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Asieh Shabahang[*]
Rasool Abedanzadeh[*]
Hesam Ramezanzadeh[**]

The Effect of Transcranial Direct Current Stimulation on Inhibitory Control and interference Control in Athletes and Non-athletes

Abstract: According to the literature, the importance of executive functions in everyday life, in the acquisition of motor skills, and in distinguishing cognitive performance of athletes and non-athletes is indisputable. Aim: The aim of this study was to investigate the effect of transcranial direct-current stimulation (tDCS) on inhibitory and interference control in athletes and non-athletes. Methods: Athletes and non-athletes were conveniently selected (N=48, age range: 18-30 years). Then, each group (athletes/non-athletes) was randomly divided into two groups: real and Sham stimulation. Real stimulation group was involved in sessions of stimulation with an intensity of 2 mA electric current applied for 20 minutes in three sessions. But Sham group was received stimulation only at the first 30 second in each session. The inhibition score in "Go/No Go" task and average response time in the Stroop's task were evaluated before and after three sessions of stimulation for real and Sham groups. Results: The results on inhibitory control variable showed that the difference between the two groups (real and Sham groups) was significant in the post-test ($p \leq .05$). The results on interference control variable showed that real stimulation compared to other group had a better performance. Conclusion: The present findings showed that tDCS improves performance in inhibitory and interference control tasks in athletes compared with non-athletes.

Keywords: *Prefrontal cortex, Go/No Go task, Stroop task, Selective attention*

INTRODUCTION

Inhibitory control is an executive function that permits an individual to inhibit, interrupt or delay the previously activated behavior (Dimoska-Di Marco, McDonald, Kelly, Tate, & Johnstone, 2011). It should be noted that inhibitory mechanisms have different types. They include stimulus inhibition in which the disturbing stimuli should be ignored and one stimulus should be considered as the target stimulus. Inhibitory control, in which specific aspects of the stimulus are aimed, and other aspects should be controlled, and inhibition of predetermined target stimuli that a person receives in one part of the task for a reward stimulus, and controls in another part (Dick et al., 2010). Response inhibition is crucial in everyday behavior. A person might need to avoid putting their hand on a countertop once they notice that the stovetop is still hot or an athlete might need to stop their action in order to not fall for a deception from the opponent (Friehs, Frings, & Hartwigsen, 2021).

The response-stopping process is estimated by a stochastic model that delivers the stop-signal reaction time (SSRT; Verbruggen & Logan, 2009), that is, the latency to inhibit prepotent responses. The right dorsolateral prefrontal cortex (DLPFC) plays a key role in goal directed cognitive control in general and particularly an increased activation has been associated with better SST performance (that is with shorter SSRT) (Friehs & Frings, 2018). It has also been shown that two tasks with different structures, such as inhibitory control and interference control, may have unique neural contributions (Dimoska-Di Marco et al., 2011). Interference control is usually measured by color-word Stroop task (Stuss, Floden, Alexander, Levine, & Katz, 2001).

Failure to inhibitory control means that there is a failure in maintaining attention and disregarding stimuli. Sustain attention is correlated with social functions, in particular, with adaptation to everyday problems and behavioral problems. Therefore, any defect in this type of function may lead to a loss in the efficiency of personal

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[*] **Shahid Chamran University of Ahvaz, Ahvaz, Iran**
[**] **Damghan University, Damghan, Iran**
Corresponding author: Rasool Abedanzadeh - r.abedanzadeh@scu.ac.ir

