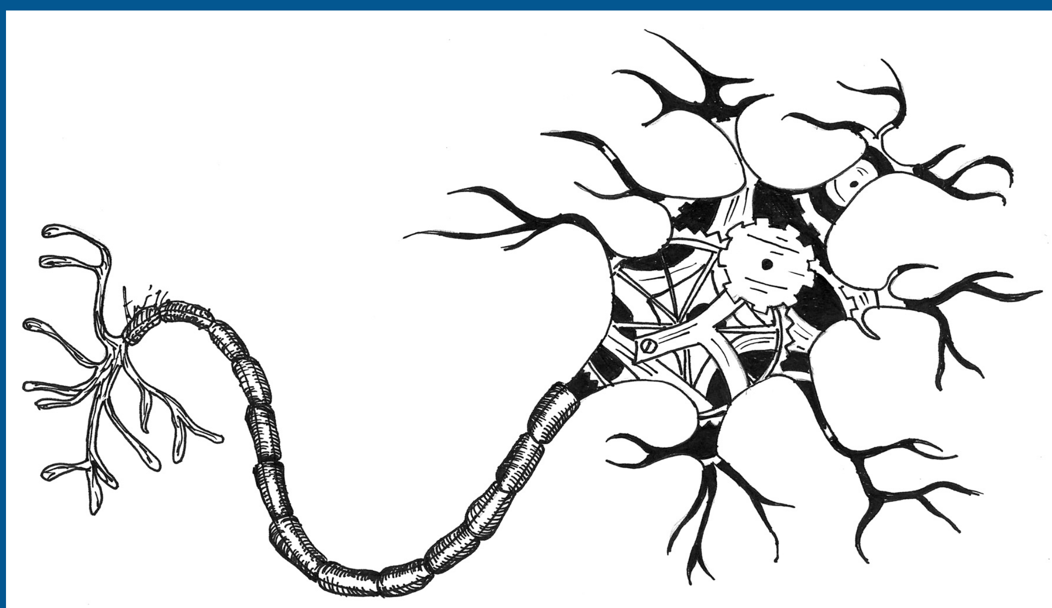
Wheaton Journal of

Neuroscience Senior Seminar Research

Issue 1, Spring 2016:

"Life 2.0: Blurring the Boundary Between our Tech and Ourselves"

R.L. Morris, Editor. Wheaton College, Norton Massachusetts.



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Transcranial direct current stimulation to enhance cognitive capabilities in healthy populations

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NEURO 400 / Neuroscience Senior Seminar
Final Research Paper
27 April 2016

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Final Research Paper written for
Wheaton Journal of Neuroscience Senior Seminar Research
Neuro 400 / Neuroscience Senior Seminar
Wheaton College, Norton Massachusetts
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Technology Background: tDCS

Transcranial direct current stimulation (tDCS) is a method of noninvasive brain stimulation that utilizes electricity to modulate neuronal excitability in the brain. The tDCS apparatus consists of the small and portable battery pack that sends a weak electrical current (0.5 – 2.5 milliamps (mA)) through wires to two electrodes which are placed onto the scalp over the desired cortical area of modulation. One electrode (the anode) is positively charged, while the second electrode (the cathode) is negatively charged. The anode causes neurons nearby to the stimulation site to depolarize and increase their excitability, while the cathode causes nearby neurons to hyperpolarize, and decreases their excitability. The charge of the electrodes dictates the direction of the electrical current between them, and the desired modulatory effects are dependent on the polarity of the stimulation (Fregni et al, 2005). tDCS is used clinically to treat numerous neurological conditions in which pharmaceutical treatments have not been effective. These include both cognitive/psychiatric and motor conditions such as major depressive disorder, bipolar disorder, schizophrenia, Alzheimer's disease, autism, and Parkinson's, (Boggio et al., 2012; Brunelin et al., 2012; Brunoni et al., 2011; D'Urso et al., 2013; Fregni et al., 2006), as well as stroke rehabilitation (Schlaug et al., 2008).

