Translational value of TMS studies in healthy subjects into clinical populations

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Transcranial Magnetic Stimulation (TMS) and transcranial Electric Current Stimulation (tES) over the dorsolateral prefrontal cortex (DLPFC) can modulate behaviors in healthy subjects.

Impair (virtual lesion)  Improve (neuroenhancement)

Can this be a concern for my patients?  Can this be relevant for my patients?
Plan

1. Noninvasive brain stimulation (NIBS) can modulate human behaviours (e.g., decision-making) in healthy subjects.

2. Translational clinical relevance of this: proof-of-concept evidence supporting that NIBS might be a valuable adjunct in the treatment of substance use disorders.

3. NIBS can modulate other human behaviours (e.g., motor learning, language): potential translational clinical relevance?
TMS and tES over the DLPFC can modulate a vast variety of behaviours in healthy subjects:

- **Attention**
  Mevorach et al. 2010 *J Neurosci*

- **Impulsivity**
  Beeli et al. 2008a, b *Behav Brain Funct*
  Cho et al., 2010 *Brain Stimul*

- **Risk-taking**
  Knoch et al. 2006 *J Neurosci, Science*
  Fecteau et al. 2007a *J Neurosci*

- **Self-control**
  Knoch et al. 2009 *PNAS*
  Figner et al. 2010 *Nat Neurosci*
  Hsu et al. 2011 *Neuroimage*

- **Planning**
  Dockery et al. 2009 *J Cogn Neurosci*

- **Reward seeking**
  Fecteau et al. 2007b *J Neurosci*

- **Emotional processing**
  D’ Alfonso et al. 2000 *Neurosci Lett*
  Harmer et al. 2001 *Nat Neurosci*
  van Honk et al. 2002 *Biol Psychiatry*
  van Rijn et al. 2005 *Eur J Neurosci*

They are all involved in decision-making skills.
Decision-making appears to rely upon a distributed bi-hemispheric network including the DLPFC, the orbitofrontal cortex, the anterior cingulated cortex, and the insula.

One role of the DLPFC is to integrate cognitive and emotionally relevant information during decision-making.

Damasio et al. 1996; Bechara 2005; Ernst & Paulus 2005; Sanfey et al. 2003; Evans 2008
Examples of how TMS or tES when applied over the DLPFC can modulate decision-making processes in healthy subjects.
1 Hz rTMS over the right (R) DLPFC can increase risk taking at the Risk Task in healthy subjects.

Knoch, Gianotti, Pascual-Leone, Treyer, Regard, Hohmann, Brugger (2006) *Journal of Neuroscience*
Can we decrease risk taking at the Risk Task in healthy subjects?

1Hz rTMS over the R DLPFC

increased risk-taking

anodal tDCS over the R DLPFC

decrease risk-taking?
tDCS (anodal over the R DLPFC coupled with cathodal over the left (L) DLPFC) can decrease risk taking and reward seeking at the Risk Task in healthy subjects.

Fecteau, Knoch, Fregni, Sultani, Boggio, Pascual-Leone (2007a) *Journal of Neuroscience*
tDCS over the DLPFC can decrease risk taking at the BART task in healthy subjects.

Fecteau, Pascual-Leone, Zald, Liguori, Theoret, Boggio, Fregni (2007b) Journal of Neuroscience
cTBS over the R DLPFC can suppress impulsivity at the Delayed Discounting Task in healthy subjects.
tACS targeting prefrontal theta activity can suppress impulsivity at the Delayed Discounting Task and augment theta oscillatory activity in healthy subjects.

Would you prefer to receive:
- $20 now
- $26 tomorrow

Mean theta power for electrode locations

Dickler, Wensing, Joyal, Thiffault, Timofeev, Fecteau (SOBP meeting, 2015; submitted article)
1 Hz rTMS over the R DLPFC can modulate self-interest at the Ultimatum Game in healthy subjects.

The Ultimatum Game

The proposer has $10 and offers you $2

If you accept:
The proposer gets $8 and you get $2

If you reject:
The proposer gets $0 and you get $0

1 Hz rTMS over the R DLPFC

Accepted more often unfair offers

Elicited activity in both DLPFCs when contrasting unfair > fair offers

Knoch et al. (2006) Science

Baumgartner et al. (2011) Nature Neuroscience
Why is this relevant for patients?
Rational of using NIBS in substance use disorders to reduce craving and consumption.

