Effectiveness of tDCS to improve recognition and reduce false memories in older adults

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Abstract: Background. False memories tend to increase in healthy and pathological aging, and their reduction could be useful in improving cognitive functioning. The objective was to use an active-placebo method to verify whether the application of tDCS in improving true recognition and reducing false memories in healthy older people. **Method**. Participants were 29 healthy older adults (65-78 years old) assigned to active or placebo group; active group received anodal stimulation at 2mA for 20 min over F7. An experimental task was used to estimate true and false recognition. The procedure took place in two sessions on two consecutive days. **Results**. A mixed ANOVA of true recognition showed a significant main effect of session ($p = .004$), indicating an increase from before treatment to after it. False recognition showed a significant main effect ($p = .004$), indicating a decrease from before treatment to after it and a significant session x group interaction ($p < .0001$). **Conclusions**. Overall, our results show that tDCS is an effective tool for increasing true recognition and reducing false recognition in healthy older people, and suggest that stimulation improves recall by increasing the number of items a participant can recall and reducing the number of memory errors.

Keywords: transcranial direct current stimulation; true recognition; false recognition; aging; experiment.

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1. Introduction

Human memory is susceptible to distortions, illusions, and false memories that tend to increase during both healthy and pathological aging [1] especially in the face of events that share perceptual or conceptual characteristics. In later life, it is important to minimize these false memories in order to carry out daily activities such as remembering whether one took medication, turned off the fire when cooking, closed the door before leaving, or just thought about it. Thus, maintaining a functional episodic memory system is vital for preserving high quality of life with age, particularly with regard to independent living [2]. Hence, there are obvious benefits if false memories can be reduced temporarily in certain circumstances.

Evidence from injury studies has identified the medial temporal lobe (MTL), particularly the hippocampus and the prefrontal cortex (PFC), as critical brain structures for coding and retrieving episodic memory [3]. Decreased hippocampal volume is associated with reduced memory performance [4], and decreased anterior, dorsolateral, and ventrolateral PFC is associated with reduced memory capacity [5]. Decreased structure and function of MLT and PFC are also associated with increased susceptibility to false memories [6]. Older adults with smaller hippocampal volume generate more false alarms on associative recognition tasks than older adults with larger volumes [7]. In addition, the connective integrity of these two regions is vital for accurate memory coding and retrieval, but there is a reduction in functional connectivity between the MTL and PFC regions with healthy aging [8].

Recently, there has been considerable interest in the use of transcranial direct current stimulation (tDCS) to improve cognition [9,10]. tDCS is a non-invasive technique that elicits constant weak electric currents through the cerebral cortex via electrodes placed on the scalp, flowing from the positively charged anode to the negatively charged cathode. This technique has been shown to modulate excitability in cortical and subcortical tissue and, therefore, may facilitate cell plasticity. The current is thought to modulate the resting membrane potential of neurons depending on the polarity of the electrode, such that anodal stimulation induces depolarization of the membrane potential and increases cortical excitability, and cathodal stimulation induces hyperpolarization and decreases cortical excitability [11].

A large number of experimental studies [12,13] have demonstrated the efficacy of tDCS in healthy subjects on different cognitive tasks such as associative verbal

learning, working memory, selective attention, visual memory, stimulus recall and recognition, or reduction of false memories [14]. However, a lack of effectiveness of tDCS has been reported which could be related to the heterogeneity of the parameters of the stimulation [13], such as the area of the stimulation (left lateral cortex, temporal parietal lobe, etc.), the type of stimulation (anodal, cathodal, or without stimulation - sham-), the intensity of the current (1mA, 2mA, etc.), the type of session (single or repeated) and its duration (15', 20', 30', etc.), the interval between repetitions, the size of the electrode in cm^2, or the type of design used (between subjects, intra-subject, with or without double-blind control, etc.).

