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Case Report

Transcranial Direct Current Stimulation for Apraxia of Speech - A Case Study

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Abstract

Apraxia of speech (AOS) has emerged as the term to describe a motor speech disorder characterized by an impaired ability to coordinate the sequential, articulatory movements necessary to produce speech sounds. The contemporary consensus is that AOS represents a speech motor programming deficit, although the precise nature of this deficit remains elusive and the cognitive base is still a subject for research. Aiming to develop a top-down intervention and improve speech deficits, the current case study aimed to explore how non-invasive transcranial direct current stimulation (tDCS) can contribute to the understanding of mechanisms underlying motor learning and motor memory formation in an AOS patient. The patient was YE, a 51-year-old, right-handed female, school manager who had a left cerebral vascular accident (CVA) due to a dissection of the left internal carotid artery two years prior to intervention. We employed anodal, cathodal and sham tDCS over the left-Inferior Frontal Gyrus (IFG) of YE and 20 healthy control participants, and measured the stimulation effects using Motor Speech Evaluation and Motor programming tasks. Stimulation effects were found only in the speech planning task, but not in the motor programming task, suggesting that speech and non-speech planning and execution procedures are controlled by different neuromotor control systems, and probably not overlapping.

Keywords: Apraxia of Speech; Transcranial Direct Current Stimulation; Speech Programming; Motor Programming; Inferior Frontal Gyrus; Generalized Motor Programmes

Abbreviations

AoS: Apraxia of Speech; IFG: Inferior Frontal Gyrus; tDCS: Transcranial Direct Current Stimulation

Introduction

Overview of apraxia of speech (AOS)

Apraxia of Speech (AOS) is a motor speech disorder characterized by impaired planning and programming of sensorimotor movements for speech. Speech characteristics include off-target articulation, visible and audible articulatory groping, atypical prosody (e.g., decreased rate of speech and prolongations), and variable attempts to self-correct incorrect productions, with error rates increasing upon utterance length and complexity [1-3]. AOS is a distinct impairment that can occur independent of language disturbances (aphasia) and/or neuromuscular involvement (dysarthria) [1,2,4]. Estimates suggest that approximately 4% of individuals diagnosed with an acquired neurological communication disorder present with AOS as the primary disorder, although individuals with stroke-induced AOS as their only communication impairment are rarely reported in the literature [1,5]. In fact, in patients with AOS, there is an estimated co-occurrence of aphasia in 81%, dysarthria in 29–47%, and non-verbal oral apraxia in 48–75% of cases [2,6]. Accordingly, because acquired AOS commonly co-occurs with other speech and/or language disturbances, it is difficult to isolate the brain-behavior relationship specific to AOS. For example, if a common lesion site is found in patients with AOS and concomitant aphasia, it is impossible to determine if damage to this region is associated with AOS, aphasia, or both. Similarly, in the

case of large lesions affecting multiple regions, identifying the exact damage responsible for the behavioral deficits is difficult. Thus, attempts to determine the characteristic behaviors for differential diagnosis, as well as the neuroanatomical localization of AOS, have generated a significant debate [7-11].

Neuroanatomical and cognitive correlates

Acquired AOS typically occurs due to stroke affecting the language-dominant hemisphere [2], but may also be caused by a degenerative process [12,13], tumor, or traumatic injury [2]. More specific lesion locations reported in the literature diverge [14]. Several studies have attempted to identify the location of crucial brain damage that results in AOS, arguing for primary involvement of the left anterior insula [15-18], Broca's area/left inferior frontal gyrus [19-22], or the left motor, premotor and supplementary motor areas [5,12,13].

The precise location of the lesion responsible for AOS thus remains subject of debate. Likewise, the precise nature of the disorder remains poorly understood. One of the main difficulties in isolating the underlying deficit(s) is diagnostic circularity. The ability to investigate the characteristics underlying AOS requires pure cases of AOS selected on the basis of clear-cut criteria, which are only available as a result of research. As lesion inducing medical accidents such as strokes, brain injuries, or tumors rarely produce isolated and one-dimensional deficits, pure cases are rare and symptom profiles show considerable variation between individuals as well as a large overlap in symptomatology with other speech disorders. Additionally, when confronted with a partial breakdown, the speech system itself is likely to adapt to the deviant circumstances and/or compensate for the impediments. Individuals may vary widely in these adaptive and compensatory mechanisms [14].

