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CLINICAL CASES

Transcranial Direct Current Stimulation improves word production in Conduction Aphasia: Electroencephalographic and behavioral evidences



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KEYWORDS

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Abstract A Conduction Aphasic patient, RH, with many difficulties at the level of phonological output, was subjected to Transcranial Direct Current Stimulation (tDCS) therapy six months after suffering a stroke. Fifteen daily sessions were administered (five days per week). The treatment led to a better intra-hemispheric electrical coherence and inter-hemispheric balance, as shown by the quantitative EEG analysis. Transcranial Direct Current Stimulation therapy was shown to be effective in inhibiting irregular activation of the right hemisphere, offering the healthy areas of the left hemisphere the possibility of reassuming their linguistic processing abilities. Also, the number of errors in picture naming and repetition of words and pseudowords dropped considerably following treatment. The recovery was greater for long stimuli and was not affected by semantic or lexical variables such as familiarity. These results suggest that the Phonological Output Buffer, a mechanism dedicated to the maintenance, ordering and production of phoneme strings, was the processing stage modified by the treatment.

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PALABRAS CLAVE

Terapia TDCS;
Afasia de conducción;
Producción del
lenguaje;
Experimento de caso
único

La Estimulación de Corriente Directa Transcaneal mejora la producción de palabras en la afasia: evidencias electroencefalográficas y conductuales

Resumen Una paciente con Afasia de Conducción, RH, con dificultades en el nivel de producción fonológica, fue sometida a la Terapia de Estimulación de Corriente Directa Transcaneal (tDCS), 6 meses después de haber sufrido un ictus, durante 15 sesiones diarias. El tratamiento produjo mayor coherencia eléctrica y equilibrio entre los hemisferios, evidenciado por el análisis

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de EEG. La Terapia tDCS demostró ser un procedimiento efectivo para inhibir la activación irregular del hemisferio derecho, y posibilitar a las áreas sanas del hemisferio izquierdo el reasumir sus habilidades de procesamiento lingüístico. Asimismo, el número de errores en nombrado de dibujos y repetición de palabras y pseudopalabras se redujo significativamente después del tratamiento. La recuperación fue mayor en los estímulos largos, y no se vio influenciada por variables léxicas o semánticas como la familiaridad. Estos resultados sugieren que el Buffer de Salida Fonológico, un mecanismo dedicado al mantenimiento, secuenciación y producción de fonemas, fue el estadio de procesamiento modificado por el tratamiento.

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Conduction Aphasia is a linguistic disorder characterized by errors of reduplication, substitution, addition, transposition or omission of phonemes or groups of phonemes in picture naming, repetition, writing and reading tasks (Shallice, Rumiati, & Zadini, 2000). The locus of the damage is situated at the level of the Phonological Output Buffer (POB), a mechanism entailing processes of working memory, phonological identification and phonological assembling previous to the articulation of the word. If a pure damage in a phonological buffer is assumed in a patient, deficits in the patient performance will be observed in all the linguistic tasks using the output mechanism (Annoni, Lemay, de Mattos-Pimenta, & Lecours, 1998; Caramazza, Miceli, Villa, & Romani, 1987; Mondini, Arcara, & Semenza, 2012). This was observed in our patient-case.

Identification and history of the case

RH is a 60-year-old, right-handed, married female with a degree in Obstetrics & Gynaecology. On February 2011, she suffered a brain stroke (see Figure 1a) with acute ischemia affecting the temporal and parietal lobes of the left hemisphere. She presented motor dysphasia and problems of naming and repetition that constituted Conduction Aphasia.

An improvement of spontaneous speech was soon observed, with the patient producing more fluent verbalization and emission of complete sentences. However, the naming deficits persisted. Reading was preserved, but she syllabified words. No other neurological or functional disorders were diagnosed. She was referred to the Rehabilitation Department of the *Hospital Universitario de Canarias* for a neuropsychological evaluation (Jurado & Pueyo, 2012; Rodríguez Pérez, González Castro, Álvarez, Álvarez, & Fernández-Cueli, 2012) and to determine her suitability for rehabilitation treatments.

