Using Transcranial Direct-Current Stimulation to Treat Stroke Patients With Aphasia

Julie M. Baker, PhD; Chris Rorden, PhD; Julius Fridriksson, PhD

Background and Purpose—Recent research suggests that increased left hemisphere cortical activity, primarily of the left frontal cortex, is associated with improved naming performance in stroke patients with aphasia. Our aim was to determine whether anodal transcranial direct-current stimulation (tDCS), a method thought to increase cortical excitability, would improve naming accuracy in stroke patients with aphasia when applied to the scalp overlying the left frontal cortex.

Methods—Ten patients with chronic stroke-induced aphasia received 5 days of anodal tDCS (1 mA for 20 minutes) and 5 days of sham tDCS (for 20 minutes, order randomized) while performing a computerized anomia treatment. tDCS positioning was guided by a priori functional magnetic resonance imaging results for each individual during an overt naming task to ensure that the active electrode was placed over structurally intact cortex.

Results—Results revealed significantly improved naming accuracy of treated items ($F[1,9]=5.72, P<0.040$) after anodal tDCS compared with sham tDCS. Patients who demonstrated the most improvement were those with perilesional areas closest to the stimulation site. Crucially, this treatment effect persisted at least 1 week after treatment.

Conclusions—Our findings suggest that anodal tDCS over the left frontal cortex can lead to enhanced naming accuracy in stroke patients with aphasia and, if proved to be effective in larger studies, may provide a supplementary treatment approach for anomia. (Stroke. 2010;41:1229-1236.)

Key Words: anomia • brain stimulation • functional magnetic resonance imaging • neuronal plasticity • recovery of function

A relation between aphasia recovery and functional brain changes of the damaged left hemisphere (LH) has recently been demonstrated.1,2 More specifically, in a review of functional neuroimaging studies investigating treatment-induced aphasia recovery, improved speech production was found to be dependent on left frontal cortical activation.3 Another recent study revealed that increased cortical activity in preserved LH areas, particularly the frontal cortex, is associated with greater naming accuracy in patients with aphasia (PWAs).4 These studies are based on observations of brain activation, however, and are generally interpreted as supporting the notion that intact regions of the LH play a crucial role in aphasia recovery. Our aim was to test this prediction by manipulating (rather than merely observing) activation of the left frontal cortex through the application of transcranial direct-current stimulation (tDCS), a noninvasive, safe, and relatively painless method for modulating cortical activity. tDCS delivers a weak polarizing electric current to the cortex through a pair of electrodes, and, depending on the polarity of the current flow, brain excitability can be either increased by anodal stimulation (A-tDCS) or decreased by cathodal stimulation (C-tDCS).5

Previous work suggests that tDCS can modulate linguistic performance in both healthy individuals and neurology patients, with results typically demonstrating that language processing can be improved by applying A-tDCS to the LH.6–8 However, recent work by Monti and colleagues9 challenged such a simple interpretation in which C-tDCS (2 mA for 10 minutes) applied to Broca’s area resulted in an improved ability to name pictures in 8 patients with chronic nonfluent aphasia; no effects were noted after A-tDCS or sham (placebo-like) tDCS (S-tDCS). We suggest 3 reasons that may help demonstrate why A-tDCS led to a null result. First, electrodes were placed on the same scalp coordinate for each patient, regardless of aphasia type or severity. Consequently, it is quite probable that the targeted region might not have been intact in some if not all patients. Second, there was only a single, brief administration of tDCS. Finally, patients were not asked to perform a language task during the tDCS session, whereas other previous studies that found effects after A-tDCS coupled the stimulation with a relevant task to engage the brain area.6,10 Therefore, although the main goal of the present study was to determine whether A-tDCS would improve naming accuracy in PWAs when applied to the left frontal cortex, the study was also designed to address the methodological limitations from the recent work by Monti and colleagues9 and to therefore incorporate the following
characteristics: (1) optimized electrode positioning, (2) multiple administrations of tDCS, and (3) a combined linguistic task.

