

Transcranial DC Stimulation

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Transcranial DC Stimulation (tDCS) is a recent neurorehabilitation technique to descend upon psychiatry and psychology. While still considered investigational by the FDA, and officially limited to research use within the United States, tDCS has shown itself to be effective in treating a wide variety of maladies, and holds great promise in clinical and rehabilitation applications. It is easy to use and only mild undesirable side-effects have been observed. There is essentially nothing that tDCS is contraindicated for, excepting use during pregnancy and with patients who have history of seizure as precautionary measures. tDCS is not to be used on those who have with a pacemaker or other implanted life-preserving bio-electric appliance. Technically, tDCS is easier to use than other neurostimulation techniques such as rTMS, or neurofeedback. However, researchers and clinicians aspiring to engage in tDCS must be knowledgeable in the neural networks associated with various training sites and potential impacts of training.

History of tDCS

In 43 AD, Scribonius Largus, a physician of the Roman Emperor Claudius, described a detailed account of the use of the (electric) torpedo fish to treat gout and headache. Since that time, a number of scientists experimented with electrical stimulation in hopes of treating various maladies as well as bringing people back from the dead. It was the invention of the battery that made DC stimulation or *faradization*, as it was termed at the time, possible. In 1755, French physician Charles Le Roy, wrapped wires around the head of a blind man in hopes of restoring his eyesight (Pascual-Leone & Wagner, 2007).

Duchenne de Boulogne (Figure 1)



Figure 1: Duchenne de Boulogne.

became the first to systematically use electricity in the diagnosis and treatment of disease. He even brought a woman back from the “dead” after she was in a coma-state from *carbonic oxide* poisoning, by using an early form of cardiac electro-shock (Pascual-Leone, & Wagner, 2007).

In the USA in 1871, Beard and Rockwell published their book on the medical uses of electricity. They presented arguments for the use of *galvanization* (the term for DC stimulation at the time) for a variety of indications, as shown in Figure 2.

In the late 1700s to early 1800s, Giovanni Aldini (Galvani’s nephew) reported experiments using galvanization to treat psychosis, depression and even revive the dead. He later went on a travelling road show demonstrating the use of electricity for bringing cadavers back to life. It is thought that this showmanship

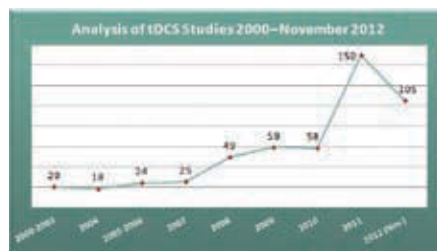


Figure 3



Figure 2: Beard and Rockwell’s Use of Faradization.

may have been the cause for damaging the reputation of electrical stimulation for the next 100 years. In the 1960s, animal experiments using weak DC stimulation on the exposed cortex showed that neuronal activity could be altered immediately, and that these changes would last for several hours. These studies marked the true beginnings of transcranial DC Stimulation (tDCS).

Much of the original tDCS research has been done by Nitsche and his colleagues at the University of Gottingen in Germany. Other authors include: Fregni, Pascual-Leone and Boggio from Beth-Israël Deaconess Medical School (Harvard), plus Antal, Kincses, Hoffman, Kruse, and a dozen or so studies a year were published. A very thorough literature review covering the years from 1998-2008 with tDCS studies all categorized was completed by Nitsche et al., (2008).

In about 2005 the fascination with tDCS was growing and by 2008, it took off and the studies published accelerated almost exponentially. According to PubMed (see figure 3), in the time span from 2000—November of 2012, more than 500 tDCS studies were completed. This would make the grand total of tDCS studies in the range of 650-700 studies as of the time this article was written (November, 2012). In my analysis, most con-

ference proceedings and single-case studies have been eliminated. And then there are the studies that I may have missed—as there are so many.

Table 1 shows the study main theme and the approximate number of studies done. About ¾ of the tDCS studies involved healthy subjects where the study focus was merely to observe the effects of tDCS with a variety of electrode placements and with varying currents and current densities. The remaining ¼ of the studies actually examined the efficacy of tDCS for clinical treatments. These studies mostly involve stroke, pain, depression plus some motor and psychiatric concerns.

Technical Aspects of tDCS

The positive electrode is termed the anode. Popular theory suggests that anodal stimulation depolarizes the local neurons from their typical resting potential of 65 mv, by 5-10 mv, to 55 mv, which in turn will require less dendritic input to fire (depolarize) the neuron. The negative electrode, termed the cathode, hyperpolarizes the neuron slightly and it will require increased dendritic input to fire it. Stagg, et al., 2009, used magnetic resonance spectroscopy to observe that anodal stimulation decreases local GABA (an inhibiting neuromodulator) levels, thus increasing neuronal activity, while cathodal stimulation primarily decreased local glutamate (an excitatory neuromodulator), thus reducing neuronal activity. It is also shown that anodal stimulation increases cerebral blood flow (Zheng, et al., 2011), beta and gamma brain wave activity (Keeser, et al., 2011). Cathodal stimulation reduces cerebral blood flow while increasing delta and theta brain wave activity. The rule-of-thumb is that brain activity (as measured with FMRI or PET) under the anode is enhanced by roughly 20% to 40% when the cur-

