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Effects of transcranial direct current stimulation on language recovery in chronic post-stroke aphasia

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Keywords
Aphasia; Stroke; Speech Therapy; Transcranial Direct Current Stimulation

Abstract

Background: Aphasia is a major cause of long-term disability in post-stroke patients. Non-invasive brain stimulation, particularly transcranial direct current stimulation (tDCS), has shown promise in enhancing language recovery. However, evidence from Indonesia remains scarce. This study aimed to evaluate the effects of tDCS on language recovery in chronic post-stroke aphasia (PSA).

Methods: This quasi-experimental study included 30 patients with chronic PSA, divided into 2 groups: 15 received 5 sessions of tDCS combined with language training, while 15 underwent language training alone. Language abilities were assessed using the Tes Afasia untuk Diagnosis Informasi dan Rehabilitasi (TADIR) or Aphasia Test for Diagnostic Information and Rehabilitation at baseline, post-therapy, and 2 weeks post-therapy. Statistical analysis was conducted using the Friedman test.

Results: Participants (93.3% male) had a median age of 56 years (range: 33-65 years). The tDCS group showed significant improvements in TADIR subtests, including verbal fluency, word naming, speech rate, verbal comprehension, and writing ($P < 0.05$). The control group showed improvements in fewer subtests, namely verbal fluency, word naming, and repetition.

Conclusion: Combining tDCS with language training may enhance recovery in specific language domains, notably writing, among patients with chronic PSA. However, most between-group comparisons did not reach statistical significance, and findings should be interpreted as exploratory. Larger controlled trials are needed to establish the efficacy and clinical relevance of tDCS in aphasia rehabilitation.

Introduction

Post-stroke aphasia (PSA) is one of the most debilitating consequences of cerebrovascular accidents, severely impairing communication and reducing quality of life (QOL).[1]

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PSA is caused by damage to the language-dominant hemisphere, usually resulting from middle cerebral artery hypoperfusion.[2] Globally, approximately 21–40% of all stroke patients experience aphasia, with ischemic strokes as the cause of most of the cases.[3,4] The incidence of PSA is estimated at 40-60 per 100000 person-years, making it a significant contributor to post-stroke disability.[5,6] Recovery from PSA varies significantly and depends on factors such as lesion location and size, age, education level, and the type and timing of therapeutic interventions.[7,8] While some patients show partial or complete recovery within 6 months, many suffer persistent language deficits. Approximately 43% of patients report language impairments 18 months post stroke, and 61% face communication-related disabilities 1 year after the event.[9] Early intervention is critical, as the rate of recovery slows dramatically after 6 months.[10] Management of PSA involves pharmacological interventions, speech and language therapy (SLT), and non-invasive brain stimulation techniques.[5,9] Among these, transcranial direct current stimulation (tDCS) has gained attention as a promising adjunct to conventional therapy. tDCS delivers a low electrical current to the scalp, modulating cortical excitability and promoting neuroplasticity. Studies suggest that combining tDCS with SLT may enhance language recovery by facilitating neural reorganization.[11] However, the evidence regarding the effectiveness of tDCS is inconsistent, partly due to differences in patient profiles, stimulation parameters, and therapeutic protocols.[12-15] Moreover, data on tDCS use in Indonesia is limited. Thus, this study aimed to evaluate the feasibility and effectiveness of tDCS in chronic PSA, contributing to the growing body of evidence and addressing gaps in local research.

Materials and Methods

Study design and setting: This non-randomized controlled before-and-after study was conducted at the Neurology Outpatient Clinic of Prof. Dr. Chairuddin P. Lubis Universitas Sumatera Utara Hospital from April to November 2024. Participants were consecutively allocated to 2 groups based on order of presentation and therapy slot availability. Due to resource and logistical constraints, randomization was not applied. This design introduces a risk of selection and allocation bias, which is acknowledged as a limitation. The study compared outcomes between a group receiving tDCS combined with language therapy and a group receiving language therapy alone.

Sample size: This study was conducted as a preliminary pilot/feasibility study to evaluate the initial effects and feasibility of the intervention. Accordingly, we considered a minimal standard sample size of 30 participants (15 per group), which is commonly recommended for pilot studies in this field. This sample size was considered sufficient to provide preliminary data on intervention acceptability, adherence, and potential outcomes, while informing the design of future adequately powered trials.

