Cognitive enhancement using tDCS

Anna-Katharine Brem, PhD, MASNP
Department of Experimental Psychology, University of Oxford
Berenson-Allen Center for Noninvasive Brain Stimulation, BIDMC
tDCS Course June 2014

Does tDCS enhance cognition?

Why combine tDCS with other treatments?

What do we need to think about when using tDCS?

Costs/Benefits and Ethics

For which applications is tDCS mostly being tested for?

- Enhancement of motor and cognitive functions…
  - …in healthy subjects (mostly young)
  - …in patients (neurological and psychiatric populations)

- Cognitive functions that are investigated:
  - Language, memory, attention and visuospatial neglect,
    executive functions, social cognition
**Young healthy subjects**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attention</strong></td>
<td>Bolognini et al., 2010; Weiss &amp; Lavinder, 2012</td>
</tr>
<tr>
<td><strong>Working memory</strong></td>
<td>Fregr et al., 2005; Chiu et al., 2009; Z威等活动, 2011; Too et al., 2011; Muqiay尼 et al., 2011; Berryhill et al., 2010; Feracci et al., 2008; Andrew et al., 2011; Jeon &amp; Han, 2012; Mijóes et al., 2012; Sandro et al., 2012; Merton et al, 2012; Jeon &amp; Han, 2012; Boehring et al., 2013; Merton &amp; Lavinder, 2013; Roy et al., 2013</td>
</tr>
<tr>
<td><strong>Language</strong></td>
<td>Iyer et al., 2009; Fertonani et al., 2010; De Vries et al., 2010; Lazzet al, 2010; Cattaneo et al., 2011; Helland et al., 2011; Witt et al., 2011; Sparling et al., 2008; Frist et al., 2008; Frist et al., 2011; Ross et al., 2010</td>
</tr>
<tr>
<td><strong>Verbal learning and memory</strong></td>
<td>Frist et al., 2009; Eber et al., 2009; Hamner et al., 2011; De Vries et al., 2010; Marshall et al., 2004, 2011; Frist et al., 2011</td>
</tr>
<tr>
<td><strong>Nonverbal learning and memory</strong></td>
<td>Chi et al., 2010; Penolazzi et al., 2010; Clark et al., 2012; Bullard et al., 2013</td>
</tr>
<tr>
<td><strong>Complex cognitive processes</strong></td>
<td>Problem-solving (Carrutti &amp; Solhaug, 2009; Chiu et al., 2011; Dockery et al., 2009), risk-taking (Feisteau et al., 2007a,b), social behavior (Knoch et al., 2006), mathematical abilities (Buomar et al., Cohen Kadosh, 2013; Snowball et al., 2013)</td>
</tr>
</tbody>
</table>

**Elderly healthy subjects**

(...and some differential results as compared to young healthy subjects)

- Verbal memory (Ross et al., 2011)
- Non-verbal learning and memory (Frist et al., 2012)
- Working memory (Berryhill & Jones, 2012)
- Working memory (and more) (Park et al., 2014)
- Decision-making (Boggio et al., 2010)
- Error awareness (Jenney et al., 2014)

**N-back task**

Assessment of working memory

“Temporary, active maintenance and manipulation of information necessary for complex tasks, while ignoring irrelevant information. It involves the manipulation of external (experienced) or internal (retrieved) stimuli.”

**Example 1**

Verbal memory (Ross et al., 2010 and 2011)
- Anterior temporal lobe (ATL) important for name retrieval
- Anode over left or right ATL (T3/T4) or sham, reference on cheek (15 min, 1.5 mA, online)
- Task: look at pictures of famous faces or landmarks and verbally recall the associated proper name

**Results**
- Young: Anode over right ATL significantly improved naming for faces
- Old: Anode over left ATL significantly improved naming for faces

**Explanation:** Hemispheric asymmetry reduction in older adults (HAROLD) model (Cabeza, 2002)

Changes reflect compensatory processes due to inefficient recruitment of specialized, unilateral networks.
Non-verbal learning and memory (Floel et al., 2012)

- Another common complaint in the elderly: inability to remember location of objects
- Learn correct position of buildings on street map (associative learning paradigm)
- Anode over right temporoparietal cortex or sham, reference supraorbital area (20 min, 1 mA, online)

