Title: Using transcranial direct current stimulation (tDCS) to treat persons with aphasia

Authors: Julie Baker, Ph.D. & Julius Fridriksson, Ph.D.

Department of Communication Sciences & Disorders
University of South Carolina

Corresponding author:
Julie M. Baker, Ph.D.
Department of Communication Sciences & Disorders
University of South Carolina
Tel: (843) 792-2712
Fax: (803) 777-3081
E-mail: bakerjm6@mailbox.sc.edu

Introduction

Recent research has revealed that increased left hemisphere (LH) cortical activity, primarily of the frontal cortex, is associated with greater naming accuracy in persons with aphasia (PWA).[1] Our aim was to determine if anodal transcranial direct current stimulation (A-tDCS), a noninvasive and safe method used to increase cortical excitability,[2,3] would improve naming accuracy in PWA when applied to the scalp overlying the left frontal cortex. In the present study, ten persons with chronic aphasia underwent two separate weeks of A-tDCS and sham tDCS (S-tDCS) while concurrently performing a computerized anomia treatment. During both types of tDCS, the active anode electrode was placed on the scalp overlying the frontal cortex. The location and polarity of the active electrode was chosen based on evidence demonstrating that increased activation in the LH, specifically of the left frontal cortex, was related to naming improvements in PWA.[1] Outcome measures included naming performance of both treated and untreated items following A-tDCS and S-tDCS. We hypothesized that multiple administrations of A-tDCS to the scalp overlying the left frontal cortex would improve naming accuracy in PWA by exciting the underlying cortex causing even greater cortical activation.

Materials & Methods

Participants

Ten persons (five females) with chronic, stroke-induced aphasia aged 45- to 81-years (M = 65.50; SD = 11.44) participated in the current study (Table 1), which was approved by the University of South Carolina's Institutional Review Board. Aphasia assessment using the *Western Aphasia Battery-Revised* (WAB-R)[4] revealed that six participants were classified with fluent aphasia, while the remaining four participants were classified with nonfluent aphasia (Table 2). Inclusion criteria were: 1) one-time stroke in the LH; 2) > 6-months post-stroke onset;

3) < 85-years of age; 4) pre-morbidly right-handed; 5) native English speaker; and 6) been a participant in a previous study that included functional magnetic resonance imaging (fMRI) examination, which was used to guide the location of cortical stimulation in the present study. Note: to allow for a blind review, this study is not referenced. Exclusion criteria were: 1) seizures during the previous 36-months; 2) sensitive scalp; 3) previous brain surgery; and 4) medications that raise the seizure threshold.

Design

Diagnostic testing was followed by electrode positioning, baseline naming tests, treatment administration, and post-treatment naming testing. The computerized anomia treatment, coupled with either A-tDCS or S-tDCS, was administered for five consecutive days followed by a seven-day rest period to avoid carry-over effects. Next, another five-day treatment period was administered, coupled with the remaining stimulation type.

Electrode Positioning

In order to locate the cortical region to be stimulated by the anode electrode, coordinates of the area of the left frontal cortex with the highest level of activation during correct naming on the previously completed fMRI naming task (Table 3) was located and demarcated on a latex cap worn by the participant. This cap was carefully fitted on the participant prior to the start of each tDCS administration in order to accurately position the anode electrode in the same area from one day to the next.

tDCS

tDCS (1 mA) was delivered for 20-min per session via two saline-soaked sponge electrodes (5 x 5 cm) and a constant current stimulator (Phoresor® II PM850; Iomed® Inc., Salt

Lake City, Utah) that was placed out of the participants' sight behind a partition. During both A-tDCS and S-tDCS, the active anode electrode was placed over the pre-designated area on the scalp overlying the left frontal cortex, while the reference cathode electrode was placed over the right shoulder (Figure 1). For S-tDCS, the stimulator was turned off following 30 s of stimulation since perceived sensations of tDCS on the skin have been found to fade away by the first 30 s of administration.[5] Thus, participants were blinded to stimulation type, which was counterbalanced among participants.

Anomia Treatment

The self-administered anomia treatment consisted of a picture-word matching task. This type of computerized treatment was utilized in a previous study and demonstrated to be useful in improving the naming abilities in PWA.[6] This treatment occurred concurrently with the application of tDCS and lasted for 20-min per session.

Treatment Stimuli

The computerized treatment included two separate word lists. Each word list was comprised of 25 color pictures depicting low-, medium-, and high-frequency nouns. The two word lists were controlled for word frequency,[7] semantic content, and word length. Word list order was counterbalanced among participants.

Outcome Measures

To determine whether the participants' ability to name the treated items improved over the course of each treatment phase, a computerized naming test consisting of the 25 treated nouns for each phase was administered at baseline, immediately following the fifth (and final) session of each treatment phase, and one-week following the final session of each treatment

phase to examine performance maintenance. To determine generalization from treated to untreated items, two additional untargeted word lists (one for each stimulation type) were administered. The untreated word lists were each comprised of 50 color pictures depicting low-, medium-, and high-frequency nouns. Similar to the treated word lists, the untreated word lists were controlled for word frequency,[7] semantic content, and word length.

