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The Effect of Electrical Stimulation on Executive Functions, Metacognition, and Emotional Regulation of Adults With Depression

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Abstract

Studies with transcranial electrical stimulation have shown a reduction in depressive symptomatology. However, it is not yet clear whether this type of intervention can also improve cognitive functions and emotional regulation strategies in major depression. This study examined the effects of transcranial direct current stimulation (tDCS) on the dorsolateral prefrontal cortex on executive functions, metacognition of thoughts and feelings, and emotional regulation. Eighteen adults between 18 and 40 years of age diagnosed with major depressive disorder were randomly assigned to active (N = 10) or simulated (N = 8) stimulation. Each participant underwent ten sessions of active or simulated tDCS over a period of two weeks. The severity of depression symptoms, executive functions, metacognition, and emotional regulation strategies of the participants were assessed at baseline, immediately after the intervention, and three months after the intervention. It was observed that the active tDCS had no significant effect on the variables compared to the *sham* intervention. Both groups increased the frequency of regulation of thoughts and feelings over time and decreased depressive symptoms after the intervention. The non-significant effects of tDCS on the evaluated variables are discussed in light of previous studies, which have yielded mixed results, both corroborating and contrasting with the findings presented here.

Keywords: tDCS; major depressive disorder; executive functions; metacognition; emotional regulation.

O EFEITO DA ELETROESTIMULAÇÃO NAS FUNÇÕES EXECUTIVAS, METACOGNIÇÃO E REGULAÇÃO EMOCIONAL DE ADULTOS COM DEPRESSÃO: UM ESTUDO EXPERIMENTAL

O Efeito da eletroestimulação nas Funções Executivas

Resumo

Estudos com estimulação elétrica transcraniana têm demonstrado que há redução na sintomatologia depressiva, mas ainda não está claro se esse tipo de intervenção pode melhorar também funções cognitivas e estratégias de regulação emocional na depressão maior. Este estudo examinou os efeitos da estimulação transcraniana por corrente contínua (ETCC) sobre o córtex pré-frontal dorsolateral nas funções executivas, metacognição de pensamentos e sentimentos e na regulação emocional. Dezoito adultos entre 18 e 40 anos de idade diagnosticados com depressão maior foram aleatoriamente designados para estimulação ativa (*N* = 10) ou simulada (*N* = 8). Cada participante foi submetido a dez sessões de ETCC ativa ou simulada por duas semanas. A gravidade dos sintomas de depressão, as funções executivas, a metacognição e as estratégias de regulação emocional dos participantes foram avaliadas no início, imediatamente após a intervenção e três meses após a intervenção. Foi possível observar que a ETCC ativa não teve um maior efeito sobre as variáveis em comparação com a intervenção *sham*. Ambos os grupos aumentaram a frequência da regulação de pensamentos e sentimentos ao longo do tempo e diminuíram os sintomas depressivos após a intervenção. Os efeitos não significativos da ETCC nas variáveis avaliadas são discutidos à luz de estudos prévios, que possuem resultados mistos, corroborando e contrastando com os achados aqui encontrados.

Palavras-chave: ETCC, depressão maior, funções executivas, metacognição, regulação emocional

EL EFECTO DE LA ESTIMULACIÓN ELÉCTRICA EN LAS FUNCIONES EJECUTIVAS, LA METACOGNICIÓN Y LA REGULACIÓN EMOCIONAL DE LOS ADULTOS CON DEPRESIÓN

Efecto de la estimulación eléctrica en las funciones ejecutivas

Resumen

Los estudios con estimulación eléctrica transcraneal han demostrado que existe una reducción en la sintomatología depresiva, pero aún no está claro si este tipo de intervención también puede mejorar las funciones cognitivas y las estrategias de regulación emocional en una mayor depresión. Este estudio examinó los efectos de la estimulación de la corriente continua transcraneal (ETCC) en la corteza de juego de retroceso en las funciones ejecutivas, metacognición de pensamientos y sentimientos y regulación emocional. Dieciocho adultos entre 18 y 40 años diagnosticados con mayor depresión fueron asignados

