Title: Combined anodal transcranial direct current stimulation and behavioural naming treatment improves language performance in post-stroke aphasic patients

Running title: atDCS and naming therapy improve aphasia

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Abstract

Primary objective: During the last decade, studies using anodal transcranial Direct Current Stimulation (atDCS) have yielded promising results in patients with aphasia. The main aim of the present pilot study was to assess the effects of combined atDCS on the left posterior perisylvian region and behavioural naming training on the behavioural outcomes on language comprehension and production of patients with post-stroke aphasia.

Research design: 2x2 quasi-experimental design, optimal to compare changes after treatment in an experimental vs a control group.

Methods and Procedures: Ten patients with post-stroke aphasia were enrolled in this study: half received atDCS on the left posterior perisylvian region while they underwent a 2-week behavioural naming training. The other half received sham stimulation. The outcomes were measured using the abbreviated form of the Boston Diagnostic Aphasia Examination, and analysed using t-tests.

Main outcomes and Results: Both groups improved their performance in Oral comprehension, Narrative writing, and Language Competence Index, but only those that received anodal tDCS presented better results in the Naming category after the treatment.

Conclusiones: AtDCS on the left posterior perisylvian area seems to be a promising tool for boosting the outcomes of behavioural naming therapy in patients with post-stroke aphasia.

Keywords: Stroke; patients with aphasia; anodal transcranial direct current stimulation (atDCS); left posterior perisylvian area; behavioural naming treatment.

INTRODUCTION

About 15 million people suffer from stroke in the world each year, and it is estimated that by 2030 there will be almost 70 million stroke survivors (1). Of these, around 30-40% suffer from aphasia (2–4) and after 6 months post-stroke about 20% still present chronic language deficits (5,6). Aphasia is a devastating form of cognitive impairment that has a major impact on patients' daily life and psychological wellbeing, and causes a significant burden on healthcare systems (4,7). Besides, it seems to be quite resistant to intervention: while behavioural aphasia treatment is often able to improve communication to a certain degree in these patients, it usually produces modest improvements (8–10). Therefore, it is compelling to develop new aphasia treatments that enhance rehabilitation outcomes after stroke.

Previous studies demonstrated that aphasia recovery is related to functional brain changes of the damaged left hemisphere (11,12), supporting the notion that intact regions of this hemisphere play a crucial role in aphasia recovery (13). Non-invasive brain stimulation (NIBS) techniques have demonstrated that are able to produce functional brain changes (14,15), and also to modulate the language system (16,17).

From NIBS, transcranial direct current electrical stimulation (tDCS) is a promising technique, as it is safe, portable, relatively low-cost and can be easily paired with existing therapies as language rehabilitation. This technique modulates spontaneous cortical activity by applying a weak direct electrical current through two (or more) electrodes placed on the scalp. Anodal stimulation (atDCS) is thought to increase cortical excitability, while cathodal stimulation (ctDCS) is thought to decrease excitability (18), although the effects of ctDCS are more controversial (19). This technique is able to induce after-effects lasting for more than 24 hours (20) and even long-term alterations in synaptic plasticity (15), making it an interesting tool to boost cognitive rehabilitation.

In the last years, several studies applied tDCS in order to improve language functions in healthy (17,21) and post-stroke aphasia participants (21,22), by combining tDCS with behavioural

aphasia treatment focused in naming therapy or speech-language treatment during several sessions (in order to induce long-term modulations) (15). Many of these studies, reviewed in very recent meta-analyses, demonstrated that atDCS is particularly effective (vs. ctDCS, see (21)) on boosting the recovery process in post-stroke aphasia, specifically regarding naming and conversational abilities (21,22). However, methodological differences between studies are large, especially regarding stimulation site. Most studies applied atDCS to the frontal cortex at Broca's area during language rehabilitation and found improvements during post-treatment naming tasks (13,23–28), but see (29). These kind of studies also found improvements in conversational assessment (25), although this is a much less studied language ability. A few studies stimulated the temporal cortex at Wernicke's Area and found improvements in naming accuracy (23,24,26), but failed to find differences with sham stimulation regarding conversational abilities (25). There are also very few studies that stimulated the motor cortex using atDCS and found better performance in naming ability and in conversational speech (30).