Participants: A total of 30 patients with chronic PSA (≥ 6 months post-stroke) were recruited through consecutive non-random sampling. The inclusion criteria required participants to be at least 18 years old, diagnosed with PSA based on clinical evaluation, and medically stable. The exclusion criteria included significant cognitive impairments, uncontrolled comorbidities, or contraindications to tDCS (e.g., metal implants near the stimulation site). The participants were divided into 2 groups: the tDCS group consisting of 15 patients received 5 consecutive sessions of tDCS combined with language training and the control group consisting of 15 patients underwent language training only, following the same protocol as the tDCS group without stimulation. We obtained written informed consent from each patient. Outcome assessment was conducted by a neurologist blinded to group allocation to minimize measurement bias. All participants completed all assessments across the 3 time points, and there were no missing data.

Intervention protocol and outcome measures: The tDCS group received a direct current of 2 mA for 20 minutes per session, applied over 5 consecutive days. Stimulation was delivered using 2 saline-soaked surface sponge electrodes (5 × 7 cm; area: 35 cm^2), with the anode placed over the left inferior frontal gyrus [F7 in the 10-20 electroencephalography (EEG) system] and the cathode over the contralateral supraorbital region.[12] This configuration resulted in a current density of 0.057 mA/cm^2. Stimulation was well tolerated; 2 participants reported mild tingling that resolved spontaneously, and no adverse effects were recorded. Language therapy in both groups was standardized. Each session lasted 45 minutes and was delivered daily for 5 consecutive days. Therapy content included structured modules on verbal fluency, picture naming, auditory

comprehension, and repetition. All sessions were supervised by the same neurologist to ensure consistency. The intervention in the control group was identical except for the absence of tDCS.

Outcome measures: Language performance was assessed using the Tes Afasia untuk Diagnosis Informasi dan Rehabilitasi (TADIR), a validated aphasia battery developed for Indonesian speakers.[16] It evaluates multiple domains of language functioning and has shown sensitivity to change in PSA across therapy intervals. This instrument evaluates various subtests, including verbal fluency, word naming, verbal comprehension, speech rate, reading and writing. Assessments were conducted at baseline, immediately after therapy, and 2 weeks post-therapy to evaluate both short-term and sustained effects.

Descriptive statistics were used to summarize demographic and clinical characteristics. Between-group comparisons at baseline were conducted using the Mann-Whitney U test or Fisher's exact test as appropriate. Within-group changes across 3 time points were analyzed using the Friedman test. A P-value < 0.05 was considered statistically significant.

Ethical clearance: This study was conducted in accordance with the Declaration of Helsinki and was approved by the Health Research Ethics Committee of Universitas Sumatera Utara (approval number: 505/KEPK/USU/2024).

Results

The flow of participants through each stage of the study is summarized in the CONSORT flowchart (Figure 1).

The study included 28 male (93.3%) and 2 female (6.7%) participants, with a median age of 56 years (tDCS group) and 58 years (control group). The groups were comparable in terms of education level, aphasia onset (median: 9 months in both groups), and aphasia type (Broca's, Wernicke's, and transcortical motor) (Table 1).

Baseline TADIR scores revealed no significant differences between groups across any subtests ($P > 0.05$). Following therapy, the tDCS group exhibited significant improvements in verbal fluency, word naming, verbal comprehension, speech rate, and writing ($P < 0.050$). The control group showed significant improvements in verbal fluency, word naming, and repetition but to a lesser extent than the tDCS group (Table 2).