- 20 subjects (mean age 62 y)

Outcome measures
- Immediate free recall and delayed free recall (1 week later)

Results
- Learning was comparable immediately after, but recall was improved 1 week after anodal stimulation

Example 2

Working memory (Berryhill & Jones, 2012)

- When older adults perform WM tasks they show greater bilateral frontal activity than younger adults
- Anode over left or right DLPFC, or sham, reference cheek (10 min, 1.5 mA, offline)
- 25 subjects (mean age 64 y): High vs. low education
- Visual and verbal 2-back WM task

Results
- High education: profited regardless of stimulation site or type of task
- Low education: worsened
- Supports HAROLD (only for highly educated?)

Explanation
- Different strategy enables better recruitment of DLPFC
- Or...different margins (cognitive reserves?)

Example 3

Decision-making (Boggio et al., 2010; Fecteau et al., 2007)

- Decision-making abilities decline with advancing age and risk-taking increases
- Bifrontal stimulation (DLPFC) or sham (10 min, 2 mA, online)
- Gambling task (Rogers et al., 1999)

Results
- Young: Anode over right DLPFC decreases risk behavior
- Old: Anode over left or right DLPFC increases risk behavior
- Supports HAROLD

Example 4

Does tDCS truly enhance cognition? Or is it simply......

...shifting processing power (not increasing)?
...reducing interference?
...increasing speed/ flexibility?

Enhancement could be achieved:
1) Directly, through stimulating areas relevant to the target function
2) Indirectly, via supportive and competitive areas
3) Indirectly, via reduction of interference
4) Through increasing speed/ flexibility (i.e., change of functional activity patterns, switching between brain states)
5) Through exploiting the margin (i.e., cognitive reserve)
Why combine tDCS with other treatments?

- Cognitive training requires repeated sessions but benefits are limited
- (Re-)learning of specific functions strengthens task-specific pathways
- Mechanisms underlying tDCS are similar to those involved in learning and are thought to promote LTP- and LTD-like plasticity. Stimulation “prepares the way”
- Interaction of stimulation (external, passive) and therapy (internal, active) may be complementary
- But beware: State- and task-dependency, neurophysiologic overload
- Timing: before, during, after training

 hodCS has a modulatory impact and may therefore enhance the effects of cognitive training if applied concomitantly

What do we need to think about when using tDCS?

- Behavior Δ
- Structural Factor
- Modulation Factor
- State-Dependent Behavior Δ
- Physiologic (state-dependent) Factor

External and internal priming

Breit et al., 2014
Costs/Benefits and Ethics

Does enhancement come with a cost?

- Level
- Amount
- Duration
- Reversibility

Macro
- Individual, Society (ethical, financial, environmental)
- System, Behavior (strategy, flexibility, attention)

Micro
- Circuit, Network (mutual competition, top-down bias)
- Neuron, Synapse (neural efficiency, consolidation)
- Potential Cost or Benefit

Brem et al., 2014

Learning and automaticity in mathematical cognition (Iuculanu & Cohen Kadosh, 2013)
- Posterior parietal cortex (PPC) important for numerical understanding
- Dorsolateral prefrontal cortex (DLPFC) important for automaticity and learning
- 19 participants (aged 20-31)
- Bilateral stimulation with anode left cathode right PPC, anode right cathode left DLPFC, sham (20 min, 1 mA, online)
- 6-day cognitive training: learn the magnitude of arbitrary symbols

Results: Double dissociation
- Stimulation over PPC improved numerical learning, BUT automaticity declined
- Stimulation over DLPFC improved automaticity, BUT numerical learning declined

Brem et al., 2014

Ethical considerations are specifically important when using tDCS.

We should not only think about benefits but...
Conclusions

- tDCS shows beneficial effects alone or in combination with therapy
- Enhancement could be achieved through direct and indirect effects
- Enhancement processes are different in young vs. old subjects
- Various factors within local and distributed networks need to be considered when using tDCS
- Costs and benefits are expressed on various levels
  - We must control for negative effects
- Ethical considerations: What is right, what is wrong?
  - Cost/benefit ratio is different in healthy vs. patients
  - We need knowledge about long-lasting changes