Behavioral analysis

In order to assess verbal capacities in comprehension and production, the patient was given the Beta Battery (Cuetos & González-Nosti, 2009). This evaluation showed that phoneme identification and auditory word recognition were normal. Semantic processing was also found to

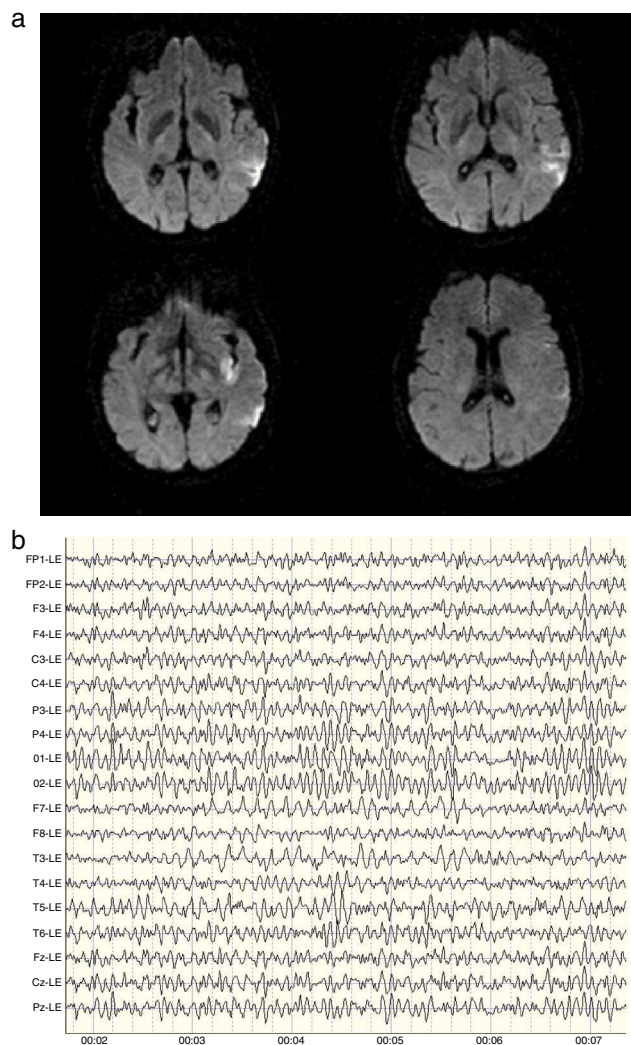


Figure 1 RH' CT brain scan (a) and Monopolar EEG fragment (b).

be efficient. However, deficits were found when task performance required cognitive mechanisms at the level of phonological output. She made many mistakes in naming and repetition, especially on the long words. Also, she had

a 50% error rate when writing pseudowords. The absence of problems in reading contrasted with the high number of errors made in naming and repetition. Some other difficulties were related to the level of sentence comprehension. The errors in sentence-picture matching supported a verbal memory span deficit at the moment of processing complex and highly demanding syntactic structures.

Selection and treatment goal

Two months after her stroke the patient started speech therapy, which she followed three days a week for four months without any apparent improvement of her linguistic production abilities (see percentage of errors at Figure 4 before the electrical stimulation). The patient was then subjected to Transcranial Direct Current Stimulation (tDCS) therapy while the speech therapy continued. Studies of the combination of electrical stimulation with speech training have shown improvement in verbal fluency in healthy subjects (Fertorani, Rosini, Cotelli, Rossini, & Miniussi, 2010) and patient samples (Baker, Rorden, & Fridriksson, 2010). In accordance with these findings, the goal of the tDCS treatment was to improve RH's linguistic production abilities. Our research case (Buela-Casal & Sierra, 2002; Montero & León, 2007) is aimed at broadening the ambit of effectiveness for such combined treatment by examining behavioral (language task) and electrophysiological evidence of brain changes after electrical stimulation. We also compare performance in language tasks as a function of words length and familiarity in order to test the hypothesis that is the Phonological Output Buffer the processing stage modified by the treatment.