- Risky decision-making: a characteristic behavioural phenotype of substance use disorders.

- Craving: powerful driving force balancing decisions toward maladaptive choices.

- Craving levels positively correlate with activations in the DLPFC.

Epstein, Bang, Botvin (2007) *Addictive Behaviors*
Patients with substance use disorders take greater risk at the Risk Task.

Patients with tobacco use disorders take greater risk at the BART.
Patients with tobacco use disorders are more impulsive at the Delayed Discounting Task.

Would you prefer to receive:

- $20 now
- $26 tomorrow

Smokers choose more often the smaller, immediate offer of money.

Mitchell & Wilson (2012) *Psychopharmacology*
Patients with tobacco use disorders display greater self-interest at the Ultimatum Game when the reward is *relevant*.

Smokers (and nonsmokers) reject most of the time unfair offers of money.

Smokers accept most of the time unfair offers of cigarette.

*Takahashi (2007) NeuroEndocrinology Letters*
NIBS over the DLPFC of healthy subjects can modulate decision-making behaviours.

Impaired decision making processes seem to be linked to increased vulnerability for substance use disorders (behavioural phenotype).

What happens when we apply NIBS over the DLPFC of individuals with substance use disorders?
Proof-of concept data supporting that tDCS can reduce craving for:

- Nicotine
- Alcohol
- Food
- Marijuana
- Psychostimulant

<table>
<thead>
<tr>
<th>Study name</th>
<th>Technique</th>
<th>Stimulation site</th>
<th>Single or combined study</th>
<th>Number of sessions</th>
<th>Number of subjects</th>
<th>Hedge's g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amiaz et al. (2009)</td>
<td>rTMS</td>
<td>Left</td>
<td>Single Study</td>
<td>10</td>
<td>21</td>
<td>0.888</td>
</tr>
<tr>
<td>Barth et al. (2011)</td>
<td>rTMS</td>
<td>Left</td>
<td>Single Study</td>
<td>2</td>
<td>10</td>
<td>-0.104</td>
</tr>
<tr>
<td>Boggio et al. (2008)</td>
<td>dDCS</td>
<td>Both</td>
<td>Combined</td>
<td>2</td>
<td>26</td>
<td>0.98</td>
</tr>
<tr>
<td>Boggio et al. (2009)</td>
<td>dDCS</td>
<td>Left</td>
<td>Single Study</td>
<td>5</td>
<td>27</td>
<td>0.824</td>
</tr>
<tr>
<td>Boggio et al. (2010)</td>
<td>dDCS</td>
<td>Both</td>
<td>Combined</td>
<td>1</td>
<td>33</td>
<td>0.341</td>
</tr>
<tr>
<td>Claudino et al. (2011)</td>
<td>rTMS</td>
<td>Left</td>
<td>Single Study</td>
<td>1</td>
<td>22</td>
<td>0.391</td>
</tr>
<tr>
<td>Fregni et al. (2008a) (food)</td>
<td>dDCS</td>
<td>Both</td>
<td>Combined</td>
<td>2</td>
<td>46</td>
<td>0.458</td>
</tr>
<tr>
<td>Fregni et al. (2008b) (smoking)</td>
<td>dDCS</td>
<td>Both</td>
<td>Combined</td>
<td>2</td>
<td>48</td>
<td>0.427</td>
</tr>
<tr>
<td>Goldman et al. (2011)</td>
<td>dDCS</td>
<td>Right</td>
<td>Single Study</td>
<td>2</td>
<td>19</td>
<td>0.08</td>
</tr>
<tr>
<td>Herremans et al. (2011)</td>
<td>rTMS</td>
<td>Right</td>
<td>Single Study</td>
<td>1</td>
<td>31</td>
<td>0.069</td>
</tr>
<tr>
<td>Hoppner et al. (2011)</td>
<td>rTMS</td>
<td>Left</td>
<td>Single Study</td>
<td>10</td>
<td>19</td>
<td>0.703</td>
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<tr>
<td>Johann et al. (2003)</td>
<td>rTMS</td>
<td>Left</td>
<td>Single Study</td>
<td>2</td>
<td>11</td>
<td>0.095</td>
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<tr>
<td>Mishra et al. (2010)</td>
<td>rTMS</td>
<td>Right</td>
<td>Single Study</td>
<td>10</td>
<td>45</td>
<td>1.165</td>
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<tr>
<td>Montenegro et al. (2012)</td>
<td>dDCS</td>
<td>Left</td>
<td>Single Study</td>
<td>2</td>
<td>9</td>
<td>0.694</td>
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<tr>
<td>Nakamura-Palacios et al. (2011)</td>
<td>dDCS</td>
<td>Left</td>
<td>Single Study</td>
<td>2</td>
<td>32</td>
<td>0.031</td>
</tr>
<tr>
<td>Uber et al. (2005)</td>
<td>rTMS</td>
<td>Left</td>
<td>Single Study</td>
<td>1</td>
<td>28</td>
<td>0.809</td>
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<tr>
<td>Wing et al. (2012)</td>
<td>rTMS</td>
<td>Bilateral</td>
<td>Single Study</td>
<td>50</td>
<td>13</td>
<td>0.476</td>
</tr>
</tbody>
</table>