Table 1: Categorical Breakdown of Studies Using tDCS

NOTE: Several of these studies had dual purposes such as looking at some sort of rehabilitation of stroke patients. In these cases, the primary study (in this case stroke) was used as the category.		
Motor Studies	70	These include all types affecting basic motor and fine motor control. Also includes MRI and other imaging studies during motor activities.
Motor Learning	10	These include studies where a motor skill is learned.
Somatosensory and Tactile sensitivity	15	
Memory		
Working & Episodic (declarative) memory	18	
Recall of names	6	This includes human, landmark and other names.
With Parkinson's	2	
Cognition		
In general	10	
Social: Recognizing facial expressions and emotions	8	
Attention	3	
Reducing fake memory	1	
Problem-solving	2	
Neuro-plasticity of various types	20	
Insight	2	
Decision-making	3	
Semantic dissonance	1	
Boosting Math	2	
Learning	1	
Behavior		
Behavioral in general	8	
Behavior inhibition	4	
Deceit and lying	3	
Threat detection	1	
Risk-taking	1	
Personality	1	
Emotion		
Depression	25	Most of these studies focus on F3 anode and/or F4 Cathode.
Bipolar	3	
Morality	1	
Psychiatric Disorders		
Schizophrenia	6	
Obsessive Compulsive Disorder	1	
Anorexia	1	
Cognitive Disorders		
General	2	
Stroke	38	These studies include aphasia, motor dysphasia, declarative and working memory and mood.
Parkinson's disease	5	
Alzheimer's and Dementia	12	
Planning	1	
Traumatic Brain Injury	2	
Epilepsy	6	
Pain		These include migraine, fibromyalgia, and chronic, post-operative pain. Most involve the motor cortex and/or the prefrontal cortex as well.
Pain of various types	30	
Migraine	5	
Fibromyalgia	6	
Language		
Aphasia (General)	26	
Verbal ability	2	
Reading	1	
Speech and vocabulary	25	
Sensory		
Visual Cortex and Perception	20	
Tactile acuity	7	
Visual-spatial (object location)	5	
Visuo-motor	5	
Auditory acuity and pitch discrimination	4	
Tinnitus	10	
Somato-sensory	2	
Addiction		These include drug & alcohol addictions and eating disorders.
Drug & alcohol	10	
Appetite cravings	4	
Autonomic		
Blood pressure, heart-rate, breathing	3	
Peripheral vasomotor	1	
Physiology		
EEG	7	An EEG examination including brain wave categories, coherence, connectivity and other measures.
Visual Evoked Potentials	5	These focus on VEPs during and following tDCS.
Theoretical models	20	A look at theoretical models including electric-field distributions, head-models of current-density.
Brain Function	19	These studies use tDCS to stimulate various regions of the brain to help determine the functions of these regions.
Cerebral Blood Flow	3	These studies look at the influence of tDCS on regional cerebral blood flow.
Neurotransmitters	16	An examination of the neurotransmitters influenced by tDCS. These include, L-dopa, GABA, dopamine, NMDA, cortisol, etc.
Effect on phosphenes	2	
Vagus nerve	1	
Glia	1	
Glucose	1	
Ethics		A look at the ethics of tDCS, its safety, its efficacy and reliability of sham conditions.
Comfort	3	
Safety	8	
Efficacy	6	
Methods		An examination of the best practices of electrode sizes, electrode distances and frequency of use for the best long-term holding.
Ring method of applying tDCS	4	
Other Studies		
Dreams	1	
Seizure	1	
MRI	1	
Cerebellum	4	These studies involve locomotion and ataxia.
Spinal Cord	5	Peripheral pain control and motor enhancement.
Animal	15	Examined memory, pain, neurotransmitters, neuroplasticity, etc.
Literature reviews		Included reviews on brain disorders, depression, efficacy, future prospects, pain, stroke, animal and general conclusions.
Literature reviews	44	
tAC Stimulation		
tAC Stimulation	5	

rent density (concentration of amperage under the electrode) exceeds $40 \mu\text{a}/\text{cm}^2$ ($260\mu\text{a}/\text{inch}^2$). The cathode reduces brain function under the electrode site by 10% to 30% at the fore-mentioned current density. Anodal stimulation is the most common form of tDCS, as most application requires enhanced brain function (with the exception of pain).