Regarding the effect of tDCS on true recall and recognition, Javadi and Walsh [15] administered anodal or cathodal tDCS over the left dorsolateral prefrontal cortex (dlPFC) during the encoding or recognition of words. With regard to encoding, the data show that only anodal stimulation over the left dlPFC improved memory; in the case of recognition, anodal stimulation was associated with a trend towards improving recognition. These data essentially support the role of the left dlPFC during the encoding and retrieval of words. The study the effects of tDCS on associative memory, measured by both recognition and recall tests, obtained significant results in the recall test indicating that tDCS improved the encoding of face-name associations, however there were no significant effects of stimulation on recognition memory performance [16]. Another research [17] assessed both immediate and delayed stimulation effects of the left dlPFC on associative memory, measured in terms of recall and recognition. They found no evidence of stimulation-induced recognition memory changes, but improved associative recall was observed. This recall advantage was evident even after a delay of 24 h, suggesting that memory effects persist after a period of consolidation. The authors also point out that these results show that a single session of tDCS while studying (encoding) improved recall performance. In sum, these results seem to indicate that tDCS stimulation applied on the left dlPFC seems to improve true recall, but it has no effect on true recognition.

However, the false memory literature contains few studies and little information. Several authors confirmed the notion that the modulating activity of the anterior temporal lobes (ATL) with tDCS brain stimulation before or during a given cognitive task is an effective way to change memory processing [14]. They found evidence that anodal tDCS on the left anterior temporal lobes (placed over T3 using the EEG International 10/20 System) is effective in reducing false memories, using a modified

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version of the DRM paradigm. Anodal left and cathodal right ATL resulted in a 73%
decrease in the formation of false memories. A substantial reduction in false memories
has been observed after anode stimulation (over site FT9, according to the International
10-10 System for EEG electrode placement), compared to sham, with word lists
composed of strong associates of the critical words; however, no effect at all emerged
when lists were composed of exemplars belonging to the same taxonomic category as
the critical lures (categorical lists) [18]. The authors suggest that the left ATL may
function as an integration hub when processing associatively related verbal materials in
the context of episodic learning.

Given these contradictory results, the objective of our study is to analyze
whether tDCS through the application of anodal stimulation is effective in improving
true recognition and reducing false memories in healthy older people, using a
recognition task to elicit false phonological memories [19].

Traditionally, the study of false memories has been carried out through
experimental procedures where the studied stimuli are semantically related to each other
(e.g., tiger, cougar, cat, ...), which can provoke the false recognition of non-studied
critical stimuli semantically related to the study list (e.g., panther). However, it is also
possible to elicit false memories of critical words (e.g., chair) after studying words
related to them phonologically rather than semantically (e.g., cheer, hair) [20]. These
phonological false memories increase with healthy aging in a similar way to semantic
false memories [21, 22]. Thus, we propose an experiment to elicit phonological false
memories, based on a perceptual manipulation of the stimuli that is implicit for the
participants, in order to increase the activation of critical words [19]. This adapted
procedure [23], mainly consists of presenting study words formed either from half of
the letters in the alphabet (Half condition) or from the entire alphabet (Entire condition).
On the subsequent recognition test, the new words can be formed either from the same
letters as the ones studied in the Half condition (or critical lures because they are
phonologically related to the studied words), distractors formed from the other half of
the letters in the alphabet, or distractors formed from the entire alphabet. Therefore, this
experimental paradigm, which uses a simple study and word recognition task, makes it
possible to obtain estimates of both true and false recognition (with the latter
operationalized from the false alarms elicited by the critical lures).

Our idea is to apply this paradigm to healthy older people in two sessions. The
materials used in both sessions will be different for each subject (and counterbalanced

between subjects). Participants will be randomly assigned to either a treatment group that will receive two sessions of electrostimulation through tDCS or a control group that will receive two sham sessions. This procedure will, therefore, allow us to determine the effectiveness of tDCS by analyzing whether in the treatment group, comparing their data before and after treatment, there is an improvement in true recognition or a reduction in false recognition.

2. Materials and Methods

2.1. Participants

The sample of older adults was composed of 29 people (18 women, 11 men) ranging from 65 to 78 years old ($M = 68.79$, $SD = 3.33$), who belong to various leisure centers for older adults in the city of Valencia. The Ethical Committee on Human Research of the University of Valencia approved this study. All the participants voluntarily gave their consent to participate, and they reported being in good physical and mental health with no known memory impairments. In this regard, the mean for the older adutls on the Mini-Mental State Examination [24] was 29.86 ($SD = .35$, range 29–30), revealing no memory impairment. Participants were randomly assigned to receive either tDCS or sham stimulation. The treatment group was composed of 16 older adults (10 women, 6 men) ranging from 65 to 77 years old ($M = 68.93$, $SD = 3.35$); the sham group was composed of 13 older adults (8 women, 5 men) ranging from 65 to 78 years old ($M = 68.61$, $SD = 3.42$).

