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Effect of Transcranial Direct Current Stimulation in Acute Anxiety and Cognitive Performance of Athletes: an Experimental, Double-Blind, Randomized Study

Efeito da Estimulação Elétrica Transcraniana na Ansiedade Aguda e Desempenho Cognitivo de Atletas: um Estudo Experimental, Duplo Cego, Radomizado

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Abstract

Anxiety is present at various times of sports competitions sometimes limiting the athletes' performance. The objective of this study was to evaluate the effect of transcranial direct current stimulation (tDCS) on athletes' acute anxiety symptoms and cognitive performance when applied for 7 days. This is an experimental, double-blind, randomized study of 23 soccer players with anxiety symptoms. Two groups: anodic tDCS and sham tDCS. Anodic stimulation was performed in the left dorsolateral prefrontal cortex (DLPFC) and the cathode positioned in the right DLPFC, current intensity 2 mA, for 20 minutes on 7 consecutive days and then on the 14th day. Anxiety was assessed by the HAM-A scale and cognitive performance was through the Stroop Color Word Test and the Trail Making Test. For statistical analysis, t-student test and Spearman's correlation coefficient were used. Statistical significance was set at $p < 0.05$. No significant differences were observed between the groups in decreasing anxiety symptoms and improving cognitive performance using a 7-day consecutive protocol. This study provides evidence that there is an inverse correlation between anxiety and inhibitory control. There was no difference in the application of tDCS compared to the control group regarding improvement in anxious symptoms and inhibitory control in this specific population using a seven-day tDCS protocol.
Keywords: Anxiety. Transcranial Direct Current Stimulation. Executive Function. Athletes. Cognition.

Resumo

A ansiedade está presente em diversos momentos das competições esportivas limitando por vezes o desempenho dos atletas. O objetivo do estudo foi avaliar o efeito da estimulação transcraniana por corrente contínua (ETCC) nos sintomas agudos de ansiedade e no desempenho cognitivo de atletas quando aplicada por 7 dias. Este é um estudo experimental, duplo-cego e randomizado com 23 jogadores de futebol com sintomas de ansiedade. Dois grupos: ETCC anódica e ETCC simulada. A estimulação anódica foi realizada no córtex pré-frontal dorsolateral esquerdo (DLPFC) e o cátodo posicionado no DLPFC direito, intensidade de corrente 2 mA, por 20 minutos em 7 dias consecutivos e depois no 14º dia. A ansiedade foi avaliada pela escala HAM-A e o desempenho cognitivo por meio do Stroop Color Word Test e do Trail Making Test. Para análise estatística foram utilizados o teste t-student e o coeficiente de correlação de Spearman. A significância estatística foi fixada em $p<0,05$. Não foram observadas diferenças significativas entre os grupos na diminuição dos sintomas de ansiedade e na melhoria do desempenho cognitivo usando um protocolo de 7 dias consecutivos. Este estudo fornece evidências de que existe uma correlação inversa entre ansiedade e controle inibitório. Não houve diferença na aplicação da ETCC em comparação ao grupo controle quanto à melhora dos sintomas ansiosos e ao controle inibitório nesta população específica utilizando um protocolo de ETCC de sete dias.
Palavras-chave*: Ansiedade. Estimulação Transcraniana por Corrente Contínua. Função Executiva. Atletas. Cognição.*

1 Introduction

Anxiety is present at various times of sports competitions and pre-training and is often a normal and adaptive response, but it can limit athletes' performance as well as affect their lives off the field. This subject has been a cause of concern and interest for researchers in the field of sport[1].

Anxiety symptoms in athletes can be physical or psychological. Pre-competition psychological symptoms include changes in thinking, decreased self-control, fatigue, insomnia, and difficulty concentrating. Moments before competition may bring distrust, negative thoughts, worry, irritability, and decreased information processing ability. Physical symptoms include increased heart rate, blood pressure, muscle tension, dyspnea, sweating, dry mouth, and nausea[2,3].

