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Approved by the Thesis Committee:

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TRANSCRANIAL DIRECT CURRENT STIMULATION (TDCS) IMPROVES PERFORMANCE ON SPELLING AND WORD DETECTION TASKS

by

J. KEVIN WILSON

BACHELORS OF SCIENCE

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of

MASTERS OF SCIENCE

Psychology

The University of New Mexico
Albuquerque, New Mexico

May, 2018

Transcranial Direct Current Stimulation (tDCS) Improves Performance on Spelling and Word Detection Tasks

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B.S., Psychology, University of New Mexico, 2014

M.S, Psychology, University of New Mexico, 2018

Abstract

Deficits in written language involving spelling can have negative effects on a person's education and occupation. Conventional spelling therapy is a time consuming and cost-prohibitive option, if even available, highlighting the need for improved methods for remediation. One solution may be through the use of transcranial direct current stimulation (tDCS). Here we examine the effects of tDCS on performance during spelling, word detection, and facial recognition tasks. Active or sham tDCS was administered to typically functioning adults. The anode electrode was placed over Broca's area and the cathode was positioned over the upper right arm. Outcome was assessed before, during, immediately after tDCS, and again 3-5 days after tDCS. When data was analyzed, significant differences were found between active and sham tDCS on both the spelling and word-search tests. There was no significant difference between active and sham tDCS on either of the facial recognition tasks.

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Transcranial Direct Current Stimulation (tDCS) Improves Performance on Spelling and Word Detection Tasks

Introduction

Effective communication skills are essential throughout one's life. Of the many ways that ideas are communicated, the use of written language has become an integral part of modern society. Deficits in written language involving spelling can have negative effects on a person's education and occupation. Researchers found that of English speakers surveyed, 32% exhibited some level of difficulty related to spelling between childhood and their mid-forties (Maughan et al., 2009). Spelling difficulties may be the result of a range of factors including a lack of effective instruction, learning disorders, or neurological difficulties. Spelling therapy is typically a time consuming and cost-prohibitive option, and may not be readily available to all those who need it (Williams & Walker, 2017). Given the importance of spelling in a person's educational and vocational life, more efficient and effective ways to improve spelling skills are needed. One possible way to address this need may be through the use of transcranial direct current stimulation (tDCS).

tDCS is a noninvasive, cost effective, and relatively safe cortical stimulation technique, and a growing number of studies have demonstrated its effectiveness in improving both memory and learning (Utz, Dimova, Oppenlander, & Kerkhoff, 2010; Carvalho et al., 2015; Rohan et al., 2015; Clark et al. 2012), as well as grammar tasks (de Vries et al. 2010). However, the findings have been mixed when examining tDCS's utility for cognition and working memory in healthy individuals, which highlights the need for continued research (Medina & Cason, 2017). To deliver tDCS, weak electrical current measured in milliamps (mA) is delivered through electrodes positioned on the scalp. Anodal stimulation, putatively leading to neuronal depolarization, takes place when positive current is delivered to a specific site, while cathodal stimulation, which may lead to cell hyperpolarization, takes place when negative current is delivered.

Research has shown that tDCS can lead to both short and long-term effects. Work by Liebetanz et al. (2002) suggests that lasting effects of tDCS are the result of the plasticity of long-term potentiation and long-term depression in combination with neurotrophic factors, specifically brain-derived-neurotrophic-factor (Fritsch et al., 2010). This also includes both intracellular changes and large-scale changes such as increased connectivity of language-related areas when using anodal tDCS in combination with memory tasks (Meinzeer et al., 2012). The Meinzeer (2012) study found that N-methyl-D-aspartate cell receptor antagonists and Na+ channel-blockers such as dextromethorphan and carbamazepine would lessen or remove effects brought about by anodal tDCS, and reciprocally, if NMDA receptors are enabled the effects of tDCS last longer. This suggests that lasting effects of anodal tDCS require a depolarization of membrane potentials (Rozisky, Antunes, Brietzke, Sousa, & Caumo 2016). Additional studies using functional near-infrared spectroscopy (fNIRS) have also documented tDCS's effect on neuroplasticity by measuring the length of hemodynamic responses and changes in task ability (Merzagora et al., 2010, Khan et al., 2013, Ishikuro et al., 2014).

There is growing evidence that outcomes from tDCS delivery are dependent on how it is delivered (Jaberzadeh & Zoghi, 2016). This includes various factors such as the strength of electrical current delivered, the size (usually given in centimeters squared) and placement (location on the participant's body) of electrodes, the direction of current flow (from anode to cathode), and the length of time that stimulation is delivered (usually in minutes). Additional elements have also been found to affect the delivery of tDCS that must be considered. These include, but are not limited to, factors such as the type of conductor used between electrodes and the participant (e.g., saline or conductive gel) and if the participant receiving the stimulation is performing a task or is at rest. Age of the participant has also been found to affect dosage (Fertonani, Brambilla, Cotelli, & Miniussi, 2014). The combination of these elements must be carefully considered given that it's been demonstrated that a small change in some of these factors has the potential to change the outcome and, in some instances, produce opposite outcomes. Javadi, Cheng, & Walsh (2012) used different timing in separate groups to compare differences within tDCS tasks, and were successful in determining the optimal dosage for best results in their study's word-memory task.