Results

All participants tolerated tDCS well and no adverse effects related to the application of tDCS were demonstrated. Table 4 displays changes in the number of correctly named treated and untreated items between post-treatment testing and baseline testing following A-tDCS and S-tDCS. A 2x2 repeated measures ANOVA (stimulation, time) was conducted for the treated items. Analysis of the main effect of stimulation type revealed that statistically more treated items were named correctly following A-tDCS as compared to S-tDCS ($F(1,9) = 5.72$, $p < 0.040$). A 2x2 repeated measures ANOVA (stimulation, time) was conducted for the untreated items. Analysis of the main effect of stimulation type yielded a significant difference in the direction predicted by our hypothesis ($p < 0.037$), although this difference did not reach two-tailed statistical significance ($F(1,9) = 5.72$, $p < 0.073$).

Discussion

The results suggest that A-tDCS significantly improves naming accuracy in PWA. Additionally, this study demonstrated that improvements in naming performance were maintained for at least one-week post-treatment. These findings are in agreement with previous evidence demonstrating that A-tDCS over the LH improves language processing.[3,8,9] A wide range of treatment outcomes were revealed across participants; yet, treatment success was not

related to biographical factors (e.g., age, education level, lesion size, aphasia severity, and AOS severity) (Table 5). The participants who benefitted the most from A-tDCS all had frontal lobe damage, whereas most of the participants who showed less improvement tended to have posterior damage. This suggests that frontal lobe stimulation is most beneficial for participants with frontal lobe damage, whereas posterior stimulation may be more beneficial for those PWA who also present with primarily posterior damage.[10] Clearly, this latter speculation cannot be verified with the present data since our study only included frontal lobe stimulation.

In closing, this study provides further evidence suggesting that preserved regions of the LH are important for aphasia recovery. Moreover, these findings suggest that A-tDCS to the scalp overlying the left frontal cortex can significantly improve naming accuracy in some PWA and may provide a supplementary treatment approach for anomia.

References

1. Fridriksson J, Bonilha L, Baker JM, Moser D, Rorden C. Activity in preserved left hemisphere regions predicts anomia severity in aphasia. Cereb Cortex 2009; In Press.
2. Higgins ES, George MS. Brain Stimulation Therapies for Clinicians. Washington, DC: American Psychiatric Press; 2008.
3. Iyer MB, Mattu U, Grafman J, Lomarev M, Sato S, Wasserman EM. Safety and cognitive effect of frontal DC brain polarization in healthy individuals. Neurology 2005; 64: 872–875.
4. Kertesz A. Western Aphasia Battery-Revised. San Antonio: Harcourt Assessment, Inc; 2007.
5. Paulus W. Transcranial direct current stimulation (tDCS). Suppl Clin Neurophysiol 2003; 56: 249-254.
6. Fridriksson J, Baker JM, Whiteside J, Eoute D, Moser D, Vesselinov R, Rorden C. Treating visual speech perception to improve speech production in nonfluent aphasia. Stroke 2009b; 40: 853-858.
7. Frances WN, Kucera H. Frequency Analysis of English Usage. Boston: Houghton Mifflin; 1982.
8. Flöel A, Rösser N, Michka O, Knecht S, Breitenstein C. Non-invasive brain stimulation improves language learning. J Cogn Neurosci 2008; 20: 1415-1422.
9. Hesse S, Werner C, Schonhardt EM, Bardeleben A, Jenrich W, Kirker SG. Combined transcranial direct current stimulation and robot-assisted arm training in subacute stroke patients: a pilot study. Restor Neurol Neurosci 2007; 25: 9–15.
10. Davis GA. Aphasiology: Disorders and clinical practice. Needham Heights, MA: Allyn and Bacon; 2000.

Table 1. Biographical information and lesion description

P	Sex	Age[*]	Education[*]	Post-Stroke Onset[†]	Lesion Location[‡]	Lesion Size[§]
1	M	60	16	64	Damage involves BA 44, BA 45, anterior portion of BA 38, and the middle and anterior insula	87.42
2	M	53	12	57	Damage involves BA 22, BA 39, BA 40, BA 42, and the posterior portion of BA 38	23.57
3	F	45	14	60	Complete destruction of BA 44, BA 45, and middle and inferior portions of BA 6, as well as damage to BA 22, BA 40, and BA 42	56.76
4	F	75	12	10	Damage involves portions of BA 22, BA 41, BA 42, and inferior portion of BA 40	8.45
5	M	58	12	14	Damage involves BA 45, BA 48, the anterior insula, and putamen, only minor involvement of BA 44	48.39
6	F	64	16	102	Damage involves BA 6, BA 44, BA 48, BA 38, and insula, deep white matter involvement including the pyramidal tract	56.23
7	F	71	18	44	Damage mostly involving BA 37 and inferior portion of the left precuneus	40.49
8	M	72	12	242	Entire MCA distribution and portions of the anterior medial frontal lobe; basal ganglia involvement	342.2
9	F	81	16	14	Damage mostly involves middle and posterior portions of the temporal lobe (BA 20, BA 21, BA 22, BA 37, BA 39) with extension into the occipital lobe	48.92
10	M	76	12	39	Damage involves posterior portion of BA 21 as well as BA 22, BA 37, and BA 39	29.13
M		65.50	14.00	64.60		74.15
SD		11.44	2.31	68.42		96.60