Application of the treatment

Electrical current of 1 mA of anodal stimulation was applied to the left frontal area. The cathodal electrode was placed over the homologous right contra-lateral area. To approach Broca's area, the electrode was placed 2 cm behind the F7 site in accordance with the International 10-20 EEG system. Fifteen daily sessions lasting 20 minutes each (5 days per week) were administered via 7 × 5 cm saline-soaked sponge electrodes. The Eldith DC-stimulator of Neuroconn was used as a micro-processor-controlled constant current source. Many studies have demonstrated that anodal stimulation has excitatory effects on the underlying left cortex, whereas cathodal stimulation produces inhibitory effects on the right hemisphere (Liebetanz, Nitsche, Tergau, & Paulus, 2002). It was expected that the assembly described above would reduce activation of the habitually over-stimulated right hemisphere, forcing the areas around the damaged cortex of the left hemisphere to reassume their linguistic processing abilities (Monti et al., 2013), thus enabling the improvement of language production (Gómez-Palacio Schjetnan, Faraji, Metz, Tatsuno, & Luczak, 2013). During electrical stimulation the patient did not perform linguistic tasks, due to we were interested in evaluating long-lasting effects of electrical stimulation, but not in evaluating online effects.

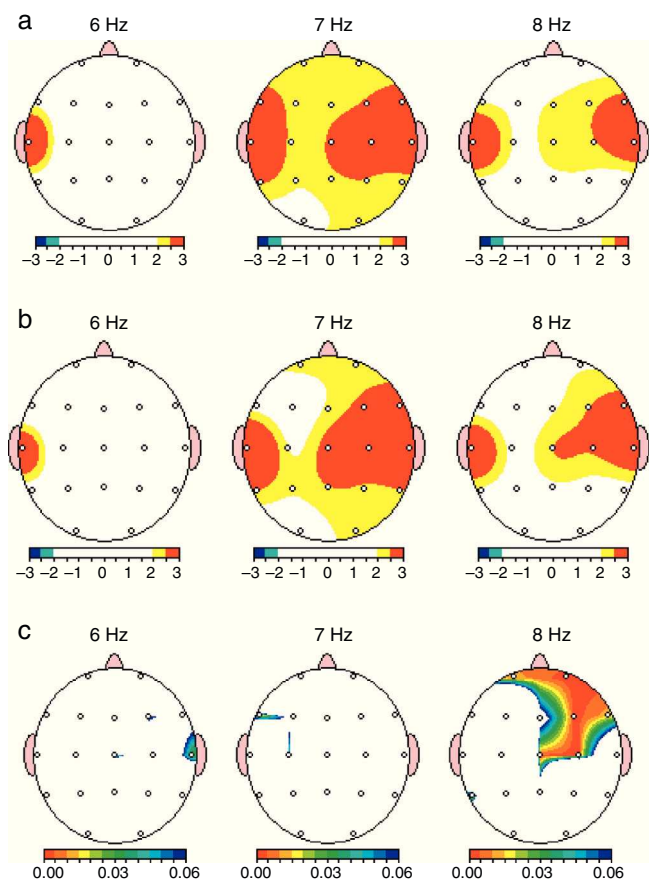


Figure 2 Power electroencephalographic measures. Z scores before tDCS (a); after tDCS (b); and p values for before and after tDCS differences (c): White represents no statistically significant differences, red indicates $p < .001$ and green and blue $p < .05$.

Evaluation of the effectiveness of treatment

Power and coherence measures were calculated on the EEG recording before and after tDCS stimulation. A fitted electrode-cap with leads placed at the International 10/20 System was applied to achieve a standardized 19-channel EEG recording. References were linked to combined mastoids. Impedances were kept under 5 KOhms prior to recording. The recording was taken with eyes closed (relaxation) and eyes open (relaxation). Sampling frequency was 200 Hz. Digitized data were submitted to an automatic artifact detection routine and visual review. Waves were filtered at delta (0-4 Hz), theta (4-8 Hz), alpha (8-13 Hz) and beta (13-30 Hz) bands. The EEG data were analyzed for frequency content using discrete Fourier Transformation (FFT) and Analysis of Variance following the Neuroguide package of Applied Neuroscience Inc.