Although major advances have been made, there is much to learn about the mechanics of tDCS. Research continues to be needed to address the influence of tDCS on brain activity and specific cognitive domains, such as language and memory. There was a call to the scientific community for further research of healthy individuals' use of language as it relates to improving attentional processes (Floel, Michka, Knecht & Breitenstein 2008). Understanding the basic mechanisms of adaptive plasticity in language networks may help researchers understand and develop useful protocols for treatment of individual deficits (Hartwigsen, 2015).

It has been established that skills utilized during spelling tasks, such as novel word learning and recall (deVries, Barth, Maiworm, Knecht, Zwitserlood, & Flöel, 2010), and the ability to complete visual detection tasks (Clark et al., 2011), can be enhanced using tDCS with healthy individuals. Medina & Cason (2017) reanalyzed previous tDCS research in their meta-analysis and concluded that tDCS should primarily be considered effective for cognitively compromised individuals. However, there have been no studies completed demonstrating the effectiveness of using tDCS with healthy individuals while using these types of skills to enhance whole-word spelling ability.

This study focuses on accelerating the cognitive speed at which spelling is learned and words are recognized through the tDCS-modulation of underlying neural processes. Specifically, this study seeks to examine the effects of tDCS on performance during spelling and word detection tasks. Additionally, because written language is a relatively new demand on the human brain, in an evolutionary sense, it has been hypothesized that the process of producing written language utilizes brain regions that were previously used for face processing (Dehaene & Cohen, 2007). It is also thought that perceiving and positioning letters and facial features requires the same computational demands, and thus, these tasks all utilize the same neural region (Kleinschmidt & Cohen, 2006; Rapp & Lipka, 2011). Thus, this study also proposes to examine the effects of tDCS on performance during a facial recognition task.

Results from this study may inform the use of tDCS as a tool capable of targeting specific brain regions for the remediation or rehabilitation of spelling difficulties and/or agraphia that may be related to age-related cognitive decline, learning disabilities, dyslexia, or neurological difficulties.

Materials and Methods

A total of 30 participants (15 males 15 females) ages 18 to 49 years were recruited from the University of New Mexico (UNM) Department of Psychology's undergraduate research pool which provides students with course credit for participating in research, along with volunteers recruited from UNM postings. Research took place at the Psychology Clinical Neuroscience Center in the UNM Department of Psychology with approval provided from both the Department of Psychology and the UNM Main Campus Internal Review Boards.

Individual consent was given by all who participated in the study. Participants were eligible for study inclusion if they were between 18-65 years of age, not pregnant, no known allergy to rubber or latex, no surgically implanted metal in the head (example; cochlear implants, aneurysm clips, brain electrodes), no pace-maker, proficient in English, right handed based on the Edinburgh Handedness Inventory (Oldfield 1971) (Appendix A1), no known loss of consciousness for greater than five minutes, good or corrected vision and hearing, and no history of substance abuse or major psychiatric or neurological disorders. Participants were required to commit to two separate visits for a total time of four hours.

At the first visit, participants were screened for study inclusion (Appendix A2). Additionally, participants confirmed that they had not consumed any caffeine that day. Informed consent was provided to participants who met inclusion criteria. Participants were then seated in a private testing suite in front of an 18" computer screen placed on the desk. Each participant wore Skullcandy® headphones and first listened to a pre-test consisting of 34 dictated words and sentences using each word (Appendix A3). After listening to the words and sentences, each participant then attempted to spell each word by writing each word on paper, which were then graded for accuracy until 15 misspelled words were identified, allowing the creation of an individualized list of 15 spelling words for each participant. These 15 words were used in each training task and test. For participants particularly adept at spelling who did not misspell at least 15 words from the original 34 words, an additional round of testing was conducted until a list of at least 15 misspelled words was identified.

After an individualized list of 15 spelling words was created, each participant then was given a short break while the study researchers input the participant's individualized spelling list into a computerized training program. Participants were randomly assigned into two different experimental groups: one active tDCS group, and one sham tDCS group. If it was found that participants from the extreme ends of the frequency distributions for spelling ability were not equally represented, we actively placed those members into the underrepresented subgroup to maintain equal balance among testing of participants at those extremes (paired participant testing).

Participants were also pre-tested on their individualized word list with a word detection task. During this timed, computerized task, participants identified their test words within a 19 x 19 array of letters. Upon locating a target word, participants used a computer mouse to highlight and select each word within the array. Next, participants were given two facial recognition pre-tests. The first facial recognition test consisted of a rapid presentation of two photos of face combinations of varied gender, age, and ethnicity. Participants were asked to respond as to whether the pair were the same person or different people. The second facial recognition test was The Cambridge Facial Task (Duchaine & Nakayama, 2006; Duchaine & Germine, 2007). This test required participants to look at a group of three computer-generated, morphed photos of people in a line-up and then identify if they recognized a target face.