aleatoriamente para la estimulación activa (n = 10) o simuladas (n = 8). Cada participante fue enviado a 10 sesiones activas o simuladas, etc. durante dos semanas. La gravedad de la depresión de los síntomas, las funciones ejecutivas, la metacognición y las estrategias de regulación emocional de los participantes se evaluaron al principio, inmediatamente después de la intervención y 3 meses después de la intervención. Se observó que el ETCC activo no tuvo un efecto mayor en las variables en comparación con la intervención simulada. Ambos grupos han aumentado la frecuencia de la regulación de los pensamientos y los sentimientos con el tiempo y reducen los síntomas depresivos después de la intervención. Los efectos no significativos de los ETCC en las variables evaluadas se discuten a la luz de estudios anteriores, que tienen resultados mixtos, corroborando y contrastando con los hallazgos encontrados aquí.

Palabras clave: ETCC, Mayor depresión, Funciones ejecutivas, metacognición, regulación emocional

Transcranial direct current electrical stimulation (tDCS) is characterized by a neuromodulation intervention that aims to alter specific brain activity patterns. It is a method of non-invasive cortical inhibition or excitation. The intensity of the stimulus is regulated according to the desired neuronal processing patterns, thereby improving dysfunctional conditions (Jog et al., 2023; Narmashiri & Akbari, 2025). Before the intervention, brain activity can be assessed through neuroimaging programs such as electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) (Lezama et al., 2024; Nardo et al., 2023). Cognitive performance tests are then performed to compare pre- and post-intervention scores (Marković et al., 2021).

To date, neuroimaging examinations have shown an excess of voltage in brain electrical activity associated with neuropsychological dysfunctions, which can manifest as persistent waves of slow or fast frequencies, depending on the type of pathological condition (Jog et al., 2022). Thus, tDCS aims to alleviate pathological symptoms by modulating the intensity and duration of electrical impulses (Fregni et al., 2021). Nerve impulses that pass from one neuron to another become faster (excitation) or slower (inhibition) as stimuli are generated in a specific brain region. More specifically, in tDCS, the type of polarity of the stimulation determines the effect to be achieved. Anodic stimulation induces depolarization of neuronal membranes and neuronal excitation, while cathodic stimulation leads to neuronal hyperpolarization and inhibition (Oathes et al., 2021).

TDCS was developed as an alternative to invasive treatments or as a supplement to medications, so it does not require anesthesia to perform. It is painless and has practically no side effects. Several studies have reported only mild headaches, redness at the site, and a tingling sensation in the applied region as side effects. Such symptoms appeared on the day of application and usually lasted a short time (Brunoni et al., 2011). Additionally, neuropsychological tests revealed no deterioration in the cognitive functioning domains tested following the intervention (Loo et al., 2012).

TDCS has been used for the treatment of several neurodevelopmental (Masuda et al., 2019) or mental disorders, including major depressive disorder (MDD) (Nikolin et al., 2023; Moffa et al., 2020). Results have shown that tDCS is effective in reducing depressive symptoms immediately after the intervention (Razza et al., 2020). In contrast, the results on its efficacy in the *follow-up* are mixed (Aparício et al., 2019; Rezaei et al., 2021).

Studies that apply electrostimulation for MDD have protocols that primarily aim to stimulate the area of the prefrontal cortex, as functional neuroimaging evaluations have revealed dysfunctions in neural circuits and anatomical changes mainly in the frontal region of the brain (Mutz et al., 2018). Most studies compare two groups: those who receive the real stimulation and another who receives it fictitiously (to evaluate the placebo effect). According to a meta-analysis (Mutz et al., 2018), the groups that received the real stimulation generally responded more to the treatment than the sham groups. Sham is a term used in clinical research to designate placebo procedures, in which the intervention is simulated to reproduce the conditions of the active treatment without producing the expected physiological effect. Nevertheless, previous

results have found similar effects in both active and simulated electrostimulation (Palm et al., 2012). In this context, a recent meta-analysis examined the magnitude of the simulated response in randomized clinical trials of tDCS for depression, revealing a high response rate for simulated tDCS (Hedges' g = 1.09) (Smet et al., 2021).