Regarding the brain areas involved in anxiety symptoms, the dorsolateral prefrontal cortex (DLPFC) plays a crucial role. It's linked to cognitive functions, emotional behavior, and regulation of mood and anxiety[4], with an important role in processing and regulating stress and emotional responses[5,6]. Further research is needed to understand the relationship among DLPFC, emotional regulation, and stress responses[5].

Athletes have a high prevalence of acute anxiety symptoms since they are under constant physical and psychological stress due to the search for the best sports performance. In this context, transcranial direct current stimulation (tDCS) is an interesting tool to investigate these processes[5], being a neuromodulatory technique that involves the application of a direct electric current through electrodes positioned on the

scalp to induce local and secondary distal neuroplasticity[7].

This study aimed to evaluate the effect of tDCS on cognitive performance and acute anxiety symptoms in soccer players using a shorter time stimulation protocol (seven days), as well as to verify the correlation between anxiety and inhibitory control.

2 Material and Methods

2.1 Type of study, population, and sample

This study is an open, prospective, and randomized clinical trial, double-blind, whose population was composed of volunteer athletes, and soccer players who presented symptoms of acute anxiety. This study was submitted to the Ethics and Research Commission of the Universidade do Sul de Santa Catarina, Tubarão, and was approved through opinion No.2.612.278 . All participants received information regarding the study and agreed to participate signing the Term of Free and Informed Consent. Regarding the authorization of the place to carry out the study, the Declaration of Science and Agreement of the Institutions involved was signed.

2.2 Inclusion criteria

To be at least 18 years old and a maximum of 40 years; to present anxiety symptoms according to screening instrument and psychiatric evaluation; to be able to participate in all phases of the study; to accept participation in the study by signing the informed consent form; to have written and verbal fluency in the Portuguese language.

2.3 Exclusion criteria

To present previous psychiatric illness that is not anxiety disorders; to make use of any medication; to have a previous history of seizures; to make use of pacemaker or metallic brain implant.

2.4 Evaluation tests and instruments

Tests were used: the Brazilian version of the Hamilton Anxiety Scale[8] (HAM-A, The Stroop Color and Words Test (SCWT)[9] and the Trail Making Test (TMT).[10,11]

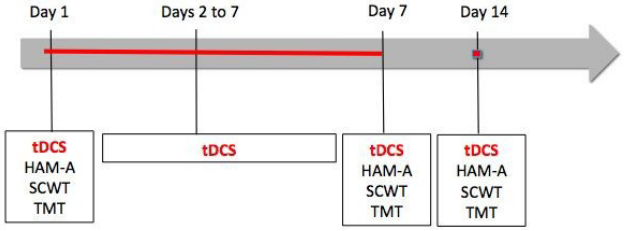
2.5 Intervention protocols

2.5.1 Enrollment and randomization

During the recruitment phase, the subjects were interviewed by a psychiatrist through an assessment made up of psychiatric anamnesis and mental state examination and evaluated by psychologists for the application of screening tools for anxiety symptoms, HAM-A.

After the recruitment phase, the selected participants were randomized to two groups: the intervention group that received anodic tDCS and the control group that received sham tDCS. All participants received the protocol for seven consecutive days, followed by a maintenance session on the 14th day as shown in Figure 1.

Figure 1 - Duration of intervention protocol and Flowchart. Abbreviations: tDCS, Transcranial direct current stimulation; HAM-A, Hamilton Anxiety Scale; SCWT, Stroop Color, and Words Test; TMT, Trail Making Test



Source: research data.

On day 1, the individuals from both groups were interviewed by psychologists and underwent HAM-A, SCWT, and TMT to obtain a baseline for further assessment of improvement in anxiety levels and cognitive performance. On the same day, they received the anodic or sham tDCS intervention (control group), whose parameters will be described below.

Between the second and the seventh day, subjects continued to receive only the tDCS protocol and at the end of day 7, the scale and test applications for further comparative analysis were performed again. From day 8 to day 13 there was a pause in the application of the protocol, and resumed on day 14, along with the performance of tests and scales for further comparative analysis of the maintenance effect of the intervention.