Some studies compared naming and conversational speech outcomes when stimulating left frontal (F5) vs left posterior (CP5) locations vs. sham stimulation (23,25,26), in order to determine which stimulation site would be more convenient for aphasia treatment. Marangolo, Fiori, Di Paola, et al. (2013) applied atDCS to patients with post-stroke aphasia during verb naming therapy, under three different conditions during 5 consecutive sessions (for each condition): real atDCS with the anode over left inferior frontal gyrus area, real atDCS over left posterior perisylvian area, and sham stimulation. These authors found that atDCS applied over the frontal region together with simultaneous intensive verb naming training leaded to the greatest amount of verb naming improvement, although all subjects significantly improved regardless of the stimulation site when compared to sham stimulation (26). Another study conducted in the same laboratory applied atDCS to patients with post-stroke aphasia during verb and noun naming training, using a similar design. The authors compared verb and noun naming accuracy across sessions, and found that participants improved in naming accuracy under both real atDCS conditions for both categories (verb and noun naming) compared to sham stimulation. However,

they observed that participants were more accurate in noun naming after the left temporal (CP5) stimulation and in verb naming after left frontal (F5) stimulation (23). On the other hand, Marangolo et al. (2013a) observed that atDCS improved outcomes of conversational therapy treatment (both applied during 10 sessions) when applying the stimulation for 10 sessions over the left inferior frontal gyrus (F5), but failed to find any differences with the sham condition when stimulating over the left posterior perisylvian area (CP5) (31).

Hence, reports on multi-session behavioral language treatment focused in naming and conversational abilities pointed that these skills can be boosted by atDCS in patients with post-stroke aphasia, especially when the target is left frontal inferior cortex (21). However, studies that applied atDCS to posterior areas in the left temporal cortex during several consecutive sessions are very scarce in post-stroke aphasia, and meta-analyses were not able to the date to draw consistent conclusions about the efficacy of atDCS regarding this site (21,22). Besides, previous studies usually focused behavioral rehabilitation and outcome measures in naming or conversational speech exclusively.

In this pilot study, we applied atDCS over the left posterior perisylvian area (CP5 site of the 10-10 International system for electrode location) to patients with post-stroke aphasia during 10 sessions while they underwent behavioral language rehabilitation based on naming (including mostly nouns, but also verbs and adjectives), with the aim of assess if atDCS was able to boost the behavioral treatment regarding naming outcomes, using a double-blind experimental design. In addition, we aimed to assess whether this combined treatment was able to improve other language abilities, as oral comprehension, oral agility, repetition or reading. We expected to find better naming performance in the post-treatment session, as a result of naming rehabilitation, that would be larger after atDCS application (compared to sham). In addition, we expected that also repetition abilities might be enhanced after real stimulation, as these have been shown to rely on Wernicke's area (32). Besides, it is also possible that these improvements may extend to comprehension abilities, due to the involvement of superior temporal structures in comprehension

processes (33), that may also be stimulated during treatment. Finally, we did not expect to find any improvement related to atDCS regarding conversational speech, in line with previous reports.

MATERIALS AND METHODS

The research followed a double-blind design, in which neither the participant nor the researcher knew if the participant was included in the experimental (atDCS) or the control (sham) group. The research followed the principles of the Declaration of Helsinki, all the participants and closest relatives were informed about the aims and procedure of the research, and they all signed written consent prior to be included as participants of the study. The study received a favourable report from the [ANONIMYZED].

Participants

Ten patients with a history of chronic stroke (> 6 month post-stroke onset), with an age range from 40 to 79 years-old (M = 56.67 years-old; SD = 15.12), participated in this study (see Table I). They were randomly divided into 2 groups: (1) Naming therapy + atDCS (atDCS group, N = 5; mean age = 62.8, SD = 16.4) and (2) Naming therapy + sham stimulation (Sham group, N = 6; mean age = 59.8, SD = 14.4). There were no differences in age and education between groups.