In the present study, 10 patients with chronic aphasia underwent 2 separate weeks (5 days per week) of A-tDCS (1 mA for 20 minutes) and S-tDCS (20 minutes) while concurrently performing a computerized anomia treatment. During both types of tDCS, the active electrode was placed on the scalp overlying the left frontal cortex and the reference electrode was placed on the right shoulder. The location and polarity of the active electrode were chosen on the basis of the previously discussed evidence demonstrating that increased activation in the LH, specifically of the left frontal cortex, was related to naming improvements in PWAs.4 Outcome measures included naming performance of both treated and untreated items after 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 PWAs by exciting the underlying cortex, causing even greater cortical activation.

Patients and Methods

Patients

Ten patients (5 female) with chronic, stroke-induced aphasia age 45 to 81 years (mean±SD, 65.50±11.44) participated in the current study, which was approved by the University of South Carolina’s Institutional Review Board. Patients varied greatly with regard to time after stroke onset, lesion location, and extent of brain damage (Table 1). For instance, the range of time after stroke onset was 10 to 242 months (mean±SD, 64.60±68.42). Additionally, the patients varied with regard to their performance on diagnostic measures. Aphasia assessment with the Western Aphasia Battery-Revised (WAB-R)11 revealed that 6 (P2, P4, P5, P7, P9, and P10) of the 10 patients were classified with fluent aphasia, whereas the remaining 4 (P1, P3, P6, and P8) were classified with nonfluent aphasia. The WAB-R also yields a composite score, the Aphasia Quotient, which provides an overall measure of severity, in which lower scores denote more severe aphasia, and a score $>93.8$ is considered to be within normal limits. Aphasia Quotient scores in the current study ranged from 26.3 to 93.5 (mean±SD, 69.36±25.97). Additionally, subtest 6 (Inventory of Articulation Characteristics) of the Apraxia Battery for Adults-Second Edition12 revealed that 5 patients (P1, P2, P3, P6, and P8) presented with apraxia of speech (AOS; Table 2). Thus, we suggest that the current patient sample was ideal for an exploratory study, as it included a group with a wide range of aphasia severity and varying biographical and lesion demographics. Specific inclusion criteria were as follows: (1) 1-time stroke in the LH, (2) $>6$ months after stroke onset, (3) $<85$ years of age, (4) premorbidly right-handed, (5) native English speaker, and (6) participant in a previous study that included functional MRI (fMRI) examination, which was used to guide the location of cortical stimulation in the present study. All 15 patients from the previous fMRI study4 were considered for participation in the current study, but only 10 patients were able to participate. As for those patients not included, 4 had relocated out of state and 1 was unable to fit the study schedule, which included full-time employment. Exclusion criteria were as follows: (1) seizures during the previous 36 months, (2) sensitive scalp, (3) previous brain surgery, and (4) medications that raise the seizure threshold.