and social activities of individuals (Barkley, 1997). Interference in attention distribution, which is another executive function, is one of the common features of dual task experience in different athletic movements such as deceiving the rival's defense players or everyday tasks. (Logan & Gordon, 2001). Align with it, in athletic area, athletes need to perform at higher levels than non-athletes as well. (Williams, Davids, Burwitz & Williams, 1994), Athletes should focus only on the most important and most relevant source of information in order to have a successful and effective performance (Casanova, Oliveira, Williams, & Garganta, 2009). In fully dynamic environments, athletes of team sports such as volleyball and basketball are under such a time limit that they need to have the best performance against their opponents in the shortest possible time. Repeated performance of such activities in sports may change the level of cognitive abilities of athletes (Aglioti, Cesari, Romani, & Urgesi, 2008). Therefore, any method that improves the cognitive performance of individuals, especially athletes, is of particular importance. Interventions as neural brain stimulation, have been investigated toward their effects improving cognition and performance in sports, although the number of peer-reviewed publication still incipient (Borducchi et al., 2016). One of these methods is Transcranial direct current stimulation (tDCS), a technique that is safe, practical and inexpensive (Jeffery, Norton, Roy, & Gorassini, 2007). It has been reported to improve behavioral performance in a diverse array of cognitive domains: attention, object recognition and memory, reaction time, and motor skill acquisition; moreover, it is also believed to support stress management through physiological control of the autonomic system, which may translate into performance gains in many sports (Borducchi et al., 2016). Non-invasive electrical brain stimulation is an emerging technique that claims to improve training effects and boost exercise performance. The rationale for such effects is based on the ability of the stimulation to safely modulate brain excitability and functional plasticity (Angius et al., 2017). The studies have reported that tDCS is a central nervous stimulant and has positive effects on cognitive functioning by affecting perception and attention (Shin et al., 2015). This finding could suggest that the performance-enhancing effects of tDCS are due to altered central nervous system function, possibly related to the attenuation of central fatigue effects (Vitor-Costa et al., 2015). In recent years, research has been conducted on the effectiveness of this technique. In a research conducted on children diagnosed with attention deficit hyperactivity disorder (ADHD), it has been shown that anodal stimulation of the left dorsolateral prefrontal cortex clearly affects memory and interference control, while cathodal stimulation of the right dorsolateral prefrontal cortex improves inhibitory control. In this study, the current intensity was 1 mA applied in 15-minute stimulation sessions with 72-hour intervals between them (Nejati, Salehinejad, Nitsche, Najian, & Javadi, 2017). In other study, Perrotta, Bianco, Berchicci, Quinzi & Perri (2021) evaluated the possibility to induce changes in the inhibitory control through non-invasive excitatory stimulation of the prefrontal cortex (PFC). Different montages of the tDCS were adopted in three separate experiments, wherein different cognitive tasks were performed before and after the stimulation. In the first experiment, a bilateral anodic or Sham stimulation was provided over the scalp area corresponding to the inferior frontal gyrus (IFG). In the second experiment, the IFG was stimulated unilaterally over the right hemisphere, and in third experiment the stimulation was provided bilaterally over the dorsolateral PFC (DLPFC). The results indicated that anodal stimulation favored a reduction of errors. Present findings suggest that the bihemispheric stimulation of the DLPFC might be effective to increase inhibition in healthy subjects (Perrotta, Bianco, Berchicci, Quinzi & Perri, 2021).

Chen, WangWang, Zhu, Zhang, Wang, & Yu (2021) investigated the effect of tDCS of the right DLPFC on response inhibition. This study involved three groups. The anode group received anodal stimulation over the right dlPFC and cathodal stimulation over the left supraorbital; the cathode group received cathodal stimulation over the right dlPFC and anodal stimulation over the left supraorbital; and the Sham group received Sham tDCS. The results showed performance on the response inhibition task after tDCS was improved in groups with both anodal and cathodal stimulation. Specifically, there was a decrease in the stop-signal reaction time in these subjects, whereas no difference was observed in the Sham group (Chen et al., 2021).

