Cognitive Enhancement with tCS

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Boston, 24th February 2017
DIY cognitive enhancement..

Zap Yourself Smarter With This DIY tDCS Brain Stimulator

Unleash Your Inner Gamer

All New Gamer Headset

The 2015 focus gamer headset

Over 100 improvements over original focus gamer headsets

The Depression Treatment Device

Use for 20 minutes, once or twice a day.
Outline

• tCS effects: theories, models, controversies
• 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)*

**Dietary regimen**
- Same as physical activity

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

**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)
Single session vs training; online-offline...

SANTARNECCHI ET AL. 2015, Curr. opin. in Behav. Sc.
Polarity specific Effects?

Is anodal tDCS more effective?  Is cathodal tDCS detrimental?

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

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

**STIMULATION SITE**
- Left DLPFC F3 56%
- F5 6%
- F4 7%
- P3 4%
- P4 4%
- P8 2%
- T3 2%
- C3 2%
- CP 5 13%
- CP6 2%

**Modeling**

Montages..?
A few examples
• The N-back working memory task (Fregni et al., 2005)

Enhancement of Working Memory

3-back task

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 Explicit Learning

- **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
• **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
• **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
• Stimulation sites target different networks.

Stimulation site as a “Gate”

• tDSCS 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.....
Net Zero sum effects?
• 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)
• 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)
Study of numerical learning in healthy participants.

6 Days of training combined with:
1) tDCS over Dorsolateral Prefrontal Cortex
   Enhance Automaticity

2) tDCS over Posterior Parietal Lobe
   Enhance Learning
Evidence for Zero-Sum? Brain connectivity

- 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
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, Tzu-Yu Hsu, Chi-Fu Chang, Ovid J.L. Tseng, Daisy L. Hung, Neil G. Muggleton, Vincent Walsh, Wei-Kuang Liang, Shih-kuen Cheng, and Chi-Hung Juan

Change Detection Task (visual short term memory)

EEG recording during the task
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?
Training AND/OR tCS?

- TMS
- tDCS
- tACS
- tRNS

Year

# Publications

Transcranial Random Noise Stimulation - tRNS
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.
Stimulation site: Primary Motor Cortex, Premotor cortex

Electrophysiological evaluation: Motor Evoked Potential (MEP), Recruitment Curve, Short-Interval Intracortical Inhibition (SICI), Intracortical Facilitation (ICF), Long-Interval Intracortical Facilitation (LICI), Cortical Silent Period (CSP).

Behavioural evaluation: Serial Reaction Time Task (SRTT)
tRNS - Results

**Experiment 1**
tRNS (1-640Hz)

*Increase in cortical excitability* lasting for 60' after stimulation.

**Experiment 2**
tRNS (1-100Hz) vs (101-640Hz)

*Effect is selective for High-Frequency tRNS (101-640Hz)*

**Behavioural effect**

tRNS improves *implicit motor learning* in its early phase (<RT).

**Significant effect on ICF (12, 15ms)**
No changes in Recruitment Curve, SICI, LICI, CSP.
No effect for premotor cortex stimulation.
### Transcranial Direct Current Stimulation (tDCS)
- **Current**: Constant/Direct
- **Stimulation parameters**: Anode: excitatory, Cathode: inhibitory
- **Mechanism**: Membrane polarization
- **Effect on**: Cortical excitability
- **Neuronal effect**: During and After

### Transcranial Random Noise Stimulation (tRNS)
- **Current**: Oscillatory/Alternating
- **Stimulation parameters**: 1-640 Hz (random), 100-640 Hz: excitatory
- **Mechanism**: Stochastic resonance
- **Effect on**: Cortical excitability
- **Neuronal effect**: During and after

### Transcranial Alternating Current Stimulation (tACS)
- **Current**: Oscillatory/Alternating
- **Stimulation parameters**: Frequency (Hz), Phase (Degrees), Entrainment
- **Mechanism**: - Brain oscillations (power, phase), - Cortical excitability (>100Hz)
- **Effect on**: Cortical excitability
- **Neuronal effect**: During and After
• tRNS on **Bilateral Dorsolateral Prefrontal Cortex** (DLPFC), a key region in **Arithmetic**.

• **5 Days of training** (Calculation and Memory-recall-based arithmetic training) + tRNS/Sham

• Near Infrared Spectroscopy (NIRS) recording during training

Calculation learning rates increase during tRNS, **Lasted for 6 months**

**tRNS effect correlates with changes in the hemodynamic response**
• 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..?

A

NUMEROSITY TASK

B

NEAR TRANSFER TASK: TIME

C

NEAR TRANSFER TASK: SPACE

CONTROL TASKS
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.

• 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.

Can be a matter of Dose (tCS alone requires longer stimulation time) and precision in terms of regions being targeted.
N=58

**tACS=1.0 mA, tRNS=1.0 mA**

**Trait Dependency of tCS effects: Fluid Intelligence**

Santarnecchi et al., in revision

**Experiment 1**

- N=58
- tACS=1.0 mA
- tRNS=1.0 mA

**Experiment 2**

- Compared tACS and tRNS effect in both fluid intelligence and Working memory tasks.

- Confirmed previous finding
• Effect of tES reflect **individual differences** → “Phenotype”, related to pre-existing oscillatory patterns (higher/lower gamma?)

• Important for the **personalization of tES protocol** and for the **ethical evaluation** of cognitive enhancement interventions.

tACS=1.0 mA, tRNS=1.0 mA
Stimulation site: Precision & Networks
State-Dependency: Can tDCS alone increase intelligence?

Sellers et al. 2015

Intelligence Quotient assessment Day 1 → tDCS (20′) → Intelligence Quotient assessment Day 2

PLEASE DO NOT COPY
tDCS decreases gain in IQ?

Effect on Intelligence Quotient

Effect on specific indexes of cognitive performance

Modeling of electric fields
Cognitive networks

Fluid Intelligence
(20 functional units)

Verbal and Visuospatial Fluid Intelligence

Processing stages
- Rule Inference
- Rule Application
fMRI-based Multifocal?

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

Targets for Fronto-parietal desynchronization

PLEASE DO NOT COPY
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 just “shake/buzz” the brain....
Controversy about efficacy

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.

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
Thank you

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