2.5.2 Blinding

The blinding was guaranteed so that the participant did not know which group belonged, as the equipment in functioning mode does not emit a sound signal. In addition, the equipment was positioned behind the participant, ensuring that there was no access to the parameters used. The psychologists who applied the scales and tests before and during the protocol also had no knowledge of which group the participant belonged to.

2.5.3 Intervention

The intervention consisted of tDCS anodic, with a current intensity of 2.0mA and duration of 20 minutes, for seven consecutive days. A transcranial electrical stimulator was used. For left anodic stimulation, the anode was positioned in the F3 area and the cathode in F4 according to the International System of EEG 10/20 corresponding to the regions on the left and right DLPFC respectively. This assembly has been used in several studies[12].

For the control group, tDCS sham mode was used, using a current of 1.5mA for 30 seconds being turned off soon after. This method proved to be reliable for blinding purposes in another study[13].

Some measures have been taken to reduce the risks of undesirable effects. The electrodes that are in contact with the scalp are covered by vegetable sponges, which were moistened in 0.9% saline solution to facilitate electrical conductivity between the electrodes and decrease the resistance of the skin,

as well as undesirable side effects such as pruritus or local irritation. In addition, a gradual increase of the current was achieved until reaching 2.0mA, with the main aim of reducing the risk of headache and dizziness as performed in other studies[13].

2.5.4 Monitoring and follow-up

Participants were monitored for side effects so that the intervention protocol was interrupted if they presented symptoms of pain or dizziness or if the participant wanted to quit at any time. No side effects and need for protocol discontinuation were reported. Subsequently, at the end of the intervention protocol, a new psychological interview for the application of HAM-A, SCWT, and TMT was performed on the seventh day. The follow-up occurred on the seventh and fourteenth days.

2.6 Data processing and analysis

Data were expressed as measures of central tendency, mean and standard deviation. The normality of the data was verified. The statistical comparisons between the intervention and control groups were performed through the difference between the means in the tests between the days and through the Student t-test for paired mean with equal standard deviations. The intragroup comparison was performed through paired Student t-tests. The correlation analysis between anxiety and inhibitory control was performed using the Spearman rank correlation coefficient or Spearman's rank for data at baseline (day 1) and later on days 7 and 14. Statistical significance will be considered for values of $p < 0.05$.