Klapp [23,24] suggested a two-stage model of motor programming that has been applied to both speech and non-speech movements. The first process (INT) organizes the internal spatiotemporal structure of an individual unit of movement and reads it into a motor buffer (a short-term memory store). The second process (SEQ) sequences units into their correct serial order after initiation. INT can be completed prior to initiation (preprogrammed), and is sensitive to unit complexity, with longer processing time for more complex units. The SEQ process involves on-line retrieval of units from the motor buffer and therefore cannot be preprogrammed. SEQ is sensitive to the number of units in the buffer but not the complexity of a unit. Maas., *et al*. [25] addressed the hypothesis that AOS reflects an impairment of the INT but not SEQ process. Specifically, features characteristic of AOS, such as the prominence of speech sound distortions, temporal and spatial incoordination and variability, and dysprosody, all point to difficulty with organizing the internal structure of units, whereas the absence of serial order errors such as phoneme transpositions indicate intact sequencing abilities (intact SEQ). In addition, they tested the hypothesis that AOS involves a central (i.e., modality-general) motor programming deficit. A reaction time paradigm was used, that provides two dependent measures: study time (the amount of time for participants to prepare a motor response; INT), and reaction time (time to initiate movement; SEQ). Maas., *et al*. [26] found longer preprogramming time for patients with AOS but normal sequencing and initiation times, relative to controls. The findings are consistent with the hypothesis of a central (modality-independent) deficit in AOS.

Non-invasive brain stimulation in speech rehabilitation

Recent years have seen growing interest in the use of non-invasive brain stimulation techniques to enhance recovery of speech and language disorders in acquired brain injury. This interest stems from the growing body of evidence indicating that non-invasive brain stimulation techniques, specifically transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS), can induce long-lasting changes in neural excitability resulting in functional re-organization and improved speech and language performance. These techniques are proving to be a promising approach to enhance recovery of communication disorders resulting from acquired brain injury [27].

Transcranial direct current stimulation (tDCS) utilizes a weak polarized electrical direct current that is delivered to the cortex via two electrodes placed on the scalp. The current starts from the positive (anodal) to the negatively charged (cathodal) electrodes. Anodal and cathodal stimulation can induce enhancement or reduction in neuronal activity, respectively, thus influencing brain function [28]. It has been applied in several studies on language recovery in post-stroke aphasia and probed as a possible adjuvant to influence different aspects of language processing, such as speech fluency, repetition abilities, picture naming [29-32], and lexical retrieval of action words [33].

In one study, two of three patients with stroke-induced aphasia without lesions of the left inferior frontal gyrus (IFG; referred to as

Broca's area) showed a significant improvement in oral production tasks, such as word repetition and reading, after 1 week of tDCS over Broca's area [34].

Wang., *et al*. [35] investigated AOS recovery in patients with post-stroke aphasia, using anodal tDCS over the left lip region of primary motor cortex (M1) or Broca's area. Their 52 patients with AOS were randomized into anodal-tDCS over the left M1, Broca's area, and sham tDCS groups who underwent 10 sessions of tDCS and speech treatment for 5 days. The EEG nonlinear index of approximate entropy was calculated for 6 subjects in each group before and after treatment. Their results showed that after treatment, the change in speech-language performance improved more significantly in the M1group than the other two groups. EEG approximate entropy indicated that both anodal-tDCS groups could activate the stimulated sites; the improvement in the M1 group was correlated with high activation in the dorsolateral prefrontal cortex and Broca's areas of the left hemisphere in addition to the stimulated site. They concluded that anodal-tDCS over the left M1 can improve the speech function in patients with post-stroke aphasia and severe AOS and excite and recruit more areas in the motor speech network.

The current study

The current study aimed to explore how non-invasive tDCS can contribute to the understanding of mechanisms underlying motor learning and motor memory formation in AOS; this understanding can result in the development of new strategies to treat patients with brain lesions. We used tDCS aiming to locate the cortical region of interest, left-IFG (inferior frontal gyrus); this location was chosen based on the results Wang., *et al*. [35].

Hypothesis and predictions

We hypothesized that brain stimulation will improve motor planning skills as well as speech and language functions of a patient with AOS.

We predicted improved performance following anodal stimulation over the left IFG compared to sham, as reflected in the following measure:

- Language and speech examination, based on the MSE – Motor Speech Evaluation [3] – we predicted improvement in the quality of speech, with reduction in signs of AOS: less effortful and more accurate speech; better rhythm, stress and intonation; more consistent articulation of the same utterance; less difficulty initiating utterances.
- Motor programming task, according to the two-stage model [23,24] – we predicted improvement in reaction times and accuracy.