Table 1. Biographical Information and Lesion Description

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age, y</th>
<th>Education, y</th>
<th>Poststroke Onset, mo</th>
<th>Damage involves BA 44, BA 45, anterior portion of BA 38, and middle and anterior insulae</th>
<th>Lesion Location</th>
<th>Lesion Size, cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>60</td>
<td>16</td>
<td>64</td>
<td>Damage involves BA 22, BA 39, BA 40, and posterior portion of BA 38</td>
<td></td>
<td>56.23</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>53</td>
<td>12</td>
<td>57</td>
<td>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</td>
<td></td>
<td>8.45</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>45</td>
<td>14</td>
<td>60</td>
<td>Damage involves portions of BA 22, BA 41, BA 42, and inferior portion of BA 40</td>
<td></td>
<td>48.39</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>75</td>
<td>12</td>
<td>10</td>
<td>Damage involves BA 45, BA 48, the anterior insula, and putamen; only minor involvement of BA 44</td>
<td></td>
<td>74.15</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>58</td>
<td>12</td>
<td>14</td>
<td>Damage involves BA 6, BA 44, BA 48, BA 38, and insula; deep white matter involvement including the pyramidal tract</td>
<td></td>
<td>56.23</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>64</td>
<td>16</td>
<td>102</td>
<td>Damage mostly involving BA 37 and inferior portion of the left precuneus</td>
<td></td>
<td>93.8</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>71</td>
<td>18</td>
<td>44</td>
<td>Damage to entire middle cerebral artery distribution and portions of the anterior medial frontal lobe; basal ganglia involvement</td>
<td></td>
<td>342.2</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>72</td>
<td>12</td>
<td>242</td>
<td>Damage mostly involves middle and posterior portions of the temporal lobe (BA 20, BA 21, BA 22, BA 37, and BA 39) with extension into the occipital lobe</td>
<td></td>
<td>29.13</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>81</td>
<td>16</td>
<td>14</td>
<td>Damage mostly involves BA 44, anterior portion of BA 38, and middle of BA 38, anterior portion of BA 39, and BA 21 as well as BA 22, BA 37, and BA 39</td>
<td></td>
<td>74.15</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>76</td>
<td>12</td>
<td>39</td>
<td>Damage to entire BA 38, BA 44, and BA 45; deep white matter involvement including the pyramidal tract</td>
<td></td>
<td>56.23</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>65.50</td>
<td>14.00</td>
<td>64.60</td>
<td></td>
<td></td>
<td>96.60</td>
</tr>
</tbody>
</table>

BA indicates Brodmann’s area.
Study Design

Diagnostic testing was followed by electrode positioning, baseline naming tests, treatment administration, and posttreatment naming testing. The computerized anomia treatment, coupled with either A-tDCS or S-tDCS, was administered for 5 consecutive days followed by a 7-day rest period to avoid carry-over effects. Next, another 5-day treatment period was administered, coupled with the remaining stimulation type. Whereas previous research revealed an improvement in naming among aphasic patients after a single tDCS session, the current study design reflected evidence suggesting that multiple treatment sessions are associated with improved outcome in aphasia. Hence, a total of 5 consecutive days were devoted to each treatment phase. We chose to administer 5 treatment sessions per phase on the basis of previous findings in which some aphasic patients showed improved picture naming after as few as 5 sessions with our computerized anomia treatment task, as well as after 5 treatment sessions of clinician-administered anomia treatment in a separate study.

The stimulation and treatment task combination lasted for 20 minutes in each session, a time based on previous tDCS research that demonstrated that tDCS administration is safe for up to 20 minutes. Finally, a stimulation intensity of 1 mA was chosen, given that no significant adverse effects have been reported at this intensity. To assess cardiovascular arousal, blood pressure and heart rate were measured before and after each session. Additionally, discomfort ratings were recorded after the end of each session on the Wong-Baker FACES Pain Rating Scale, a visual description scale designed for patients with limited verbal skills.

fMRI Task and Procedure

Previously acquired high-resolution T1 MRI and fMRI results associated with an overt picture-naming task were used to determine placement of the anode electrode on a patient-by-patient basis. MRI data collection relied on a Siemens Trio 3T system. For details on the placement of the anode electrode on a patient-by-patient basis, see Fridriksson et al. The location of voxels with the highest scores in the left frontal cortex associated with correct naming for each patient is listed in Table 3. These coordinates were targeted for placement of the anode electrode.

Electrode Positioning

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 were entered into MRIreg, a computer program that allows for identification of a region of the scalp near a particular brain region (available at www.mricro.com/mrireg.html). Using MRIreg and a magnetic positioning tracker system (Flock of Birds; Ascension Technology, Burlington, Vt), we located and demarcated the desired cortical region on a latex cap worn by the patient. This cap was carefully fitted on the patient before the start of each tDCS administration to accurately position the anode electrode in the same area from 1 day to the next. After the cap was positioned, it was removed and the electrodes were held in place with self-adhesive bandages. This was accomplished on a patient-by-patient basis and was therefore tailored for each individual to ensure that the active electrode was placed over structurally intact rather destroyed cortex.