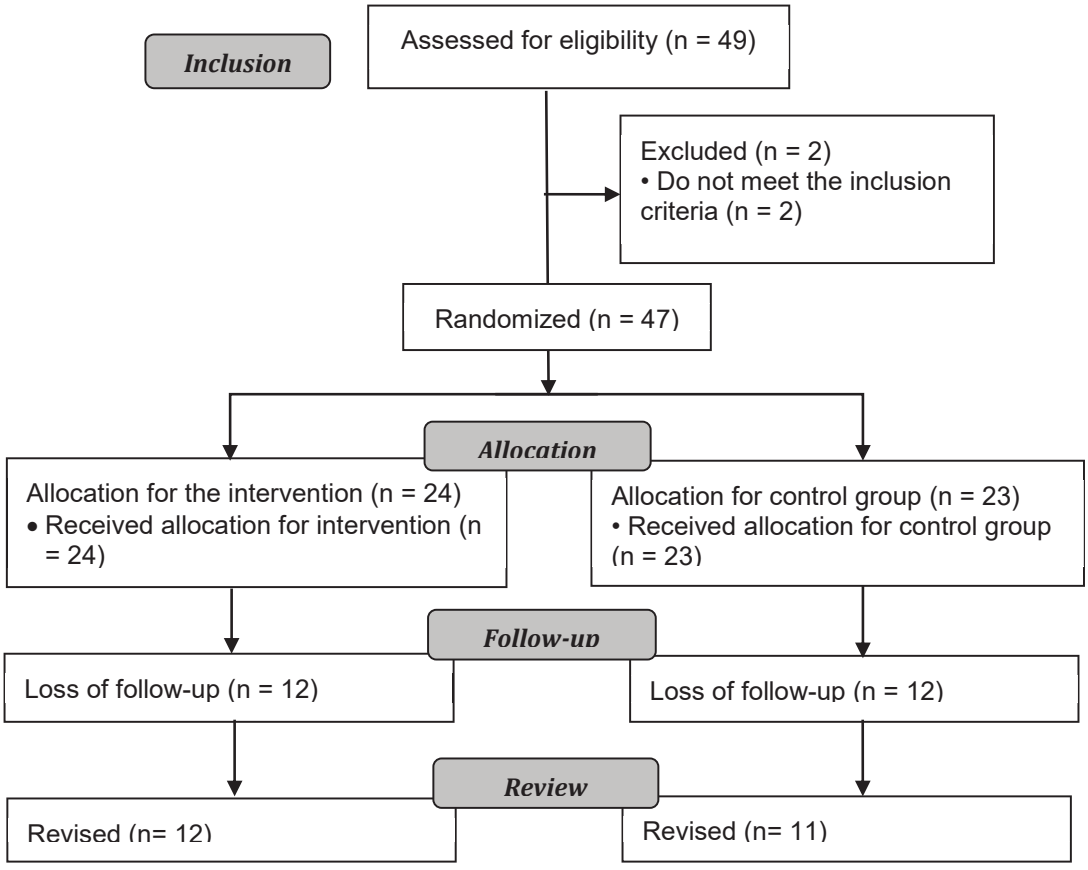
3 Results and Discussion

3.1 Sample characteristics

49 individuals were eligible to participate in the study, two of whom were excluded in the first phase because they were foreign players and had no fluency in Portuguese. Forty-seven players were randomized to participate in the intervention (24) and control groups (23), and in the follow-up, there was a loss of 12 players in the intervention group, 1 of them being dismissed from the club and 11 being called to play. In the control group, there was a loss of 12 participants because they were also called to play. The final sample for analysis consisted of 23 participants, 12 from the anodic tDCS group and 11 from the sham tDCS group, as observed in Figure 2.

Figure 2 - Sample flowchart

The groups were homogeneous, with most participants in both groups having an average age between 19.75 and 21 years, an average weight of 72.66 and 72.81 kilograms, and the average height of 1.76 and 1.78 meters. Participants in both



groups presented HAM-A Anxiety Score averages of 24.0 for the anodic tDCS group and 20.1 for the control group, with participants in both groups being classified as having mild anxiety. Further details can be seen in Table 1 which describes the characteristics of the intervention and control groups.

Source: research data.

Table 1 - Characterization of the sample

Socio-demographic variables	Anodic tDCS (N = 12)	Sham tDCS (N = 11)	P value
AGE			
Mean / Standard deviation	19.75 / 3.33	21 / 3.06	0.361
Minimum	18	19	
Maximum	30	28	
WEIGHT			
Mean / Standard deviation	72.66 / 6,28	72.81 / 6.58	0.956
Minimum	62	65	
Maximum	85	83	
HEIGHT			
Mean / Standard deviation	1.76 / 0,06	1.78 / 0.06	0.488
Minimum	1.69	1.67	
Maximum	1.87	1.92	
HAM-A			
Mean / Standard deviation	24.0 / 2.93	20.1 / 2.08	0.200
Minimum	20	18	
Maximum	29	25	

Abbreviations: tDCS, Transcranial direct current stimulation.
Source: research data.

Over time, different therapeutic strategies emerged, such as medications, psychotherapies, and brain neuromodulation techniques, to improve anxiety and executive functions such as inhibitory control. Among the techniques of cerebral neuromodulation, transcranial direct current stimulation by direct current has been the subject of research in recent years because it is a non-invasive technique, has low cost, has and good tolerability[13].

The present study chose to study the use of tDCS in athletes due to the high index of anxious symptoms in this population since they are in constant physical and psychological stress due to the search for the best sporting performance[1,14]. According to the literature, athletes are more likely to suffer from psychological problems, particularly depression, and anxiety[14]. Mental health is not only essential for better athletic performance, but also for a more stable and enduring sports career[15].

Few studies in the sports field assess the effect of tDCS on cognitive performance and anxious symptoms. In team sports, only one study was found with athletes' soccer players, whose sample consisted of 20 female adolescent athletes which evaluated the effect of the tDCS on the isometric strength of the quadriceps with the result of a temporary increase of muscle strength suggesting that the tDCS can be useful for strength training and rehabilitation. However, the study did not evaluate cognitive performance and anxiety symptoms[16].