Jansen, Daams, Koeter, Veltman, van den Brink, Goudriaan (2013) *Neuroscience and Biobehavioral Reviews*
<table>
<thead>
<tr>
<th>NIBS in patients with tobacco use disorders.</th>
<th>Craving</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 x 20Hz L DLPFC (Johann et al. 2003)</td>
<td></td>
<td></td>
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<tr>
<td>1 x 20Hz L DLPFC (Eichhammer et al. 2003)</td>
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<tr>
<td>10 x 10Hz L DLPFC (Amiaz et al. 2009)</td>
<td></td>
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<tr>
<td>1 x 1Hz L SFG (Rose et al. 2011)</td>
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<tr>
<td>1 x 10Hz SFG (Rose et al. 2011)</td>
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<tr>
<td>1 x 10Hz L DLPFC (Li et al. 2013)</td>
<td></td>
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<tr>
<td>1 x 10Hz L DLPFC (Pripfl et al. 2013)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 x 1Hz L DLPFC (Hayashi et al. 2013)</td>
<td>=</td>
<td></td>
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<tr>
<td>13 x HF lateral PFC (Dinur-Klein et al. 2014)</td>
<td></td>
<td></td>
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<tr>
<td>10 x 1Hz R DLPFC (Trojak et al. 2015)</td>
<td>=</td>
<td></td>
</tr>
<tr>
<td>1 x 2mA R/L DLPFC (Fregni et al. 2008)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 x 2mA R/L DLPFC (Boggio et al. 2009)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 x 2mA R/L DLPFC (Fecteau et al. 2014)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 x 2mA L DLPFC/ R supraorbital area (Xu et al. 2013)</td>
<td>=</td>
<td></td>
</tr>
<tr>
<td>1 x 1mA occipital / FPT (Meng et al. 2014)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 x 1mA L DLPFC/ R supraorbital area (Faclone et al. 2015)</td>
<td></td>
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</tbody>
</table>
tDCS over the DLPFC suppressed craving in nicotine smokers.

This was a 3-arm, crossover, sham controlled, blind at 3 levels (subjects, tDCS provider, outcome assessors) study with smokers who do not wish to quit smoking receiving 3 single tDCS sessions.

tDCS over the DLPFC decreased the reported number of cigarettes smoked.

This was a parallel, sham controlled, blind at three levels (subjects, tDCS provider, outcome assessors) study with nicotine smokers who do not wish to quit smoking receiving a 5-day tDCS regimen (anodal over the L DLPFC coupled with cathodal over the R DLPFC).

1Hz rTMS over the L DLPFC suppressed craving and impulsivity in nicotine smokers.

Hayashi, Ko, Strafella, Dagher (2013) PNAS
tDCS over the DLPFC decreased the number of cigarettes smoked and reward seeking for cigarettes in adults with tobacco use disorders.

This was a 2-arm, crossover, sham controlled, blind at 3 levels (subjects, tDCS provider, outcome assessors) study with smokers receiving two 5-day tDCS regimens (real, sham).