Transcranial Direct-Current Stimulation

tDCS (1 mA) was delivered for 20 minutes per session with 2 saline-soaked, sponge electrodes (5 × 5 cm) and a constant-current stimulator (Phoresor II PM850; Iomed, Salt Lake City, Utah) that was placed out of the patients’ sight behind a partition. During both A-tDCS and S-tDCS, the anode electrode was placed over the predesignated area on the scalp overlying the left frontal cortex. To avoid potential confounding factors arising from placing electrodes

Table 3. Coordinates and Location of Voxels With the Highest Z-Scores Associated With Correct Naming/Location of the Anode Electrode

<table>
<thead>
<tr>
<th>Patient</th>
<th>x*</th>
<th>y*</th>
<th>z*</th>
<th>Location†</th>
<th>BA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>−39</td>
<td>−15</td>
<td>60</td>
<td>Precentral gyrus 6</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>−55</td>
<td>−4</td>
<td>12</td>
<td>Precentral gyrus 6</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>−36</td>
<td>52</td>
<td>−4</td>
<td>Middle frontal gyrus 10</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>−48</td>
<td>−4</td>
<td>46</td>
<td>Precentral gyrus 6</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>−44</td>
<td>6</td>
<td>44</td>
<td>Precentral gyrus 6</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>−28</td>
<td>46</td>
<td>14</td>
<td>Middle frontal gyrus 46</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>−54</td>
<td>20</td>
<td>10</td>
<td>Inferior frontal gyrus 45</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>−12</td>
<td>46</td>
<td>30</td>
<td>Superior frontal gyrus 9</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>−52</td>
<td>16</td>
<td>16</td>
<td>Inferior frontal gyrus 44</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>−60</td>
<td>2</td>
<td>12</td>
<td>Precentral gyrus 6</td>
<td></td>
</tr>
</tbody>
</table>

*BA indicates Brodmann’s area.
*x, y, and z are Montreal Neurological Institute coordinates.
†Anatomic locations were determined from the Talairach Daemon (www.talairach.org).
Patients were randomly assigned to stimulation by using a random-sequence algorithm during the first week and then proceeded to S-tDCS during the second week, while the other half received the opposite order. Each word list comprised 25 color pictures depicting low-, medium-, and high-frequency nouns. Similar to the treated word lists, the untreated word lists were controlled for word frequency, semantic content, and word length. The treated and untreated word lists were combined (treated list A was combined with untreated list A and vice versa for list B) during testing to equal 75 items. Pictures representing each item were displayed on a laptop computer screen, and patients were asked to overtly name each picture as soon as it was displayed. Responses were audiorecorded and later transcribed and scored by 2 speech-language pathologists who were blinded to the stimulation type (A-tDCS vs S-tDCS). administration attempt (baseline vs T1 vs T2), and type of item (treated vs untreated). In cases of disagreement, a third speech-language pathologist, who was also blinded, made tie-breaking decisions.

Statistics
To examine the effect of tDCS on treatment outcome, a $2 \times 2$ repeated-measures ANOVA was performed for both treated and untreated items with stimulation type (A-tDCS, S-tDCS) and time (T1, T2) as factors. Note that treatment outcome was determined as the change in correct naming at the end of treatment compared with baseline. Additional $2 \times 2$ repeated-measures ANOVAs were performed to determine the influence of stimulation order on treatment outcome for both treated and untreated words, as well as to determine the influence of the 2 sets of word lists that were used for treatment and testing for both treated and untreated items. All ANOVAs were performed with ezANOVA (available at www.mricro.com/ezanova). Changes in blood pressure and heart rate before and after tDCS administration as well as discomfort ratings were compared between both tDCS conditions with Mann–Whitney U tests. Finally, correlation analyses were performed to examine the relations between treatment outcome and patient demographics, which were executed, along with the Mann–Whitney U tests, with the SPSS version 15.0 software package (SPSS, Inc, Chicago, Ill).