3.2 Differences between groups

Initially, differences between the anodic tDCS and Control groups were tested to understand the intervention's effects on the HAM-A, TMT, and SCWT. Student's t-test showed that there was no statistically significant difference among the groups in any of the measurements of the tests performed as shown in Tables 2, 3, and 4.

Table 2 - Comparison among groups in the reduction of anxiety score (HAM-A) by t-Test

Days	Average difference	P value
Day 1 to 7	0.74242	0,658
Day 1 to 14	0.43182	0,835
Day 7 to 14	-0.31061	0,837

Source: research data.

Table 3 - Comparison among groups in the reduction of the time of execution of the Trail Making Test by Test t

Trail Making Test	Average Difference	P value
Time A1		
Day 1 to 7	-1.54568	0.586
Day 1 to 14	-3.65038	0.313
Day 7 to 14	-2.10470	0.112
Time A2		
Day 1 to 7	-0.93568	0.603
Day 1 to 14	-0.10879	0.918
Day 7 to 14	0.82689	0.512
Time B		
Day 1 to 7	-1.65152	0.841
Day 1 to 14	4.66235	0.515
Day 7 to 14	6.31386	0,.335

Source: research data.

Table 4 - Comparison among groups in reducing the execution time of the Stroop Test Colors and Words by Test t

SWCT	Average Difference	P value
Rectangles card		
Day 1 to 7	-1.79629	0.075
Day 1 to 14	-1.21000	0.151
Day 7 to 14	0.58629	0.286
Words card		
Day 1 to 7	-2.9326	0.792
Day 1 to 14	-1.17848	0.087
Day 7 to 14	-0.88523	0.347
Color card		
Day 1 to 7	-1.26765	0.424
Day 1 to 14	-1.71614	0.328
Day 7 to 14	1.47331	0.764
Interference		
Day 1 to 7	0.19424	0.215
Day 1 to 14	0.03977	0.736
Day 7 to 14	-0.15447	0.282

Abbreviations: SCWT, Stroop Color, and Words Test.

Source: research data.

Regarding anxiety symptoms, few studies have

evaluated the effect of tDCS on this outcome[17]. Our study was the second to evaluate the effects of tDCS on anxiety in athletes and showed that there was no statistical difference in the improvement of anxiety symptoms comparing tDCS and Control groups in this specific population and the time interval analyzed. These findings are consistent with those found in other studies, which found no improvement in anxious symptoms assessed by the Beck Anxiety Inventory in the assessed athletes[5]. A possible explanation for this finding in the present study could be related to the fact that the athletes analyzed present anxious symptomatology, mostly classified as mild, being, therefore, a specific population, different from the clinical population, as well as the duration of the protocol being short.

In clinical populations, a recent systematic review sought to evaluate the therapeutic efficacy of non-invasive brain stimulation in the treatment of anxiety disorders and found only five studies using the use of tDCS in anxious patients. Many of them have difficulty generalizing the results because they have small samples, case study design, different stimulation parameters, or because they do not have a control group[18].

In the first single case study of tDCS in a 58-year-old woman afflicted with generalized anxiety disorder, the authors performed 15 consecutive sessions of tDCS once daily (except on weekends). The cathode was positioned on the right DLPFC, and the anode was placed on the contralateral deltoid. The stimulation intensity was 2.0 mA. The results showed significantly decreased anxiety symptoms after 15 days of treatment. This improvement remained stable in follow-ups after 30 and 45 days[19].

One study evaluated eight patients affected by phobic postural vertigo to modulate disease-related symptoms such as dizziness and anxiety. An antactic tDCS, 2mA, was used on the left DLPFC once daily for five consecutive days. The symptoms of anxiety were reduced by both tDCS and pharmacotherapy, and the difference between the two methods was not significant[20].

A double-blind protocol was conducted on 19 female individuals diagnosed with social anxiety. Participants received a single anode (2mA) or sham session on the left DLPFC. The results showed that there was an improvement in attention, but this finding was not observed in the improvement of anxiety symptoms. The study had the limitation of having applied only a single session of tDCS[21].