The brain-stimulating electrode is termed the *active* electrode, whereas the circuit-completing inactive electrode is called the *reference* electrode. In most of the studies, the reference has been placed over the contralateral orbit (above the left or right eye). However, most studies have neglected to look at the inhibiting or boosting effects that the reference electrode might have on the brain regions where it is placed. Some recent studies, and in particular a study by Nitsche, et al., (2007), show that it is better to have a small stimulating electrode and large reference electrode. This way, the current density is high under the treatment electrode and low under the reference electrode. This arrangement allows the reference electrode to be placed most anywhere over the scalp without it affecting brain function beneath it. Most studies have used stimulation at 1 mA of current through 7 cm x 7 cm (49 cm^2) electrodes (there are 2.54 cm in one inch, therefore a 1" square electrode is 2.54 cm x 2.54 cm = 6.45 cm^2). Fregni and his group at Harvard have suggested using a shoulder for the reference placement. I also advocate using a shoulder placement except possibly for treating depression, where the active electrode (anode) is placed over the dorsolateral prefrontal cortex (F3 on the 10-20 electrode montage) and the cathode over F4.

Nitsche and Paulus (2000) found that a minimum current density of $17 \mu\text{a}/\text{cm}^2$ was needed to excite motor neurons. Studies involving other regions of the brain have suggested that 20 to $25 \mu\text{a}/\text{cm}^2$ are needed to excite neurons under the electrode. One depression study using anodal stimulation at F3 noted al-

leviated depression using 1 mA into a 35 cm^2 electrode ($28 \mu\text{a}/\text{cm}^2$). Iyer, et al., observed that when stimulating the left prefrontal cortex there was no effect on verbal fluency with a 1 mA current, but significant improvement at 2 mA (current density of $20 \mu\text{a}/\text{cm}^2$ vs. $40 \mu\text{a}/\text{cm}^2$). Two depression studies by Boggio, et al., (2007a; Boggio, et al., 2007b) also used 2 mA.

Safety considerations when using tDCS

A literature review by Poreisz, Boros, Antal, & Paulus, (2007) verifies that low-intensity transcranial stimulation is safe for use in humans and that it is linked with only rare and relatively minor adverse effects. Contrast-enhanced MRI and EEG studies have also found no pathological concerns associated with application of tDCS (Iyer et al., 2005; Nitsche, et al., 2003). Although patients with history of seizures are routinely excluded from current tDCS studies, no instances of epileptic seizures caused by tDCS have been observed in humans (Poreisz et al., 2007), and tDCS has actually been used to treat seizure (Fregni et al., 2006; Soon-Won, 2011). The safety of tDCS use in pregnant women and children has not yet been investigated.

The most common side effects observed with tDCS are mild tingling (71%), moderate fatigue (35%), sensations of light itching (30.4%), slight burning (22%), and mild pain (16%) under the electrodes (Poreisz et al., 2007). Some subjects report headache (12%), trouble concentrating (11%), nausea (2.9%), and sleep disturbances (1%) (Poreisz et al., 2007). Burn-type skin lesions following administration of tDCS have been reported (Palm, 2008), but typically only occur when standard techniques have not been followed. Visual sensations (phosphenes) are sometimes experienced with frontally placed electrodes. There is nothing unpleasant about phosphenes, but they may be avoided by using devices which gently increase the current at startup and

vice-versa at the session end. tDCS delivered at levels of up to 2 mA and administered according to current stimulation guidelines (Nitsche, 2008) has been shown to be safe for use in both healthy volunteers and patients (Iyer et al., 2005). Again, current density is the most important consideration when using tDCS, as even 1ma will cause significant discomfort and skin burns if the electrode used is small or a part of the sponge is dry.

It is important that the tDCS device is current controlled. This means that the device will automatically adjust the voltage up and down as skin resistance changes so that the current always stays the same. For instance, if the resistance of the skin is 10,000 ohms, then 10 volts will be needed to "push" 1 mA through the body. If the connection becomes poor and jumps to 20,000 ohms, then the device will automatically increase the voltage to 20 volts in order to push the 1 mA current through the body. At some point the device must be able to determine if the connection is too poor at which time it shuts down automatically to avoid injury.

To demonstrate the degree of which non-regulated current can vary, I tested a 9-volt battery supplying a $1\frac{5}{8}$ " by 2" ($4 \times 5 \text{ cm} = 20 \text{ cm}^2$) tap-water wet sponge anode at F3 and a 2" x 4" ($5 \times 5 \text{ cm} = 25 \text{ cm}^2$) wet sponge cathode on the left arm and found that at the onset, the current flow was $300 \mu\text{a}$ (0.3 mA) making a current density of $15 \mu\text{a}/\text{cm}^2$ ($300/20\text{cm}^2$). By applying a mild pressure on the arm electrode, the current rose to $600 \mu\text{a}$. When I increased the anode at F3 to 2" x 4", the current was $600 \mu\text{a}$ and rose to 1.2 mA when pressure was applied to the shoulder electrode. The currents in both situations are well below the necessary clinical value of $40 \mu\text{a}/\text{cm}^2$, and therefore not effective. The variance was 2 to 1 just by applying mild pressure to the electrode. When I soaked the electrodes ($1\frac{5}{8}$ " x 2" and 2" x 4") in a 5% salt solution (about 1tsp in 100ml of water), the current was a whopping 3 mA, (current density of $150 \mu\text{a}/\text{cm}^2$) and

I felt painful stinging on my forehead as the current density was much too high. If the reference cathode was also used on the head instead of the shoulder, there would have been a significant inhibition effect around it.