Guamez and Diaz (2016) examined the effect of electrical stimulation of the brain on athletes' attention and found that this type of intervention remarkably increases their attention. The physical parameters of the electrical transcranial stimulation used in their study were: a current intensity of 2 mA, stimulation period of 20 minutes, and the stimulation location of the left dorsolateral prefrontal cortex. On the other hand, in terms of response inhibition among athletes and non-athletes, it was shown that those who attended higher levels of competitions showed better performance in the stop-signal task (Liao, Meng, & Chen, 2017). Pavel et al. (2018) also states that athletes have higher cognitive performance in the Stroop test than non-athletes. Along with this line of research, the present study attempts to apply this type of intervention to cognitive functions using a different and more comprehensive methodology than previous studies, in order to further clarify this type of intervention. According to Cheng et al. (2015), the position of electrodes and polarity can lead to different effects in different regions of the brain. With this in mind, we used two simultaneous stimulations in the present study, namely an anodal stimulation in the right dorsolateral prefrontal cortex and a cathodal stimulation in the left dorsolateral prefrontal cortex. The present study deals with the effect of transcranial direct current stimulation on two different and simultaneous variables: inhibitory control and interference control. According to the literature, the importance of executive functions in everyday life, in the acquisition of motor skills, and in distinguishing cognitive performance of athletes and non-athletes is indisputable. Therefore, aim of this study was to investigate the effect of transcranial direct-current stimulation (tDCS) on inhibitory and interference control in athletes and non-athletes**.**

METHODS

Participants

The design of this single-blind semi-experimental research was pre-test/post-test with a control group. The study was single-blind in that the participants did not know the type of stimulation (real or Sham stimulation). The sample included 24 athletes (all female) and 24 non-athletes (all female) selected by convenience sampling method. The athlete group and non-athlete group were randomly divided into two groups of real stimulation and Sham stimulation. The mean and standard deviation of age of participants in athlete-stimulation, athlete-Sham, non-athlete-stimulation and non-athlete-Sham groups are respectively 22.75±3.9, 23.58±4.2, 22.83±5.25 and 25.41 ±4.85. The inclusion criteria were: having 18 to 30 years of age, being right-handed (as determined by the Edinburgh handedness questionnaire), having no history of mental illness, having no injury to the brain, having no metal transplantation in the body, having no epilepsy or seizure (self-report), and having a normal or corrected (by glasses) vision. The athlete's participants were selected from sport clubs and were a member of at least the regional teams. They have been members of sports teams for at least two years. The non-athlete's participants were selected from university students of Shadegan city who had no official sport background and were not a member of sport teams. All participants were provided with a written consent form approved by the institutional review board for the protection of human subjects and informed of their right to withdraw participation at any time before obtaining their consent. All procedures performed in this study were in accordance with the ethical standards of the institutional and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Apparatus and Tasks

Transcranial direct current stimulation device. This device (Neurostim 2, Medina Teb Iranian Company) has two completely separate channels and each channel can be independently adjusted. Different stimulation parameters such as current intensity, length, and frequency are adjustable. The output current of this unit is from 0.2 to 2 mA, the duration of stimulation is up to 45 minutes, and the output wave frequency is up to 200 Hz. The size of the electrodes in this study was 7×7 cm, placed inside a sponge with 9% sodium chloride, so as to increase the conductivity of the flow and to prevent heat elevation. Also, in this study we set the output current on 2 mA with the frequency of 200 Hz for 20 minutes.

Edinburgh Handedness Questionnaire. This questionnaire contains ten questions about doing routine daily activities, such as writing, drawing, throwing balls, etc. by the dominant hand. Attributing more than 6 items in the above activities to one specific hand suggests the importance and dominance of that hand in the individual. The validity and reliability of this questionnaire have been reviewed and approved in different countries.

Go/No Go Task. The Go/No Go task has been widely used to examine motor inhibitory functions (Kelly et al., 2004). This test consists of two sets of stimuli. The respondents should either respond to a number of these stimuli or withhold the response to others. The Go stimuli make up 70 percent of the total number of stimuli. Thus, the subject's bias is toward the answer Go. Lack of proper inhibition or committing a mistake means giving a response when there is a stimulus No Go (Liddle, Kiehl, & Smith, 2001). Given the multiple outputs of this task, in this study, the inhibition score was evaluated for inhibitory control. The inhibition score is obtained from the score of commission error (answering No go or giving a wrong answer to Go) and the omission error score (with no a response to Go). An occurrence of either of commission or omission error was resulted in the reduction of the inhibition score. The stimulus for Go trials was the letter 'X' and the stimulus for No-go trials was 'A,' each presented within 6 cm ′ 6 cm square box for a period of 250 ms. A single run containing 28 Go and 12 No-go trials was presented. The presentation of each trial began with a plus sign presented on the screen so as to heighten preparedness to respond. The series started with a blank screen 1000 ms followed by a plus sign presented for 500-800 ms, and then either an 'X' or an 'A' presented for 250. Participants were instructed to respond as quickly and accurately as possible with their right index finger every time 'X' was presented and not to respond when 'A' was presented. The procedure of this task has shown on Fig 1.