In another case study where the authors treated a 44-year-old woman with 10 sessions of tDCS (5 sessions per week, one per day, for 2 weeks) of cathodal stimulation (2 mA) on the right DLPFC. There was a significant reduction in anxiety symptoms compared to baseline scores. Moreover, this pattern remained stable in the follow-up of 30 days[19].

In a study, a total of 18 patients affected by generalized anxiety were randomly assigned to receive 2mA of cathodic tDCS trough (n = 6) on the right DLPFC, pharmacotherapy (n = 6), or sham stimulation (n = 6). The symptoms were measured using the HAM-A. The results showed improvements in anxiety index in the tDCS group compared to the sham group[22].

No definite information on a preferable prefrontal subregion is possible given the few studies of tDCS in anxious individuals. This is also due to the heterogeneity of stimulation protocols, cortical targets (some studies applied inhibitory stimulation over right DLPFC, while the rest of the study stimulated the left DLPFC with an excitatory protocol), number of sessions (1 to 15 sessions), quality of the respective studies and heterogeneous outcome parameters. However, studies demonstrating a reduction in anxiety symptoms used at least 10 to 15 consecutive sessions, different from the one proposed in this study (7 sessions and one-fourteenth single session).

3.3 Differences Among the Sessions

As a function of the equivalence among the groups, paired sample tests were performed, comparing the intervention sessions with each other within the same group to identify changes at the beginning of the protocol. There was a decrease in the HAM-A score from day 1 to day 7 ($p < 0.001$) and from day 1 to day 14 ($p < 0.001$) for both groups. There was no statistically significant difference from day 7 to day 14 ($p > 0.05$).

Regarding performance in the TMT, it was verified that when comparing the performance of part B of the test from day 1 to day 7, there was a decrease in resolution time ($p = 0.013$), as well as from day 7 to day 14 ($p = 0.041$) and from day 1 to 14 ($p = 0.003$) for the anodic tDCS group.

Regarding the evaluation of the SCWT, it was verified that in the first phase (rectangle card), for the anodic tDCS group, there was an improvement in response time comparing from day 1 to 7 ($p = 0.001$) and day 1 to 14 ($p = 0.002$). There was no statistically significant difference from day 7 to day 14.

The same could be observed in the second stage of the test (word card) of the same group, comparing the sessions from the 1st to the 7th day ($p = 0.031$) and from the 1st to the 14th day ($p = 0.002$), as well as in the third stage color card) for days 1 to 7 ($p = 0.025$) and 1 to 14 ($p = 0.003$).

Regarding the number of errors during the tests, the descriptive analysis showed that the anodic tDCS group showed a progressive reduction in the number of errors in the TMT from day 1 to day 7 and day 7 to day 14. In the SCWT, the anodic tDCS group presented a reduction in the number of errors from day 1 to day 7, but there was no reduction from day 7 to day 14.

In the sports field, a study evaluated the mechanism of tDCS in the performance of professional rowing athletes using executive function evaluations, fatigue perception, lactate threshold potency, and isokinetic muscle strength, as

well as the collection of functional magnetic resonance data[23]. Twelve athletes were randomly divided into two groups: low stimulation (1mA) and high stimulation (2mA) and received 10 sessions of tDCS twenty minutes a day. As a result, the authors noticed an improvement in cognitive performance tests in both groups, but there was no significant difference between them[23]. If we compare the results of this study with our work, we noticed in the latter that there was also an improvement in the cognitive performance of the athletes who received tDCS if we analyzed the group alone. However, there was no statistically significant difference between the tDCS groups and control in the improvement of cognitive performance when compared to them. The mentioned study describes some limitations as a small sample, but mainly of not having a simulated group, therefore, being cautious in the generalization of its findings.

In individual sports, modalities were evaluated the for use of tDCS in ten professional athletes of three different modalities, who received anodic stimulation (2 mA) for 20 min in the left DLPFC for ten consecutive working days. The authors observed a positive effect of tDCS on cognitive performance, including a significant improvement in alternating, sustained, and divided attention and memory scores. However, this study also had a small sample and there was no comparison with a simulated group[5].