After completion of pre-testing, participants prepared for tDCS. First, they completed a mood questionnaire to assess mood/state (Appendix A4) and to elucidate possible state-dependent effects of tDCS. Measurements of the participant's head were taken to determine the location of the anodal electrode placement over the scalp at the location referred to as Broca's area (F7 in the 10/20 EEG system), with the cathode electrode placed over the upper-right arm. Participants were blinded to which condition they received (active or sham). Blinding was accomplished using a coded switch box with inputs for positive and negative leads from two current generators and outputs for one pair of electrodes. One current generator was set to the sham current strength (0.1 mA) and the other set to the active current strength (2.0 mA).

tDCS was delivered using Activa-Tek Activa-Dose stimulators for 40 minutes through Amrex 2x2 inch saline-soaked sponges. Anodal amperage was delivered at 2.0 mA for active tDCS, with sham tDCS delivered at 0.1 mA. tDCS was delivered for the first five minutes without a task to assess possible negative side effects (i.e. discomfort) of the stimulation. During these first five minutes, participants completed a sensation questionnaire to report sensations on 10-point Likert scales for itching, tingling, and heat (Appendix A5). tDCS was to be stopped if participants reported above a seven on any one of the sensation scales. Two additional sensation questionnaires were administered – one 15 minutes after the start of tDCS and another 25 minutes after the start of tDCS.

Participants then used a computerized training program to listen to the words from their individualized word list, one at a time, and attempt to spell them again. Each time a word was misspelled, the participant was given the opportunity to study the word before continuing to the next word. Participants also trained to learn their misspelled words in a word scramble, a hangman game, and a practice spelling bee. This training session lasted 20 minutes. After the training session, during the delivery of tDCS, participants completed testing consisting again of spelling and word detection tests based on their individualized word list followed by the two facial recognition tests.

After the delivery of tDCS was complete, the electrodes and sponges were removed. Participants were given another mood questionnaire to ensure that there were no lingering negative side-effects of the stimulation. If negative emotions were reported, the participant would be given the opportunity to relax for 15 minutes and then repeat the mood assessment. This was never needed during this study as all the participants reported feeling the same or better after receipt of tDCS. Participants were then given a 10-minute break. After this break, each participant was given post-tests consisting of a spelling test and word detection test based on their individualized word list, followed by the two facial recognition tests.

Participants returned for a follow-up visit 3 to 7 days after their initial visit to complete a second post-test consisting of a spelling test and word detection test based on their individualized word list, followed by the two facial recognition tests. No tDCS was used during the second visit (see Figure 1 for study timeline).

Results

Thirty volunteers from the UNM area were recruited. Two participants were excluded from the study, one due to use of neuroleptic medications and a second for left-handedness. Data from the remaining 28 participants were analyzed as follows with alpha set at .05. This study consisted of a total of 14 females and 14 males. 21 were between the ages of 18-24 years old, 3 between 25-32 and 4 over the age of 33. Of those participants who returned for the second visit, 10 were from the active stimulation group and 7 were from the control group.

Significant results were found on the spelling test when comparing active versus sham groups during stimulation ($N=28, F(1,26)=13.578, p=0.0011$, Table 1 and Figure 2), post-testing immediately after stimulation, ($N=28, F(1,26)= 7.156, p=0.0127$, Table 1) and post-testing 3-7 days after stimulation ($N=17$, $F(1,15)=16.36$, $p=0.0011$ Table 1).

Since the data showed such strong results, the original data were re-evaluated to see if outliers could be skewing the outcome. Statistical analysis using SPSS data exploratory procedures did not identify specific outliers. To understand the effects of the highest and lowest scores, the data from two individuals who scored the highest on the stimulation test (scoring a perfect score of 15 each) from the active group, along with two individuals who scored the lowest (scoring 1 and 2) from the sham group were removed. Significant differences were still found when comparing active and sham groups ($N=24$, $p=0.0152$). Removing only the two low scores ($N=26$, $p=0.0055$), or removing only the two high scores ($p=0.0036$) also did not change our findings of significant differences between the two test groups.

Part of the original objective was to analyze the number of words found by participants during the allotted time. Those results showed a ceiling effect because too many perfect scores in both groups were obtained. This problem was addressed by examining the number of seconds it took the participants to detect their words. Using a time-spent method showed significant differences between active and sham groups, with the active group detecting their words faster than the sham group during the delivery of tDCS ($N=28$, $F(1,26)=5.55$, $p<0.03$, $d=0.68$, Table 1 and Figure 3) and immediately after receiving tDCS ($N=28$, $F(1,26)=5.47$, $p<0.03$, $d=0.87$, Table 1). Among participants who returned for post-testing 3-7 days later, the active group showed a modest decline from prior testing, but remained faster at detecting words than the sham group ($N=17$, $F(1,15)=7.97$, $p<0.01$, $d=1.48$. Table 1).

Comparison of accuracy scores between active and sham groups from the Cambridge Facial Task revealed no significant differences ($N=28$, $F(1,26)=4.89$, $p=0.7743$).