[Table I about here]

Nine patients were premorbidly right-handed (only patient 2 was left-handed), all the sample had lesions within the left hemisphere due to stroke that happened at least 6 months previously to the assessment or more, and they all were native Spanish speakers. The exclusion criteria were: (1) history of seizures or epilepsy, or currently use of anticonvulsant medications, (2) history of heart disease, respiratory disease or other serious medical conditions, (3) lack of personal autonomy previous to stroke, (4) presence of any contraindications for magnetic resonance exploration (metallic implants, pregnancy or claustrophobia), (5) peripheral neuropathy or any other chronic pain disorders, (6) absence of informed consent to receive tDCS during the study, (7) high suicide risk, (8) have receive electroconvulsive therapy during the last 6 months, (9) age over 85 years old, (10) absence of errors in naming according to the Boston

Naming Test (BNT) (34): percentile 80 or less and at least one verbal paraphasia. Aphasia symptoms and severity were assessed before starting treatment using the Boston Diagnostic Aphasia Examination – Spanish version (35), and brain lesions were determined by a magnetic resonance imaging (MRI) exploration in the pre-treatment session (see Figure 1).

[Figure 1 about here]

From the 10 participants that took part in this study, 6 showed non-fluent aphasia and four showed fluent aphasia. Both were equally distributed between groups (3 non-fluent and 2 fluent aphasia in each group). See Table I for the detailed diagnosis of each participant. Regarding brain lesions, all patients showed lesions within the left hemisphere compatible with a residual gliosis/malacic lesion within left middle cerebral artery territory. P1 showed brain damage to the superior, middle and inferior frontal giry, orbitofrontal cortex (superior, middle and inferior), inferior frontal operculum, insula, rolandic operculum, precentral gyrus, postcentral gyrus, caudate and putamen. P2 showed brain damage to precentral and postcentral gyri, rolandic operculum, inferior frontal operculum, insula, inferior parietal lobule, angular, supramarginal and Heschl's gyri, and superior and middle temporal gyri. P3 showed brain damage to frontal gyri (superior, middle, inferior), superior and medial orbitofrontal cortex, precuneus, inferior frontal operculum, rolandic operculum, precentral gyrus, postcentral gyrus, insula, anterior and middle cingulum, superior and middle occipital gyrus, superior and inferior parietal gyri, angular gyrus, middle temporal gyrus, and caudate. P4 showed brain damage to inferior frontal gyrus, inferior orbitofrontal gyrus, inferior frontal operculum, precentral and postcentral gyri, rolandic operculum, insula, Heschl's gyrus, superior and middle temporal gyri (including superior temporal pole), caudate, putamen and pallidum. P5 showed brain damage to middle and inferior frontal gyri, inferior frontal operculum, insula, caudate, putamen and pallidus. P6 showed brain damage to middle and inferior frontal gyri, inferior orbitofrontal gyrus, inferior frontal operculum, rolandic operculum, precentral and postcentral gyri, insula, inferior parietal lobule, supramarginal, angular and Heschl's gyri, caudate, putamen and pallidus. P7 showed brain damage to superior and inferior orbitofrontal cortices, olfactory cortex, insula, putamen, pallidus

and thalamus. P8 showed brain damage to rolandic operculum, insula, middle occipital gyrus, postcentral gyrus, superior and inferior parietal gyri, supramarginal, angular and Heschl's giry, superior and middle temporal gyri (including superior temporal pole) and putamen. Finally, P10 showed brain damage to middle and inferior frontal gyri, inferior frontal operculum, precentral and postcentral gyri, rolandic operculum, insula, Heschl's gyrus, superior temporal gyrus, caudate, putamen and pallidum. P9 was not able to undergo MRI exploration due to mobility problems. Figure 1 depicts the common lesion site for all participants.

