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Research report

# Electrical stimulation over the left inferior frontal gyrus (IFG) determines long-term effects in the recovery of speech apraxia in three chronic aphasics

P. Marangolo[a,c,*], C.V. Marinelli[b,c], S. Bonifazi[a], V. Fiori[a,c], M.G. Ceravolo[a], L. Provinciali[a], F. Tomaiuolo[d,1]

[a] Department of Neuroscience, Faculty of Medicine, University of Ancona, Ancona, Italy
[b] Faculty of Psychology, University of Rome, Rome, Italy
[c] IRCCS Fondazione Santa Lucia, Rome, Italy
[d] Unità Cerebrolesioni Acquisite – Auxilium Vitae Volterra, Pisa, Italy

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A B S T R A C T

A number of studies have shown that modulating cortical activity by means of transcranial direct current stimulation (tDCS) affects the performance of both healthy and brain-damaged subjects. In this study, we investigated the potential of tDCS for the recovery of apraxia of speech in 3 patients with stroke-induced aphasia. Over 2 weeks, three aphasic subjects participated in a randomized double-blinded experiment involving intensive language training for their articulatory difficulties in two tDCS conditions. Each subject participated in five consecutive daily sessions of anodic tDCS (20 min, 1 mA) and sham stimulation over the left inferior frontal gyrus (referred to as Broca's area) while they performed a repetition task. By the end of each week, a significant improvement was found in both conditions. However, all three subjects showed greater response accuracy in the anodic than in the sham condition. Moreover, results for transfer of treatment effects, although different across subjects, indicate a generalization of the recovery at the language test. Subjects 2 and 3 showed a significant improvement in oral production tasks, such as word repetition and reading, while Subjects 1 and 2 had an unexpected significant recovery in written naming and word writing under dictation tasks. At three follow-ups (1 week, 1 and 2 months after the end of treatment), response accuracy was still significantly better in the anodic than in sham condition, suggesting a long-term effect on the recovery of their articulatory gestures.


## 1. Introduction

Apraxia of speech (AOS), also known as verbal apraxia, is an acquired motor speech disorder characterized by an impaired ability to coordinate the sequential, articulatory movements necessary to produce speech sounds [1,2].

Though there may be some disagreement as to its precise location, there is a general consensus that the disorder results from brain injury in the language-dominant (usually left) hemisphere due to a damage either to the inferior frontal gyrus [3], in the left anterior insula [4] and/or in the subcortical structures, particularly in the basal ganglia [5,6].

The severity of AOS varies from person to person. The disorder can be so mild to give the patient troubles with very few speech sounds or only occasional problems pronouncing words with many syllables. In the most severe cases, a patient may not be able to communicate effectively with speech, and may need the help of alternative or additional communication methods. One of the most notable symptoms is the tendency of the patient to make groping oral movements to locate the correct articulatory position, and the presence of increasing articulatory errors with increasing word and phrase length [7, for a review]. Another common characteristic is the incorrect use of "prosody", that is, the varying rhythms, stresses, and inflections of speech that are used to express one's emotional state.

Although AOS is not due to weakness or paralysis of the speech muscles (the muscles of the face, tongue and lips), it may occur together with muscle impairments or concomitant acquired language difficulties, such as Broca's aphasia.

There is no single factor or test that can be used to diagnose verbal apraxia. The person making the diagnosis generally looks for the presence of some of the symptoms described above in verbal production tasks such as naming, repetition and reading stimuli of increasing length and articulatory complexity [2].

Numerous treatment approaches have been developed to remediate the apraxia motor speech disorder. However, no single approach has been proven to be the most effective [e.g. 7–10].

* Corresponding author at: Department of Neuroscience, Faculty of Medicine, Ancona, Italy. Tel.: +39 0712206093/3477548995; fax: +39 071887262/0712206214.
*E-mail addresses:* p.marangolo@univpm.it (P. Marangolo), f.tomaiuolo@riabilitazione-volterra.it (F. Tomaiuolo).

[1] Dr. F.Tomaiuolo should be referred for neuroanatomical analysis.

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Typically, the therapy is concentrated on the disordered articulation. It emphasizes the relearning of adequate points of articulation and the sequencing of articulatory gestures in order to provide conditions such that the patient can advance from limited, automatic-reactive speech to appropriate, volitional-purposive communication. Apraxic patients, in general, may achieve greater phonemic accuracy if they are allowed to monitor their own speech in a mirror and if they can watch the articulatory movements of the clinician as he/she speaks [11]. In some cases, people with apraxia of speech recover some or all of their speech abilities. However, in the most severe conditions, persistent difficulties in articulating speech sounds may be observed also after an intensive language treatment period [12].