As can be seen in Figure 1b, abnormal electrophysiological activity at T3 (record in line 13) and F7 (record in line 11) was shown in agreement with the localization of the left temporal lesion.

As can be seen in Figure 2a, before tDCS the cartography shows the medium-temporal power in left delta (T3) and theta diffuse. The Alpha 1 is fronto-temporal. Only the left

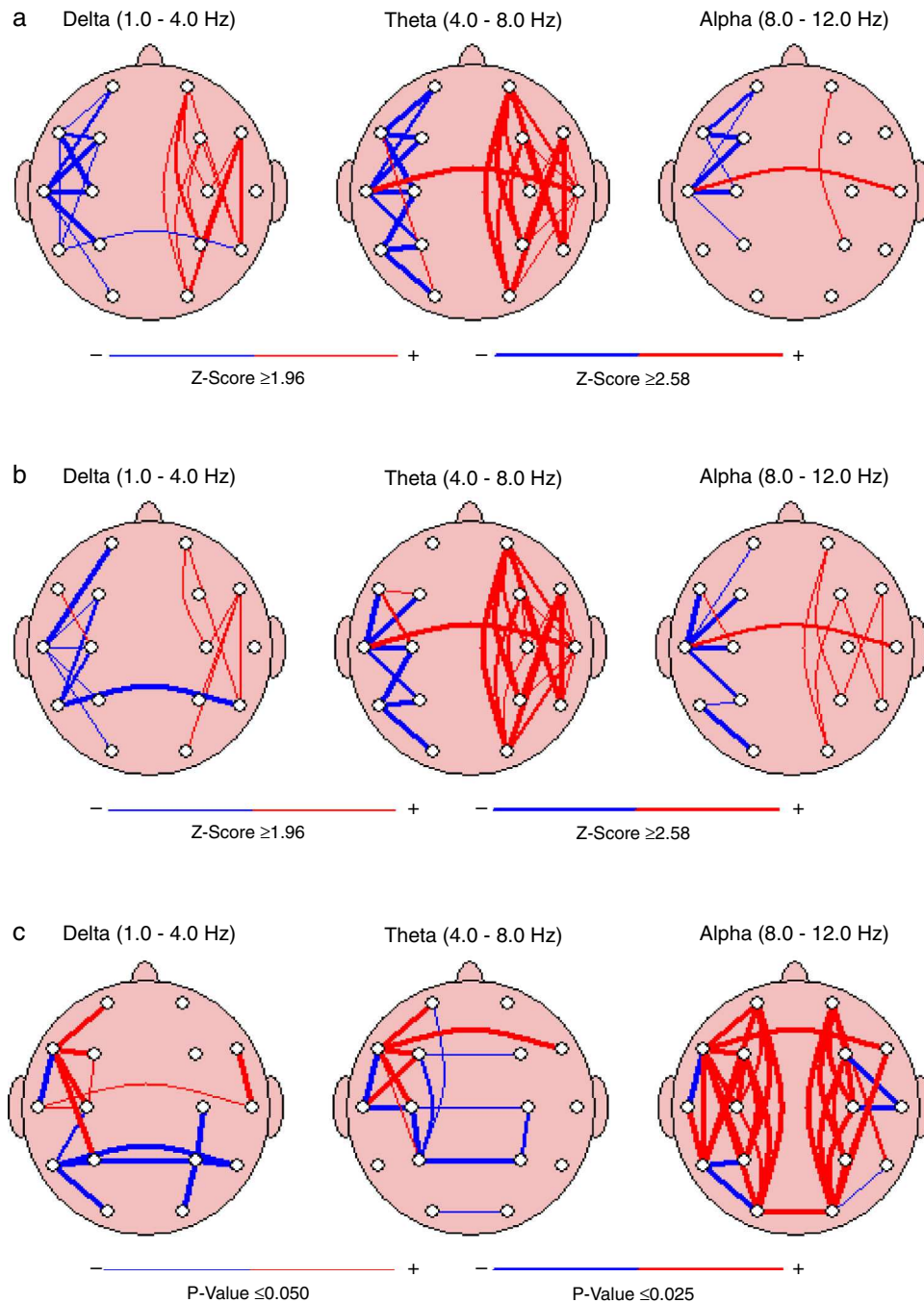


Figure 3 Coherence electroencephalographic measures. Z scores before tDCS (a); after tDCS (b); and p values for before and after tDCS differences (c): Red indicates more coherent values between electrodes and blue less coherent electrodes. Thicker lines indicate higher statistical t-test values.