Materials and Methods

Participant

The case

YE is a 51-year-old, right-handed female, school manager who had a left cerebral vascular accident (CVA) due to a dissection of the left internal carotid artery two years prior to intervention. Computerized Tomography (CT) identified a large infarct in the territory of the left middle cerebral artery and obstruction of the left internal carotid artery (Figure 1). YE was independent with her activities of daily living. She lived at home with her husband and 3 children. Following her stroke, YE first underwent endovascular thrombectomy procedure, and then received 4 months of inpatient and 12 months of outpatient rehabilitation in a multidisciplinary center. Informed written consent was obtained before initiating testing and stimulation procedures. YE was characterized as having Broca's aphasia and apraxia of speech by a certified speech-language pathologist.

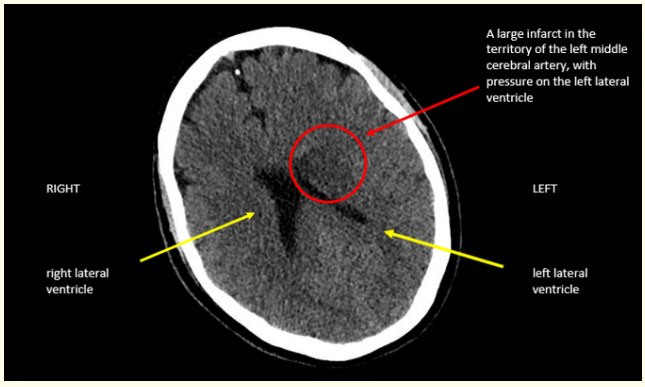

Figure 1: YE's Computerized Tomography (CT) identified a large infarct in the territory of the left middle cerebral artery with pressure on the left lateral ventricle. With permission from YE.

Control participants

Twenty healthy subjects served as controls. They were randomly assigned to two stimulation groups. The left-IFG anodal stimulation group included 8 participants, mean age = 25.13 ± 3.23; left-IFG cathodal stimulation group had 12 subjects, mean age = 22.5 ± 1.51.

Experimental tasks

MSE – Motor Speech Evaluation [3]

The MSE consists of seven subtests, which include:

1. Sequential Diadochokinesis. The examinee repeats one-syllable strings multiple times ("pa, pa, pa", "ta, ta, ta", and "ka, ka, ka").
2. Alternating Diadochokinesis. The examinee alternates between the three-syllable utterance "pataka" as rapidly and smoothly as possible.
3. Single Repetition of Multisyllabic Words. The examinee repeats three multisyllabic words ('gingerbread', 'snowman', and 'television') one time after the examiner provides a model. Stimuli contain consonant clusters and require movement between different places of articulation.
4. Multiple Repetitions of Multisyllabic Words. The examinee repeats three polysyllabic words ('artillery,' 'impossibility', and 'catastrophe') five times each. Words include consonant clusters and require rapid movement between multiple places of articulation during productions of each word.
5. Single Repetition of Monosyllabic Words. The examinee is asked to repeat single, monosyllabic words one time after the tester provides a model. Each word begins and ends with the same consonant (e.g., 'nine', 'judge'), so that minimal movement is required between places of articulation.
6. Words of Increasing Length. The examinee repeats similar words that increase in number of syllables (e.g., 'jab,' 'jabber,' and 'jabbering'). This subtest measures the ability to sequence the correct number of syllables in the proper order. Some speakers of AOS have shown a tendency to make more errors on longer words than on shorter words.
7. Repetition of sentences. The examinee repeats sentences composed of frequent and infrequent word choices (e.g. 'In the summer they sell vegetables,' 'Arthur was an oozy, oily sneak').

Each experimental session included different subtests' stimuli (total of 3 sets of stimuli).

The preparation time was the time measured from when the experimenter finished reading the stimulus till when the subject started repeating it (the amount of time for the participant to prepare a speech response). The completion time was the time measured from when the experimenter finished reading the stimulus till when the subject finished repeating it (time to complete the repetition). The accuracy was calculated as the sum of errors by judgments of speech quality: effort and accuracy; rhythm, stress and intonation; consistency of articulation of the same utterance; initiation of utterances.