Discussion

Spelling is a key part of reading achievement and written language acquisition (Adams, 1990; Caravolas, Hulme, & Snowling, 2001; Ehri, 2000; Holmes & Castles, 2001; Moats, 2005). A major goal of our study was to examine how tDCS could be used to increase a person's spelling ability. Results from our analysis showed that those who received active tDCS produced spelling accuracy scores at more than twice the rate of those who received sham tDCS. Additionally, our findings demonstrated that active tDCS over Broca's area improved rapid visual detection of words, which is a critical component of reading efficiency (Williams & Walker, 2017) and may suggest a future use for tDCS as a means to improve written word processing. Our findings of improved performance on a spelling task and on a rapid visual detection of words task, is in contrast to Medina & Cason's (2017) analysis paper in which they stated that tDCS has no effect on healthy human cognitive abilities.

Prior tDCS research has typically been conducted using 30 minutes or less of stimulation per session at less than 2.0 mA. There are few published studies that have utilized 40 minutes of stimulation at 2.0 mA. The length of time and mA we administered, as well as the electrode placements chosen for stimulation, may have been contributing factors in the overall improvements seen in the participants' performance on the spelling and word-search tasks, as well as in the retention of these tasks at their second visit three to five days after stimulation. Hopefully, our findings contribute to the body of research regarding the use of 40-minute stimulation sessions using 2.0 mA of current and outcomes due to our electrode montage. Sensation forms did not show that the groups were experiencing differences in the overall amount of itching, heat, or tingling. Future studies should investigate further dosage elements such as matching current flow with each distinct element (trigger) of a presented task, along with adjusting for individual differences (e.g. age, education level and/or living environment) (Fertonani, Brambilla, Cotelli, & Miniussi, 2014; Javadi, Cheng, & Walsh, 2012).

While significant differences were found on the spelling and word-search tasks when comparing active to sham tDCS conditions, we did not find significant differences on either of our facial recognition tasks, which is important as it indicates that results from tDCS may be relevant to electrode placement for neural targeting and do not occur as a side-effect, regardless of location or length of under 4.0 mA stimulation, such as Kozak, Kincses et al. (2018) have suggested.

Our findings also emphasize the need for further research into the application of tDCS to accelerate rehabilitation for individuals with brain injury related agraphia, as well as for interventions for individuals with learning disabilities (Hartwigsen, 2015). Also, this research study, like the majority of other tDCS studies, excluded left-handed participants. It may be important to include left-handed individuals to inform future tDCS studies and elucidate the differences that may exist between left- and right-handed individuals' responses to stimulation.

An observation noted during this study was that participants who received active tDCS returned for the follow-up study at a higher rate than the sham participants (10 vs. 7). This observation was not statistically significant, but could suggest that future research may find it beneficial to measure participants' mood responses after receipt of active tDCS compared with sham to investigate further if these responses impact participant return rates during research studies. Additionally, we observed that there were more participants in the active tDCS group who self-identified as being fluent in more than one language (n=5) compared to the control group (n=2). However, on average, the spelling scores of the active tDCS additional-language group was 3.3 words lower than the single-language active stimulation group and less than 1 word higher than the control single and multi-language groups. This may limit the generalization of the effects found in this study to single-language English speakers.

Several important limitations should be considered. Participants in this study were all high school graduates and had received at least some college education. The most obvious implication of our results would be treatment of children, and we do not know if our results would generalize to that group. With a younger group, brain plasticity may play a role in their learning abilities that may not be found in a differing group. It may also be more useful to have a greater number of words available for the participants to learn, if not just to reduce the ceiling effects experienced in this study, but also to replicate a more real-life situation where therapy would likely require more than just 15 words. Clearly future studies would also benefit from systematic manipulation of each of the stimulation parameters utilized in this study.

Table 1.

Spelling and Word-Search data for all three testing points for active and sham tDCS groups.

Task		Active Group		Sham Group		
	N	Mean	Var	Mean	Var	p value
Spelling during stimulation	28	12.3	12.4	7	17.2	0.0011
Spelling after stimulation	28	12.6	12.8	8.7	17.2	1.0127
Spelling 2nd visit	17	12.6	8.7	6.1	13.1	0.0011
Word search during stimulation	28	30.52	99.1	43.42	202	0.0197
Word search after stimulation	28	24.8	103	37.1	302	0.0273
Word search 2nd visit	17	27.1	90.9	41.8	106.6	0.0144

Figure 1.

Complete timeline for the participants in this study.