N of reported cigarettes smoked

Real tDCS (anode and cathode over the right and left DLFPC)

Sham tDCS (anode and cathode over the right and left DLFPC)

rTMS over the left lateral prefrontal cortex reduced cigarette consumption and nicotine dependence in adults with tobacco use disorders.

This was a sham controlled and blind study with smokers who previously failed smoking cessation treatments receiving 13 rTMS sessions (10Hz, 1Hz, and sham; H coil).

- Reduction of self reported number of cigarettes smoked with 10Hz rTMS compared to 1Hz rTMS and sham rTMS. This was also observed at the 6-month follow-up visit.

- Reduction of urinary cotinine level with 10Hz rTMS compared to 1Hz rTMS and sham rTMS.

- Reduced FTND scores in the 10Hz rTMS group compared to the 1Hz rTMS and sham rTMS groups.

- No significant change in craving scores.

Dinur-Klein, Dannon, Hadar, Rosenberg, Roth, Kotler, Zangen (2014) Biological Psychiatry
rTMS over the right DLPFC combined with nicotine replacement therapy in adults with tobacco use disorders.

This was a sham controlled and blind study with smokers who previously failed smoking cessation treatments receiving 10 sessions of 1Hz rTMS with nicotine replacement therapy (NRT).

**Active rTMS + NRT vs. Sham rTMS + NRT:**

- Greater number of patients maintained smoking abstinence at 2 weeks, but not at 6 or 12 weeks.

- Reduced craving scores.

Trojak, Meille, Achab, Lalanne, Poquet, Ponavoy, Blaise, Bonin, Chauvet-Gelinier (2015) *Brain Stimulation*
tDCS can decrease level of food craving and intake.

This was a 3-arm, crossover, sham controlled, blind at 3 levels (subjects, tDCS provider, outcome assessors) study with adults with abnormal food craving (3 times/day) receiving 3 single tDCS sessions.

Fregni, Orsati, Pedrosa, Fecteau, Tome, Nitsche, Mecca, Macedo, Pascual-Leone, Boggio (2008) *Appetite*
tDCS induced an attentional shift from food to non-food related items.

Fregni, Orsati, Pedrosa, Fecteau, Tome, Nitsche, Mecca, Macedo, Pascual-Leone, Boggio (2008) *Appetite*
NIBS studies indicate promising results for substance use disorders, but there are still many questions unanswered.

1. Stimulation parameters
   - Brain target;
   - rTMS LF vs HF;
   - tES anodal vs cathodal;
   - Neuronavigation.

2. Brain state
   - Initial state of craving within a cue-provoked paradigm;
   - Initial neurological functioning and state of abstinence;
   - Level of expectancy and anticipation of reward or gain.

3. Measures of craving
   - Influence of initial state of craving and abstinence;
   - Cue-reactivity;
   - Questionnaires and subjective craving scales.

4. Subjects' characteristics
   - Age and sex;
   - Level of engagement in treatment;
   - Level of dependence and co-occurrence with other SUDs or psychiatric disorders.

Hone-Blanchet, Ciraulo, Pascual-Leone, Fecteau (2015) *Neuroscience & Biobehavioral Reviews*
**Future directions**: to identify in which brain state we should stimulate.

The effects of NIBS on craving for cigarettes differ in regards to state.

<table>
<thead>
<tr>
<th>rTMS</th>
<th>Craving</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 x 20Hz L DLPFC (Amiaz et al. 2009)</td>
<td>Greater decreased when presented with <strong>smoking</strong>-related pictures.</td>
</tr>
<tr>
<td>1 x 1Hz L SFG (Rose et al. 2011)</td>
<td>when presented with <strong>smoking</strong>-related pictures.</td>
</tr>
<tr>
<td>1 x 10Hz L SFG (Rose et al. 2011)</td>
<td>when presented with <strong>neutral</strong> pictures.</td>
</tr>
</tbody>
</table>
The use of NIBS to decrease craving for psychostimulant in substance use disorders.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Parameter 1</th>
<th>Parameter 2</th>
<th>Parameter 3</th>
<th>Parameter 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>rTMS</td>
<td>1 x 10Hz R DLPFC (Camprodon et al. 2007)</td>
<td>1 x 10Hz L DLPFC (Camprodon et al. 2007)</td>
<td>10 x 15Hz L DLPFC (Politi et al. 2008)</td>
<td>1 x 1Hz L DLPFC (Li et al. 2013)</td>
</tr>
<tr>
<td>tDCS</td>
<td>1 x 2mA R DLPFC / L supraorbital area (Shahbabaie et al. 2014)</td>
<td>5 x 2mA R DLPFC / L DLPFC (Conti et al. 2014)</td>
<td></td>
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</tbody>
</table>

When assessed at rest:

- 

When assessed with a cue-induced paradigm:

- 

PLEASE DO NOT COPY
The use of NIBS to decrease craving in patients with alcohol use disorders.