2.2. Materials

The *Half* condition included two lists of 50 words each, formed entirely from the following letters of the Spanish alphabet: a, e, u, b, d, g, j, n, r, z (List A) or i, o, c, f, h, l, m, p, s, t, v, y (List B). List C (*Entire* condition) contained 50 words formed from the entire alphabet, with the only criterion being that each word had to contain at least one letter from List A and at least one letter from List B. Lists A, B, and C were balanced on mean frequency per two million [25], 93.30 ($SD = 166.69$), 91.28 ($SD = 129.87$), and 92.40 ($SD = 165.46$), respectively, and length, 5.00 ($SD = 1.20$), 4.70 ($SD = 1.30$) and 4.95 letters ($SD = 1.15$), respectively.

2.3. Procedure

The experiment took place in two sessions on two consecutive days (one session each day). On day one, participants performed a first study and recognition task with stimuli and no tDCS stimulation that would serve as a *pre-test* or baseline (*Before*

condition in Table 1). They were then assigned either to the treatment group or the sham group, receiving either a tDCS or sham stimulation session for 20 minutes. On the second day (24 hours later), five minutes before starting the experimental task, the participants began to receive either the tDCS stimulation session or the sham, which continued until a second study and recognition task began with different stimuli, which would serve as a *post-test* (*After* condition in Table 1). This experimental task was initiated five minutes after the stimulation started because three minutes of stimulation has been shown to be the minimum time to induce significant after-effect changes in cortical excitability [11].

Each study and recognition task lasted about 15 minutes. Each study task consisted of 50 words (presented in random order for 1.5 seconds each, with an inter-stimuli period of one second) [23]. Half the words pertained to the *Half condition* (taken from either list A or list B and counterbalanced across participants; that is, they were formed from half the letters in the alphabet), whereas half the words belonged to the *Entire condition* (from list C; that is, they were formed from all the letters in the alphabet). After the study task, the participants performed the recognition task (self-paced) with 66 words (presented in random order): 15 studied words from the Half condition (e.g., from list A), 15 studied words from the Entire condition (list C), 12 critical lures formed from the same half of the letters as the studied Half condition list (e.g., from list A), 12 distractors from the other Half condition list (e.g., from list B), and 12 distractors from the Entire condition (list C). The stimuli from the study and recognition tasks were counter-balanced between subjects, so that, for example, a participant who studied 25 stimuli from list A and 25 from list C on the first day studied 25 stimuli from list B and the remaining 25 stimuli from list C on the second day. That is, no stimulus was repeated within subjects throughout the two sessions. Because distractors from list A and list B of the *Entire* condition produced similar false alarm (FA) rates, as would be expected based on the equivalence of the two lists, for interpretive simplicity we decided to average them into only one condition, called *FA (half of the letters in the alphabet;* Table 1).

Finally, a debriefing questionnaire asked the participants if they were aware of any relationships between the words. None of the participants was excluded for this reason, which seems to indicate that our experimental procedure guarantees an implicit manipulation of the independent variable.

2.4. Transcranial direct current stimulation

A CE-certified battery-driven stimulator (NeuroConnDC–Stimulator Plus) was used to conduct non-invasive tDCS with a constant current intensity of 2mA. Two 5 X 5 cm rubber electrodes covered with saline-soaked sponges were used to transfer constant direct current, resulting in a density of .08 mA/cm². The anode was placed over site F7 according to the International 10-20 System for EEG electrode placement; this site has been used in previous studies to stimulate the PFC [15, 17, 26, 27]. The cathode was placed over Fp2 in the right supraorbital (rSO) area to minimize its effects on the brain. The stimulation application time was 20min, with 30s ramping up and down of current; the same procedure was used for sham stimulation, but in this case, electric current was only applied in the ramping.

3. Results

The overall results of our experiment are shown in Table 1.

INSERT TABLE 1

In the Half condition, the true recognition estimates for each participant are derived by subtracting the proportion of false alarms on words with the same letters, as in the study list (critical words), from the proportion of hits, whereas in the Entire condition, the true recognition estimates are derived by subtracting the proportion of false alarms on words with all the letters in the alphabet from the proportion of hits, as a way to control the response bias of the participants [28, 29].