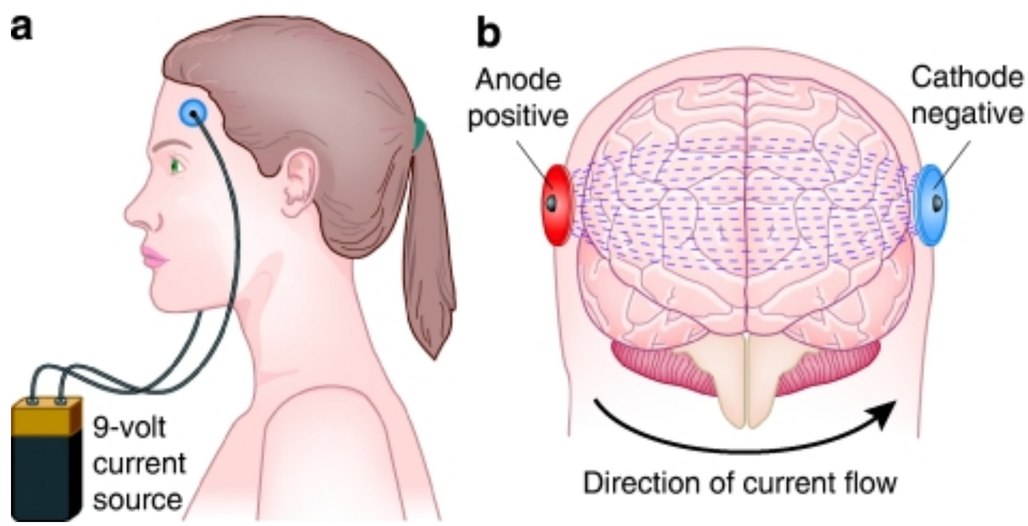

Figure 1: tDCS device and method of application. The tDCS device utilizes a 9-volt battery to send weak electrical currents between 0.5 – 2 mA through the skull and into brain tissue, modulating the excitability of neurons. The anode increases excitability in nearby neurons, while the cathode decreases it in nearby neurons. Adapted from "Noninvasive techniques for probing neurocircuitry and treating illness: vagus nerve stimulation (VNS), transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS)" by M.S. George and G. Aston-Jones, 2010, *Neuropsychopharmacology,* 35(1), p. 301-316. Copyright 2010 by the Nature Publishing Group.

Biology Background: Cognition

The term "cognition" refers to what are considered "higher executive functions," which include decision-making, planning and strategizing, logic and reasoning, associative and procedural learning, knowledge recall, working memory, judgment, certain aspects of perception, spatial awareness, attention span, reaction times, and the comprehension and production of language. These mental processes all derive from the frontal lobe, with functional neuroimaging studies noting the particular involvement of frontal lobe structures such as the dorsolateral, ventrolateral, and medial prefrontal cortex. Outside of the frontal lobe, brain areas involved in cognition lie in the temporal, parietal, and occipital lobes, as well as in the limbic system and the cerebellum (Schmahmann & Caplan, 2006).

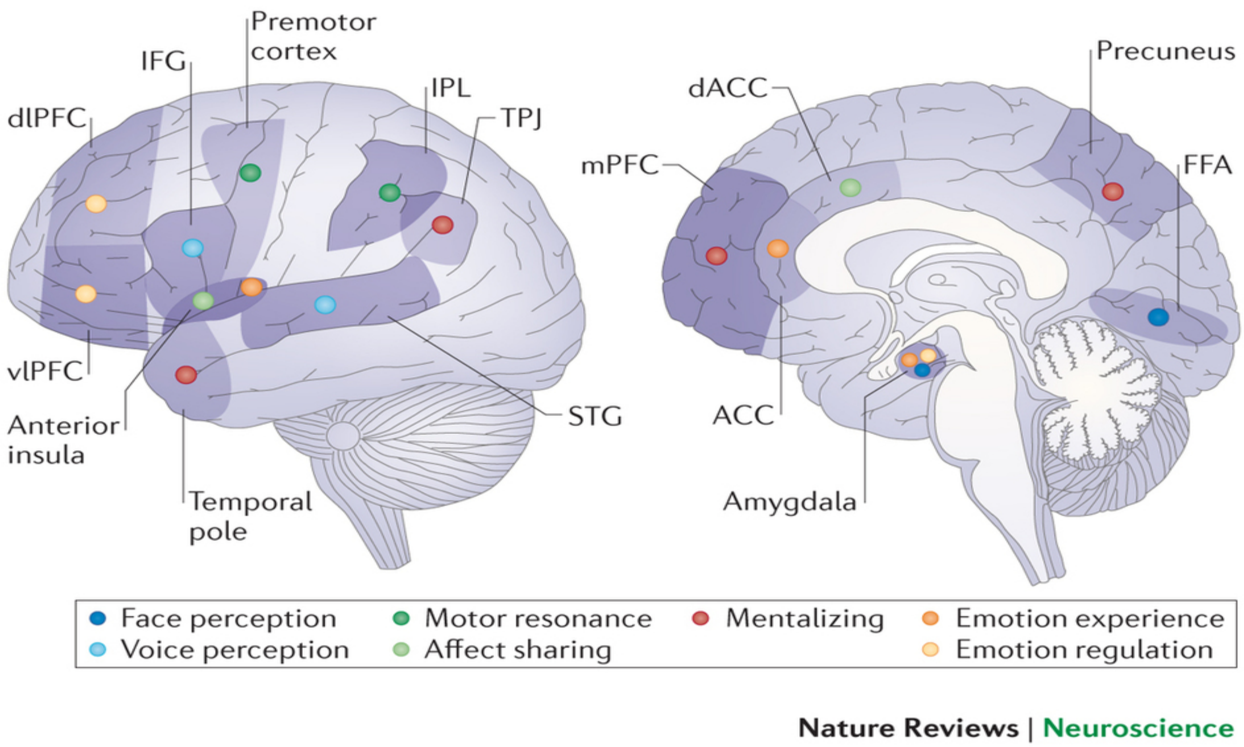

Figure 2: Areas of the brain important for cognition. Anatomical areas of the cortex involved in various aspect of cognition. Adapted from “Social Cognition in Schizophrenia” by M.F. Green, W.P. Horan, and J. Lee, 2015, *Nature Reviews Neuroscience,* 16, p. 620-631. Copyright 2015 by the Nature Publishing Group.