temporal delta focus could be related to the peri-lesional area. The remaining power areas in the map represent non-adaptive changes after ischemia.

Figure 2b shows the cartography after tDCS and Figure 2c shows the *p*-value FFT absolute power in band differences before and after tDCS. The only significant difference was located in the right frontal area with an increase in the power of the alpha band. The coherence measures taken before (Figure 3a) and after (Figure 3b) tDCS, and the

p-values of coherence comparing both conditions (Figure 3c), are more informative.

Prior to tDCS (Figure 3a) we observe a reduced coherence in the left hemisphere and, as a consequence, there is a significant compensatory increase of coherence in the right hemisphere. After tDCS, however, we observe an increase of coherence in the frontal left hemisphere in delta and theta bands, as evidenced in z-scores (Figure 3b) and paired *t*-tests (Figure 3c). More importantly, a positive coherence

ratio affects the entire left hemisphere at the 8 Hz band (alpha).

In the light of these results, tDCS therapy would appear to be an effective treatment to inhibit irregular activation of the right hemisphere, and thus to assist the healthy areas of the left hemisphere to reassume their linguistic processing abilities.

Monitoring the effectiveness of treatment

Three tasks were employed to evaluate the phonological output level: picture naming, word repetition and pseudoword repetition. These tasks were run before the stimulation with tDCS as well as one month, two months and one year later. The stimuli were taken from the picture database of [Snodgrass and Vanderwart \(1980\)](#). Two lists of 36 pictures were constructed to alternate their presentation and so avoid stimulus repetition in the same session. The stimuli were ordered by two factors: familiarity ([Alameda and Cuetos, 1995](#)) and length (short words of 4-5 letters and long words of 6-8 letters). The two factors were crossed orthogonally to obtain four categories of nine stimuli per list. Pseudowords were formed by changing one letter on the lists of words.

Figure 4 shows an improvement in verbal production tasks of over 10%, which was consolidated one year later. The improvement mainly affected the long stimuli (see Figure 5);

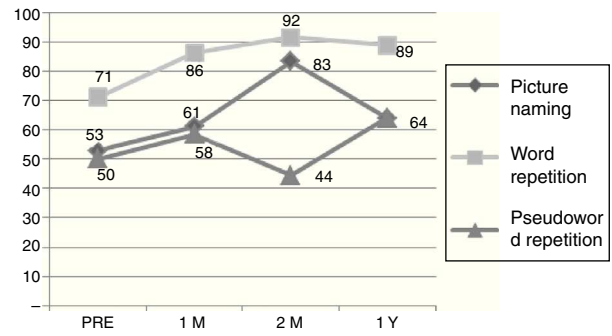


Figure 4 Percentage of correct responses in picture naming, word repetition and pseudoword repetition along the pretreatment phase and the three subsequent to tDCS phases: 1 month, 2 months and one year later.

the difference of errors between long and short words in the repetition task at the pretreatment stage ($N=10$ vs. $N=16$) was about 32%, which was reduced to 11% ($N=15$ vs. $N=17$) one year after treatment. The difference was even more dramatic for pseudowords, where a drop from 87% ($N=1$ vs. $N=17$) to 5% ($N=11$ vs. $N=12$) was observed. In contrast, familiarity was not differentially affected by treatment: the difference of errors produced on frequent and infrequent words was similar before and after treatment.