tDCS Devices

There are presently only a few stand-alone tDCS devices available. They are: the Eldith DC Stimulator by Neuro Conn, of Germany, which sells for \$10,500 US, the HDCKit, (Italy), distributed by Magstim, which sells for just under \$10,000, the StarStim (Spain), also about \$10,000, the 1x1 tDCS by Soterix (USA) at about \$4500 and the OASIS Pro, by Mind Alive Inc., (Canada), which sells for about \$600.00 US. There is one device selling for \$380, but it uses a metal mono-headphone plug which violates FDA safety standards, as insulated plugs are mandatory. A static shock through the exposed plug might rattle the brain quite well. I assume that all tDCS systems are officially available in the USA for investigational use only, as there is no evidence of tDCS device for sale within the USA prior to 1976, when medical device regulations were strengthened. As demonstrated above, tDCS devices should be *current controlled*, in that the device automatically maintains the exact current (amperage) set by the practitioner, regardless of electrode and body electrical resistance. It helps if the tDCS device is programmable and supports sham stimulation as

described in research. The OASIS Pro™ by Mind Alive Inc., has these features plus the added benefits of providing cranio-electro stimulation (CES) and microcurrent electro therapy (MET) for muscle work.

Currently, the accepted maximum current for human use is 2 mA and often 1 mA or less is used. Consistent with published safety guidelines, the OASIS Pro has been tuned with the electrodes provided, so that at 1 mA stimulation, the active electrode delivers 50 µa/cm² while the reference electrode produces 18 µa/cm². Table 2 shows the current density using various sizes at 1 and 2 mA currents.

Depression, Mood, and Brainwave

The left hemisphere activates (and therefore suppresses alpha electrical activity as seen on an EEG) with happy thoughts and the right hemisphere activates (suppresses alpha) with negative thoughts. Right-brain strokes spawn cheerful sur-

Table 2: Electrode Size vs. Current Density

25 cm²	5 x 5	@	1 mA	=	40 µa/cm²
25 cm²	5 x 5	@	2 mA	=	80 µa/cm²
36 cm²	6 x 6	@	1 mA	=	27 µa/cm²
49 cm²	10 x 10	@	1 mA	=	20.4 µa/cm²

vivors while left-brain strokes leave the survivor with depression (Rosenfeld, 1997). This supports the “happy-left” and “depressed-right” scenario. Other studies (Davidson, 1992; Coan & Allen, 2004), as well as my own observa-

tions, have shown increased left frontal alpha concurrent with a negative outlook. As one could expect, people with unresolved trauma are plagued with negative thoughts, often waiting for something bad to happen to them. Therefore, what one thinks also has a reinforcing impact one’s degree of depression.

Quantitative EEG (QEEG) Assisted Treatments

One method to help determine electrode polarity and placement is to use a 19-channel qEEG and a normative database to assess where brain activity may be too little or excessive. This can be determined by observing delta, theta and alpha activity. If any of these brain wave frequency bands are excessive, then as a rule of thumb, I would use anodal stimulation. If beta brainwave activity is high, I would choose cathodal stimulation.

qEEG Based tDCS (an anecdote)

Obsessive-Compulsive Disorder (OCD) is a condition in which a person obsesses on an item and has compulsions to return to the point of obsession as a means to help reduce the anxiety associated with the obsession. One of the regions involved in OCD is the cingulate gyrus. OCD can develop from both an under- or over-aroused condition of the cingulate; therefore a qEEG is helpful in forming a diagnosis. The following case is of a woman person who was struggling with OCD, in which her prominent obsessions were hoarding. Despite having a house

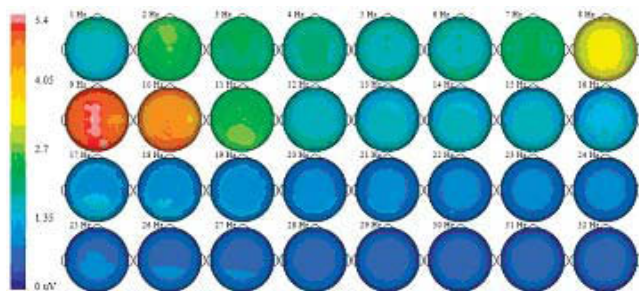


Figure 4: qEEG—Magnitude Measure in 1Hz Bins of a Person with OCD of the High Alpha

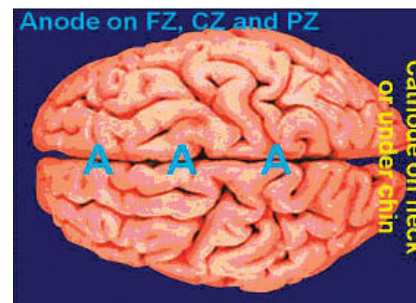


Figure 5: Electrode Placement for Reducing OCD of the High Alpha/Theta Type

and garage full of junk, newspapers, and magazines (and despair about her condition), she could not stop herself from collecting even more stuff nor bring herself around to clean her home.