TDCS has been effective in decreasing depressive symptomatology (Razza et al., 2020). However, it is still unclear whether this type of intervention can also improve cognitive functions in major depressive disorder (Martin et al., 2018) since people with this disorder may have cognitive deficits and reduced structural connectivity (Gruber et al., 2023). Furthermore, evidence suggests that cognitive deficits may persist after remission from a major depressive episode (Semkovska et al., 2019). Other studies have indicated deficits in executive functions in this population, as well as a greater susceptibility to using maladaptive metacognitive and emotional regulation strategies (Li et al., 2021; Shimony et al., 2021; Zhou et al., 2021).

Some interventions in the treatment of major depressive disorder, based on metacognitive training, emotional regulation, and therapeutic activities that promote cognitive flexibility, have been shown to be effective (Barnhofer et al., 2019; Goodkind et al., 2016; Jelinek et al., 2019). However, other studies (Hjemdal et al., 2019; Zheng et al., 2024) suggest that further research should evaluate the effects of interventions on cognitive and emotional components related to MDD to generate more clarification on this theme. In this sense, tDCS can be one of these interventions, as it can stimulate specific regions of the prefrontal cortex that mediate, for example, executive functions, metacognition, and emotional regulation.

The preliminary evidence on the role of tDCS in improving cognitive impairments in MDD indicates that working memory is the most frequently evaluated cognitive function (Loo et al., 2012; Kumar et al., 2020). In addition, Woodham et al. (2021) highlighted the need for further investigation into whether the long-term effect of tDCS on improving cognitive functions in individuals with MDD persists.

Thus, the present study aims to expand the knowledge of this theme by evaluating the effects of tDCS on executive functions (inhibitory control and cognitive flexibility), metacognition, and emotional regulation in adults with MDD, and comparing the effect of active electrostimulation with that of the *sham* intervention on the primary variables of the study. Thus, it is assumed that tDCS will contribute to the development of executive functions, including cognitive flexibility and inhibitory control, as well as metacognition and the use of more adaptive strategies for emotional regulation, in adults with MDD. Such intervention may contribute to cognitive development of altered neurobiological functions in depressive patients, which are involved in the mediation of emotional behavior.

Method

The study is an experimental, randomized, double-arm, triple-blind clinical trial. Executive functions, metacognition, and emotional regulation are the dependent variables, and the tDCS is the primary independent variable.

Sample

The participants were 18 adults, ranging in age from 18 to 40, who met the DSM-5 criteria for the diagnosis of major depressive disorder, according to a previous medical or psychological assessment, and who had a minimum score of 20 on the Beck Depression Scale. Participants could be using an antidepressant; if so, the medication should have been stable for at least a month. Exclusion criteria included individuals who underwent medication adjustment in the last 30 days; who use benzodiazepines with a dosage greater than 20 mg, as this type of medication can decrease the effects of electrostimulation (Brunoni et al., 2013); who have other psychiatric, neurological, motor diseases, or some neurodevelopmental disorder. Additionally, people who have metal in the skull or skin lesions on the scalp, as well as pregnant women or people who abuse alcohol or medications, could not participate in the research.

Participants were recruited through referrals made by psychologists of the city and the school clinic of the Faculdade Adventista da Bahia. Interested parties contacted the principal investigator by phone or WhatsApp, or authorized the researcher to come into direct contact with them. In the latter case, the psychologist passed the contact information of the interested party on to the researcher. Participants were randomly allocated into two groups: (1) participants in the experimental tDCS group; (2) participants in the sham tDCS group.

Instruments

The first instrument consisted of a sociodemographic and clinical questionnaire, requesting the following information: 1) Name; 2) Gender; 3) Age; 4) Marital status; 5) Education; 6) City where you live; 7) Do you use medications (name and dosage)? 8) Have you made any medication changes in the last 30 days? 9) Do you abuse alcohol or drugs? 10) Do you have another psychiatric or neurological disorder or neurodevelopmental disorder (e.g., autism, ADHD, schizophrenia, epilepsy)? If so, which one? 11) Do you have any metal or injuries on the skull? 12) Do you have any skin lesions on your scalp? 13) For women: are you pregnant or suspected of pregnancy?

