Brain Stimulation 12 (2019) 1307–1308

Contents lists available at ScienceDirect

Brain Stimulation

journal homepage: http://www.journals.elsevier.com/brain-stimulation

Artificial grammar learning with transcranial direct current stimulation (tDCS): A pilot study

Dear Editor:

The relationship between attention and learning has been well-established [1], with many studies showing that increased attention can improve learning and decreased attention can be detrimental to learning. Although stroke-induced aphasia is defined as a primary language impairment, many persons with aphasia also have attention deficits [2]. Sustained attention, the ability to maintain attention to a stimulus for an extended period of time, is an important prerequisite for participating in speech and language therapy and has been shown to be impaired in persons with aphasia [2]. Even though there are clinical treatments that aim to help persons with aphasia recover their language ability, these treatments can take a long time before individuals show sufficient improvement [3].

Recent research suggests that transcranial direct current stimulation (tDCS) is a promising new approach to improve aphasia treatment outcomes [4–6]. However, current protocols require the addition of expensive functional neuroimaging to target specific brain regions that surround damaged brain areas, making it impractical for clinical use. An alternative approach is to target tDCS to areas of the brain that are less likely to be damaged in aphasia, but play a significant role in language and cognitive processing (e.g., prefrontal brain regions). Previous studies have shown that tDCS applied to dorsolateral prefrontal cortex (DLPFC) can improve attention in stroke participants [7] and that tDCS has been shown to enhance artificial grammar learning when applied to Broca's area [8]. Artificial grammar learning is a common paradigm for testing how grammatical knowledge is acquired [8]. We conducted a pilot study in healthy control participants to determine if anodal tDCS administered to left DLPFC and cathodal tDCS to right supraorbital area would improve performance on a sustained attention task and/or increase learning of an artificial grammar.

This research protocol was approved by the Syracuse University IRB and written consent was obtained for all participants prior to study enrollment. Syracuse University undergraduate students without neurological disorders were recruited ($N = 11$; $M_{age} = 21.18$; 54.5% female) and pseudorandomized to either an active or sham tDCS condition. To measure sustained attention, we used a Continuous Performance Task (CPT), in which a series of single letters are presented one at a time at the center of the screen and the participant presses a button for all letters except the target, 'X'. To measure artificial grammar learning, we used a 2-choice grammaticality judgement task asking about shape strings that were developed using the rules of the artificial grammar. The artificial grammar we used for this study was modified from a commonly used artificial grammar [9] and included strings of different colored shapes instead of letters. Both the CPT and the grammaticality judgement task were administered prior to and following our tDCS training period.

During each of three training sessions, participants were administered 20 minutes of behavioral attention training while active or sham anodal tDCS was delivered to left dorsolateral prefrontal cortex (DLPFC) and cathodal tDCS to right supraorbital area. Behavioral attention training consisted of a modified Stroop task [10] in which color words were written in different colored font (e.g., the word "red" written in blue font) and participants pushed a button to indicate the color of the font and ignore the word. Feedback on participant response accuracy was provided by an auditory signal that was generated for each error. After the initial 20 minutes of attention training, tDCS was discontinued and participants received 30 minutes of artificial grammar training. Artificial grammar training consisted of a matching task in which the participant was shown strings of shapes that followed rules of our artificial grammar and auditory feedback was provided on response accuracy.

Stimulation was administered at 2mA using an ActivaDoseII® tDCS device (Caputron) and 2″x2″ carbon rubber electrodes with saline-saturated sponges. The anode electrode was positioned over left hemisphere DLPFC (corresponding to F3 as defined by the international 10–20 EEG system) and the cathode electrode positioned over right supraorbital area (corresponding to Fp2). Participants who received sham tDCS had electrodes placed in the same locations, but current was ramped up to 2mA over the first minute to simulate sensation of tDCS and then slowly decreased down to zero. Participants and the research assistant administering the tDCS were blinded to the experimental condition. To do this, we used a custom-designed "blinding box" with an internal switch labeled generically as 'X' and 'Y'. Prior to each session, the PI informed the research assistant to switch the box to either 'X' or 'Y' without disclosing the corresponding condition. Due to a scheduling issue, the PI collected data for one subject and had knowledge of the tDCS condition (active tDCS), but the participant did not. At the end of the session, participants were asked what they felt or experienced during the stimulation period.

Given the small sample size of our pilot study, nonparametric statistics were used for data analysis. The dependent measures were accuracy on the grammaticality judgment task and accuracy on the CPT. When compared to expected performance on the accuracy of grammaticality judgment task (50% chance accuracy given a 2-choice task), accuracy in the active tDCS condition was significantly higher than chance ($p < .05$), whereas accuracy in the sham

https://doi.org/10.1016/j.brs.2019.07.002

Table 1
A) Accuracy on the artificial grammar grammaticality judgment task after training as compared to chance-level before training; B) Accuracy on the Continuous Performance Task of sustained attention after training as compared to accuracy of responses before training.