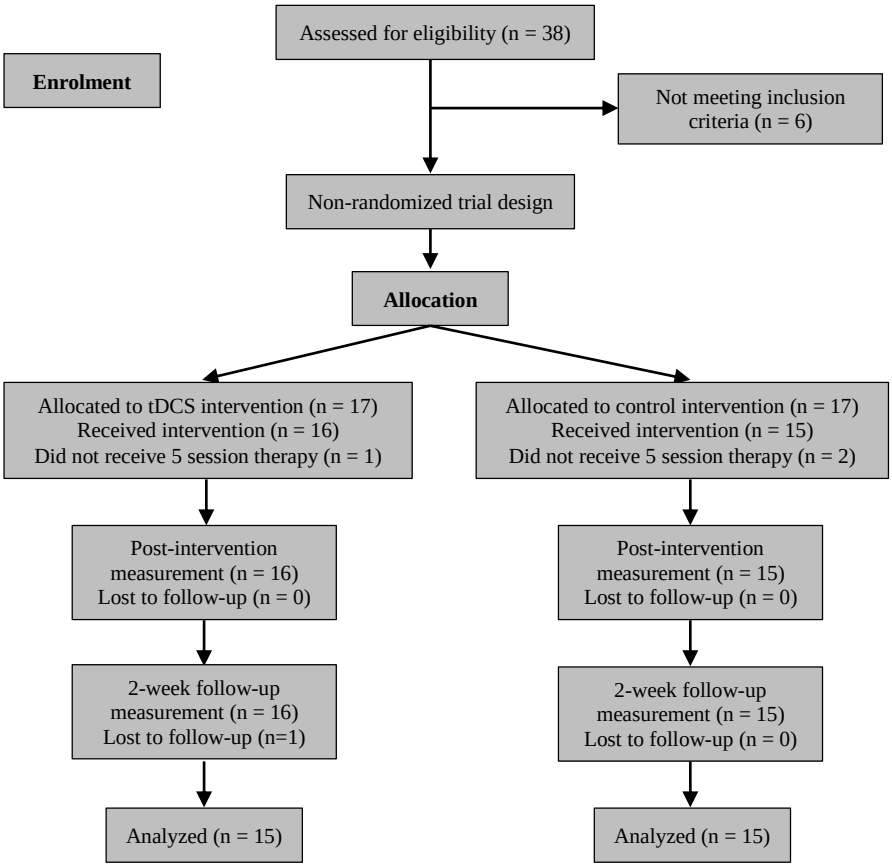

Figure 1. Flowchart of participant progress

Table 1. Subject characteristics

Variables	tDCS (n = 15)	Control (n = 15)	P
Age (years)			
Median (min-max)	56 (33-65)	58 (39-72)	0.677*
Gender [n (%)]			> 0.999**
Male	14 (93.3)	13 (86.7)	
Female	1 (6.7)	2 (13.3)	
Length of education (years) [n (%)]			0.900**
6	1 (6.7)	2 (13.3)	
7-9	2 (13.3)	2 (13.3)	
10-12	6 (40)	7 (46.7)	
≥ 13	6 (40)	4 (26.7)	
Onset of aphasia (months)			
Median (min-max)	13 (6-121)	9 (6-122)	0.835*
Aphasia syndromes [n (%)]			0.715**
Broca	8 (53.3)	7 (46.7)	
Wernicke	1 (6.7)	0 (0)	
Transcortical motor	6 (40.0)	8 (53.3)	

*Mann-Whitney test, **Fisher's exact test

Table 2. Tes Afasia untuk Diagnosis Informasi dan Rehabilitasi (TADIR) baseline score

Language subtests	tDCS	Control	P*
	Median (IQR)		
Verbal fluency	3 (6)	6 (4)	0.241
Word naming	6 (7)	6,5(1)	0.172
Verbal comprehension	5 (2)	6 (2)	0.116
Word repetition	2 (3)	2 (1)	0.447
Speech rate	15 (38)	22 (18)	0.707
Reading	2 (4)	3 (4)	0.656
Writing	4 (6)	3 (8)	0.575

*Mann-Whitney test
IQR: Interquartile range

In the tDCS group, 2 patients experienced changes in aphasia syndrome; the first transitioned from Broca's aphasia to transcortical motor aphasia, while the other transitioned from Wernicke's aphasia to conduction aphasia. No syndrome changes were observed in the control group (Table 3).