Hybrid System: tDCS to Enhance Cognition

Due to its effectiveness in treating cognitive deficits in populations with neurological conditions, the effects of tDCS on the healthy human brain is being increasingly studied and examined. Results from stimulation include increases in object recognition, reaction time, planning abilities, word retrieval and recall, associative learning, working memory, and problem solving skills. However, similar to when this technology is used in a medical setting, the achieved results on cognition vary depending on the location, intensity, length, and frequency of stimulation. Table 1 shows the results from a sample of seven studies, including variances in stimulation specifics.

Table 1: Prior studies of tDCS and cognition

Author	Intensity (mA)	Location	Type	Length	Result
Clark et al (2012)	2	Right inferior frontal, right parietal	Anodal	30 minutes	Increased learning to identify objects
Coffman et al (2012)	2	Right inferior frontal	Anodal	30 minutes	Increased learning to identify objects
Fiori et al (2011)	1	Wernicke's area	Anodal	20 minutes	Increased word retrieval ability
Floel et al (2008)	1	Posterior left peri-sylvian area	Anodal & cathodal (not simultaneously)	20 minutes	Anodal: faster and better associative learning Cathodal: No increase
Hoy et al (2013)	1 & 2	Left prefrontal cortex	Anodal	20 minutes	Increase in working memory (with better results at 1 mA)
Metuki et al (2012)	1	Left dorsolateral prefrontal cortex	Anodal	11 minutes	Significant increase in insight problem solving skills
Nelson et al. (2015)	2	Left frontal eye field	Anodal and cathodal (simultaneously)	30 minutes	Significantly improves object detection accuracy

Once we decide to start using tDCS on a large-scale to increase our cognitive functioning, we have created an irreversible merger. This is because although the effects of tDCS can last up to weeks after the last stimulation session, these effects are by no means permanent. This will make us dependent on the technology if we wish to remain enhanced. While this hybrid system is not physically irreversible (yet), once we wire ourselves we cannot disconnect and maintain the level of functioning that we have with the technology.

tDCS for this intended purpose has clear advantages. In allowing humans to extend their mental capabilities beyond normal levels, they could see benefits in school, careers, socialization, and behavior. If we make ourselves able to think faster, better, and more accurately, we will be able to achieve more than we ever have before in all fields. Children who struggle with certain subjects in school, have learning disabilities, or having difficulty paying attention need only to stimulate their brains and overcome their difficulties. Tasks, both in our own lives and in the workplace, will get done faster, and employees will be able to take on more responsibilities because they cognitively function at a higher rate.

While the adoption of tDCS into our everyday lives as a means to enhance our mental and intellectual abilities would result in a hybrid system of mind and machine that was intentionally created to allow humans to reach beyond their typical mental capacity, there are some downsides to this combination of biology and technology. As previously mentioned, we will become completely dependent on this technology to maintain our enhanced state. We must receive constant or daily stimulation to keep our brains enhanced. This, then, leads to another problem in that researchers do not currently know the effects of constant, long-term stimulation, and how the brain will react to constantly being wired. Another problem is that of commercial and homemade ("do it yourself/DIY") devices. Currently, you are able to go online and purchase a personal tDCS for under $300. Similarly, you can also go online and find instructions and tutorials on how to make your own device from household items such as a 9-volt battery and sponges. This issue here is that these devices are unregulated and unapproved by medical or psychological professionals. Not only do they have the potential to not work and provide the subject with no cognitive benefits, but they also have the potential to cause harm to the subject should the device be used or constructed incorrectly. Jwa (2015) conducted an in-depth investigation into the widespread use of DIY tDCS devices and noted multiple potential problems, including the regulation of intensity of duration of each stimulation session, the assessment of potential effects by users who are untrained and unknowledgeable about cognitive assessment methods, the lack of ability to control for placebo effects, and safety concerns regarding electrode placement and the potential for errors during the construction of the device.

The final problems that could arise are ones of ethics. How can we accurately measure intelligence in people if everyone is stimulating their brains? Who exhibits true intellectual talent and who acquires it from tDCS? Who will have access to this technology – will it be available to everyone or only to a privileged few, and how can we prevent certain people from having an unfair advantage over those who are not able to have the technology?

Future Directions

Based upon the problem that in order to keep our enhanced cognitive status we must be wired to the tDCS device constantly or at least for the majority of the time, I would make the prediction that similar technologies which stimulate the brain for the purpose of enhancement will one day become implantable, finally making this hybrid system truly irreversible. McGee and MaGuire (2007) make a similar assertion that physically intertwined brain-machine interfaces will one day become quite common. They claim that these technologies may initially have their start in the medical field as therapeutic technologies (as is the case with tDCS and other brain stimulation methods), but will quickly grow into widely utilized and eventually essential technologies to go about our daily functions. I think that tDCS is only the beginning of what is to come, and in the future we will use this technology to not only increase our natural cognitive functions but to allow us to have functions and abilities that previously only belonged to machines.

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I have abided by the Wheaton College Honor Code in this work.