Figure 4 shows an eyes-closed *magnitude* qEEG in 1 Hz bins. Notice the high magnitude, slowed alpha (9Hz) activity along her cingulate gyrus (the pink strip). I have observed nearly identical activity for “tappers” and “counters.” For this type (a “no-brakes” cingulate), I would suggest placing the anode at various positions along the cingulate from FZ to PZ to boost cingulate activity as shown in Figure 5. For those with the beta (“foot on the gas”) type of OCD, use the cathode along the cingulate to bring the beta down.

Clinical Research Regarding Stroke

Given that the majority of the tDCS studies are of academic interest in learning about the brain and evaluating the effects of tDCS on healthy individuals, it is difficult to argue efficacy in the clinical population and instill faith in practitioners. Fortunately, stroke, one of the severest of neuropsychological maladies, has been studied extensively with tDCS.

In a sense, there are three generations of treatment techniques regarding

stroke. They are:

1. First generation motor improvements.
2. Second generation motor improvements.
3. Studies involving cognitive aspects of stroke.

First Generation Studies

These studies involved anodal or cathodal stimulation over the motor cortex of healthy individuals or in those with stroke over the affected sensorimotor region. The reference electrode (anode or cathode) was typically placed over the contralateral orbit as indicated in the literature review by Nitsche, et al., (2008). This was the traditional way of doing things for many years. Unfortunately, the negative effects of extra-orbital (pre-frontal) cathodal stimulation were largely ignored.

Second Generation Studies

These studies came about with the discovery by Vines, Nair & Schlaug (2006), that cathodal stimulation over the motor strip of healthy adults improved finger sequence movements on the contralateral side. Boggio et al., 2007, may have been the first to report that either anodal stimulation of the lesional side or cath-

odal stimulation of the non-lesional side were equally effective in improving motor function in stroke patients, and this technique was confirmed by Nair, et al, (2008), (a colleague of Boggio). The contralesional cathode placement technique gained in popularity over the years in both motor and cognitive studies as reported by Nair, et al, 2011. These studies involved anodal stimulation over the lesional sensorimotor region in one group of sessions and cathodal stimulation over the contralesional region in another group of sessions. This eventually morphed into simultaneous anodal stimulation over the lesional region with cathodal placement over the contralesional area.

Third Generation Studies

These studies focused on other aspects of stroke such as apraxia, aphasia, depression, and memory. Anodal stimulation has been applied to the left dorsolateral prefrontal cortex for improving attention, with significant result lasting for several hours (Kang, 2009), for improving working memory (Jo, et al, 2009), and for treating depression (Bueno, et al, 2011). Anodal stimulation over Broca’s area has been used by Marangolo, et al., (2011), to treat apraxia and by Baker, Rorden & Fridriksson, (2010), to treat aphasia. Baker’s group also found that placing the electrode

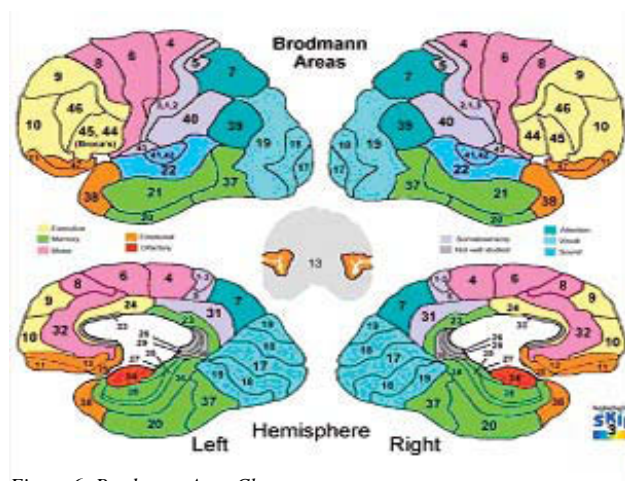


Figure 6: Brodmann Area Chart

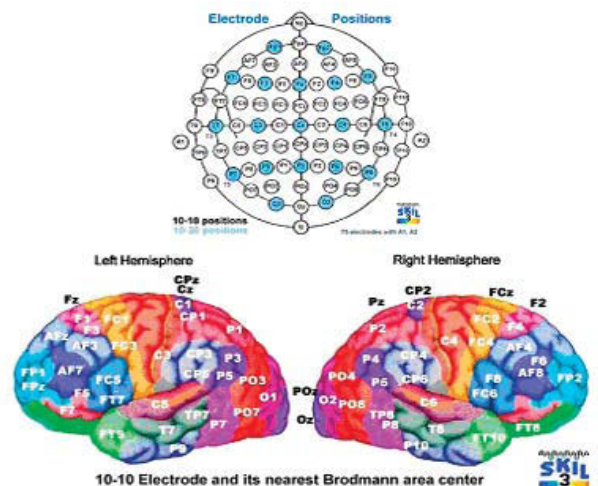


Figure 7: 10-10 Electrode Placement Overlay

most closely over healthy *parilesional* areas yielded the best improvements, as did Fridriksson, et al., (2011), using MRI-guided electrode placement.

