Neuromodulation Technology for Neuroergonomics

Marom Bikson
Department of Biomedical Engineering
City College of New York

Lucas Parra, Jacek Dmochowski, Devin Adair, Yu Huang, Mohamad Rad, Nigel Gebodh, Asif Radman, Thomas Radman, Niranjan Khadka, Dennis Truong, Helen Borges, Gozde Unal, Zeinab Esmaeilpour, Henry Bernstein, Bashar Badran, Alfred Yu, Bhaskar Paneri
Disclosure:

(Patents) The City University of New York on brain stimulation. Boston Scientific on electrical stimulation. (Equity) Soterix Medical Inc. produces tDCS and High-Definition tDCS. (Scientific Advisory Board) Boston Scientific Inc. produces neuromodulation products.

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Neuromodulation in Neuroergenomics
Neuroergonomics

“The study of the human brain in relation to performance at work and in everyday settings.”

“How to design technologies to be more compatible with human capabilities and limitations.”

Neuromodulation in Neuroergonomics

Application of energy to the nervous system to study or enhance performance at work and in everyday settings.

Design of neuromodulation technology for work or in everyday settings.
Neuromodulation in Neuroergonomics

Neuromodulation Device

Person

Device (instrument)

Performance
What is tDCS: transcranial Direct Current Stimulation

Cathode (-) Electrode

Anode (+) Electrode

2 mA
20 minute session

“Anodal” / “Cathodal” refer to proximity of target
Why tDCS for Neuroergonomics? tDCS is ergonomic.

1) Battery power, deployable, wearable (self-application)

2) Non-invasive, tolerated and mild. Suitable for healthy subjects and not distracting.

3) Possible to integrate sensors. Real time adjustments.
Enhancing vigilance in operators with prefrontal cortex transcranial direct current stimulation (tDCS).

Nelson JT¹, McKinley RA, Golob EJ, Warm JS, Parasuraman R.

Abstract
Sustained attention, often referred to as vigilance in humans, is the ability to maintain goal-directed behavior for extended periods of time and respond to intermittent targets in the environment. With greater time-on-task the ability to detect targets decreases and reaction time increases—a phenomenon termed the vigilance decrement. The purpose of this study was to examine the role of dorsolateral prefrontal cortex in the vigilance decrement. Subjects (n=19) received prefrontal transcranial direct current stimulation (tDCS) at one of two different time points during a vigilance task (early or late). The impact of tDCS was examined using measures of behavior, hemispheric blood flow velocity, and regional blood oxygenation relative to sham stimulation. In the sham condition greater time-on-task was accompanied by fewer target detections and slower reaction times, indicating a vigilance decrement, and decreased blood flow velocity. tDCS significantly altered baseline task-induced physiologic and behavioral changes, dependent on the time of stimulation administration and electrode configuration (determining polarity of stimulation). Compared to the sham condition, with more time-on-task blood flow velocity decreased less and cerebral oxygenation increased more in the tDCS condition. Behavioral measures showed a significant improvement in target detection performance with tDCS compared to the sham stimulation. Signal detection analysis revealed a significant change in operator discriminability and response bias with increased time-on-task, as well as interactions between time of stimulation administration and electrode configuration. Current density modeling of tDCS showed high densities in the medial prefrontal cortex and anterior cingulate cortex. These findings confirm that cerebral hemodynamic measures provide an index of resource utilization and point to the central role of the frontal cortex in vigilance. Further, they suggest that modulation of the frontal cortices—and connected structures—influences the availability of vigilance resources. These findings indicate that tDCS may be well-suited to mitigate performance degradation in work settings requiring sustained attention or as a possible treatment for neurological or psychiatric disorders involving sustained attention.
Using noninvasive brain stimulation to accelerate learning and enhance human performance.

Parasuraman R, McKinley RA.

Abstract

OBJECTIVE: The authors evaluate the effectiveness of noninvasive brain stimulation, in particular, transcranial direct current stimulation (tDCS), for accelerating learning and enhancing human performance on complex tasks.

BACKGROUND: Developing expertise in complex tasks typically requires extended training and practice. Neuroergonomics research has suggested new methods that can accelerate learning and boost human performance. TDCS is one such method. It involves the application of a weak DC current to the scalp and has the potential to modulate brain networks underlying the performance of a perceptual, cognitive, or motor task.

METHOD: Examples of tDCS studies of declarative and procedural learning are discussed. This mini-review focuses on studies employing complex simulations representative of surveillance and security operations, intelligence analysis, and procedural learning in complex monitoring.

RESULTS: The evidence supports the view that tDCS can accelerate learning and enhance performance in a range of complex cognitive tasks. Initial findings also suggest that such benefits can be retained over time, but additional research is needed on training schedules and transfer of training.

CONCLUSION: Noninvasive brain stimulation can accelerate skill acquisition in complex tasks and may provide an alternative or addition to other training methods.

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Neuroenhancement: enhancing brain and mind in health and in disease.

Clark VP¹, Parasuraman R.