Instruments

In the atDCS group, the anode was placed over CP5 using a saline-soaked sponge of 5x4 cm and the cathode was placed over the contralateral supraorbital area (RSO) using a saline-soaked sponge of 5x7cm. Current intensity was set at 1mA (30s ramp-up/down) during 20 minutes using BrainStim stimulators (EMS, Italia). For the Sham group the electrode montage was identical, but a sham protocol was set in a different BrainStim stimulator, with the same 30s ramp-up/down at the beginning and at the end, but with 19 minutes of no stimulation in between. These protocols were applied during 10 consecutive sessions (from Monday to Friday, for two weeks), while participants underwent naming therapy (see below). All the protocols agreed with the Galician Research Ethics Committee and followed the safety recommendations in Fregni et al. (2015).

Behavioural naming treatment consisted in the presentation of 20 image sets of different categories (2 in each session, for one hour): musical instruments, bodyparts, actions, sports, games, animals, household utensils, furniture and decoration, appliances, clothes, professions (I and II), physical world, adjectives, food (I and II), holidays, means of transport, fruits, vegetables and other. Each set consisted in the presentation of 20 items that the participant was asked to name aloud. If the participant was not able to name the required word, the therapist would aid the participant using several cues. In the first place, a definition of the required word was read aloud by the therapist (for example, for the word "luna", that is "moon" in Spanish: Natural satellite of Earth). Second, the therapist formed a phrase that may be completed by the participant with the

required word (we wouldn't be able to see anything at night if it there was no…). Third, the therapist said aloud a made-up word (not a real word in Spanish) that rhymes with the required word (it rhymes with "sula"). Fourth, the therapist would repeat the rhyme cue along with the first syllable of the required word (it rhymes with "sula" and begins with "lu"). Finally, the therapist read aloud the required word and asked the participant to repeat it. If the participant was able to say the required word after any of the cues, the next item was presented.

We used the percentile scores of the abbreviated form of the Spanish version of the Boston Diagnostic Aphasia Examination (BDAE) – Spanish version (35) as outcome measures. Specifically, we analyzed the scores for every subtest of the battery, excluding those items that consisted exclusively in a subjective valuation of the experimenter. In addition, when there was more than one subtest that belong to the same category (p. e. NAMING is composed by the subtests "naming response", "Boston Naming Test (BNT)" and "category naming"), we also analyzed the combined score for the category (i. e. NAMING). In Table II we summarize the scores for each subtest (in lowercase letters) and for each analyzed category (in uppercase letters). In addition, we also included the global measure included in BDAE "Language Competence Index", or LCI.

Data analyses

Two-factor analyses of variance (ANOVAs), with the between-subject factor Group (two levels: atDCS, Sham) and the within-factor Session (two levels: pre-treatment and post-treatment) were applied to the percentile scores of the BDAE (see detail in the previous section). Whenever the ANOVAs revealed significant effects due to the factors or their interactions, post hoc comparisons of the mean values (adjusted to Bonferroni correction) were conducted. Differences were considered significant at $p \leq 0.05$. All the statistical analyses were performed using IBM SPSS Statistics 19.

RESULTS

Main results are summarized in Table II. The two-factor ANOVAs applied to the percentile scores obtained for the Sentence length subtest (from Fluency category), Simple social responses and Complexity index (from the Conversation category), Word discrimination, Commands and Complex material (from the Oral comprehension category), Automated sequencies (from the Recitation category), Words and Sentences (from the Repetition category), Naming response, Boston Naming Test (BNT) and Category naming (from the Naming category), Phonemic, Neologistic and Multiple words (from the Paraphasia category), Writing matching, Number matching, Word reading, Sentence reading, Sentence comprehension, Paragraph comprehension (from the Reading category), Mechanics, Letter selection, Motor skills, Basic vocabulary, Regular phonetics, Common irregular words and written picture naming (from the Writing category) did not show any effects of the factors or their interaction.