Results
All patients tolerated the tDCS well, and no adverse effects related to the application of tDCS were demonstrated. All patients completed both treatment phases and all accompanying testing sessions. The total number of treatment and testing sessions was 17 per patient, including 1 diagnostic testing session, 6 testing sessions, and 10 treatment sessions.

Treated Items
During A-tDCS, the mean number of correctly named treated items was 14.2 of 25 (SD=8.69; range, 0–24) at baseline, 17.8 of 25 (SD=9.44; range,0–25) at T1, and 17.7 of 25 (SD=9.07; range, 0–25) at T2. After A-tDCS treatment, the total increase in correct naming responses for the entire group was 36 treated items at T1 and 35 treated items at T2. During S-tDCS, the mean number of correctly named treated items was 14.1 of 25 (SD=9.79; range, 0–25) at baseline, 15.6 of 25 (SD=9.81; range, 0–25) at T1, and 15.2 of 25 (SD=9.53; range, 0–25) at T2. After S-tDCS treatment, the total increase in correct naming responses for the entire group was 15 items at T1 and 11 items at T2 (Table 4). A $2 \times 2$ 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 after A-tDCS than after S-tDCS (F[1,9]=5.72, 2-tailed P<0.040). To estimate the magnitude of this statistically significant effect, we used the generalized eta squared as suggested for repeated-measures designs by Olejnik and Algina, in which a medium effect size (0.140) was found. Neither the analysis of the main effect of time (F[1,9]=0.116,
During S-tDCS, the mean number of correctly named untreated items was 27.3 of 50 (SD = 18.25; range, 0–48) at T2. After S-tDCS treatment, the total increase in correct naming responses for the entire group was 40 untreated items at T1 and 42 untreated items at T2 (t9 = 2.60, P < 0.015; t9 = 1.95, P < 0.042).

**Treatment Generalization**

During A-tDCS, the mean number of correctly named untreated items was 27.3 of 50 (SD = 17.15; range, 0–47) at baseline, 31.3 of 50 (SD = 18.35; range, 0–48) at T1, and 31.5 of 50 (SD = 18.25; range, 0–48) at T2. After A-tDCS treatment, the total increase in correct naming responses for the entire group was 40 untreated items at T1 and 42 untreated items at T2. During S-tDCS, the mean number of correctly named untreated items was 28.6 of 50 (SD = 18.18; range, 0–48) at baseline, 28.9 of 50 (SD = 18.63; range, 0–50) at T1, and 30.1 of 50 (SD = 18.36; range, 0–50) at T2. After S-tDCS treatment, the total increase in correct naming responses for the entire group was 3 items at T1 and 15 items at T2 (Table 4). A 2 × 2 repeated-measures ANOVA (stimulation, time) did not reach 2-tailed statistical significance (F[1,9] = 5.72, P < 0.073). As with treated items, we performed a post hoc analysis consistent with our prediction that tDCS leads to improved naming performance compared with sham. Accordingly, we conducted planned (uncorrected) 1-tailed t-tests that revealed a benefit from tDCS versus sham at both T1 and T2 (t9 = 1.90, P < 0.045; t9 = 1.89, P < 0.046). To estimate the magnitude of this effect, we used generalized eta squared,21 in which a medium effect size (0.167) was revealed. Neither the analysis of the main effect of time (F[1,9] = 0.880, P < 0.373) nor the analysis of the interaction (stimulation, time) reached statistical significance (F[1,9] = 0.584, P < 0.464).

**Correlations**

Multiple correlations were performed to examine the relation between naming performance after A-tDCS treatment and the following variables: (1) age, (2) years of education, (3) months after stroke onset, (4) lesion size measured in cubic centimeters, (5) aphasia severity as measured by the Aphasia Quotient from the WAB-R, and (6) AOS severity as measured by the Apraxia Battery for Adults-Second Edition. No significant (P < 0.05) relations were revealed (Table 5).