<table>
<thead>
<tr>
<th>NIBS</th>
<th>Frequency</th>
<th>Side</th>
<th>Region</th>
<th>Effect on Craving</th>
</tr>
</thead>
<tbody>
<tr>
<td>rTMS</td>
<td>10 x 10Hz</td>
<td>R DLPFC</td>
<td>(Mishra et al. 2011)</td>
<td>↓</td>
</tr>
<tr>
<td></td>
<td>10 x 20Hz</td>
<td>L DLPFC</td>
<td>(Hopnner et al. 2011)</td>
<td>=</td>
</tr>
<tr>
<td></td>
<td>15 x 1Hz</td>
<td>dorsal ACC</td>
<td>(De Ridder et al. 2011)</td>
<td>↓</td>
</tr>
<tr>
<td></td>
<td>1 x 20Hz</td>
<td>R DLPFC</td>
<td>(Herremans et al. 2012)</td>
<td>=</td>
</tr>
<tr>
<td></td>
<td>1 x 10Hz</td>
<td>SFG</td>
<td>(Herremans et al. 2013)</td>
<td>=</td>
</tr>
<tr>
<td>tDCS</td>
<td>1 x 2mA</td>
<td>L/R DLPFC</td>
<td>(Boggio et al. 2008)</td>
<td>↓</td>
</tr>
<tr>
<td></td>
<td>5 x 2mA</td>
<td>L DLPFC / R suprideltolectoid area</td>
<td>(Nakamura-Palacios et al. 2012)</td>
<td>=</td>
</tr>
<tr>
<td></td>
<td>5 x 2mA</td>
<td>L DLPFC / R supraorbital area</td>
<td>(da Silva et al. 2013)</td>
<td>↓</td>
</tr>
</tbody>
</table>
Future directions: to identify in which brain state we should stimulate.

*Nicotine intake can cancel the effects of iTBS on motor function.*

↑ thumb acceleration with iTBS over the contralateral M1.

Nondominant thumb abduction

Teo et al. (2011) *Cerebral Cortex*
Conceptual neurocognitive model of the NIBS over the DLPFC

Fecteau, Camprodon, Boggio, Fregni, Pascual-Leone (2010) Substance Use & Misuse
Future directions: to identify the neural effects of NIBS applied over the DLPFC. *Online effects on prefrontal and striatal metabolites*

This was a 2-arm, crossover, sham controlled, blind at 3 levels (subjects, tDCS provider, outcome assessor) study with subjects receiving 2 single tDCS/MRS sessions.

Hone-Blanchet, Edden, Fecteau (2016) *Biological Psychiatry*
Contribution of animal models in the use of NIBS in substance use disorders
Pre-conclusion

NIBS, such as rTMS and tDCS, applied over the DLPFC:

- Can suppress symptoms in mood disorders;
  *Could NIBS carry clinical benefits for other clinical populations (e.g., substance use disorders)?*

- Can modulate cognitive functions relevant for substance use disorders;
  *Any translational value of these findings into clinical populations?*

- Might be a valuable adjunct in the treatment of substance use disorders.
  *How can we promote these beneficial effects (e.g., Should we combine NIBS with existing treatments)?*

Future studies should include patients with co-morbidities, especially those with substance use disorders, depression, anxiety and PTSD.
Other behaviors can be modulated in healthy subjects with NIBS; Is there any translational value for clinical populations?

Cognitive enhancement:
- Pharmaceutical development
- Genetic engineering
- TMS, tDCS

NIBS studies in healthy subjects support enhancement in:
- Executive functions
- Memory
- Motor learning
- Language
tDCS can improve working memory in healthy elderly subjects.

↑ accuracy in an object-location task with atDCS over the R temporoparietal cortex.