[Table II about here]

The two-factor ANOVA applied to the percentile scores obtained for the Oral comprehension category (formed by the Word discrimination, Commands and Complex material subtests) showed a significant main effect of the Session factor ($F (1, 8) = 10.4$, $p = .012$), as the scores were higher in the post-treatment session than in the pre-treatment session.

The two-factor ANOVA applied to the percentile scores obtained for the Naming category (formed by the Naming response, Boston Naming Test -BNT- and Category naming subtest) showed a significant main effect of the Session factor ($F (1, 8) = 4.8$, $p = .05$) and of the Session x Group interaction ($F (1, 8) = 5.5$, $p = .048$), as the scores were higher in the post-treatment session than in the pre-treatment session only in the group that received atDCS.

The two-factor ANOVA applied to the percentile stores obtained for the Verbal subtest from the Paraphasia category showed a main effect of the Session factor ($F (1, 7) = 10.1$, $p = .015$), as the scores were higher in the pre-treatment session than in the post-treatment session.

The two-factor ANOVA applied to the percentile stores obtained for the Picture-word matching subtest from the Reading category showed a main effect of the Session factor (F (1, 8)

= 6.5 p = .034), as the scores were higher in the pre-treatment session than in the post-treatment session.

The two-factor ANOVA applied to the percentile stores obtained for the Narrative writing subtest from the Writing category showed a main effect of the Session factor (F (1, 7) = 6.4 p = .039), as the scores were higher in the post-treatment session than in the pre-treatment session.

Finally, the two-factor ANOVA applied to the percentile stores obtained for the Language Competence Index (LCI) showed a main effect of the Session factor (F (1, 8) = 16.7 p = .003), as the scores were higher in the post-treatment session than in the pre-treatment session.

DISCUSSION

The present pilot study aimed to evaluate the effects on language outcomes of the 2-week treatment combining atDCS over the left posterior perisylvian region and naming training, in post-stroke aphasic participants. The results revealed that atDCS over the left posterior perysilvian areas might contribute to improve the recovery of language production.

Several results showed that performance had been modified in the post-treatment assessment respect to pre-treatment. Thus, the percentile scores obtained by the participants for the Oral comprehension category (formed by the Word discrimination, Commands and Complex material subtests, see Table II), for the Narrative writing subtest from the Writing category and for the LCI were larger in the post-treatment evaluation than in the pre-treatment evaluation. On the other hand, the percentile scores obtained for the Verbal subtest from the Paraphasia category and for the Picture-word matching subtest from the Reading category were larger in the pre-treatment session than in the post-treatment session. Finally, the percentile scores obtained by the participants in the Naming category (formed by the Naming response, Boston Naming Test -BNT- and Category naming subtest) were larger in the post-treatment session than in the pre-treatment session, but only in the atDCS group.

As predicted, the application of anodal tDCS over the CP5 electrode location of the 10-10 international system at the same time as behavioural naming treatment improved naming

abilities, while those participants that received sham tDCS stimulation did not show any improvements regarding naming. This result is in accordance with previous studies that stimulated over the left posterior perysilvian area while participants underwent naming therapy for several sessions (23,26,36). Also as expected, we found no differences in performance in the Conversation category, nor in the subtests that form it (Simple social responses and Complexity index), in line with the results reported by Marangolo, Fiori, Calpagnano et al. (2013). Hence, this study provides further evidence indicating that atDCS applied over posterior regions is able to enable naming therapy improvements in patients with post-stroke aphasic when combined with behavioural therapy, while it does not affect conversational abilities. These improvements induced by atDCS may happen even if behavioural naming therapy is not effective by itself in ameliorating naming deficits, as our sham group did not show differences in any of the evaluated scores regarding naming performance (see Table II).