Regarding these true recognition estimates, a mixed ANOVA with 2 study conditions (Half vs Entire; within subjects) X 2 sessions (Before vs After treatment; within subjects) X 2 groups (Treatment vs Control; between subjects) showed that the main effect of the sessions variable was significant ($F(1, 27) = 10.06$, $p = .004$, $\eta^2p = 0.27$, indicating that true recognition increases from before treatment to after it; $M = 0.52$ and $M = 0.60$, respectively), and the session X group interaction was significant ($F(1, 27) = 33.55$, $p < .0001$, $\eta^2p = 0.55$). The remaining main effects and interactions were not significant ($p > .05$). Post-hoc Bonferroni t-tests conducted to analyze the significant session X group interaction showed that: a) the true recognition means of the treatment and control groups did not significantly differ before treatment ($M = 0.46$ and $M = 0.58$, respectively; $t(27) = 1.85$, $p > .05$); b) but the true recognition mean of the treatment group was significantly higher than the mean of the control group after

treatment ($M = 0.69$ and $M = 0.51$, respectively; $t(27) = 2.76$, $p = .01$); c) the control group's mean before treatment did not significantly differ from its mean after treatment ($M = 0.58$ and $M = 0.51$, respectively; $t(12) = 1.97$, $p > .05$); d) but the treatment group's mean after treatment was significantly higher than its mean before treatment ($M = 0.69$ and $M = 0.46$, respectively; $t(15) = 6.21$, $p < .0001$).

With regard to the false recognition estimates, we used the relative false recognition index [21, 22] by dividing, for each participant, the proportion of false alarms on critical lures by the proportion of hits in the Half condition (Table 1), as a way to control the response bias of the participants.

Regarding these false recognition estimates, a mixed ANOVA with 2 sessions (Before vs After treatment; within subjects) X 2 groups (Treatment vs Control; between subjects) showed that the main effect of the sessions variable was significant ($F(1, 27) = 9.96$, $p = .004$, $\eta^2 p = 0.27$, indicating that false recognition decreases from before treatment to after treatment; $M = 0.38$ and $M = 0.29$, respectively), and the session X group interaction was also significant ($F(1, 27) = 16.55$, $p < .0001$, $\eta^2 p = 0.38$). The main effect of the group variable was not significant ($F < 1$, $p > .05$). Post-hoc Bonferroni t-tests conducted to analyze the significant session X group interaction showed that: a) the false recognition means of the treatment and control groups did not significantly differ before treatment ($M = 0.43$ and $M = 0.34$, respectively; $t(27) = 1.52$, $p > .05$); b) but the false recognition mean of the treatment group was significantly lower than the mean of the control group after treatment ($M = 0.21$ and $M = 0.36$, respectively; $t(27) = 2.60$, $p = .015$); c) the control group's mean before treatment did not significantly differ from its mean after treatment ($M = 0.34$ and $M = 0.36$, respectively; $t(12) = 0.73$, $p > .05$); d) but the treatment group's mean after treatment was significantly lower than its mean before treatment ($M = 0.21$ and $M = 0.43$, respectively; $t(15) = 6.21$, $p < .0001$).

Overall, our results show that tDCS is an effective tool for increasing true recognition and reducing false recognition in healthy older people.

4. Discussion

Several studies investigating memory indicate that tDCS can improve true recognition or reduce false recognition. However, few studies have systematically examined the effects of tDCS on both recognition and false recognition in a single experiment. This

study aimed to compare the effects of tDCS, comparing an active stimulation group and a placebo group.

Although some studies have demonstrated stimulation-induced memory improvements, as measured by recognition, others have found no improvements. Overall, our results show that tDCS seems effective in increasing true recognition in healthy older adults in both study conditions, coinciding with other research [15, 30], but disagreeing with another [16, 17], who found no improvement in recognition memory after the application of the tDCS.