Symptoms and severity of MDD were assessed using the Beck Depression Inventory – BDI II, which is a self-assessment instrument with 21 items. Each item has four alternatives with scores ranging from 0 to 3; the higher the score, the greater the severity of depressive symptoms. The final score ranges from 0 to 63 points. The instrument employs 21 items that represent symptoms, according to the criteria of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV): sadness, sense of failure, lack of satisfaction, pessimism, feeling of guilt, social withdrawal, decreased libido, self-deprecation, sense of punishment, loss of appetite, self-accusations, crying crises, suicidal ideation, inhibition to work, irritability, sleep disorder, indecision, distortion of body image, fatigue, weight loss, and somatic concern.

Emotional regulation was evaluated using the Emotional Regulation Questionnaire (ERQ) (Gross & John, 2003), adapted for Brazil by Boian et al. (2009), following the three-factor proposal by Gouveia et al. (2018). The questionnaire contains ten items on a Likert-type scale,

ranging from 1 (strongly disagree) to 7 (strongly agree). The first factor is cognitive reassessment, the second is redirection of attention, and the third is emotional suppression. It is a self-report questionnaire that assesses the probability of an individual using each type of emotional regulation strategy based on the score value (the higher the score, the more likely the individual is to use such a strategy).

Metacognition was assessed using the Metacognition of Thoughts and Feelings Scale (EMETAPS) (Aleixo et al., 2022). It is a 15-item self-report instrument with two factors: cognition, knowledge, and cognitive regulation. The responses are evaluated using a five-point Likert scale to assess the frequency of behaviors. In the "cognition knowledge" factor, the results are interpreted considering that the higher the score, the higher the frequency. In the "cognition regulation" factor, the higher the score, the lower the frequency of use of the metacognitive strategy.

The Five Digit Test (FDT) (Sedó, 2007) was used to evaluate executive functions. This instrument has four stages of execution: 1. Reading, 2. Counting, 3. Choosing, 4. Alternation. The reading stage requires reading knowledge of 1 to 5, and the second stage requires counting the number of asterisks ranging from 1 to 5. The ability to ignore the reading of numbers and counting stimuli is necessary for the third stage. The last stage requires the ability to alternate between reading and counting. The response time in each task was counted to correct the test.

A specialized equipment, Model Microestim Genius-NKL (ANV registration: 80191680008), was used for the tDCS intervention. It consists of a device powered by a 9-volt battery that emits an electric current to a pair of electrodes (a cathode electrode and an anode electrode), through two cables. The cathode electrode is negatively charged to inhibit brain electrical activity. The anode electrode is positively charged, facilitating the firing of neurons over the area in which the electrode is coupled.

Ethical aspects

The present study received approval from the Research Ethics Committee of the Institute of Psychology (CEP-IPS) of the Federal University of Bahia (CAAE: 29837520.8.0000.5686). In addition, it was approved by the Brazilian Registry of Clinical Trials (ReBEC), with the following registration number: UTN: U1111-1299-2702.

Randomization and blinding

Participants were randomized through the online lot drawing platform: www.sorteador.com.br. To ensure blinding, the participants and the researchers responsible for applying the assessment instruments remained blind until the end of the follow-up. To assess blinding, the participants were asked to answer which group they thought they had been allocated to after the last assessment. The electrostimulation applicator was unaware of the study's objectives and remained blinded to the evaluation results until the conclusion of the research. The person responsible for randomization informed the applicator only whether the participant was in the sham or experimental groups. The statistician also remained blind to the groups.

Procedures

Adults with major depressive disorder were recruited, following the inclusion criteria of the research and other ethical precepts in research with human beings. The participants signed an Informed Consent Form, having been informed that they could be assigned to one of the two research groups: sham or experimental. They were informed of their group assignment after the research follow-up.

Applications for participation in the survey were open from March to October 2022. Data collection commenced with a group of five participants, conducted over eight months (from July 2022 to February 2023). The participants were divided into four groups. At the end of the study, the members of the sham group had the opportunity to also participate in the real tDCS, if they wished, to ensure that everyone could enjoy the possible benefits of the intervention.