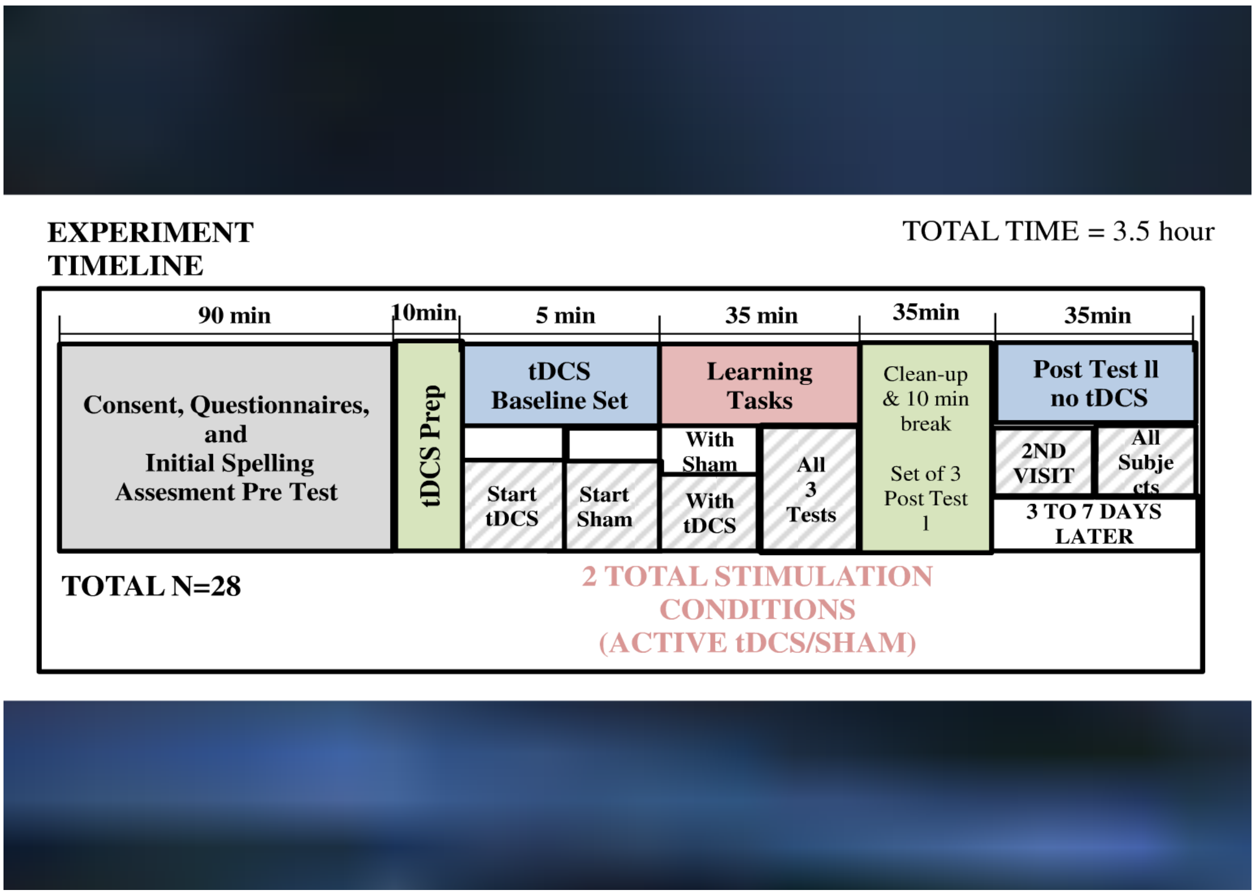
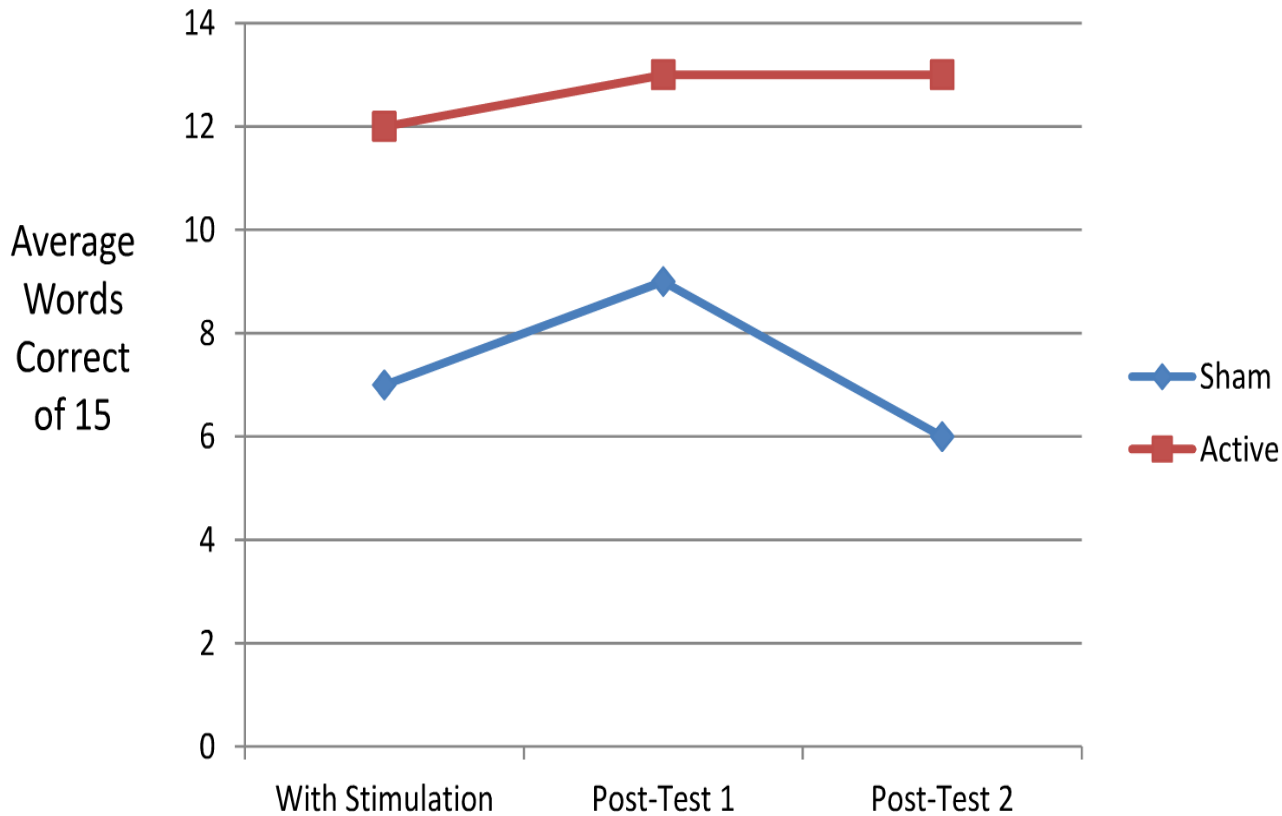