Nevertheless, the present results show that our behavioural naming treatment had an impact in some language abilities different from naming, as narrative writing (subtest where participants should describe a picture with some actions going on) or oral comprehension (group of subtests where participants should point to the image corresponding to the word the experimenter said aloud, follow some simple orders and make yes/no judgements about factual issues). We predicted that comprehension might be improved after behavioral naming treatment, as comprehension and naming abilities rely on networks with common brain structures, and the behavioural training of the latter might have benefitted both type of processes (i. e. the superior temporal gyrus) (37). On the other hand, narrative writing abilities may have benefited from the improvements in naming abilities, as the subtest assessing this ability consisted in describing a scenario where some people were performing different activities and manipulating different objects, and hence, naming abilities were important for successful writing. However, we cannot rule out that the comprehension and narrative writing improvements may have simply been due to a practice effect, as in this study there was not a pure control group that underwent no behavioural treatment.

Finally, we found contradictory results regarding two subtests, that showed higher scores in the pre-treatment session compared to the post-treatment session, indicating that somehow performance declined after treatment: Verbal subtest from the Paraphasia category and Picture-word subtest of the Reading category. It is not easy to explain why these language abilities may have declined due to the treatment, and there is apparently no reason that explains why they might have declined due to the passing of time. However, these results may be due to subtest features. Both subtests show a great sensitivity to errors, unlike most other subtests in the BDAE. For example, in the Picture-word subtest only one error lowers the percentile score from 100 to 40, while in the Verbal subtest having only one paraphasic error lowers the percentile score from 100 to 70. In addition, participants were much more comfortable in the post-treatment session than in the pre-treatment session, producing more spontaneous conversation between them and the experimenter. This may have also led to more paraphasic errors in the BNT.

Limitations

This pilot study encourages new studies with larger samples in order to confirm our results. In addition, future research should include a pure control group of patients that undergo no treatment between the first and the second BDAE assessments, in order to confirm whether the improvements observed in both groups in the present pilot study (atDCS and sham) were due to the behavioural treatment or just a learning effect. Finally, future studies should also include follow-up sessions in order to determine the duration of the identified effects.

Conclusions

In conclusion, the results obtained in this study contribute to point out the benefits of combining atDCS on posterior perisylvian areas with behavioural training, indicating that atDCS is a promising useful tool for improving the outcomes of behavioral naming therapy in patients with post-stroke aphasia, encouraging further research in this line.

Acknowledgements

[ANONIMYZED]. The funding sources were not involved in any aspect of the research or the submission of this study.

Disclosure of interest

The authors report no conflict of interest.

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Table I.

Demographic, diagnostic, intervention and lesion data of each of the participants.

Patient	Age (years)	Sex	Education (years)	Aphasia type	Lesion site (left hemisphere)	Intervention
1	50	M	20	Anomic	IFG, MFG, SFG, OFC, IFO, PreCG, PostCG, insula, rolandic operculum, caudate, putamen	Sham
2	40	F	14	Conduction	PreCG, PostCG, rolandic operculum, IFO, insula, IPL, AG, supramarginal and Heschl's gyri, STG and MTG	atDCS
3	79	F	12	Global	IFG, MFG, SFG, OFC, precuneus, IFO, rolandic operculum, PreCG, PostCF, insula, ACC, MCC, SOG, MOG, SPG, IPG, AG, MTG, and caudate	Sham
4	46	M	24	Mixed transcortical	IFG, inferior OFC, IFO, PreCG, PostCG, rolandic operculum, insula, Heschl's gyrus, STG, MTG, caudate, putamen and pallidum	Sham
5	77	M	23	Transcortical sensory	MFG, IFG, IFO, insula, caudate, putamen, pallidum	atDCS
6	71	F	14	Global	MFG, IFG, inferior OFC, IFO, rolandic operculum, PreCG, PostCG, insula, IPL, supramarginal, angular and Heschl's gyri, caudate, putamen and pallidum	Sham
7	53	F	20	Anomic	OFC, olfactory, insula, putamen, pallidus and thalamus	Sham
8	51	M	14	Mixed transcortical	Rolandic operculum, insula, MOG, PostCG, SPG, IPG, supramarginal, angular and Heschl's giry, STG, MTG and putamen	atDCS
9	73	F	10	Global	---	atDCS
10	73	M	12	Mixed transcortical	MFG, IFG, IFO, PreCG, PostCG, rolandic operculum, insula, Heschl's gyrus, STG, caudate, putamen and pallidum	atDCS