[*]Measured in years

[†]Measured in months

[‡]BA: Brodmann's area

[§]Measured in cc^3

Table 2. Diagnostic testing information

P	*Western Aphasia Battery-Revised*						
	Content [*]	Fluency [*]	Auditory Comprehension [*]	Repetition [*]	Naming [*]	AQ[†]	Aphasia Type
1	8	4	8.65	7.7	7.7	72.1	Broca's
2	9	8	9.75	9.5	8.6	89.7	Anomic
3	7	4	7.15	3.1	4.7	51.9	Broca's
4	10	9	9.95	9.0	8.8	93.5	Anomic
5	9	9	10	9.4	8.6	92.0	Anomic
6	2	1	9.85	0.30	0	26.3	Broca's
7	9	9	9.85	9.8	8.3	91.9	Anomic
8	2	1	5.05	3.7	2.0	27.5	Broca's
9	7	7	7.05	7.2	5.6	67.8	Anomic
10	9	9	8.15	6.5	7.8	80.9	Anomic

[*]Maximum score of 10

[†]AQ: Aphasia Quotient; Maximum score of 100

Table 3. Coordinates and location of voxels with the highest Z-scores associated with correct naming/location of the anode electrode

P	x*	y*	z*	Location†	BA‡
1	-39	-15	60	Precentral gyrus	6
2	-55	-4	12	Precentral gyrus	6
3	-36	52	-4	Middle frontal gyrus	10
4	-48	-4	46	Precentral gyrus	6
5	-44	6	44	Precentral gyrus	6
6	-28	46	14	Middle frontal gyrus	46
7	-54	20	10	Inferior frontal gyrus	45
8	-12	46	30	Superior frontal gyrus	9
9	-52	16	16	Inferior frontal gyrus	44
10	-60	2	12	Precentral gyrus	6

*x, y, & z: Montreal Neurological Institute coordinates

†Anatomical locations were determined using the Talairach Daemon (www.talairach.org)

‡BA: Brodmann's area

Table 4. Change in the number of correctly named treated and untreated items between post-treatment testing and baseline testing following anodal tDCS (A-tDCS) and sham tDCS (S-tDCS)

P	Immediate Post-Treatment > Baseline				1-Week Post-Treatment > Baseline			
	A-tDCS Treated Items	*S-tDCS Treated Items*	*A-tDCS Untreated Items*	*S-tDCS Untreated Items*	*A-tDCS Treated Items*	*S-tDCS Treated Items*	*A-tDCS Untreated Items*	*S-tDCS Untreated Items*
1	5	0	17	-2	8	-2	10	1
2	5	4	6	1	3	2	9	-1
3	10	10	3	-1	5	5	5	0
4	1	0	1	2	1	0	1	2
5	6	0	6	-1	6	-2	2	0
6	0	0	0	0	0	0	0	0
7	1	1	1	1	1	0	1	-1
8	2	2	2	-1	3	0	3	-1
9	3	-3	-1	2	5	2	1	6
10	3	1	5	2	3	6	10	9
Total	**36**	**15**	**40**	**3**	**35**	**11**	**42**	**15**

Table 5. Correlations matrix for treatment outcome (change scores) and biographical information. None of the relationships reached significance ($p < 0.05$).

	Age[*]	**Education**[*]	**Post-onset**[†]	**Lesion size**[‡]	**Aphasia severity**[§]	**AOS severity**[‖]
Treated items	-0.613	-0.152	-0.182	-0.030	0.126	0.306
Untreated items	-0.402	-0.175	-0.043	-0.049	0.252	0.233
Total items[#]	-0.535	-0.186	-0.105	-0.048	0.229	0.290

[*] Measured in years

[†] Measured in months

[‡] Measured in cc^3

[§] Measured by the Aphasia Quotient from the *Western Aphasia Battery-Revised*

[‖] AOS: Apraxia of speech; measured by Subset 6 from the *Apraxia Battery for Adults-Second Edition*

[#] Treated and untreated items combined

Figure 1. Example of the treatment set-up. Participants trained on a computerized picture-word matching task (a) while receiving transcranial direct current stimulation (tDCS). During both anodal tDCS and sham tDCS treatment phases, the anode electrode (b) was placed over the pre-designated area on the scalp overlying the left frontal cortex, while the reference cathode electrode (c) was placed over the right shoulder. The constant current stimulator (d) was placed out of the participants' sight behind a partition.