It has been shown that when applying stimulation with the anode over the left dlPFC, participants performed significantly better on memory accuracy than with cathodal stimulation [30]. The results support the hypothesis that anodal tDCS will lead to higher memory accuracy on the memory recognition task. However, the exact functional role that anodal tDCS plays in improving memory accuracy remains unclear. Memory enhancement derived from stimulating the left dlPFC could have resulted from stronger encoding of target words, better retention of encoded words, or even the engagement of other systems. Moreover, anodal stimulation of the left dlPFC during the encoding phase enhanced memory performance on a later recognition task [30]. Conversely, on a face-name associative memory task, showed improvements in recall, but not in recognition [16, 17]. tDCS applied over F9 during encoding improved associative memory, measured as recall, suggesting that even within the same study, memory effects may be evident only under some testing conditions, specifically those that rely on recollection [16]. The authors speculate that, given the nature of associative memory, tDCS may be effective in promoting cortical connections that support memory in the active stimulation group. After stimulating the dlPFC, it has been suggested that stimulation produces improved memory through both immediate and delayed mechanisms, but that these improvements are only evident under more stringent memory test conditions (recall not recognition) [17]. One reason is that the dlPFC is thought to play an important role in building relationships between simultaneously presented items at the time of study, which in turns leads to enhanced associative memory performance.

Neuroimaging and brain damage studies have identified the dlPFC as a key brain region in the ability to recollect specific details, and research indicates that tDCS on the dlPFC during encoding or retrieval can also boost performance [31]. It has also been concluded [32] that, if the dlPFC subserves the cognitively controlled aspects of

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episodic recollection, then tDCS should also increase the quality of memories, enabling people to more accurately recollect specific details associated with studied items and avoid false recollection of erroneous details.

In some studies, false recognition results have shown the positive effects of tDCS in reducing rates of false recall (i.e., producing an item not previously studied) [14]. As in the case of recognition, these results suggest that stimulation improves recall by increasing the number of items a participant can recall and reducing the number of memory errors. Overall, our results clearly show that tDCS also seems effective in reducing false recognition in older people in both study conditions similar to previous research [12, 14]. Evidence has been found that anodal tDCS on the left anterior temporal lobe (ATL) before the encoding and retrieval phase is effective in reducing false memories, and they confirm the notion that modulating activity in the ATL, with brain stimulation before or during a given cognitive task, is an effective method to change memory processing [14]. Also been found substantial reductions in false memories were observed after anodal stimulation, compared to sham, and their results converge by showing that modulating neural activity in the left ATL modifies the pattern of false recognition [12]. Although the results are convergent, some differential aspects must be pointed out in relation to these studies: the tasks applied were different and, in our study, the anodal stimulation was on the dlPFC. Previous studies have demonstrated the role of prefrontal regions in forming the inter-item associations necessary for successful associative encoding [33]. In our study, participants received stimulation in both the encoding and recall phases, and some studies targeting the dlPFC have reported facilitatory effects when anodal tDCS was administered during online encoding [34, 35] or when the stimulation was delivered during retrieval [31].

Positive results may indicate that dlPFC plays an important role in reducing false recognition. Taking into account that in AD patients the temporal zone is the most affected, it is likely that stimulation of the prefrontal zone could produce an improvement in memory.

5. Conclusion

Results showed, as a novel finding in the literature, that tDCS improved the recognition memory of older people, verifying both an increase in true recognition and a decrease in false recognition.

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Table 1. Means (and *SE*) of hits (H), false alarms (FA), and estimations of true and false recognition.

	TREATMENT GROUP		CONTROL GROUP	
	BEFORE	AFTER	BEFORE	AFTER
Half condition				
H	0.75 (0.04)	0.83 (0.04)	0.80 (0.04)	0.76 (0.04)
FA (same letters as in the study list)	0.31 (0.03)	0.17 (0.03)	0.26 (0.04)	0.25 (0.03)
FA (different letters from the study list)	0.14 (0.02)	0.06 (0.02)	0.15 (0.02)	0.15 (0.03)
True recognition	0.44 (0.05)	0.67 (0.05)	0.53 (0.05)	0.50 (0.05)
False recognition	0.43 (0.04)	0.21 (0.04)	0.34 (0.05)	0.36 (0.05)
Entire condition				
H	0.68 (0.05)	0.80 (0.04)	0.77 (0.05)	0.69 (0.04)
FA (all the letters in the alphabet)	0.19 (0.03)	0.08 (0.03)	0.14 (0.03)	0.17 (0.03)
True recognition	0.49 (0.05)	0.71 (0.05)	0.63 (0.06)	0.53 (0.06)