To evaluate the effects of tDCS on executive functions, emotional regulation, and metacognition in adults with MDD, the experiment was conducted in three stages: pre-test (baseline), intervention, and post-test. During the pre-test, each participant completed the sociodemographic questionnaire, the Beck Depression Inventory - BDI II, the Emotion Regulation Questionnaire (ERQ), the Metacognition Scale of Thoughts and Feelings (EMETAPS), and the Five-Digit Test (FDT) in a single encounter.

The intervention stage consisted of ten sessions of tDCS, on consecutive days (except weekends), lasting 20 minutes each. A direct current of 2mA was applied to the prefrontal cortex using the anode electrode at the F3 site and the cathode at the F4 site, as determined by the International 10-20 Electroencephalography System. Both electrodes had dimensions of 5 x 7 cm (35cm^2). The sham group received the same current for 30 seconds; only the current was gradually deactivated over that time. Therefore, it had no effect and simulated the real treatment. On all days of electrostimulation, the applicator asked if the participant was experiencing any adverse effects during and after the session. The same baseline procedures were applied twice after the intervention in both groups. The first assessment was performed on the day of the last session (post-test), after its completion. The follow-up was conducted three months after the last session.

Data analysis

According to the Shapiro-Wilk test, the data presented a normal distribution. Thus, parametric tests were adopted for data analysis. After assessing normality, descriptive measures were used to characterize the sample, including mean, frequency, and standard deviation.

A mixed ANOVA was performed to compare the effects of tDCS, as a function of phase (baseline, immediate post-test, and follow-up), and type of stimulation (sham or active) on the dependent variables. The Bonferroni post hoc analysis was performed to assess the significant differences between the groups and identify where the differences lie. The effect size was evaluated using the Partial eta squared ($\eta 2$), used in ANOVA. A p-value < 0.05 was considered a statistically significant result. The intention-to-treat principle (ITT) was used due to losses

during the follow-up (4 absences), which consists of including all participants according to the group that was randomized initially in the statistical analysis, avoiding the exclusion of participants who did not adhere to any stage of the assessment (Fergusson et al., 2002; Gupta, 2011). ITT was used because there was no serious deviation from the initial proposal, as all participants completed all sessions of the intervention, as well as the baseline and post-test assessments. More specifically, there was a lack of participants only in the follow-up.

All data were analyzed using the Statistical Package for the Social Sciences (SPSS), version 22.0.

Results

A total of 18 participants were randomized, with ten assigned to the active group and eight to the sham group. Subsequently, two participants dropped out, one from each group. A sample of 16 participants was selected for the analyses, comprising 11 women and five men, with a mean age of 27.5 (SD = 6.84). Figure 1 represents the flowchart of the study stages.

Figure 1

Flowchart

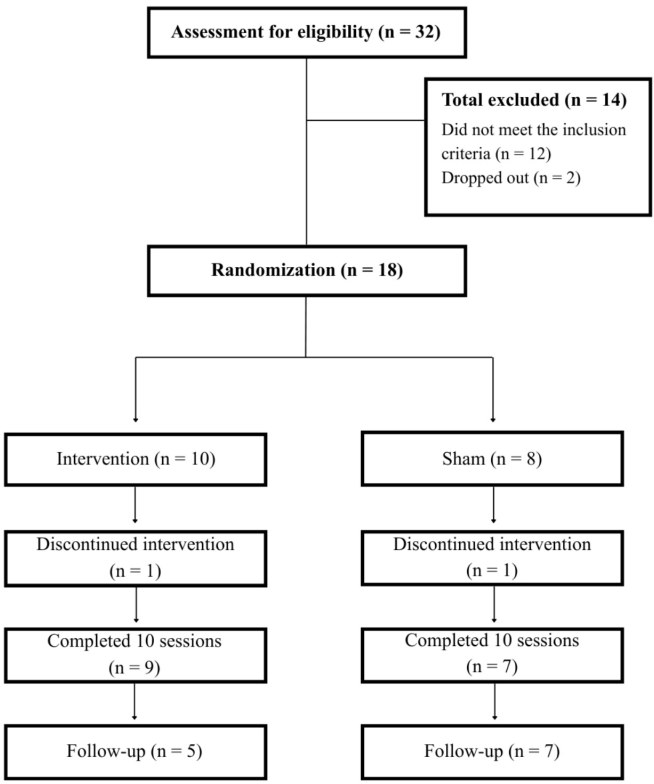

Table 1 presents the sociodemographic data and data on the participants' use of antidepressant medications.