**Treatment Order**

To determine whether the order of stimulation affected treatment outcome, a 2 × 2 repeated-measures ANOVA (order of treatment, time) was performed and revealed that an order effect was not present for the treated items (F[1,9] = 0.116, P < 0.742) or untreated items (F[1,9] = 0.880, P < 0.373).

### Table 4. Change in the Number of Correctly Named Treated and Untreated Items Between Posttreatment Testing and Baseline Testing After A-tDCS and S-tDCS

<table>
<thead>
<tr>
<th>Patient</th>
<th>Immediate Posttreatment &gt;Baseline</th>
<th>1 Week Posttreatment &gt;Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-tDCS Treated Items</td>
<td>S-tDCS Treated Items</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>−3</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>15</td>
</tr>
</tbody>
</table>

This table shows the change in the number of correctly named treated and untreated items between posttreatment testing and baseline testing after A-tDCS and S-tDCS. The data are presented as the number of items from baseline to immediate posttreatment and then to 1 week posttreatment for each patient, separated by treatment type (A-tDCS or S-tDCS). The data are presented for both treated and untreated items.

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### Table 5. Correlation Matrix for Treatment Outcome (Change Scores) and Biographical Information

<table>
<thead>
<tr>
<th>Age, y</th>
<th>Education, y</th>
<th>Poststroke Onset, mo</th>
<th>Lesion Size, cm³</th>
<th>Aphasia Severity*</th>
<th>AOS Severity†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated items</td>
<td>−0.613</td>
<td>−0.152</td>
<td>−0.182</td>
<td>−0.030</td>
<td>0.126</td>
</tr>
<tr>
<td>Untreated items</td>
<td>−0.402</td>
<td>−0.175</td>
<td>−0.043</td>
<td>−0.049</td>
<td>0.252</td>
</tr>
<tr>
<td>Total items‡</td>
<td>−0.535</td>
<td>−0.186</td>
<td>−0.105</td>
<td>−0.048</td>
<td>0.229</td>
</tr>
</tbody>
</table>

AOS indicates apraxia of speech.

None of the relations reached significance (P > 0.05).

*Measured by the Aphasia Quotient from the Western Aphasia Battery-Revised.

†Measured by subtest 6 from the Apraxia Battery for Adults-Second Edition.

‡Treated and untreated items combined.
Word Lists
To determine whether the word lists differed in difficulty, a 2×2 repeated-measures ANOVA (list, time) was performed. No difference in treatment outcome between the usage of list A and list B was found for the treated items (F[1,9]=2.41, P<0.155) or untreated items (F[1,9]=0.844, P<0.382).

Blood Pressure and Heart Rate
Changes in blood pressure and heart rate from before to after tDCS administration were calculated to determine whether the measures were comparable in both tDCS conditions. Mann–Whitney U tests revealed that changes in systolic blood pressure (P<0.812), diastolic blood pressure (P<0.948), and heart rate (P<0.641) from before to after tDCS administration did not differ between A-tDCS and S-tDCS.

Discomfort Ratings
Patient discomfort ratings ranged between 0 and 2 of 5 (mean±SD, 0.24±0.56) during A-tDCS and ranged between 0 and 2 of 5 (mean±SD, 0.12±0.39) during S-tDCS. Statistical analysis revealed that the discomfort ratings were comparable between A-tDCS and S-tDCS (Mann–Whitney U, P<0.477), indicating that patients did not report a difference in comfort level between the 2 conditions.

Discussion
To better understand the effect of tDCS on aphasia recovery, the present study included 10 patients with chronic, stroke-induced aphasia, each of whom underwent 5 sessions of A-tDCS (1 mA for 20 minutes) and 5 sessions of S-tDCS (20 minutes) combined with a computerized anomia treatment. The results suggest that A-tDCS significantly improves naming accuracy in PWAs. Explicitly, statistically more treated items were named correctly after A-tDCS compared with after S-tDCS, and numerically more untreated items were named correctly after A-tDCS than after S-tDCS. Additionally, this study demonstrated that improvements in naming performance were maintained for at least 1 week after treatment. These findings are in agreement with previous evidence demonstrating that A-tDCS over the LH improves language processing.6–8