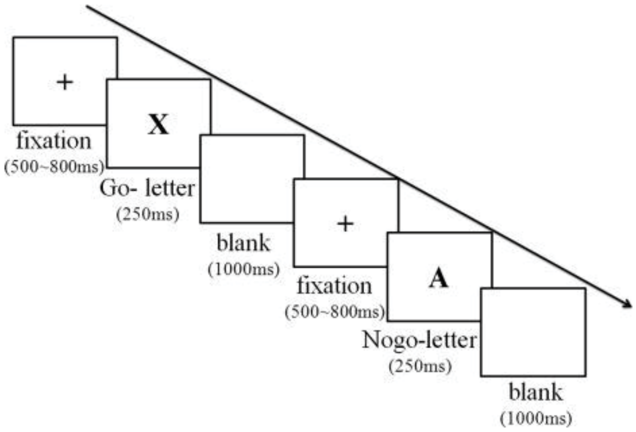

Fig 1. The flow chart of Go/No Go task illustrating the procedure.

Stroop Task. Stroop task was first developed in 1935 by Ridley Stroop to measure selective attention and cognitive flexibility through visual processing. This test has been used in various clinical trials with the aim of measuring the ability in response inhibition, interference control, selective attention, cognitive variability, and cognitive flexibility. The validity of this test was reported through a test/retest method to be in a range from 0.8 to 0.91 (Lezak, Howieson, Loring & Fischer, 2004). The duration of each stimulus on the screen is for 2 seconds and the interval between the presentations of the two stimuli is 800 milliseconds. The task requires participants to view color names presented in various ink colors (e.g., red, blue, yellow, green) and name the color of the ink. Participants were given four buttons marked with four colors and were instructed to select a color when presented with the word as fast as possible. During the neutral trials, the word is written in black ink (e.g., "red" in black ink) and participant should press the button with the corresponding color; during the congruent trial, the word matches the ink color (e.g., "blue" in blue ink) and in the incongruent trials, the word conflicts with the ink color (e.g., "red" in yellow ink) and participants should respond to the color of the ink and inhibit the word. Interference time is measured by the proportion of false answer and RT of the third stage (i.e., incongruent trials) that shows interfering stimuli.

Procedure

After investigation the inclusion criteria, we explained to the participants how the transcranial direct current stimulation device works, and an informed consent form was completed by them. Subsequently, explanations were given about the process of conducting the test. At the first session, the participants were familiarized with how to do the test. They took Go/No Go test and Stroop test as a pre-test of inhibitory control and interference control, respectively. Afterwards, they received a 2 mA electric stimulation for 20 minutes in each session. The sponge pad used as cover to the electrodes, was soaked with 9% sodium chloride. Using a rubber band, the anode electrode was placed on the left dorsolateral prefrontal cortex, which is equivalent to the F3 point, and the cathode electrode, was placed on the right dorsolateral prefrontal cortex, which is equivalent to the F4 point in the 10-20 electroencephalographic system. Upon completion of stimulation, the laptop screen was placed in front of the participants at a distance that they can easily respond to the Go/No Go and Stroop tasks. In order to minimize the transfer of the test step effects, at least a 24-hour interval between sessions was considered. At the end of the stimulation sessions, the participants took a post-test (after 24-hour interval with last stimulation session), with conditions exactly the same as the pre-test. The Sham stimulation in the control group was performed in such a way that the location of the electrodes was the same as the actual stimulation electrodes, that in order to trigger the initial itching, the current was on only in the first 30 seconds and then it was shut during the test. At each stimulation (whether real or Sham) the test conditions and the order in which the tests were performed were the same.