A	Artificial Grammar Judgment Task				
	Pre-Tx Accuracy (chance)	Post-Tx Accuracy	Confidence Interval	Chi sq value	p-value
Active tDCS	50%	70%	±8%	4.9	0.027*
Sham tDCS	50%	60%	±9%	2.5	0.114, ns
B	Continuous Performance Task (CPT)				
	Pre-Tx Accuracy	Post-Tx Accuracy	Confidence Interval	Wilcoxon test statistic	p-value
Active tDCS	77%	84%	±6%	15	0.042*
Sham tDCS	80%	84%	±11%	11	0.345, ns

tDCS condition did not differ from chance ($p = .11$) (Table 1A). For the CPT, there was a significant difference between median pre- and post-training scores ($p < .05$); accuracy for the active tDCS condition improved significantly from pre-to post-training ($p < .05$), but improvement for the sham tDCS condition was not significant ($p = .345$) (Table 1B). The effect on CPT performance appears to be driven at least partially by pre-training CPT score differences (lower initial scores for the active tDCS group); however, there was not a significant difference between pre-training CPT scores for the active and sham groups ($p = .537$). No participants reported adverse side effects following tDCS. All participants reported feeling a mild itching or burning sensation at the beginning of stimulation; we noted mild skin redness under the stimulation sites for three participants, which subsided within 30 minutes of electrode removal.

These preliminary data suggest that active anodal tDCS applied to left DLPFC and cathodal tDCS applied to right supraorbital area may have a positive effect on artificial grammar acquisition by improving attention. Our findings suggest that active tDCS applied using the same montage could have a similar effect when applied to participants with aphasia during language therapy. Although these results are encouraging, they should be interpreted with caution as we did not include an active control condition and our sample size was small and limited to healthy participants.

Conflicts of interest

The authors do not report any conflicts of interest related to this study.

Acknowledgments/Funding

This work was partially supported by a Syracuse University Neuroscience Summer Research Fellowship awarded to undergraduate student, Ying Wu, under the direction of the Principal Investigator, Ellyn Riley.

References

[1] Le Pelley ME, Mitchell CJ, Beesley T, George DN, Wills AJ. Attention and associative learning in humans: an integrative review. Psychol Bull 2016;142:1111–40. https://doi.org/10.1037/bul0000064.
[2] Villard S, Kiran S. To what extent does attention underlie language in aphasia? Aphasiology 2016:1–20. https://doi.org/10.1080/02687038.2016.1242711.
[3] Bhogal SK, Teasell R, Speechley M. Intensity of aphasia therapy, impact on recovery. Stroke 2003;34:987–93. https://doi.org/10.1161/01.STR.0000062343.64383.D0.
[4] Fridriksson J, Rorden C, Elm J, Sen S, George MS, Bonilha L. Transcranial direct current stimulation vs sham stimulation to treat aphasia after stroke: a randomized clinical trial. JAMA Neurol 2018:14260. https://doi.org/10.1001/jamaneurol.2018.2287.
[5] Lee SY, Cheon H-JH, Yoon KJ, Chang WH, Kim YY-H. Effects of dual transcranial direct current stimulation for aphasia in chronic stroke patients. Ann Rehabil Med 2013;37:603–10. https://doi.org/10.5535/arm.2013.37.5.603.
[6] Vines BW, Norton AC, Schlaug G. Non-invasive brain stimulation enhances the effects of melodic intonation therapy. Front Psychol 2011;2:1–10. https://doi.org/10.3389/fpsyg.2011.00230/abstract.
[7] Kang EK, Baek MJ, Kim S, Paik NJ. Non-invasive cortical stimulation improves post-stroke attention decline. Restor Neurol Neurosci 2009;27:645–50. https://doi.org/10.3233/RNN-2009-0514.
[8] de Vries MH, Barth ACRR, Maiworm S, Knecht S, Zwitserlood P, Flöel A. Electrical stimulation of Broca's area enhances implicit learning of an artificial grammar. J Cogn Neurosci 2010;22:2427–36. https://doi.org/10.1162/jocn.2009.21385.
[9] Reber AS. Implicit learning of artificial grammars. J Verb Learn Verb Behav 1967;6:855–63.
[10] Stroop JR. Studies of interference in serial verbal reactions. J Exp Psychol 1935;18:643–62. https://doi.org/10.1037/h0054651.

Ellyn A. Riley*, Ying Wu
SU Aphasia Lab, Department of Communication Sciences & Disorders, 621 Skytop Rd., Syracuse University, Syracuse, NY, 13244, USA

* Corresponding author. 621 Skytop Rd. Suite 1200, Syracuse, NY, 13244, USA.
E-mail address: earil100@syr.edu (E.A. Riley).

5 June 2019
Available online 2 July 2019