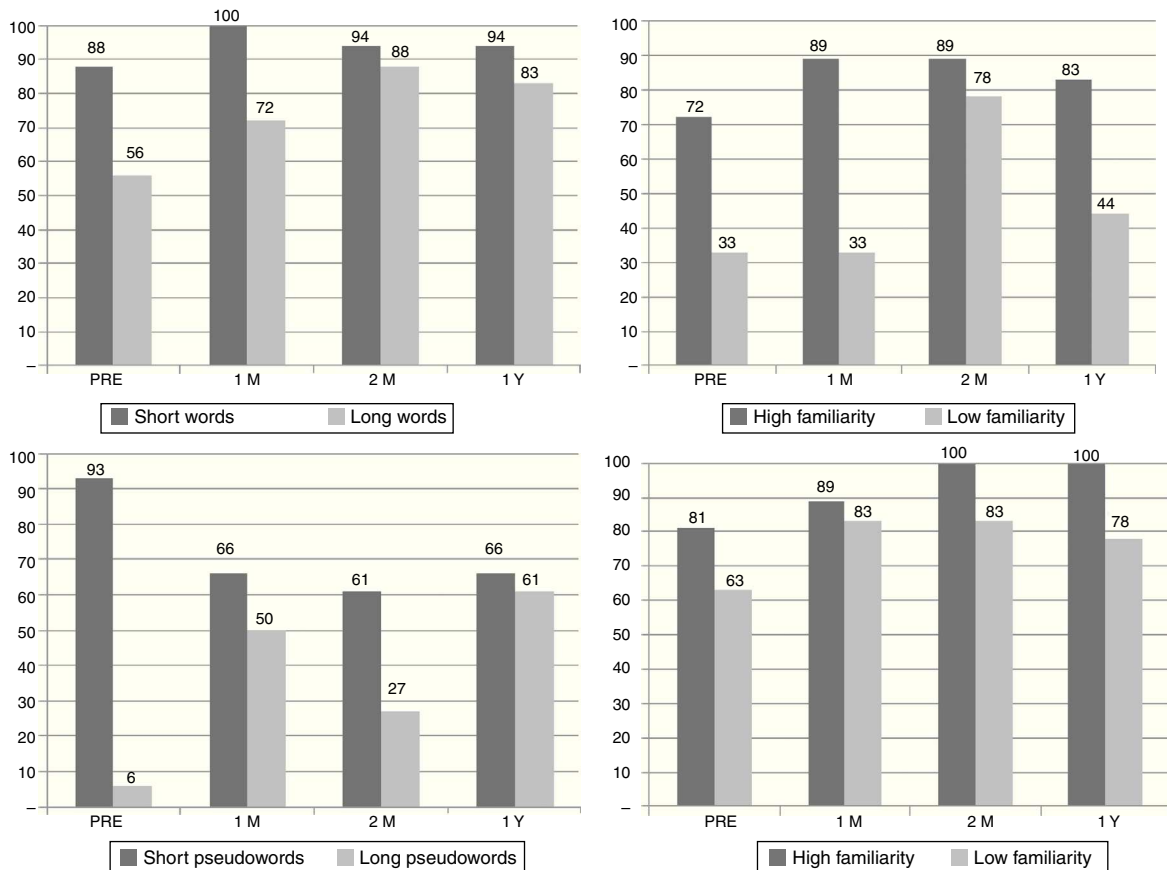


Figure 5 Percentage of correct responses for long and short stimuli in repetition task (left panels) and for familiar and unfamiliar words (right) in picture naming (upper right panel) and repetition (lower right panel).

Conclusions

tDCS therapy would appear to produce a significant increase of activation of the peri-lesional areas in RH's left hemisphere, as a consequence of the inhibitory electrical current applied on the right hemisphere (see [Figures 2 and 3](#)).

The electrical therapy develops the patient's ability to produce words in the three tasks employed, even one year after treatment. Also, the different impact received by length of stimuli in relation to familiarity supports the idea that tDCS affects a stage of processing not related to semantic or lexical memory but to a more peripheral stage dedicated to the maintenance, ordering and production of phoneme strings forming words: the Phonological Output Buffer ([Romani, Galluzzi, & Olson, 2011; Shallice et al., 2000](#)).

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