Floel et al. (2012) *Neurobiol Aging*
tDCS can modulate executive functions in healthy subjects.

↑ careful driving behaviors with atDCS over the R or L DLPFC

There was no significant difference of average speed and revolutions per minute.

Beeli et al. (2008) *Behav Brain Functions*
tDCS can improve **verbal fluency** in healthy subjects.

Better letter-cued word generation with atDCS over the L PFC.

1 mA  
2 mA

There was no difference between ctDCS and sham.

There was no effect on control tasks (psychomotor speed, mood).

Safety and cognitive effect of frontal DC brain polarization in healthy individuals
*Neurology* 2005;64;872-875
Changing social norm compliance with noninvasive brain stimulation.
Ruff CC, Ugazio G, Fehr E.

The truth about lying: inhibition of the anterior prefrontal cortex improves deceptive behavior.

Disrupting the prefrontal cortex diminishes the human ability to build a good reputation.
Knoch D, Schneider F, Schunk D, Hohmann M, Fehr E.

Disrupting the right prefrontal cortex alters moral judgment.
Tassy S, Oullier O, Duclos Y, Coulon Q, Mancini J, Deniselle C, Attarian S, Felician O, Wicker B.

Enhancing social ability by stimulating right temporoparietal junction.
Santiesteban I, Banissy MJ, Catmur C, Bird G.

The world can look better: enhancing beauty experience with brain stimulation.
How NIBS can induce enhancement?

Conceptual framework of NIBS enhancement

Three potential mechanisms:
1. Zero-sum
2. Stochastic resonance
3. Entrainment enhancement
Concept of NIBS enhancement

The **Zero-Sum** theory supposes the brain has a finite amount of processing power.

It supposes a relocation of neural resources within a given network and a behavioral detrimental tradeoff.
Concept of NIBS enhancement

**Zero-Sum theory**

Example: Speed/Accuracy tradeoff

At the neural level:

At the behavioral level:
Concept of NIBS enhancement

Zero-sum theory

What are the detrimental effects?
The **Stochastic Resonance** theory supposes that small amounts of noise injected into a system enhances low-level signals, thereby improving stimuli detection within systems.

It is a bistable system (i.e., with measurable threshold leading two states: on or off).
Concept of NIBS enhancement

Stochastic Resonance theory

Lower level of TMS enhanced processing of visual stimuli; higher level impaired it.

Lower level of TMS facilitated visual motion detection; higher level disrupted it.

Effects of transcranial magnetic stimulation on visual evoked potentials in a visual suppression task
A. Reichenbach, K. Whittingstall, A. Thielisch
Concept of NIBS enhancement

Stochastic Resonance theory

How much noise should be injected?
The **Entrainment theory** supposes that neural oscillation can be mimicked and can trick the brain into a natural state known to correlate with success in a given trait.
Concept of NIBS enhancement

The Entrainment theory suggests that NIBS can mimic slow-wave sleep patterns.

Modulating slow-wave sleep with DC seem to improve memory consolidation.
Concept of NIBS enhancement

Entrainment theory
Applying tDCS over the DLPFC during slow wave oscillations periods during sleep
↓
Prolong periods of slow wave oscillations periods
↓
Better retention

Transcranial Direct Current Stimulation during Sleep Improves Declarative Memory

Lisa Marshall, Matthias Mölle, Manfred Hallschmid, and Jan Born
Concept of NIBS enhancement

Which frequencies should be used to enhance performance?
Noninvasive brain stimulation can modulate behaviours in healthy individuals.

Take Home Message

Impair (virtual lesion)  Improve (neuroenhancement)

Can this be a concern for my patients?

Can this be relevant for my patients?

These NIBS protocols in the cognitive neuroscience field may be relevant and translated into clinical benefits.
tDCCS can decrease risk taking leading to different performance.

anodal over the R DLPFC/cathodal over the L DLPFC

\[ \downarrow \]

decreased risk-taking

\[ \downarrow \]

won more

Fecteau et al. (2007a) *J Neurosci*

anodal over the R DLPFC/cathodal over the L DLPFC

\[ \downarrow \]

decreased risk-taking

\[ \downarrow \]

won less

Fecteau et al. (2007b) *J Neurosci*
Thank you!

Questions?

sfecteau@bidmc.harvard.edu