The practice of bilateral stimulation involving cathodal (contralesional) stimulation proved to be an even more effective means of inducing improvements in speech and language. It does so by inhibiting the Broca's and Wernicke's homologous areas (right hemisphere), which have a tendency to dominate the lesioned area and thus impede rehabilitation. Kang, et al., (2011), observed improved picture naming in 10 aphasia stroke patients when the cathode was placed over the right Broca's homologue area and the anode was placed over the left supra-orbit (which may have had some influence over the left-side Broca's area). You, et al., (2011) found that bilateral stimulation of Wernicke's area and its associated homologous area improved comprehension of speech. A very good review on aphasia and language was completed by Monti, et al., (2012).

Literature reviews by Chrysikou & Hamilton, (2011), and Schlaug, et al., (2011), explored the benefits of anodal stimulation over the lesioned area with simultaneous cathodal stimulation over the homologous (non-lesional) area. A very good literature review of tDCS in relation to stroke by Schlaug, et al., (2008), is available as a pdf file for free on the Internet. This review includes diagrams of electrode placement montages, regional cerebral blood flow images, and diffusion tensor imaging of a lesioned hemisphere vs. a non-lesioned hemisphere.

Electrode Placement

Electrode positioning is best chosen by observing a Brodmann Area chart (Figure 6), and then overlaying it with a 10-20 or 10-10 Electrode Placement Guide as shown in Figure 7. To learn more about functionality of the brain regions for determining electrode placements, visit: www.skiltopo.com. You will see a wonderful compilation of Brodmann

maps with a detailed explanation of the functions for most Brodmann Areas.

Studies

The Frontal Cortex

There have been several studies of the right dorsal-lateral prefrontal cortex (DLPFC) in around F4. Anodal (+ve) stimulation with simultaneous cathodal (-ve) stimulation at F3 has been shown to reduce risk-taking behavior, whereas anodal stimulation only was not effective (Fecteau, et al., 2007a and 2007b). A study by Beeli, et al., (2008), showed that cathodal stimulation at F4 with the anodal reference over the contralateral mastoid, increased impulsiveness by 215%. Electrodermal responses to a simulated roller-coaster ride increased by 164%, which the authors referred to as a "being in the present" effect, although it could reflect a lack of pre-frontal inhibition over the amygdala (Ledoux, 1996). Cathodal stimulation at F4 with a left-orbital reference produced social improvements, in that the subject's propensity to punish unfair behavior was reduced significantly (Knoch, et al., 2008). Figure 8 shows F3 electrode placements for boosting organizational skills and planning ability (Smith & Clithero, 2009), and for reducing depression. If a brain map warrants it, the same size cathode may be placed over the right DLPFC at F4, as shown in Figure 9. With F3 anodal and F4 cathodal stimulation, cigarette cravings were reduced by 21% (Fregni, et al., 2007), alcohol cravings were reduced (Boggio, et al., 2008), and junk-food cravings were reduced (Fregni, et al., 2008). Although there were better results using the F3 anode/F4 cathode arrangement, an F3 cathode/F4 anode electrode placement was, surprisingly, also quite effective.

Figure 10 shows the electrode placements for improving attention. The anode is placed on FP1 or FP2, with a contralateral shoulder cathode. A large anode electrode could also be placed across FP1 and FP2 at 2 mA, with a neck-placed cathode. Chi & Snyder (2011), found an

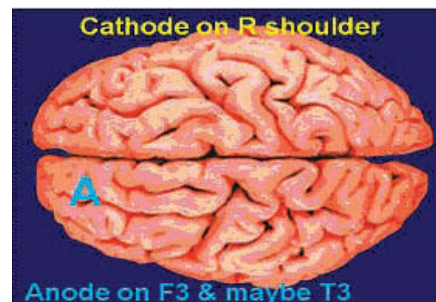


Figure 8: Electrode Placement for Reducing Alcohol and Food Cravings (and Depression)