Table 3. Changes in aphasia syndrome before and after therapy

Aphasia syndromes	tDCS (n = 15)		Control (n = 15)	
	Before therapy	After therapy	Before therapy	After therapy
Broca	8	7	7	7
Transcortical motor	6	7	8	8
Wernicke	1	0	0	0
Conduction	0	1	0	0

The results of this study indicated significant differences in TADIR scores before therapy, immediately after therapy, and 2 weeks following a combination of tDCS and language training. These differences were observed across several language subtests, including verbal fluency, word naming, speech rate, verbal comprehension, and word writing (Friedman test; $P < 0.050$). Similarly, the control group showed significant improvements, particularly in verbal fluency, word naming, and repetition (Friedman test; $P < 0.050$) (Table 4). In the tDCS group, significant within-group improvements were observed over time in verbal fluency, word naming, verbal comprehension, speech rate, and writing (Friedman test; $P < 0.050$). In the control group, improvements were noted in verbal fluency, word naming, and word repetition (Friedman test; $P < 0.050$). Between-group comparisons of change scores revealed that writing was the only subtest with statistically significant differences at both post-therapy ($\Delta 1$; $P = 0.018$) and 2-week follow-up ($\Delta 2$; $P = 0.029$), favoring the tDCS group. No significant between-group differences were found for other subtests at either time point ($P > 0.050$) (Table 4). No significant adverse effects were reported during or after tDCS therapy, demonstrating its safety and tolerability.

Discussion

This study demonstrated the positive impact of tDCS combined with language training on language recovery in chronic PSA. Significant improvements were observed in multiple language subtests, highlighting the potential of tDCS as an adjuvant therapy for enhancing neuroplasticity.

Table 4. Changes in baseline, post-therapy, and 2 weeks post-therapy scores

Language subtest	Group	Median (IQR)			Change score		Between-group P	
		Baseline	After therapy	2 Weeks Post	Δ1 (After–Baseline)	Δ2 (2 Weeks–Baseline)	After	2 Weeks
Verbal fluency	tDCS	3 (6)	3 (11)	4 (11)	1 (5)	1 (2)	0.240	0.317
	Control	6 (4)	8 (4)	7 (3)	2 (1)	1 (2)		
Word naming	tDCS	6 (7)	7 (7.5)	7 (8)	2 (1)	0.5 (0)	0.965	0.388
	Control	6.5 (1)	7 (1)	7 (1)	0.5 (1)	0.5 (1)		
Verbal comprehension	tDCS	5 (2)	6 (3)	5 (3)	0 (1)	0 (0)	0.341	0.594
	Control	6 (2)	6 (2)	6 (2)	0 (1)	0 (0)		
Word repetition	tDCS	2 (3)	2 (3)	2 (3)	0 (0)	0 (0)	0.671	0.671
	Control	2 (1)	3 (1)	3 (1)	0 (1)	0 (0)		
Speech rate	tDCS	15 (38)	18 (42)	18 (41)	2 (3)	0 (2)	0.849	0.749
	Control	22 (18)	24 (15)	25 (15)	2 (3)	1 (4)		
Reading	tDCS	2 (4)	4 (4)	4 (4)	0 (0)	0 (0)	0.944	0.944
	Control	3 (4)	4 (3)	4 (3)	0 (0)	0 (0)		
Writing	tDCS	4 (6)	6 (8)	5 (8)	1 (2)	1 (0)	0.018	0.029
	Control	4 (8)	5 (8)	5 (8)	0 (1)	0 (0)		

Δ1 = Change from Baseline to After Therapy; Δ2 = Change from Baseline to 2 Weeks Post-Therapy. Within-group p-values from Friedman test are reported in manuscript text. Between-group p-values are from Mann-Whitney U test. Bold indicates statistical significance ($p < 0.05$).
IQR: Interquartile range

As adjuvant therapy, tDCS is thought to be able to optimize brain restoration capacity and improve aphasia recovery in chronic phase.[9] A randomized controlled trial found that most studies on tDCS are performed in chronic PSA patients with varying onset (more than 3 months).[11] Several previous studies have shown the effectiveness of tDCS in chronic PSA marked by improvement in language subtests after therapy. Furthermore, tDCS modulates cortical excitability, enhancing synaptic connections and facilitating long-term potentiation in the language-dominant hemisphere. The application of tDCS over the left inferior frontal gyrus likely contributed to improvements in word naming, verbal fluency, and comprehension, as this region is critical for language production and processing. Our findings align with studies demonstrating significant improvements in naming tasks, verbal fluency, and comprehension following tDCS. For instance, Baker et al. reported enhanced naming accuracy in chronic PSA patients after 5 tDCS sessions.[17] Many previous studies also showed an improvement in different language subtests, such as phonemic fluency, picture-naming, speech rate, verbal comprehension, and word writing after tDCS therapy.[18-21]