M: Male; F: female; atDCS: anodal transcranial direct current stimulation; IFG: inferior frontal gyrus; MFG: middle frontal gyrus; SFG: superior frontal gyrus; OFC: orbitofrontal cortex; IFO: inferior frontal operculum; PreCG: precentral gyrus; PostCG: postcentral gyrus; IPL: inferior parietal lobule; AG: angular gyrus; STG: superior temporal gyrus; MTG: middle temporal gyrus; ACC: anterior cingulate cortex; MCC: middle cingulate cortex; SOG: superior occipital gyrus, MOG: middle occipital gyrus; SPG: superior parietal gyrus; IPG: inferior parietal gyrus.

Table II. **BDAE scores.** Mean scores and standard deviations (SDs, in parentheses) of the percentile scores obtained in each subtest (in lowercase letters) of the Boston Diagnostic Aphasia Examination (Spanish version), for each group (anodal tDCS and sham tDCS) in each session (pre-treatment and post-treatment). Combined mean scores for those subtests that belong to the same category (in uppercase letters) are also provided.

CATEGORY/subtest	atDCS group			Sham group			RESULT
	pre-T	post-T	p ≤ [1]	pre-T	post-T	p ≤ [1]	
FLUENCY							
Sentence lenght	50.0 (46.9)	66.0 (47.7)	n.s.	42.0 (53.1)	46.0 (49.8)	n.s.	
CONVERSATION	57. 0 (35.1)	49.6 (40.0)	n.s.	47.0 (41.5)	43.5 (48.5)	n.s.	
Simple social responses	54.0 (45.6)	46.0 (49.8)	n.s.	53.0 (46.6)	47.0 (48.9)	n.s.	
Complexity index	47.6 (31.6)	53.2 (33.7)	n.s.	33.2 (38.7)	40.0 (48.3)	n.s.	
ORAL COMPREHENSION	35.5 (32.0)	42.0 (34.3)	**.012* (M)**	45.3 (32.9)	52.7 (35.0)	**.012* (M)**	post-T > pre-T
Word discrimination	28.0 (24.1)	44.0 (38.5)	n.s.	61.0 (39.7)	48.0 (34.2)	n.s.	
Commands	42.6 (43.1)	44.0 (41.6)	n.s.	45.0 (38.7)	62.0 (40.2)	n.s.	
Complex material	36.0 (46.2)	38.0 (39.6)	n.s.	30.0 (24.5)	48.0 (47.6)	n.s.	
RECITATION							
Automated sequencies	66.0 (47.7)	80.0 (44.7)	n.s.	48.0 (48.7)	52.0 (45.5)	n.s.	
REPETITION	43.5 (33.1)	53.0 (36.0)	n.s.	59.5 (37.9)	70.0 (41.2)	n.s.	
Words	37.0 (36.3)	48.0 (38.3)	n.s.	75.0 (37.7)	68.0 (44.4)	n.s.	
Sentences	50.0 (30.8)	58.0 (38.3)	n.s.	64.0 (35.1)	72.0 (38.3)	n.s.	
NAMING	37.8 (26.6)	54.8 (35.0)	**.013* (I)**	43.0 (37.0)	42.5 (38.2)	n.s.	post-T > pre-T
Naming response	48.0 (34.2)	67.0 (45.5)	n.s.	44.0 (39.8)	47.0 (49.2)	n.s.	
Boston Naming Test	45.0 (26.7)	46.0 (23.1)	n.s.	49.6 (37.3)	42.6 (31.0)	n.s.	
Category naming	22.4 (18.9)	51.4 (44.6)	n.s.	35.4 (40.6)	37.8 (39.1)	n.s.	
