area enhances grammatical learning (de Vries et al., 2009)

• Anodal tDCS of Wernicke’s area enhances lexical learning (Flöel et al., 2008)
• **Remote associates test** (Cerruti & Schlaug, 2009)
  - Given 3 words, have to find a word associated with all 3
  - E.g., “Child, Scan, Wash” → “Brain”

• **Anodal tDCS of the left DLPFC enhances performance**
Motor Learning

Implicit Learning

Explicit Learning

Working Memory

Attention

Language

Complex Cognition

Overlapping effects and stimulation sites.
1) Stimulating Different Networks?

- Stimulation sites target different networks.
  Stimulation site as a “Gate”

- tDCS can alter functional connectivity between brain regions (Coffman et al., 2014), as demonstrated with fMRI and EEG

Zahele et al. 2011 (EEG)
2) Overlapping Cognitive Skills?

- Enhancement of explicit learning with tDCS correlates with enhancement of attention (Coffman et al., 2012)

- Enhancement of working memory with tDCS mediated by enhancement of selective attention (Gladwin et al., 2012)

- Learning (memory acquisition/consolidation) linked to working memory and attention (Coffman et al., 2014)

Common denominator → Improvement of attention, therefore reaction times, and filtering ability, working memory, etc.....
Polarity specific Effects?

Is anodal tDCS more effective?  
Is cathodal tDCS detrimental?

Santarnecchi et al. 2015, Curr. opin. in Behav. Sc.
That's not necessarily the case

Filmer et al. 2014

Response selection task

Fixation 200–600 ms

Target

200 ms

Response window 1800 ms

(A)

Practice

Before -tDCS task

tDCS applied

Immediate post-tDCS task

Wait

20 min post-tDCS task

10 min

10 min

10 min

10 min

10 min

(D)
Non-specific effects

Filmer et al. 2014
• Net zero-sum derived from notion of conservation of energy

• A gain in function is accompanied by an equal loss of function

• Is brain enhancement a zero-sum game?
  – Distribution of processing power
  – Example: Trade-offs (e.g. speed-accuracy)

Brem et al., 2014
Evidence for Zero-Sum: Interhemispheric inhibition

- Inter-hemispheric inhibition
  - Motor Learning
  - Attention

- Anodal tDCS increases Learning and Neuronal energy status related metabolites (Glutamine/glutamate-Glx, N-acetylaspartate/N-acetylaspartylglutamate - tNAA) locally, but decreases them in the opposite hemisphere (Clark et al., 2011)
Evidence for Zero-Sum?

Iuculano & Cohen Kadosh, 2013

Study of numerical learning in healthy participants.

6 Days of training combined with:
1) tDCS over Dorsolateral Prefrontal Cortex
2) tDCS over Posterior Parietal Lobe

Enhance Automaticity

Enhance Learning

Please do not copy.
• Brain is organized in distinct networks (Zhang et al. 2010)
• Negatively correlated networks (Fox et al., 2005)

Task positive and Default Mode Networks

Resting-State Networks
Trait Dependency of tCS effects: Working Memory

Unleashing Potential: Transcranial Direct Current Stimulation over the Right Posterior Parietal Cortex Improves Change Detection in Low-Performing Individuals

Philip Tseng,1* Tzu-Yu Hsu,1,2* Chi-Fu Chang,1 Ovid J.L. Tzeng,1,2,3 Daisy L. Hung,1,2 Neil G. Muggleton,1,4 Vincent Walsh,4 Wei-Kuang Liang,1 Shih-kuen Cheng,1 and Chi-Hung Juan1

Fixation  Memory array  Retention interval  Test array

1000 ms  200 ms  900 ms  2200 ms

Change Detection Task (visual short term memory)

EEG recording during the task

Right Posterior Parietal cortex Anodal tDCS
Trait Dependency of tCS effects

Low and High Baseline performers

Performance indexes
N2pc = Negative parietal contralateral wave (200ms)
SPCN = Sustained parietal contralateral negativity

High performers at baseline cannot push their physiological limit → Higher Intensity?
tRNS - Method

Terney et al., 2008 (first tRNS evidence)

Random level of current generated for every sample. The signal is normally distributed, with the current intensity constantly fluctuating around 0uA. For a 1mA amplitude, 99% of the Current is between -500/500uA (Peak to Peak amplitude)

Stimulation frequency constantly change within a predefined spectrum
Training AND/OR tCS?

- Training of “ability to discriminate numerosity” (6 days)
- Key region → **Parietal lobe**
- Tested for other Parietal lobe functions linked to *quantity judgement* (time and space discrimination) as well as other quantity judgment unrelated functions.
- Stimulation = **High frequency tRNS**
Is tCS alone not enough...?
Is tCS alone not enough..?

- Better and longer lasting improvement (up to 16 weeks post-training) for tRNS+training compared to (1) *cognitive training without stimulation*, (2) cognitive training coupled to stimulation of a control site (motor areas), (3) *stimulation in absence of cognitive training*.

  Can be a matter of **Dose** (tCS alone requires more time) and **precision** in terms of regions being targeted

- Task improvement induced by parietal tRNS + Training **transferred to proficiency in other parietal lobe-based quantity judgment**, i.e., time and space discrimination, but not to quantity-unrelated tasks measuring attention, executive functions, and visual pattern recognition.

  Again, **Time** and **Precision**
State-Dependency: Can tDCS alone increase intelligence?

Intelligence Quotient assessment Day 1

→ tDCS (20')

→ Intelligence Quotient assessment Day 2

Sellers et al. 2015
tDCS decreases gain in IQ?

Effect on Intelligence Quotient

Effect on specific indexes of cognitive performance
Cognitive networks

Fluid Intelligence (20 functional units)

Verbal and Visuospatial Fluid Intelligence

Processing stages
- Rule Inference
- Rule Application

Santarnechi et al., in prep
Optimization of multifocal transcranial current stimulation for weighted cortical pattern targeting from realistic modeling of electric fields

*Ruffini et al. 2013*
fMRI-based Multifocal tCS...not enough?

Meta-analysis map of fMRI activation map during Executive functions tasks

Targets for Fronto-parietal desynchronization
Cognitive enhancement...

- Irrespectively of individual performance, each brain is a balanced system.
  - Each modification probably comes at a Cost.
  - Plasticity requires Time (and Sleep..)
  - Each brain respond differently
  - Enhancement requires finely tuned interventions which do not “shake/buzz” the system.
Quantitative Review Finds No Evidence of Cognitive Effects in Healthy Populations From Single-session Transcranial Direct Current Stimulation (tDCS)

Jared Cooney Horvath*, Jason D. Forte, Olivia Carter

- Included every study of the cognitive effects of tDCS among healthy adults (59)
- Cognitive tasks must be used by 2 or more groups
- Included only studies of single session tDCS
- Spanned executive function, memory, language, and other
- No significant effects of any.

Controversy about efficacy

A few studies in each category (~3)

Small sample size

Anodal & Cathodal tDCS
Evidence that tDCS can enhance:
- Learning
- Working memory
- Attention
- Language
- Social Cognition
- Complex problem-solving .....etc..

**tCS effects: theories and models** (Net-Zero sum; overlapping cognitive networks;...)

- tCS as a stand-alone intervention
- Trait – Dependency of tCS effects
- Single sessions vs training
Grazie mille!
esantarn@bidmc.harvard.edu