However, our results should be interpreted with caution due to the non-randomized design of the study, small sample size, and limited control for confounding variables such as lesion site, education level, and baseline severity. These factors limit internal validity and generalizability. Future randomized controlled trials with larger samples and longer follow-up durations are needed to confirm these preliminary findings.

In this study, tDCS was implemented simultaneously with language training task, which is in line with the reports of previous studies that language recovery in aphasia can be achieved optimally through a combination of tDCS and speech and language training (SLT).[11,22] This effect can be achieved through the modulation of inhibitory or excitatory neuron networks in impaired and normal cerebral hemisphere.[22] The combination of tDCS with language training further amplified these effects, aligning with previous findings which showed that simultaneous behavioral tasks optimize the therapeutic potential of tDCS. By engaging neural networks during stimulation, language exercises may reinforce synaptic changes, leading to more robust and sustained recovery.[22]

In this study, there were no significant differences between the study groups at baseline in the scores of the language subtests, such as verbal fluency, word naming, verbal comprehension, repetition, speech rate, reading, and writing. The results of this study show significant differences between baseline, post-therapy, and 2 weeks post-therapy scores in both the tDCS and control group. However, we found improvements in more language subtests in the tDCS group compared to

the control group. In the tDCS group, there were 5 language subtests that had improvements, including verbal fluency, word naming, verbal comprehension, speech rate, and writing, while in the control group the language subtests that showed improvements were verbal fluency, word naming, and repetition.

Our study found that there were 2 patients in the tDCS group who had a change in aphasia syndrome, 1 patient with Broca aphasia becoming transcortical motor and 1 patient with Wernicke aphasia becoming conduction aphasia. This is in line with a previous study that stated that the type of aphasia can improve from non-fluent aphasia to a fluent aphasia.[23] There are several factors that influence aphasia recovery in patients who received tDCS therapy, such as the size and location of the lesion, clinical severity, duration of disease, age, and level of education. On the other hand, the neuroplasticity mechanism that occurs after an ischemic event or reperfusion therapy can also influence the recovery mechanism.[8,10]

Previous studies showed the effect of tDCS on certain language subtests, such as verbal fluency, picture naming, word production, and repetition which could be seen several months after therapy.[22] Most studies also showed that improvement mainly occurred in the naming subtest.[2] In their study, Lifshitz-Ben-Basat et al. stated that even when tDCS was implemented in different stimulation areas, such as inferior frontal gyrus, superior temporal gyrus, and prefrontal cortex, significant improvement was observed in the naming subtest.[24] Another study showed that tDCS stimulation on inferior frontal gyrus and superior temporal gyrus can improve verbal comprehension.[20] The inferior frontal gyrus is the main area for language comprehension and word production, while the anterior part plays a role in semantic and lexical processes and the posterior area plays a role in syntactic and phonological processes.[20] However, we found no significant improvement in the reading subtest in either groups. In previous studies, varying findings of tDCS neuromodulation effects on reading performance have often been found in the adult population. These negative findings might be due to a reduced capacity in neural plasticity mechanism. Categorization of reading ability is a complicated process, and the negative findings from previous studies are limited to the reading language task approach, for instance, the remediation approaches that focus on the small sound units are most often effective at younger ages, meanwhile training on phonemic ability is a common approach in adults.[25]

In this study, we found that the effect of tDCS therapy on several language subtests was still present 2 weeks after therapy. This finding is in line with that of a previous study that showed an improvement in naming accuracy after 5 sessions of tDCS with picture-naming task training and 3 weeks after therapy.[26] Other studies also showed improvement in different language subtests such as word and sentences production, verbal fluency, and naming task after tDCS therapy sessions in aphasia that were still present 2 weeks and 1 month after therapy.[11,20] Although changes in potential membrane after receiving tDCS therapy are transient, it could strengthen synaptic connections by producing long-term effects that can last after cessation of stimulation. This long-term effect might be due to long-term potentiation and long-term depression processes, which are the main mechanisms underlying neuroplasticity in the brain that is involved in learning and memory processes.[27,28]