In recent years, new approaches for the treatment of motor and language impairments, such as non-invasive neurostimulation techniques, have emerged. Transcranial direct current stimulation (tDCS) makes use of a weak polarizing direct current delivered to the cortex via two electrodes placed on the scalp. The nature of the effect depends on the polarity of the current. Generally, the anode increases cortical excitability when applied over the region of interest with the cathode above the contralateral orbit or above the shoulder (as the reference electrode), whereas the cathode decreases it, limiting the resting membrane potential. In particular, during anodic stimulation in healthy subjects enhanced visuomotor performance [13], motor learning [14], verbal fluency [15] and working memory [16] have been observed. Recent studies of chronic neurological subjects have further demonstrated how increased cortical excitability influences the recovery of motor [17,18], neurological and psychiatric symptoms [19–21].

With regard to the language domain, few studies have already shown that tDCS may be effective in enhancing verbal learning in normal subjects [22,23] and in the recovery of oral word production in aphasic patients [24–27].

However, there have been no reports to date that have explored its influence for the improvement of articulatory disturbances in the aphasic population. Recent studies suggest that long-term effects might be more easily obtained with repeated tDCS applications. It has been proposed that the greatest improvement is obtained when the damaged areas are stimulated during simultaneous specific language training [25–27].

The main purpose of the present study was to investigate in three chronic nonfluent aphasic patients whether the application of anodic tDCS over the left inferior frontal gyrus (referred to as Broca's area) during concomitant language training would lead to an improvement of their articulatory disturbances. The choice to stimulate this area was based on the results of previous research which demonstrates the importance of this region for articulating speech sounds [3].

Since all patients had damage to cerebral structures functionally connected to Broca's area (see Fig. 1), we wondered whether stimulation of this region would ameliorate their articulatory difficulties.

In order to measure the potential, long-term beneficial effects in the aphasic subjects, three follow-up sessions were carried out 1 week, 1 month and 2 months after the end of each treatment condition.

## 2. Experiment

### 2.1. Materials and methods

#### 2.1.1. Subjects

Three subjects (2 males and 1 female) who had suffered a single left hemispheric stroke were included in the study. Inclusion criteria during this study were subjects with native Italian proficiency, pre-morbid right-handedness, a single left hemispheric stroke at least 6 months prior to investigation and no acute or chronic neurological symptoms requiring medication. The data analyzed in the current study were collected in accordance with the Helsinki Declaration and the Institutional Review Board of the Ospedale Riuniti Torrette in Ancona, Italy. Prior to participation, all patients signed informed consent forms.

#### 2.1.2. Clinical data

Subjects 1 and 3 suffered from an ischemic lesion involving the left hemisphere (see Fig. 1). In Subject 2, MRI revealed a hemorrhagic lesion involving the same hemisphere. As shown in Fig. 1, none of the patients had damage to the inferior frontal gyrus where the tDCS anode was positioned.

Formal testing was conducted within 1 week prior to stimulation. Aphasic disorders were assessed using standardized language tests (i.e. Esame del Linguaggio II [28]; Token test [29]).

The three subjects were classified as nonfluent aphasics because of their severely compromised oral production due to AOS. Two subjects (1 and 2) were not able to produce any sounds in spontaneous speech with severe articulatory groping in naming, repetition and reading tasks. Subject 3 exhibited marked difficulties in initiating speech and presented with distortions of phonemes and articulatory groping with bisyllabic words for naming, repetition and reading tasks. Written naming and writing under dictation tasks were markedly compromised in Subjects 2 and 3, while Subject 1 showed a partial recovery in the word writing task (see Table 1).

For all cases, auditory comprehension abilities were functionally adequate in the Esame del Linguaggio II and in the Token test in which two patients obtained scores of medium severity (Subjects 2 and 3) and one patient (Subject 1) showed complete recovery (the cut-off score which discriminates between pathological and normal performance is 29/36) (see Table 1).

To evaluate nonverbal oral motor skills, the Oral Apraxia test [30] was administered. None of the patients showed apraxic disturbances.

### 2.2. Materials

A list of 60 syllables (e.g. PA, MO, CA, FU) and a list of 50 CVCV (CV consonant–vowel, e.g. luna [moon], pipa [pipe], dito [finger], vino [wine]) and 40 CVCCV (e.g. palla [ball], nonno [grandfather], panna [cream], letto [bed]) very simple bisyllabic words were used [Fanzago test, 31].

According to the International Phonetic Alphabet (IPA, [32]), syllables included different places (e.g. plosive, nasal, fricative) and manners of articulation (e.g. bilabial, dental, velar).

### 2.3. Procedure

One week before the language training, different stimulus sets were developed for each participant, based on their profile of deficits and stimulability for speech behaviours. First, all the 150 stimuli (syllables and words) were auditorily presented, one at a time, through an audiotape for 3 consecutive days. The participants had to repeat each stimulus within 15 s. We identified the stimuli the patients could not correctly produce or always omitted.

Since Subject 1 had severe difficulties in producing syllables and words, a list of 56 CV syllables (i.e. /pa/, /me/) and a list of 14 CVCV and 10 CVCCV bisyllabic words were considered. For Subjects 2 and 3, stimuli included a list of 44 CVCV (CV consonant–vowel) and 36 CVCCV bisyllabic words.

For each subject, the selected stimuli were subdivided into two groups of 40 stimuli each with bisyllabic words matched for frequency and length. Two stimulation conditions were carried out,