The difference in treatment outcome between A-tDCS and S-tDCS could not be explained by nonspecific arousal differences, as changes in the patients’ blood pressure and heart rate recordings from before to after tDCS administrations were found to be comparable across both tDCS conditions. Furthermore, differences could not be explained by scalp sensation attributed to the different stimulation types, as patients did not report a difference in their comfort levels between A-tDCS and S-tDCS. Finally, differences could not be attributed to the order of stimulation type or word list difficulty, as an order effect was not revealed between A-tDCS and S-tDCS, nor was a difference revealed for the difficulty level between words lists A and B.

Various observations can help explain why A-tDCS over a region of the left frontal cortex improves the naming abilities in PWAs. Primarily, this region has been revealed to be exceedingly important for aphasia recovery. For instance, a recent fMRI study investigated the activation of both hemispheres in 15 patients with chronic aphasia during an overt picture-naming task. The results revealed a positive linear relation between intensity of activation of the LH, especially the left frontal cortex, and naming accuracy in PWAs.4 Results from the present study reinforce this finding, as it suggests that improved naming in PWAs is supported by the left frontal cortex. Thus, because A-tDCS increases cortical excitability, it presumably improved the patients’ ability to name pictures by focally stimulating function of the left frontal cortex. Similar to the present research, other studies have implicated the LH in aphasia recovery, and although the specific cortical location may vary, it is probable that improved speech and language functioning after aphasia treatment relies, at least partly, on spared LH regions.1–4 It is important to note, however, that the present results do not discount the role of the right hemisphere in aphasia recovery, as several studies have revealed that right hemisphere regions reflect a compensatory network.22,23 Therefore, it may be possible that the positive treatment outcome revealed in the current study after A-tDCS to the left frontal cortex may be specific to naming improvements and that administration of A-tDCS to other areas of the LH and possibly even to the right hemisphere may improve the performance of other linguistic functions in PWAs.

Although the current study revealed a statistically significant enhancement after A-tDCS, individual patients exhibited a wide range of treatment outcomes. Understanding this variability may be important in optimizing treatment and justifying the clinical benefit of tDCS. Therefore, we believe it important to speculate regarding the source of this variability. Although our small sample size (n=10) makes strong conclusions impossible, we believe that these are important considerations for the development of future studies. We suggest that treatment success was not related to biographical factors (eg, age, education level, lesion size, aphasia severity, and AOS severity; Table 5). For instance, the patient (P8) with the longest time after stroke (242-months), largest lesion (342.2 cm³), and second-most-severe aphasia according to the WAB-R (Aphasia Quotient=27.5) displayed improved naming. However, not all patients showed improved naming. For example, 2 patients (P4 and P7) performed nearly at ceiling during baseline testing, and thus, had limited room for improvement. Additionally, 1 patient (P6) presented with very severe speech and language deficits and did not produce a single correct naming response during any of the 6 testing sessions. Other patients (P3, P9, and P10) displayed improvements after both A-tDCS and S-tDCS, and the remaining 4 (P1, P2, P5, and P8) displayed clear improvements after A-tDCS compared with S-tDCS. Three of these latter 4 (P1, P2, and P8) presented with AOS, and 2 of the 4 (P1 and P8) were classified as having nonfluent aphasia. Interestingly, both AOS and nonfluent aphasia are associated with damage to the left frontal cortex,24 which was the area stimulated in the present study. It should also be noted that 1 of these 4 patients who did not present with AOS (P5) suffered damage to the left frontal cortex. These observations lead us to offer 2 possible reasons why some patients benefited from tDCS more than others. First, it may be possible that PWAs who
benefit the most from A-tDCS to the left frontal cortex were those with AOS, nonfluent aphasia, or both. Second, it is possible that stimulating areas closest to a patient’s perilesional area will result in the greatest amount of naming improvement (presumably, the residual portions of a damaged module are often crucial for rehabilitation). That is, 3 of the 4 patients (P1, P5, and P8) who benefitted most from A-tDCS had frontal lobe damage, whereas most of the patients who showed less improvement tended to have posterior damage. This suggests that frontal lobe stimulation is most beneficial for patients with frontal lobe damage, whereas posterior stimulation may be more beneficial for those PWAs who present with primarily posterior damage. Clearly, this latter speculation cannot be verified with the present data as our study only included frontal lobe stimulation.