PARAPHASIA	64.3 (14.0)	71.3 (20.7)	n.s.	71.3 (13.7)	65.5 (17.4)	n.s.	
Phonemic	76.0 (32.8)	76.0 (13.4)	n.s.	77.5 (28.7)	65.0 (41.2)	n.s.	
Verbal	80.0 (18.7)	58.0 (26.8)	**.015* (M)**	66.3 (30.9)	55.0 (38.7)	**.015* (M)**	pre-T > post-T
Neologistic	72.0 (38.3)	66.0 (47.7)	n.s.	82.5 (35.0)	65.0 (40.4)	n.s.	
Multiple words	84.0 (35.8)	83.0 (38.0)	n.s.	100.0 (0)	100.0 (0)	n.s.	
READING	49.5 (39.4)	50.2 (35.0)	n.s.	55.9 (39.1)	59.8 (40.1)	n.s.	
Writing matching	45.0 (50.7)	48.0 (48.2)	n.s.	61.0 (53.4)	80.0 (44.7)	n.s.	
Number matching	61.6 (52.7)	80.6 (43.4)	n.s.	80.0 (44.7)	62.4 (51.6)	n.s.	
Picture-word matching	40.0 (37.4)	30.0 (42.4)	**.034* (M)**	46.0 (32.9)	34.0 (39.8)	**.034* (M)**	pre-T > post-T
Word reading	56.3 (50.6)	61.3 (45.2)	n.s.	50.0 (48.0)	64.0 (49.3)	n.s.	
Sentence reading	57.5 (22.2)	60.0 (35.6)	n.s.	44.0 (37.8)	54.0 (33.6)	n.s.	
Sentence comprehension	64.0 (43.6)	52.5 (36.9)	n.s.	62.0 (52.2)	64.0 (49.3)	n.s.	
Paragraph comprehension	60.0 (42.4)	45.0 (41.2)	n.s.	48.0 (50.2)	60.0 (54.8)	n.s.	
WRITING	66.9 (34.1)	72.3 (34.5)	n.s.	43.8 (36.1)	47.5 (41.2)	n.s.	
Mechanics	61.3 (48.4)	11.5 (16.5)	n.s.	61.3 (48.4)	48.8 (50.2)	n.s.	
Letter selection	35.0 (45.1)	42.0 (43.8)	n.s.	50.0 (50.0)	52.0 (50.2)	n.s.	
Motor skills	75.0 (50.0)	75.0 (50.0)	n.s.	48.0 (48.2)	44.0 (51.8)	n.s.	
Basic vocabulary	51.3 (56.3)	55.0 (52.6)	n.s.	60.0 (54.8)	60.0 (54.8)	n.s.	
Regular phonetics	65.0 (40.4)	65.0 (40.4)	n.s.	56.0 (43.9)	56.0 (43.9)	n.s.	
Common irregular words	60.0 (46.2)	60.0 (46.2)	n.s.	56.0 (45.6)	44.0 (38.5)	n.s.	
Written picture naming	30.0 (28.3)	40.0 (34.6)	n.s.	38.0 (39.6)	38.0 (44.4)	n.s.	
Narrative writing	38.6 (45.2)	50.8 (49.1)	**.039* (M)**	31.0 (42.5)	38.0 (40.3)	**.039* (M)**	post-T > pre-T
LANGUAGE COMPETENCE INDEX	45.0 (29.9)	48.5 (29.2)	**.003** (M)**	44.8 (37.8)	49.0 (35.9)	**.003** (M)**	post-T > pre-T

Note: atDCS: anodic transcranial direct current stimulation; pre-T: pre-treatment evaluation

Figure Legends.

Figure 1. Participant's common lesion site. Cold colors represent voxels that correspond to damaged areas in a smaller number of participants (e.g. dark purple = 1 participant with a lesion involving those particular voxels), while hot colors represent those voxels corresponding to damaged areas in a larger number participants (e.g. red = 7 participants with a lesion involving those particular voxels).