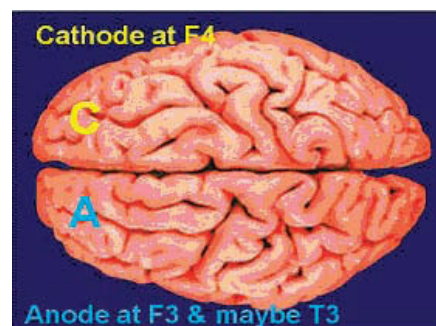


Figure 9: Electrode Placements for Reducing Depression

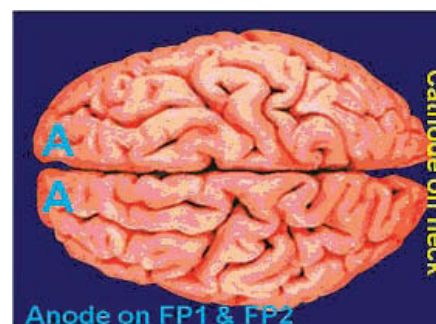


Figure 10: Electrode Placement for Boosting Attention

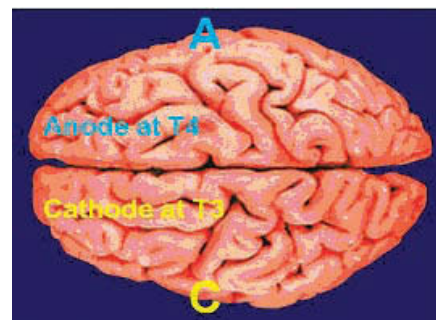


Figure 11: Electrode Placements for Improving Insightfulness

innovative way to increase insight. They used a well-known experimental paradigm involving “matchstick arithmetic.” Participants were asked to correct a false arithmetic statement, presented in Roman numerals constructed from matchsticks, by moving one stick from one position to another position without adding or removing a stick. Part of the reason that insightfulness is boosted is because the left temporal lobe is inhibited, as shown in Figure 11.

Figure 12 shows electrode placements for boosting socializing, including facial recognition and body language. A study by Kadosh (2010) showed that anodal stimulation at P4, with the cathode at P3 (Figure 13), improved math ability, but did not test to see if the cathode caused verbal impairments.

Perception Studies

At least 15 studies have examined the effects of tDCS on the visual system (Antal & Paulus, 2008). The main conclusion from these studies is that anodal stimulation of the visual cortex (Figure 14) improves contrast discrimination and visual-motor reaction times, while cathodal stimulation reduces these abilities. The benefits from improved visual processing may include art, painting, home decorating, flying jets, and action sports, etc. Cathodal stimulation at O1 and O2 has been shown to reduce the pain level of migraine (Antal, 2011). Figure 15 shows the electrode placement for improved auditory processing and pitch discrimination. (So you just might sing better in the choir.)

Motor Strip and Pain Studies

There are many motor strip studies showing that anodal stimulation at C3 or C4, with a contralateral orbit reference, enhances fine motor control, while cathodal stimulation impairs it. A motor-strip study of stroke patients by Lindenberg, et al., (2010), found that by placing the anode over the motor-strip lesion and the cathode over the contralateral motor-

strip, motor function increased by 21% and lasted for one week.

There are several studies on the treatment of pain. Most of them found that anodal stimulation of the motor strip, exactly as the motor enhancement studies with a contralateral supraorbital placement of the cathode, is ideal for reducing pain on the opposite side of the body (Fregni, 2006), as shown in Figure 16. Here, the A1/C1 placement would suppress pain in the right side and vice-versa for A2/C2. It seems counterintuitive that boosting the motor strip would reduce pain—or could the reference electrode over the prefrontal lobe be involved?

Mendonca (2011) found that the pre-frontal lobes play a much larger role in pain modulation than was realized in previous studies. He found that either anodal or cathodal stimulation over the supra-orbit, with a neck reference, reduced pain equally well (Figure 17). However, the supra-orbit is the location of the pre-frontal lobes. This is a sensitive area for attention and impulse control, and he did not assess the effects of stimulating here. But because Beeli (2008), found that impulsiveness and emotional reactivity increased substantially with cathodal stimulation, it makes sense, in my opinion, given that either anodal or cathodal stimulation work equally well, that it would be wise to use anodal stimulation over the supra-orbital regions and place the cathode at the base of the neck.

Figure 18 and 19 depict 3rd generation applications of tDCS, especially where applied to language and speech deficits resulting from stroke.

Conclusion

Transcranial DC Stimulation is site specific and, like neurofeedback, may be used to up-modulate or down-modulate any region of the brain. tDCS is also easy to use and doesn't require the constant attention of the therapist, thus allowing the therapist to engage in talk therapy, some forms of biofeedback and/or collect client information during the treatment. tDCS