The results of our study differ from that of at least 3 previous studies that found no significant improvements in language subtests—particularly in naming tasks—following tDCS therapy with a 2-week follow-up.[29-31] A key distinction is that, in those studies, tDCS was not administered concurrently with language training, which may have limited its effectiveness in promoting neuroplastic changes. For instance, Santos et al., in a study conducted in Brazil, applied only a single session of tDCS without coupling it with structured speech-language therapy, which may explain the lack of effectiveness of the treatment.[31] In contrast, our protocol involved 5 sessions of tDCS delivered in combination with language training, which is in line with evidence suggesting that simultaneous engagement in cognitive-linguistic tasks and stimulation may enhance therapeutic outcomes. Moreover, the feasibility and tolerability of this approach in our study population supports its applicability in low- and middle-income countries (LMIC), reinforcing findings from similar contexts such as Brazil, where the integration of tDCS into rehabilitation protocols has also shown promise. In previous studies, the number of tDCS therapy sessions recommended varied from 1 to 30 sessions, but the improvements in language ability are generally seen after receiving 5 sessions of therapy.[27] The

limitation of this study is that not all the patients were able to follow the therapy in 5 consecutive days. As the study was only conducted at a single institution, the findings cannot be generalized to other institutions.

Limitations: This study has several limitations. First, while this study supports the potential effectiveness of tDCS combined with structured language therapy in chronic PSA, the evidence should be considered exploratory. The modest sample size, short follow-up period, and absence of randomization limit the strength of causal inference. Nonetheless, the observed improvements across multiple language domains and absence of adverse effects suggest feasibility and warrant further investigation in rigorously designed trials. Second, while the TADIR scale is the standard tool for assessing PSA in Indonesia and is routinely used in clinical practice, there is currently limited evidence regarding its psychometric properties, including validity, reliability, and sensitivity to change within the PSA population. This represents a limitation in interpreting our findings, as the measurement accuracy and responsiveness of the TADIR remain to be fully established. Future research should focus on rigorous validation studies to better characterize the psychometric robustness of the TADIR, which would strengthen its utility for both clinical and research applications in Indonesian PSA patients. Third, while outcome assessments were conducted at 3 appropriate time points—pre-treatment, post-treatment, and 2-week follow-up—the relatively short duration of follow-up limits our ability to evaluate the sustainability of treatment effects over the longer term. Future studies with extended follow-up periods are needed to better understand the durability and clinical relevance of the observed improvements in language function among chronic PSA patients. Fourth, this study only reports the P-values for statistical significance without including effect size measures such as Cohen's d and rank-biserial correlation or 95% confidence intervals (CIs). The absence of these metrics limits the ability to fully interpret the clinical relevance and magnitude of the observed effects. Future studies with larger sample sizes should incorporate effect size calculations and CIs to provide a more comprehensive understanding of the intervention's practical impact. The study did not apply correction methods for multiple comparisons, which increases the risk of inflated Type I error due to the analysis of multiple TADIR subtests. Future research should incorporate appropriate adjustments, such as Bonferroni or Holm corrections, to enhance the robustness of statistical findings.

Conclusion

This study suggests that tDCS combined with language therapy may offer additional benefits for improving specific language functions in patients with chronic PSA. Notably, 2 participants in the tDCS group showed changes in aphasia syndrome classification after therapy. Improvements across time points were observed in both the tDCS and control groups, though more language subtests showed improvement in the tDCS group. However, most between-group comparisons did not reach statistical significance, and findings should be interpreted as exploratory. These preliminary findings support the potential value of integrating tDCS with language training in PSA rehabilitation. Further research with larger cohorts and longer follow-up is needed to confirm these effects and evaluate their sustainability.

Conflict of Interests

The authors declare no conflict of interest in this study.

Acknowledgments

None.

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