One important caveat related to the present work is that it did not address the effect of C-tDCS on naming. This was a clinical decision based on our hypothesis, which suggested that naming performance is positively correlated with cortical excitability. Therefore, it was presumed that the opposite outcome might be true, in which decreased cortical activation elicited by C-tDCS might inhibit picture naming. This decision was also based on the results of numerous studies suggesting greater benefit associated with A-tDCS compared with C-tDCS.6–8 Therefore, although our findings provide clear evidence regarding the beneficial role of A-tDCS, we do not have evidence to comment on the intriguing beneficial effect for C-tDCS reported by Monti and colleagues.9 Although it is convenient to consider increased and decreased cortical excitability as being mutually exclusive, we concede that it is possible that both A-tDCS and C-tDCS may be beneficial. Specifically, one could imagine a situation in which beneficial changes are preferentially sustained through a Hebbian process while detrimental changes have no long-term consequences. In this scenario, A-tDCS entrains parts of the network that need to be upregulated, and C-tDCS stimulation encourages downregulation of other portions of the same network.

The current experimental design necessarily limits the inferences that can be drawn from this study, which, in turn, provides clear directions for future research. For instance, it is possible that measuring reaction time rather than just naming accuracy could have revealed a more sensitive measure of performance change for those patients who performed nearly at ceiling during baseline testing (e.g., P4 and P7). Additionally, the current study did not assess functional language abilities; thus, future studies should consider the inclusion of functional communication measurements to determine the functional relevance of tDCS. Finally, follow-up testing was performed relatively soon after treatment completion; therefore, it is important for future tDCS studies to conduct follow-up testing at longer intervals (e.g., 2 weeks, 1 month, etc) to determine whether treatment effects endure past 1 week after treatment.

It is imperative to note that the positive treatment outcome associated with the administration of A-tDCS combined with an anomia treatment does not lessen the importance of clinician-administered aphasia treatment. Rather, the current treatment was designed to reveal that the inclusion of tDCS could supplement behavioral aphasia treatment, owing to its portability and simplicity of application. Given the beneficial effect observed after five 20-minute A-tDCS (1 mA) sessions, it is possible that more sessions (>5), longer sessions (>20 minutes), and greater stimulation intensity (>1 mA) could have elicited even greater success, as long as current safety guidelines are strictly followed.9 Furthermore, it is straightforward to speculate that improved treatment outcome could be obtained by tailoring the treatment to better fit individual patients. This could be accomplished by manipulating factors such as overall word frequency (e.g., incorporating more higher-frequency words for patients with severe aphasia and more lower-frequency words for patients with mild aphasia), semantic content (e.g., modifying word lists by selecting words that are meaningful and functionally relevant for each patient), and the time interval between the picture display and onset of the spoken word (e.g., lengthening the time for patients with slower reaction time).

In closing, this study provides further evidence suggesting that preserved regions of the LH are important for aphasia recovery. Moreover, these findings suggest that tDCS can aid in anomia recovery among stroke patients. However, as is always the case with exploratory research, further investigation involving greater numbers of patients is needed to confirm the effect revealed in the current pilot study. Finally, as is almost always the case with aphasia treatment, there was a wide range of treatment outcomes among the current patients, but nevertheless, the current study demonstrates that A-tDCS to the scalp overlying the left frontal cortex can significantly improve naming accuracy in some PWAs and, if proved effective by larger studies, may provide a supplementary treatment approach for anomia.

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Disclosures

None.

References


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Julie M. Baker, Chris Rorden and Julius Fridriksson

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