A study of 36 male cyclists to evaluate the effect of tDCS on individual exercise performance in three separate sessions, corresponding to three stimulation conditions: anodic, cathodic, and sham, being administered before each test for 20 min at a current intensity of 2.0 mA, with an anodic electrode placed on the DLPFC and the cathodic on the contralateral shoulder did not observe improvement in the performance as well as reported that neither heart rate nor EEG activity was affected by tDCS[24].

3.4 Correlation Between Anxiety and Inhibitory Control

Table 5 shows the correlations between scores of the anxiety assessment instrument (HAM-A) and inhibitory control (TMT and SCWT). It was possible to perceive a high correlation between instrument scores, indicating that higher anxiety was present in participants with weaker inhibitory control.

Table 5 - Correlation between anxiety tests and inhibitory control

	HAM-A	
Test	Correlation	p-value
TMT - Part A1	0,68	0,036
TMT - Part A2	0,414	0,180
TMT – Part B	-0,141	0,662
SWCT - Rectangles	0,71	0,041
SWCT - Words	0,65	0,029
SWCT - Color	0,44	0,782

Abbreviations: HAM-A, Hamilton Anxiety Scale; SCWT, Stroop Color and Words Test; TMT, Trail Making Test.

Source: research data.

In clinical populations, meta-analyses and reviews of the effects of acute tDCS on cognition performed so far provide mixed results on its ability to modulate cognitive performance. While some studies report small to moderate beneficial effects[25], others report no effect using tDCS in a single session in healthy young humans[26] or when individuals perform work memory tasks[27]. However, due to several experimental models related to electrode configurations, intensities, durations, electrode size, and state dependence, no general assumption about efficacy seems to be valid until more clarity is collected[27].

In a systematic review and meta-analysis of studies on the effects of non-invasive brain stimulation on the cognitive performance of healthy subjects and clinical patients, the area of stimulation considered for analysis was the DLPFC, the same region stimulated in the present study. The results showed that non-invasive brain stimulation is effective in improving cognitive performance[28]. Interestingly, when only the tDCS was analyzed, there was an improvement only in the reaction time, but not in the number of errors, findings that corroborate in part with that found in the present study, since in the TMT, there was a gradual reduction in the number of tDCS errors from the first to the seventh day and from the seventh to the fourteenth day. However, this effect was not observed in the SCWT, where there was a reduction in the number of errors from the first to the seventh day, but this reduction did not remain constant from the seventh to the fourteenth day. One of the possibilities suggested for explaining this selective improvement is the cross-sectional design of the experiment. In this sense, participation in the same experiment multiple times could result in an improvement in accuracy due to the learning with the repetition of the task. Regarding the accuracy of the responses in young adults, the same review reports that it is not uncommon for reaction time to improve, but that anodic ECEC results in a lack of benefit for performance accuracy[28].

Some authors suggest that the resulting tDCS effects have been proposed to be more readily observed with complex tasks[29]. Studies have shown that greater demands on cognitive systems during tDCS significantly affect post-stimulation performance, indicating that the task and timing of stimulation is an additional critical factors to be considered[30]. Not only the left DLPFC but also the right DLPFC could be a potential target area to improve cognitive performance and particularly in the components of more complex tasks[31].

There is also some evidence that tDCS can modulate the ability to inhibit when the hemisphere of the right prefrontal cortex is stimulated by anodic tDCS with a duration of 10 to 20 minutes as indicated by better reaction times[32]. In contrast, when using the SCWT, performance enhancement was identified by the right DLPFC anodic tDCS and the left DLPFC anodic tDCS[33]. The anodic improvements initiated by tDCS were observable up to 2 weeks after the stimulation

session. Another study showed that anodal tDCS to the left DLPFC led to a significant improvement in reaction time, an increase in P300 amplitude and a decrease in N200 amplitude in a state-dependent manner: baseline ERP amplitudes conditioned the effects of tDCS[34].