Table 1

Sociodemographic and clinical characteristics of the study participants

Variables	N	%
Gender		
Female	11	68.8
Male	5	31.3
Marital status		
Single	13	81.3
Married	2	12.5
Divorced	1	6.3
Education		
Incomplete higher education	12	75.0
Complete higher education	4	25.0
Use of antidepressant medications		
Yes	11	68.75
No	5	31.25

The intervention was well tolerated in both groups. There were no absences or dropouts due to tolerability issues. Regarding adverse effects, only one participant in the active group reported a headache after application, which was mild in intensity and did not persist throughout the day. Two people in the active group reported tolerable tingling during the session. One person from the active group reported the appearance of a melasma on his forehead three months after the intervention, attributing it to electrostimulation. Even though it was not a common adverse effect of the intervention reported in previous studies, all measures guided by the Ethics Committee on Research with Human Beings were taken. Regarding the blinding assessment, when asked about the type of stimulation they received, all participants answered that they thought they had received the real stimulation.

Regarding the scores per group in the instruments that evaluate the primary study variables, Table 2 provides a description of the means of these scores for each of the three assessment stages.

Table 2

Means (standard deviation) of the scores in each instrument evaluated as a function of the group.

Instrument	Baseline		Post-test		*Follow-up*	
	Active tDCS group	*SHAM* group	Active tDCS group	*SHAM* group	Active tDCS group	*SHAM* group
FDT	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Inhibition	17.11 (4.91)	15.0 (6.32)	15.67 (3.67)	12.29 (4.53)	14.67 (3.96)	10.57 (5.50)
Flexibility	28.00 (7.95)	25.57 (7.50)	23.11 (4.47)	20.71 (6.92)	23.67 (4.00)	17.57 (7.20)
EMETAPS						
Metacognitive knowledge	25.33 (5.22)	26.14 (6.59)	24.56 (6.62)	27.29 (3.84)	27.44 (3.64)	27.0 (7.11)
Cognition regulation	29.00 (4.69)	26.86 (5.24)	25.11 (6.05)	23.0 (5.41)	22.67 (4.95)	21.71 (9.04)
ERQ						
Cognitive reassessment	8.78 (7.71)	13.0 (4.39)	12.44 (3.67)	14.57 (2.63)	11.44 (4.24)	14.14 (3.71)
Attention focus redirection	9.22 (4.23)	12.86 (4.63)	10.44 (5.00)	14.43 (2.22)	10.33 (4.77)	13.71 (3.09)
Suppression	14.22 (5.35)	18.71 (6.70)	14.00 (4.06)	17.71 (5.09)	13.44 (4.06)	16.71 (7.04)
DBI	34.11 (7.89)	25.85 (4.45)	23.78 (11.16)	13.86 (6.79)	24.89 (11.59)	14.29 (5.31)

Score. SD = Standard deviation.

Mixed ANOVA showed no effect of time on any of the executive function factors ($p > 0.05$). There was also no interaction between time and group ($p > 0.05$) in either factor.

For metacognition, the ANOVA results indicated that there was no effect of intragroup time ($p > 0.5$), nor interaction between time and group ($p > 0.5$) on the cognition knowledge factor. Concerning cognitive regulation, there was an intra-group effect of time [$F(2.28) = 8.69$, $p = .00$. $n^2 = 38$]. Bonferroni's post-hoc analysis revealed a difference between baseline and post-test ($p = 0.02$), 3.88 CI 95% [7.27, 0.50], and between the baseline and the follow-up ($p = 0.02$), 6.33 *CI* 95% [11.75, 0.91] in the active group. There were no significant differences between the post-test and the follow-up ($p > 0.5$). There was a difference between baseline and post-test ($p = 0.49$) 3.85 *CI* 95% [7.69, 0.1] in the *sham* group. However, there were no significant differences between the baseline and the follow-up, nor between the post-test and the follow-up ($p > 0.5$). ANOVA showed no interaction between time and group concerning cognition regulation ($p > 0,5$).