Motor programming task, according to the two-stage model [23,24]

In this task, the participant saw a sequence of 1-3 digits on the computer screen, and was asked to press the number buttons on the response box according to the sequence she had seen (for example, if the presented digits were "1, 2", the correct response would be to press button "1" and then button "2"). The stimuli consisted the digits "1", "2", and "3"; There were one-digit numbers (1, 2, 3), two-digit numbers (12, 13, 21, 23, 31, 32), and three-digit numbers (123, 132, 213, 231, 312, 321). The experiment consisted of a practice block, followed by 5 experimental blocks. Each practice block consisted of 9 stimuli, presented in random order: 3 one-digit numbers, 3 two-digit numbers, and 3 three-digit numbers. Each experimental block consisted of 15 stimuli, presented in random order: 3 one-digit numbers (1, 2, 3), 6 two-digit numbers (12, 13, 21, 23, 31, 32), and 6 three-digit numbers (123, 132, 213, 231, 312, 321). The digits were presented on a screen, and the participant had to press the space bar while preparing the upcoming response; this preparation period is termed Study Time (ST) and reflects the INT process. When she was ready to respond, she left the space bar, and pressed the number buttons on the response box according to the number she had seen; the interval between leaving the space bar and pressing the first number button reflects the SEQ process.

We employed a reaction time paradigm that provides two dependent measures for the tested processes, INT (internal structure organization of each chunk) and SEQ (the process which organizes the chunks into a sequence). INT is indexed by study time, that is the amount of time for the participant to prepare a motor response. SEQ is indexed by the time to initiate a movement. The

task involves hand movements of pressing big, comfortable buttons (diameter = 5cm) of a specially made response box (Figure 2). The pressing action therefore is not challenging for patients with motor difficulties [36].

Figure 2: The response box used in the Motor programming task.

tDCS protocol

The coordinates of the stimulated area were marked using the international EEG 10/20 system.

Two 5x7 electrodes were placed on the subjects' head: one on the stimulation area, left IFG, defined as the crossing point between T3-Fz and F7-Cz [32] and the other on the forehead above the right eye. In the anodal condition, the anodal electrode was placed over the left IFG and the reference (cathodal) over the right orbita. The reverse montage was employed for the cathodal stimulation.

The stimulation was applied for 20 minutes at 1.5mA intensity. We also applied a control placebo condition called sham [37], in which the stimulation is turned on and off after 30 seconds, sufficient to generate the initial itching sensation, therefore participants are unable to distinguish this condition from real stimulation.

Stimulation was always applied gradually using a ramp up and ramp down of current to avoid discomfort [28].

Procedure

The subject (and control subjects) participated in 2 sessions, which differed in stimulation conditions. Each session started with a sham stimulation to measure baseline performance, followed by anodal stimulation in the first session and cathodal stimulation in the 2nd session. Performance following every stimulation was evaluated using the Language and speech examination, based on the MSE – Motor Speech Evaluation [3]; and the Motor programming task, according to the two-stage model [23,24] (Table 1). Control participants conducted the motor programming task under stimulation conditions similar to YE.

Session	task	Baseline assessment	Sham stimulation	Anodal Stimulation	Cathodal Stimulation
1	Motor speech evaluation	√	√	√	
	Motor programming task	√	√	√	
2	Motor speech evaluation		√		√
	Motor programming task		√		√

Table 1: Experimental procedure detailed by session, task and stimulation condition.

Results and Discussion

MSE – Motor Speech Evaluation [3]

Since it is a case study, we first conducted item-analysis to evaluate how the experimental conditions affected YE performance.

Two separate repeated measures ANOVA were conducted on RT and accuracy of responses for the items. The analyzed within-subject factors were stimulation condition (baseline, sham-before-anodal, anodal, sham-before-cathodal and cathodal) and task stage: preparation time (the amount of time to prepare a speech response) and completion time (time to complete repetition).

There was a significant stimulation effect, indicating a significant difference in all RT's (preparation time and completion time) following stimulation, $F(4,80) = 3.417$, $p = 0.012$.

The preparation time and the completion time after anodal or cathodal tDCS were significantly shorter than at baseline.

As expected, task stage effect was significant, $F(1,20) = 52.017$, $p < 0.0001$, however that was due to the different time ranges of the task stages and therefore has no theoretical contribution.

There was a significant interaction of stimulation condition and task stage, $F(4,80) = 3.392$, $p = 0.013$. A review of the data revealed an overall improvement after each session (learning effect). There was no selective effect of stimulation type (anodal vs. cathodal), but an overall effect of stimulation (as mentioned before) on improvement of RT's. It seems that stimulation improves performance, even after only two stimulation sessions (Table 2).