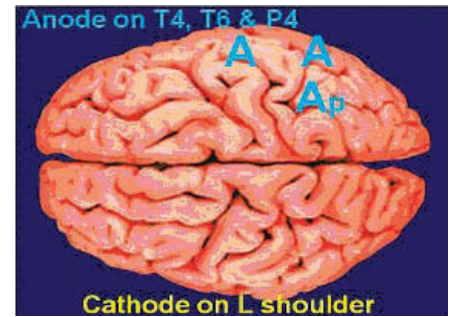


Figure 12: Electrode Placement for Improving Socialization

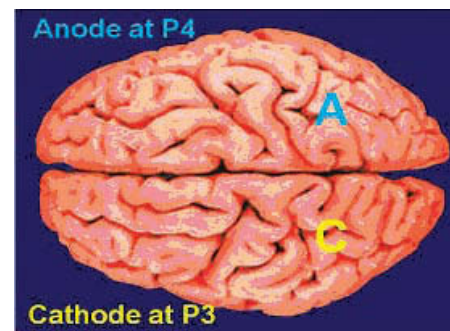


Figure 13: Electrode Placements for Increasing Math Ability

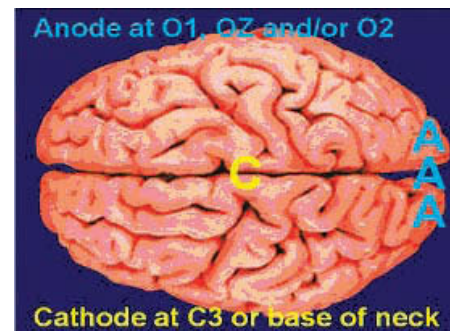


Figure 14: Electrode Placement for Improving Ability

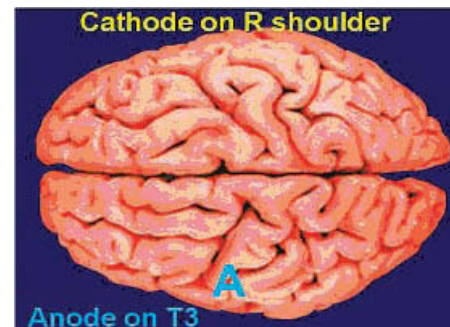


Figure 15: Electrode Placements for Improving Visual Audio-Pitch Discrimination

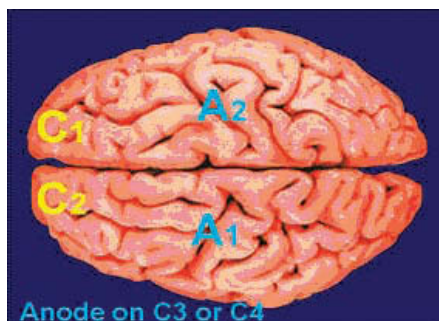


Figure 16: Electrode Placement for Enhancing Motor Ability & Reducing Pain

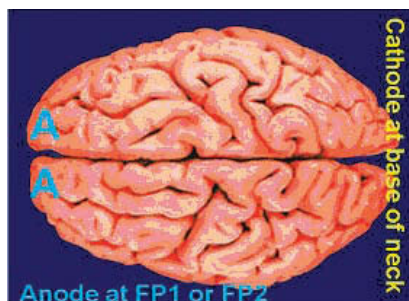


Figure 17: Electrode Placements for Reducing Pain—“Mendonca Method”

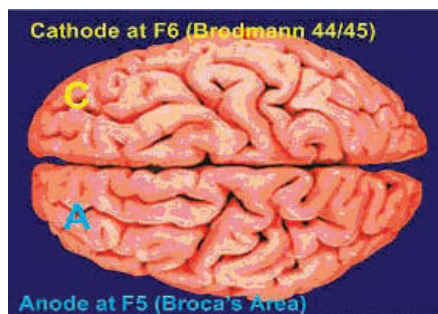


Figure 18: Electrode Placements for Reducing Broca's Aphasia (improving speech)

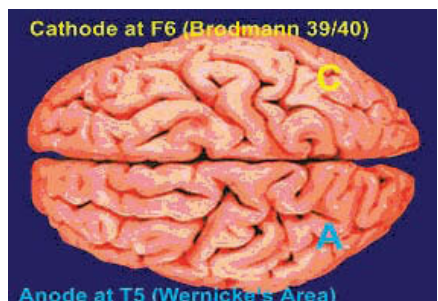


Figure 19: Electrode Placements for Reducing Wernicke's Aphasia (improving comprehension)

overcome stage fright. Dave later began developing transcranial DC stimulation devices in 2007. Dave has lectured and provided workshops with leading psychological institutions including the Association of Applied Psychophysiology and Biofeedback, the International Society of Neurofeedback and Research, the College of Syntonic Optometry, the American College for the Advancement of Medicine, Walden University, the University of Alberta, the Open University-England, A Chance to Grow Charter School, the International Light Association, accredited Biofeedback Training Programs, and other venues.

ONLINE SUPPLEMENT
References are available in the supplement at: <http://isnr.org/neurofeedback-info/neuroconnections-newsletters.cfm>.


produces immediate and lasting sharpness and reasoning of mind. Prior to 2000, few studies considered the effects of tDCS beyond a few hours. In the past 10 years, however, an increasing number of studies administered tDCS on a daily basis for one to two weeks and then performed follow up testing a week or two later. Most studies showed lingering improvements. One depression study observed a holding effect 30 days later (which personal experience confirms).

It is important to be aware that sometimes there can be undesirable trade-offs. For instance, up-training insightfulness may impair auditory pitch discrimination. Up-training math ability may induce Wernicke's aphasia. Down-training the right frontal lobe when treating pain could increase impulsiveness and anxiousness, while down-training the left dorsolateral pre-frontal cortex may bring on depression. However, between the existing research and my personal experiences, I suspect that with appropriate training, tDCS will become a common clinical approach to neurotherapy.

About the Author

Dave Siever, CEO of Mind Alive Inc., of Edmonton, Alberta, Canada, has been studying the mind and designing Audio-visual Entrainment (AVE), Transcutaneous Electro-neural Stimulators (TENS), and cranio-electro stimulation (CES) devices since 1981. He originally developed the Neuropulse II (TENS device) to relax the jaws of TMJ patients and the DAVID1 (AVE device) to help performing-arts students

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