Data Analysis

The individual characteristics of the participants and the research variables were described by descriptive statistics of mean and standard deviations, normality of distribution by Shapiro-Wilk's test, and the homogeneity of variances by the Levene's test. Since normal distribution was not confirmed, Mann-Whitney *U* test was used to assess the effect of transcranial stimulation and Sham stimulation in the two stages of testing and also to assess the effect of transcranial stimulation on the in athletes and non-athletes, two non-parametric Wilcoxon Signed Ranks tests were used for each group. To determine the effect of electrical stimulation of the brain on the athlete and non-athlete groups as well as the real stimulation group and the Sham group, factor analysis of variance 2 (athlete) × 2 (stimulation type) × 2 (test step) was used. Independent and dependent t-tests were used for significant interactions. All analyses were performed at a significant level of $p \leq .05$, using SPSS version 22 (SPSS Inc., Chikago, IL, USA). Also, in order to estimating of statistical power of used statistical tests, we used the priori power analysis power analysis approach. By using G*Power software and setting the significant level ($\alpha = .05$), effect sizes mean in previous background research (.41 for Stroop task, and .25 for Go/No Go task), the samples number (48), the number of the research groups (two groups), the number of the measurements (twice) and the mean of between measurements correlations ($r = .52$), statistical power for the test of within-between factor analysis of variance with repeated measures, .96 and for the Wilcoxon test, .86 was calculated that according to Cohen index were very large and acceptable. The data that support the findings of this study are available from the corresponding author upon reasonable request.

RESULTS

The means and standard deviations of inhibition score of four groups are shown in Table 1.

Table 1. The *M*±*SD* of inhibition score.

	Pre-test	**Post-test**
Athlete-tDCS	39.17 ± 0.94	40 ± 0.0
Athlete-Sham	38 ± 3.77	38.4 ± 2.31
Non athlete-tDCS	38.75 ± 1.21	39.42 ± 0.67
Non athlete-Sham	38.75 ± 1.21	35.83 ± 3.35

In order to study the effect of transcranial stimulation on inhibitory control (time of interference) of athletes and non-athletes in two phases of the test, the mixed-ANOVA 2 (group 1: athletes/non-athletes) × 2 (group 2: real stimulation/Sham) × 2 (test: pre/post) was used for inhibitory score. The results of this test are shown in table 2. Note the hypothesis of Muchly's sphericity assumed.

As shown in table 2, the main effects of group 2 ($p = .005$), and two-way interactive effects of test×group1 ($p = .004$), test×group2 ($p = .001$), and three-way interactive effect of test×group1×group2 ($p = .008$) are significant. For further investigation, the significant effect of three-way interaction, we conducted two mixed-ANOVA 2 (group1)×2 (test) and mixed-ANO-

Table 2. The results of mixed-ANOVA 2 × 2 × 2 for inhibitory score in Stroop task.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	*Sig.*	Partial Eta Squared
Test	1.5	1	1.5	0.78	0.38	0.02
Test×Group1	18.37	1	18.37	9.5	0.004*	0.18
Test×Group2	24	1	24	12.41	0.001*	0.22
Test×Group1×Group2	15.04	1	15.04	7.78	0.008*	0.15
Error (Test)	85.08	44	1.93			
Group1	12.04	1	12.04	1.76	0.19	0.04
Group2	60.17	1	60.17	8.81	0.005*	0.17
Group1×Group2	1.04	1	1.04	0.15	0.75	0.003
Error (Group)	300.58	44	6.83			

Note: Group1 is athlete/non athlete and group2 is real stimulation/Sham.
*: Significant at $p \leq 0.01$

VA 2 (group2)×2 (test) with repeated measure on last factor, and two two-way ANOVA 2 (group1)×2 (group2), once for pre-test and again for post-test. The results of two-way ANOVA in pre-test were not significant ($p > .05$). But for two-way ANOVA in post-test, the main effects of group1 ($F_{(1.44)} = 7.06$, $p = .011$, $\eta_p^2 = .14$) and group2 ($F_{(1.44)} = 18.79$, $p = .0001$, $\eta_p^2 = .3$) were significant. The interaction effect of group1×group 2 was not significant ($F_{(1.44)} = 2.82$, $p = .1$, $\eta_p^2 = .06$).