There was an effect of time on intra-group cognitive reassessment [$F(2.28) = 5.36$, $p = .01$. $n^2 = 27$] in emotional regulation. This effect is not found in the *sham* group ($p > 0.5$). In the active group, the post-hoc analysis found differences in reassessment scores between

baseline and post-test (p = 0.03) -3.66 *CI* 95% [- 0.22, -7.10]. There was no difference between the baseline and follow-up, nor between the post-test and the follow-up. Although the active group showed increased cognitive reassessment scores after the intervention (post-test), there was no significant difference in the interaction between time and group.

On the depression scale, ANOVA revealed the effect of time on intra-group BDI scores [F (2.28) = 14.74, p = .00. n^2 = 51], but there was no interaction between time and group (p > 0.05). In the active group, according to the *Bonferroni* analysis, there were significant differences between the baseline and post-test (p = 0.01), 10.33 CI 95% [18.37, 2.28], and between the baseline and follow-up (p = 0.01), 9.22 *CI* 95% [16.95, 1.49]. In the *sham* group, there was also a significant difference between baseline and post-test (p = 0.00), 12.00 CI 95% [21.12, 2.87], and between baseline and follow-up (p = 0.00), 11.57 *CI* 95% [20.33, 2.80]. There was no significant difference between the post-test and follow-up in either group (p > 0.05). Thus, both groups decreased their depression scores shortly after the real or fictitious intervention. These effects were sustained throughout the follow-up period.

In the assessment performed at baseline, there were no significant differences between the groups in scores for executive function factors, metacognition, and emotional regulation, indicating that both groups started from the same condition. There was also no significant difference in depression scores between participants who used medication and those who did not (p >0.5). In contrast, the mean depression scores were different at baseline depending on the group (p = 02), 8.254 *CI* 95% [1.07, 15.43], so that the active group had higher means than the sham group. However, the decrease in scores after the intervention occurred proportionally between groups.

Discussion

This study aimed to assess the effects of transcranial electrical stimulation by direct current on executive functions, metacognition, emotional regulation, and symptoms of depression in a sample of people diagnosed with MDD. The results were analyzed according to the group (active and *sham*) and the three assessment moments (baseline, post-test, and follow-up - three months after the last intervention session. The present study chose to determine the effect of tDCS on cognitive aspects in individuals with depression, due to the high prevalence of cognitive deficits associated with the disorder (Gruber et al., 2023), as well as the low rate of use of adaptive emotional regulation strategies (Vanderlind et al., 2020).

Contrary to what was hypothesized, there was no improvement in the performance of the executive functions evaluated over time in either group. These findings corroborate those of Wong et al. (2019). Furthermore, in line with our results, previous studies (Brennan et al., 2017; Loo et al., 2012) demonstrated that anodic stimulation in the left dorsolateral prefrontal cortex (F3) did not affect cognitive flexibility in patients with major depression. Brunoni et al. (2016) found an improvement in inhibitory control after the intervention, although this occurred in both groups.

Methodological moderators may influence the effect of tDCS on executive functions, as presented in a meta-analysis (Imburgio & Orr, 2018), which found that electrodes of 25 cm^2 significantly improve executive function, while those of 35 cm^2 do not. The smaller electrodes are likely to increase the focus of stimulation on the target area, increasing effectiveness. Larger electrodes are more likely to produce incidental effects in non-target areas. Another explanation for the lack of effect on executive functions is that our sample exhibited high performance in executive functioning, possibly because the depressive profile of the participants was generally not severe. As discussed in previous results (Wong et al., 2019), subtle improvements in executive functioning may not be found due to the ceiling effect. Thus, samples with higher cognitive deficits could benefit more from electrostimulation, at least in terms of relative results.

Regarding metacognition, both groups decreased cognition regulation scores, which represents an increase in the frequency of this strategy. On the other hand, there was no interaction between time and group. It is possible that the sample size weakened the evidence that found differences between groups. To our present knowledge, this is the first study to evaluate the effect of tDCS on the metacognition of thoughts and feelings in adults with MDD. Further research is needed to investigate this effect in more detail. Future studies may evaluate the effect of tDCS on metacognition in a more significant sample and explore whether the improvement in the regulation of thoughts and feelings occurs independently of the improvement in depression levels.