Abstract
Humans have long used cognitive enhancement methods to expand the proficiency and range of the various mental activities that they engage in, including writing to store and retrieve information, and computers that allow them to perform myriad activities that are now commonplace in the internet age. Neuroenhancement describes the use of neuroscience-based techniques for enhancing cognitive function by acting directly on the human brain and nervous system, altering its properties to increase performance. Cognitive neuroscience has now reached the point where it may begin to put theory derived from years of experimentation into practice. This special issue includes 16 articles that employ or examine a variety of neuroenhancement methods currently being developed to increase cognition in healthy people and in patients with neurological or psychiatric illness. This includes transcranial electromagnetic stimulation methods, such as transcranial direct current stimulation (tDCS) and transcranial magnetic stimulation (TMS), along with deep brain stimulation, neurofeedback, behavioral training techniques, and these and other techniques in conjunction with neuroimaging. These methods can be used to improve attention, perception, memory and other forms of cognition in healthy individuals, leading to better performance in many aspects of everyday life. They may also reduce the cost, duration and overall impact of brain and mental illness in patients with neurological and psychiatric illness. Potential disadvantages of these techniques are also discussed. Given that the benefits of neuroenhancement outweigh the potential costs, these methods could potentially reduce suffering and improve quality of life for everyone, while further increasing our knowledge about the mechanisms of human cognition.
>1000 tDCS trials since 2005

Very abbreviated list of applications:

**Medical**: Depression, Pain, Migraine, Parkinson's, Alzheimer’s, Epilepsy, PTSD, Schizophrenia, Tinnitus, Neglect, Rehabilitation (motor, aphasia), TBI, OCD, MS...

**Performance/Behaviour**: Attention / Vigilance, Accelerated learning (reading, motor skills, math, threat detection), Memory, Creativity, Sleep, Lucid dreaming, Threat detection, Impulsivity, Compassion, Jealousy, IQ, Prejudice...

**How can a 9V battery enhance targeted performance at work and in everyday settings?**
tDCS polarity helps explain how can a 9V battery enhance targeted performance at work and in everyday settings.
Anode

Cathode

Scalp

Cortex

+ 

-
"Cathodal" tDCS
Soma hyper-polarized
Apical dendrite depolarized

"Anodal" tDCS
Soma depolarized
Apical dendrite hyper-polarized

Anode / Cathode positioned on the scalp to polarize target brain regions
tDCS (big electrodes)  
Example: M1-SO tDCS montage

HD-tDCS (small electrodes)  
Example: 4x1 HD-tDCS montage


- **tDCS (big electrodes)**
  - Example: M1-SO tDCS montage

- **HD-tDCS (small electrodes)**
  - Example: 4x1 HD-tDCS montage

Experimentally-verified Anatomical MRI derived models of current flow
tDCS (big electrodes)

Experimentally-verified Anatomical MRI derived models of current flow

Example: M1-SO tDCS montage

HD-tDCS (small electrodes)

Non-invasive Targeted

Example: 4x1 HD-tDCS montage

Different (HD) tDCS electrode montages may be as functionally distinct as different drugs.
Different anatomy → Different brain current flow for same tDCS dose.

Several fold variations across healthy adults, Amplified for neurodegenerative disorders, brain injury, extremes of age.

With MRI based models: Possibility to control brain current flow by adjusting tDCS dose per subject.
Realistic vOlmetric-Approach-based Simulator for Transcranial electrical stimulation

From MRI to Brain Currents: Free, Open Source, Validated.

Huang et al. ROAST -- a fully automated open-source pipeline, bioRxiv 217331, Nov 10, 2017
Neuromodulation in Neuroergonomics
Neuromodulation in Neuroergonomics

Current flow model → Neuromodulation Device → Person → Device (instrument) → Performance

Anatomical Imaging → Anatomical Targeting
That tDCS is “low intensity” is not news. And is a mechanistic virtue.
Network of interest (e.g. attention, creativity, trained task)

Other networks – not targets for neuromodulation

Current flow across entire region

Preferential modulation of selected active neurons

Synaptic efficacy is modulated by Direct Current (pathway + polarity specific)

Evoked Response + Cathodal or Anodal Direct Current Stimulation

Synaptic efficacy is modulated by Direct Current (pathway + polarity specific)

- Direct Current stimulation does not generate synaptic activity or neuronal firing (Functional Targeting)

Theta Burst Stimulation (TBS) generates LTP which is modulated by concurrent Direct Current Stimulation (DCS)

LTP from theta burst stim + Cathodal or Anodal Direct Current Stimulation

Theta Burst Stimulation (TBS) generates LTP which is modulated by concurrent Direct Current Stimulation (DCS)

- DCS does generate synaptic plasticity de novo (Functional Targeting)

Repeated DCS accelerates LTP and boosts the ceiling for synaptic learning

- Hypothesis: Combing Direct Current stimulation with ongoing training of a task may enhance the rate and ceiling learning specifically of that task (Functional Targeting)

tDCS: Optimize both Anatomical + Functional Targeting
Neuromodulation in Neuroergonomics

Current flow model
Anatomical Imaging

Neuromodulation Device

Brain State
Person

Task
Device (instrument)

Performance

Anatomical Targeting  Functional Targeting
Wearable stimulation and sensors

Functional Near Infrared Spectroscopy (fNIRS) + HD-tDCS

EEG + HD-tDCS
Any EEG can be automatically “inverted” to an optimal HD-tDCS montage

- Decades old hypothesis of reciprocity, but based on head model
- Activity guided targeting, but does not require source localization (!)

Dmochowski, et al. Optimal use of EEG recordings to target active brain areas with tES BioRxIv 2016
Neuromodulation in Neuroergonomics

Current flow model

Anatomical Imaging

Neuromodulation Device

Brain State

Person

Task

Device (instrument)

Performance

Anatomical (Imaging) Targeting - Functional Targeting
Neuromodulation in Neuroergonomics

Anatomical (Imaging) Targeting - Functional Imaging Targeting - Functional Targeting
Largest meeting spanning human performance, neuromodulation and digital healthcare.
Dynamic format from basic science, to clinical trials, to technology. Hand-on Courses and Workshops.
and…. **new classes of stimulation technology focused on deployment and performance**

- Disposable
- Principles of ‘reasonable’ integrated sensing
- Personalized / Optimized with closed-loop
- Based in principled target engagement