Stimulation condition	Preparation Time – mean (SD)	Completion Time – mean (SD)
Baseline	0.659 (0.032)	3.151 (0.409)
Sham-before-Anodal	0.672 (0.039)	2.786 (0.339)
Anodal	0.652 (0.037)	2.503 (0.275)
Sham-before-Cathodal	0.624 (0.027)	2.712 (0.325)
Cathodal	0.621 (0.025)	2.519 (0.232)

Table 2: Mean and SD of RT's (preparation time and completion time in seconds) in the Motor Speech Evaluation task.

There was no main effect of stimulation condition on accuracy, $F(4,80) = 1.362$, $p = 0.255$, n.s. However, the data did show a trend of improvement after stimulation compared to sham (Table 3).

Stimulation condition	Accuracy – mean (SD)
Baseline	0.333 (0.159)
Sham-before-Anodal	0.286 (0.156)
Anodal	0.095 (0.066)
Sham-before-Cathodal	0.333 (0.174)
Cathodal	0.048 (0.048)

Table 3: Mean and SD of number of errors in the Motor Speech Evaluation task.

Motor programming task

Two separate repeated measures ANOVA were conducted on RT and accuracy of responses to all items. Following this, we compared her performance to healthy controls using non-parametric comparisons.

For RT as the dependent measure we analyzed stimulation condition (baseline, sham-before-anodal, anodal, sham-before-cathodal and cathodal) and task stage [Study Time (ST) – reflects the INT process and Reaction Time (RT) – reflects the SEQ process] as the within-subject factors.

For Accuracy we analyzed stimulation condition (baseline, sham-before-anodal, anodal, sham-before-cathodal and cathodal) and digit accuracy (first digit, second digit and third digit) as the within-subject factor.

There was a significant stimulation condition effect, indicating a significant difference in all RT's after each session, $F(4,140) = 32.348$, $p < 0.0001$.

As expected, task stage effect was significant, $F(1,35) = 364.795$, $p < 0.0001$, however that was due to the different time ranges of the task stages and therefore has no theoretical contribution.

There was a significant interaction of stimulation condition and task stage, $F(4,140) = 6.297$, $p < 0.0001$. It seems that this interaction stems from lack of improvement in RT following cathodal stimulation (1027msec vs 1003msec) compared to larger improvements in RT following anodal stimulation, and study time after anodal and after cathodal stimulation.

When comparing YE performance to healthy controls, her study times before and after anodal stimulation did not differ from those of controls (Z comparison using control's confidence intervals), however before and after cathodal stimulation her study times were shorter, probably due to practice. Her reaction time was slower in all other stimulation conditions (Table 4).

	Study Time (ST) – mean (SD)		Reaction Time (RT) – mean (SD)	
Stimulation condition	YE – AOS subject	Healthy control subjects 95% Confidence Interval	YE – AOS subject	Healthy control subjects 95% Confidence Interval
Sham-before-Anodal	507 (18)	370-690	1313 (22)**	329-674
Anodal	487 (16)	450-907	1153 (19)**	166-571
Sham-before-Cathodal	370 (10)*	615-929	1027 (13)**	244-413
Cathodal	309 (7)*	523-846	1003 (13)**	223-437

Table 4: Comparison of RT's between YE and healthy controls in the Motor programming task.

* denotes significant differences at $p < 0.05$ between YE and controls

** denotes significant differences at $p < 0.01$ between YE and controls

There was a significant stimulation condition effect, indicating a significant difference in all digit accuracy's (first digit, second digit and third digit) after each session, $F(4,296) = 31.059$, $p < 0.0001$.

There was a significant interaction of stimulation condition and digit accuracy, $F(8,592) = 5.646$, $p < 0.0001$.

A review of the data revealed an overall improvement after each session, both in all RT's and in all accuracy's (learning effect). There was no selective effect of real stimulation condition (anodal vs. cathodal), but an overall effect of stimulation session on improvement of RT's and accuracy's. In this task it seems that it is not the stimulation that improves performance, but the mere practice (learning effect).

Stimulation condition	YE – AOS subject	Healthy control subjects
	Accuracy – mean (SD)	95% Confidence Interval
Sham-before-Anodal	0.867 (0.035)	0.592-0.953
Anodal	0.969 (0.019)	0.486-0.987
Sham-before-Cathodal	1 (0)	0.714-1.064
Cathodal	1 (0)	1-1

Table 5: Comparison of accuracy between YE and healthy controls in the Motor programming task.