Figure 2.

Average number of correct spelling words each treatment group achieved at each testing point.

[redacted]



[redacted]

Appendices

A1 -Handedness Questionnaire

A2 -Initial Visit Screening Questionnaire

A3 -Spelling List

A4 -Mood/State Questionnaire

A5 -tDCS Sensation Questionnaire

A1).

Handedness Questionnaire

For the following activities, please indicate your hand preference by marking the most appropriate space. Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets. The phrases “Never right” and “Never left” mean you would only use that hand if forced to.

Writing *

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

Drawing *

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

Throwing *

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

Scissors *

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

Toothbrush *

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

Spoon *

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

Broom (Upper hand)*

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

Striking Match (Match)

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

Opening box (lid)

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right, Never Left

Foot used for kicking *

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

Preferred eye when using only one (e.g. looking in a camera or telescope) *

Only Left, Never Right

Left Preferred

No Preference

Right Preferred

Only Right , Never Left

A2).

INITIAL VISIT QUESTIONAIRE

Are you between the age of 18 to 65?*

O Yes

O NO

If Yes, Please indicate a range:

- **18-25**
- **26-35**
- **36-50**
- **51-65**

Have you ever experienced a learning difficulty or been enrolled in special education classes?

O Yes

O No

If yes, please explain:

If you are female; are you pregnant or do you think you could be pregnant?*

O Yes

O No

Do you have a cardiac pacemaker or had surgery involving implants to the head (cochlear implants, aneurysm clips or brain electrodes)?*

O Yes

O No

Do you have an allergy or sensitivity to latex?*

O Yes

O No

Have you ever participated in a tDCS research study?

O Yes

O No

Are you currently taking any anti-convulsnat or neuroleptic medications?

O Yes

O No

Have you ever been diagnosed with or thought you might have an attention deficit?

Yes

No

If yes, please explain:

Have you ever had a head injury?*

O Yes

O No

If so, did you lose consciousness for over 5 minutes?*

O Yes

O No

Have you ever had seizures, fainting spells, or migraines?*

O Yes

O No

If yes, please explain:

Have you been hospitalized for a possible psychological disorder in the last 6 months?*

O Yes

O No

Have you ever been diagnosed with any neurological or psychiatric disorders, such as:

1. Schizophrenia

2. Bipolar disorder

3. Major depression

4. Anxiety disorders

5. Substance use disorders

6. Epilepsy

7. Stroke

8. Encephalitis

9. Multiple Sclerosis

10. Parkinson's Disease

11. ALS (Lou Gehrig's disease)

12. Or any other neurological or psychiatric disorder that was not listed

Have you ever been treated (or thought you needed treatment) for alcohol or drug abuse?

O Yes

O No

If yes, please explain:

Are you currently taking any medications?

O Yes

O No

If yes, please list what and how much, including prescription or over-the-counter medicines,

pain relievers, oral contraceptives, herbal supplements, etc.

Do you wear glasses or contacts?*

Glasses

Contacts

Both

Neither

If yes, are you:

Nearsighted

Farsighted

Both

Do you have any visual problems not correctable by lenses, such as color blindness or astigmatism?*

O Yes

O No

Do you have any hearing loss that you are aware of?*

O Yes

O No

If yes, please explain:

Have you had any major surgeries or received long-term treatment for any illness?

O Yes

O No

If yes, please explain:

How many hours did you sleep last night?

What is your average amount of sleep per night?

If you drink caffeine- Have you consumed any today?

O Yes

O No

Have you used any illicit drugs (e.g. stimulants, opiates, hallucinogens) in last 24 hours?*

O Yes

O No

Have you consumed alcohol today?*

O Yes

O No

Do you regularly drink alcohol?