In our study, there was no difference between the intervention and control groups in the SCWT, but when analyzing the intervention group separately, it was observed an improvement in the performance of the reaction time from day 1 to day 7 and from day 1 to day 14. There was no improvement in reaction time from day 7 to day 14, which may raise the discussion of the cumulative effect of stimulation and suggest future studies that use maintenance doses between sessions to be able to analyze the effect of the tDCS maintenance.

Although there is some evidence to date that tDCS can modulate executive functions, divergence in different pacing protocols, and high variability among subjects, suggesting that the effects of tDCS are dependent on individual factors, such as the brain's instantaneous state[35] or genetic variations[36], as well as a contrasting meta-analysis[25], further research is needed to be sure of how executive functions are modulated by the tDCS.

The results showed a high correlation between anxiety and inhibitory control, and this correlation was reversed, that is, the most anxious individuals had a lower inhibitory control. Other authors have demonstrated results corresponding to those found in this study, in general contexts[14]. Using a computerized task, a study observed that more anxious individuals present greater difficulty than individuals with low anxiety inhibiting irrelevant stimuli. The authors suggest that anxiety interferes with the recruitment efficiency of mechanisms required for the inhibition of probable responses and this effect occurs in the presence or absence of emotional stimuli[37]. The relationship found raises the question of whether elevated anxiety is primary over reduced inhibitory control, or if the opposite occurs. This relationship is not defined yet.

The neuropsychological models of anxiety highlight a series of maladaptive deviations in attention and cognitive control processes that increase hypervigilance for threats and negatively affect inhibitory control, cognitive flexibility, and working memory[38]. Attention control theory proposes that anxiety is characterized by reduced attention control that impairs processing efficiency and performance effectiveness in goal-directed tasks[38]. This suggests that anxious individuals are motivated to perform tasks with high standards and to invest cognitive resources and additional efforts to achieve performance goals.

Individuals with anxiety treated with drugs showed improvements in the tasks of inhibitory control, which implies that anxiety is a reversible cause of impulsivity. However, there are most likely two directions in this relationship. In a review, it was observed that the preexisting presence of deficits in inhibitory control may increase the risk of developing and maintaining anxiety, and on the other hand, worry or anxiety could lead to compromised inhibitory control. The author hypothesizes that these factors are mutually influenced[39].

3.4.1 Limitations of the study

Our study had a significant sample loss due to the difficulty keeping participants in consecutive interventions. This was due to variations in the athletes' schedules due to games. Still, this is the study with the largest number of soccer players to analyze the effects of tDCS on anxiety and cognitive performance in this population.

Another limitation was the absence of neuroimaging data or biochemical anxiety markers demonstrating functional or neurochemical changes that could further characterize the nature of the tDCS effects.

Whether stimulation produced a sustained cumulative effect or a more acute change in participants' response to stimulation also remains to be determined. It was realized after the conclusion of the study that a protocol with more days of consecutive sessions could suggest more promising results.

In forthcoming research, a comprehensive battery of assessments can be employed longitudinally to elucidate the enduring effects that were not captured by initial investigation. By incorporating evaluations of executive function, it will be feasible to differentiate between the immediate and enduring advantages of stimulation, juxtaposing tasks that subjects are proficient with those with limited familiarity. This methodology will permit inferences regarding the generalization of effects and produce more comprehensive outcomes that can influence everyday functioning.

4 Conclusion

This was the study with the largest number of soccer athletes evaluated with the use of tDCS in anxiety symptoms and cognitive performance. It was concluded in this study that there is an inverse correlation between anxiety and inhibitory control, that is, the higher the anxious symptoms the worse the cognitive performance. It was also observed that there was no difference in the application of tDCS compared to the control group regarding improvement in anxious symptoms and inhibitory control in this specific population (athletes with mostly mild acute anxiety symptoms) in a protocol of only seven days of tDCS.

tDCS proves to be a promising technique according to studies found in the literature, but further research with more stimulation sessions is needed to consolidate the real benefits in anxious individuals and to improve cognitive performance using tDCS as a cerebral neuromodulation technique. It is necessary to standardize the methodology of the studies to obtain the generalization of the results since the studies found in the literature have different designs, reduced samples, and different stimulation protocols.

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