When comparing YE performance to healthy controls, her accuracy scores did not differ from those of controls (Z comparison using control's confidence intervals), so we can conclude that her difficulties are reflected in slower response times but accuracy level is preserved.

Discussion

The purpose of the current study was to explore how non-invasive tDCS can contribute to the understanding of mechanisms underlying motor learning and motor memory formation in AOS. We used tDCS aiming to locate the cortical region of interest – left-IFG (inferior frontal gyrus) and examined the influence of our stimulation protocol as facilitative that may improve the speech planning difficulties in AOS.

Regarding the speech planning task [3], our results revealed an overall improvement after each session (learning effect). There was no selective effect of stimulation polarity (anodal vs. cathodal), but an overall effect of left IFG stimulation on improvement of RT's. It seems that active stimulation, compared to sham, improves performance, even after only two stimulation sessions.

Regarding the motor programming task [23,24], our results revealed an overall improvement after each session, both in all RT's and in all accuracy's. There was no selective effect of real stimulation condition, but an overall effect of stimulation session on improvement of RT's and accuracy's. In this task it seems that it is not the stimulation that improves performance, but the mere practice, in other words learning effect.

The results suggest that each task relates to a separate underlying mechanism. The fact that stimulation effect was found only in the speech planning task, but not in the motor programming task, suggests that speech and non-speech planning and execution procedures are controlled by different neuromotor control systems, and probably not overlapping.

Acquired AOS typically occurs due to damage affecting the language-dominant hemisphere [2]. More specific lesion locations reported in the literature diverge [14], and the precise location of the lesion responsible for AOS thus remains subject of debate. Our findings support the involvement of Broca's area/left inferior frontal gyrus, as suggested by several researchers [19-22]. We found significant improvement of speech preparation time and speech completion time after anodal or cathodal tDCS over the left inferior frontal gyrus.

Cortical reorganization develops in the damaged brain, which plays an important role in recovery from acute stroke. Well-known recovery mechanisms from stroke deficits are improvement from diaschisis, or functional reorganization of the ipsilesional or contralesional cortex with involvement of uncrossed corticospinal tract fibers. The importance of co-activation of the perilesional or contralesional cortex is unknown; however, neuronal plasticity plays an important role in neurologic recovery. Motor learning is associated with structural changes, such as axonal or dendritic growth along with new synapse formation and functional modulation including long-term potentiation or long-term depression, which may enhance or suppress synaptic activities [38].

Some studies based on the assumption that suppression of activity in the 'overactive' right hemisphere after left-hemisphere stroke may promote language recovery, while others provided evidence that the right hemisphere might play a beneficial role in aphasia recovery. Consequently, it was argued that language recovery is a dynamic process that may involve a variety of plastic changes in both hemispheres [39].

Our results revealed an overall effect of stimulation (anodal and cathodal) on improvement of RT's. Several studies have applied tDCS in post-stroke aphasic and/or apraxic patients to facilitate treatment in language recovery. Few of these studies investigated the effects of cathodal tDCS over perilesionel left-hemispheric regions to facilitate language. For instance, Monti., *et al*. [32] showed that cathodal tDCS significantly improved picture naming in eight ischemic stroke patients with aphasia. It was concluded that the effect of cathodal stimulation may be a downregulation of overactive inhibitory cortical interneurons in the lesioned hemisphere that ultimately gave rise to increased activity and function in the damaged left hemisphere. In contrast, several other researchers have reported improved language performance after either anodal stimulation of the left hemisphere or cathodal stimulation of the right hemisphere. These results suggest that an upregulation of right-hemisphere activity may be beneficial for language recovery in some patients. Those studies show that tDCS might be of potential benefit in promoting aphasia or apraxia recovery after stroke. However, the results are heterogeneous, and it remains to be determined whether anodal or cathodal tDCS should be applied to perilesional left-hemisphere regions or contralateral right-hemisphere areas [39].

Conclusion

In conclusion, tDCS over the damaged left inferior frontal gyrus improves language performance in YE, a chronic non-fluent aphasic and apraxic patient. tDCS is simple, safe and inexpensive and thus it might possibly be useful in the management of post-stroke apraxia of speech.

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Conflict of Interest

We declare no financial interests or any conflict of interest.

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