O Yes

O No

What is your primary language?*

List any other languages you speak fluently:

List any other languages you speak, but not fluently:

Do you play video games?

O Yes

O No

What is your dominant hand?*

O Left

O Right

O No Preference

A3).

Spelling List:

Absenteeism

Abysmal

Archaic

Belligerence

Bouillabaisse

Camaraderie

Chrysanthemum

Daiquiri

Disciplinarian

Elliptical

Etiquette

Phenomenon

Eligibility

Anesthesia

Affiliated

Pedagogical

Parsimonious

Oscillate

Martyrdom

Marshmallow

Limousine

Lieutenant

A4).

Mood/State Questionnaire

The words listed below describe different feelings and emotions. Read each item and indicate the extent to which you generally feel that way, that is, how you feel on the average.

interested

very slightly or not at all

a little

moderately

quite a bit

extremely

distressed

very slightly or not at all

a little

moderately

quite a bit

extremely

excited

very slightly or not at all

a little

moderately

quite a bit

extremely

upset

very slightly or not at all

a little

moderately

quite a bit

extremely

strong

very slightly or not at all

a little

moderately

quite a bit

extremely

guilty

very slightly or not at all

a little

moderately

quite a bit

extremely

scared

very slightly or not at all

a little

moderately

quite a bit

extremely

hostile

very slightly or not at all

a little

moderately

quite a bit

extremely

enthusiastic

very slightly or not at all

a little

moderately

quite a bit

extremely

proud

very slightly or not at all

a little

moderately

quite a bit

extremely

irritable

very slightly or not at all

a little

moderately

quite a bit

extremely

alert

very slightly or not at all

a little

moderately

quite a bit

extremely

ashamed

very slightly or not at all

a little

moderately

quite a bit

extremely

inspired

very slightly or not at all

a little

moderately

quite a bit

extremely

nervous

very slightly or not at all

a little

moderately

quite a bit

extremely

determined

very slightly or not at all

a little

moderately

quite a bit

extremely

attentive

very slightly or not at all

a little

moderately

quite a bit

extremely

jittery

very slightly or not at all

a little

moderately

quite a bit

extremely

active

very slightly or not at all

a little

moderately

quite a bit

extremely

afraid

very slightly or not at all

a little

moderately

quite a bit

extremely

A5).

tDCS Sensation Questionnaire

URSI____________________ Date____________ RA_______________

tDCS Sensation Questionnaire

Circle the number which best describes what you are feeling for the following descriptors using the following scale:

0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
None					**Moderate**					**Excessive**

Circle the number which best describes what you are feeling for the following descriptors:

Itching

0	1	2	3	4	5	6	7	8	9	10

Heat/Burning

0	1	2	3	4	5	6	7	8	9	10

Tingling

0	1	2	3	4	5	6	7	8	9	10

Other Sensations you are feeling:

____

____

Time Point____ Time_____________

Circle the number which best describes what you are feeling for the following descriptors:

Itching

0	1	2	3	4	5	6	7	8	9	10

Heat/Burning

0	1	2	3	4	5	6	7	8	9	10

Tingling

0	1	2	3	4	5	6	7	8	9	10

Other Sensations you are feeling:

____

____

Time Point____ Time__________

Circle the number which best describes what you are feeling for the following descriptors:

Itching

0	1	2	3	4	5	6	7	8	9	10

Heat/Burning

0	1	2	3	4	5	6	7	8	9	10

0	1	2	3	4	5	6	7	8	9	10

References

Adams, M. J. (1990). *Beginning to read: Thinking and learning about print*. Cambridge MA: MIT Press.

Caravolas, M., Hulme, C., Snowling, M. J. (2001). The foundations of spelling ability: Evidence from a 3-year longitudinal study. *Journal of Memory and Language, 45*, 751-774.

Carvalho, S., Boggio, P. S. et al. (2015). Transcranial direct current stimulation based metaplasticity protocols in working memory. *Brain Stimulation 8*(2), 289-294.

Clark, V.P., Coffman, B.A., Trumbo, M.C., Gasparovic, C. (2011). Transcranial direct current stimulation (tDCS) produces localized and specific alterations in neurochemistry: A 1H magnetic resonance spectroscopy study. *Neuroscience Letters* 500(1), 67-71.

Clark, V.P., Coffman, B.A., Mayer, A.R., Weisend, M.P., Lane, T.D.R., Calhoun, V.D., Raybourn, E.M., Garcia, C.M., Wassermann, E.M. (2012). TDCS guided using fMRI significantly accelerates learning to identify concealed objects. *NeuroImage* 59(1), 117-128.

Dehaene, S., Cohen, L. (2007). Cultural recycling of cortical maps. *Neuron, 56*, 384-399.

de Vries, M. H., Barth, A. R., Maiworm, S., Knecht, S., Zwitserlood, P., Flöel, A. (2010). Electrical stimulation of Broca's Area enhances implicit learning of an artificial grammar. *Journal of Cognitive Neuroscience, 22(11),* 2427–2436.

Duchaine, B. C., Nakayama, K. (2006). The Cambridge face memory test: Results for neurologically intact individuals and an investigation of its validity using inverted face stimuli and prosopagnosic participants. *Neuropsychologia*, *44*, 576-585.