In emotional regulation, the active group increased their cognitive reassessment scores over time, but this increase was only significant between baseline and the post-test, and did not persist until the follow-up. However, there was no interaction between time and group in any of the components of emotional regulation. Perhaps evaluating this construct through experimental tasks is the most appropriate way to find a significant effect of the intervention on the evaluated factors, rather than assessing it only through a self-report questionnaire. In this regard, a meta-analysis (Zhang et al., 2022) conducted with studies in which emotional regulation was measured by self-report found no significant effect of tDCS applied to the dorsolateral prefrontal cortex (DLPFC) or ventrolateral prefrontal cortex (VLPFC) on the regulation of negative emotions in samples with various mental and neurological disorders. In a study with adults without severe neurological, psychiatric, or psychological impairment, Marques et al. (2018) found that tDCS did not modulate responses in the emotion regulation task in DLPFC. However, the authors found that tDCS modulated in the VLPFC. Another study involving patients with MDD demonstrated a predictive effect of DLPFC tDCS on improving performance in cognitive reassessment tasks (Chrysikou et al., 2022). Given the divergent results in the literature and the scarcity of studies on this topic in MDD, further research is needed to clarify which stimulation protocols are most effective in improving emotional regulation in this population.

Similar to previous results (Palm, et al., 2012; Razza et al., 2018), no significant differences were found in depression scores between the active and *sham* groups as a function of time. Both groups showed a decrease in depressive symptoms after the intervention, such

that the mean post-test scores of each group remained stable until the follow-up. According to a recent meta-analysis (Smet et al., 2021) performed with 23 studies, encompassing 501 subjects in the simulated tDCS group, the simulated response is significant for treating MDD. Their results indicated some factors that may contribute to the high response in the simulated group. The first factor considered is the location of the cathode. The placement of the electrode in the F8 area (electroencephalography system 10-20) showed a lower simulated response than when placed in the F4 area. The latter was chosen as part of the research protocol. The second factor is simulation protocols. This simulation usually occurs through the gradual increase in electric current to an intensity similar to active stimulation, followed by a decrease in the current to zero for 30 to 90 seconds. Smet et al. (2021) observed that the acceleration protocol followed by a deceleration current at the beginning and end of the tDCS session presented a significantly lower simulated response compared to the same procedure applied only at the start of the tDCS session.

Although the mean in the depression score of the *sham* group was lower than that of the active group at baseline, previous results (Smet et al., 2021) showed that the initial severity of depressive symptoms is not associated with the magnitude of the simulated response.

The present study has some limitations that should be considered. The sample size was small, which may have impacted the effect size of the results. Attempts to recruit participants began when restrictive measures were in place due to the COVID-19 pandemic. Therefore, we had difficulty gaining access to a larger number of potential participants. Because of this, we opted for a convenience sample, which represents another limitation of this study. In addition, all stages of collection were delayed because the school clinic where the research was conducted was closed. Therefore, there was no time to continue selecting participants and perform the intervention.

Another limitation is the inhomogeneity of the sample concerning the use of medications for treating MDD. Only five participants used antidepressants, which made it impossible to perform a more reliable analysis of the differences between these two conditions. The selection of these participants was allowed, as the interventions occurred in groups of five people, formed to avoid dropouts and prevent delays in collection. Thus, we initially expected to recruit more participants until we achieved a balance in the number of participants who used and those who did not use the medication. However, given the difficulties caused by the social isolation period, we chose to include everyone in the statistical analysis to increase the sample size. When analyzing the differences in depression scores as a function of the use of medication, we found no significant differences in any of the assessment moments.

Another limitation was that the *sham* group presented significantly lower mean depression scores than the active group at baseline, which demonstrates that they did not start from the same condition in this aspect. However, the decrease in scores over time was proportional between groups. We suggest that future studies aim to address this limitation by using a larger sample. Additionally, new research can compare different simulation protocols and

types of stimulation protocols across various areas of the cortex, which are associated with executive functions, metacognition of thoughts and feelings, and emotional regulation in adults with major depressive disorder.

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