Duchaine, B. C., Germine, L., Nakayama, K. (2007). Family resemblance: Ten family members with prosopagnosia and within-class object agnosia. *Cognitive Neuropsycholgy, 24(4)*, 419-43.

Ehri, L. C. (2000). Learning to read and learning to spell: Two sides of a coin. *Topics in Language Disorders, 20*(3), 19-36.

Fertonani, A., Brambilla, M., Cotelli, M., Miniussi, C. (2014). The timing of cognitive plasticity in physiological aging: A tDCS study of naming. *Frontiers in Aging Neuroscience, 6*, 131-139.

Floel, N., Rosser, O., Michka, S., Breitenstein, K. C. (2008). Noninvasive brain stimulation improves language learning. *Journal of Cognitive Neuroscience 20,* 1415-1422.

Fritsch, B., Reis, J., Martinowich, K., Schambra, H., Ji, Y., Cohen, L., Lu, B. (2011). Direct current stimulation promotes BDNF-dependent synaptic plasticity: Potential implications for motor learning. *Neuron 66*, 198-204.

Hartwigsen, G. (2005). The neurophysiology of language: Insights from non-invasive brain stimulation in the healthy human brain. *Brain & Language 148,* 81-94.

Holmes, V. M., Castles, A. (2001). Unexpectedly poor spelling in university students. *Scientific Studies in Reading, 5*, 319-350.

Ishikuro, K., Urakawa, S., Takamoto, K. (2014). Cerebral functional imaging using near-infrared spectroscopy during repeated performances of motor rehabilitation tasks tested on healthy subjects. *Frontiers in Human Neuroscience 8*(292), 1-13.

Javadi, A. H., Cheng, P., Walsh, V. (2012). Short duration transcranial direct current stimulation (tDCS) modulates verbal memory. *Brain Stimulation 5*(4), 468-474.

Khan, B., Hodics, T., Hervey, N., Kondraske, G., Stowe, A., Alexandrakis, G. (2013). Functional near-infrared spectroscopy maps cortical plasticity underlying altered motor performance induced by transcranial direct current stimulation. *Journal of Biomedical Optics 18*, 1160-1177.

Kleinschmidt, R., Cohen, E. (2006). Is the fusiform face area specialized for faces, individuation, or expert individuation? *Journal of Cognitive Neuroscience*, *16*(2), 189-203.

Kozak, G., Kincses, Z. T., Ivanyi, B., Buzsaki, G. (2018). Direct effects of transcranial electric stimulation on brain circuits in rats and humans. *Nature Communications 9*(483). 1-17

Liebetanz, D., Nitsche, M. A., Tergau, F., Paulus, W. (2002). Pharnacological approach to the mechanisms of transcranial DC stimulation-induced after-effects of human motor cortex excitability. *Brain 125*(10), 2238-2247.

Maughan, B., Messer, J., Collishaw, S., Pickles, A., Snowling, M., Yule, W., & Rutter, M. (2009). Persistence of literacy problems: Spelling in adolescence and at mid-life. *Journal of Child Psychology and Psychiatry 50(8)*, 893–901.

Medina, J., Cason, S. (2017). No evidential value in samples of transcranial direct current stimulation (tDCS) studies of cognition and working memory in healthy populations. *Cortex 94*, 131-141.

Meinzer, M., Antonenko, D., Lingenberg, R., Hetzer, S., Ulm, L., Avirame, K., Flaisch, T., Floel, A. (2012) Electrical brain stimulation improves cognitive performance by modulation functional connectivity and task-specific activation. *Journal of Neuroscience 32*, 1859-1866.

Merzagora, A., Foffani, G., Panyayin, I., Mordillo, L., Aguilar, J., Oraral, B., Oliviero, A. (2010). Prefrontal hemodynamic changes produced by anodal direct current stimulation. *Neuroimage 49*, 2304-2310.

Moats, L. C. (2005). How spelling supports reading: And why it is more regular and predictable

than you may think. *American Educator, Winter 05/06*, 12-43.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia 9*, 97-113.

Rapp, B., & Lipka, K., (2011). The literate brain: The relationship between spelling and reading. *Journal of Cognitive Neuroscience, 23*(5), 1180-1197.

Rohan, J., Carhuatanta, K., McInturf, S., Miklasevich, M., Jankord, R. (2015). Modulationg hippocampal plasticity with in vivo brain stimulation. *Journal of Neuroscience 35*(37), 12824-12832.

Utz, K.S., Dimova, V., Oppenlander, K. & Kerkhoff, G. (2010). Electrified minds: Transcranial

direct current stimulation (tDCS) and galvanic vestibular stimulation (GVS) as methods of non-invasive brain stimulation in neuropsychology—a review of current data and future implications. *Neuropsychologia*, *48*, 2789–2810.

Williams, K., Walker, M. (2017). A synthesis of reading and spelling interventions and their effects on spelling outcomes for students with learning disabilities. *Journal of Learning Disabilities*, *50*(3), 286-297.