The results of mixed-ANOVA 2 (group1)×2 (test) showed only interaction effect of test×group1 is significant ($F_{(1.46)} = 6.81$, $p = .01$, $\eta_p^2 = .13$). The results of mixed-ANOVA 2 (group2)×2 (test) showed the main effect of group 2 ($F_{(1.46)} = 8.82$, $p = .005$, $\eta_p^2 = .16$) and also interaction effect of test×group2 is significant ($F_{(1.46)} = 9.32$, $p = .004$, $\eta_p^2 = .17$).

For significant interaction effect of test×group1, we run two independent t-test, once in the pretest ($t_{(46)} = -.27$, $p = .79$) and again in the post-test ($t_{(46)} = 2.22$, $p = .03$), and two dependent t-test, once in the athlete group ($t_{(23)} = -1.97$, $p = .06$) and again in the non-athlete group ($t_{(23)} = 1.9$, $p = .07$).

Also For significant interaction effect of test×group2, again we run two independent t-test, once in the pretest ($t_{(46)} = .96$, $p = .34$) and again in the post-test ($t_{(46)} = 4.01$, $p = .001$), and two dependent t-test, once in the real stimulation group ($t_{(23)} = -3.71$, $p = .001$) and again in the Sham stimulation group ($t_{(23)} = 2.01$, $p = .006$). Based on the mean values obtained for both stimulation groups (real/Sham) in the post-test, it was determined that subjects receiving the real stimulation compared to those receiving Sham stimulation (Regardless of athleticity) had a better performance. Also, with regard to the mean values, it was found that the real stimulation group (Regardless of athleticity) experienced improvements in their performance from pre-test to post-test.

Figure 1 shows an overview of the performance of the groups (athlete and non-athlete) and intervention (real and Sham stimulation) in inhibitory scores.

The mean and standard deviation of the interference time variable for the evaluation of the interference control factor are reported in table 3.

In order to study the effect of transcranial stimulation on interference control (time of interference) of athletes and non-athletes in two phases of the test, the mixed-ANOVA 2 (group 1: athletes/non-athletes) × 2 (group 2: real stimulation/Sham) × 2 (test: pre/post) was used, the results of which are shown in table 4. Note the hypothesis of Muchly's sphericity assumed.

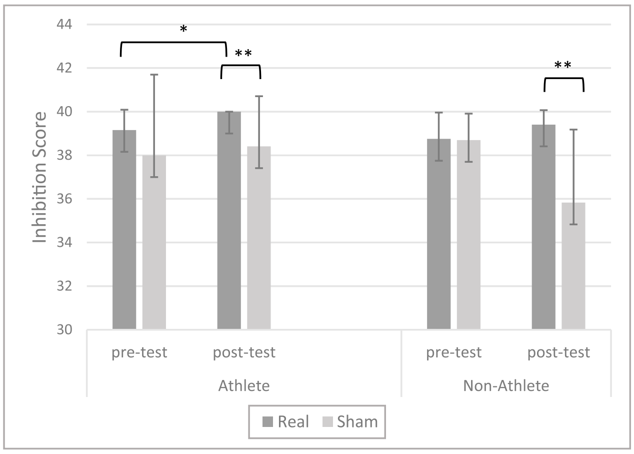

Fig. 1. Comparison of two groups of athlete and non-athletes in real and Sham stimulation conditions in pre and post- tests (inhibition score)

*: Significant at $p < .05$
**: Significant at $p < .01$

Table 3. The *M*±*SD* of inference time (ms).

	Pre-test	*Post-test*
Athlete-tDCS	46.58 ± 25.07	19.16 ± 12.67
Athlete-Sham	33.33 ± 22.69	47.67 ± 25.58
Non athlete-tDCS	47.25 ± 21.06	32.67 ± 21.77
Non athlete-Sham	58.42 ± 3.95	58.83 ± 26.41

Table 4. The results of mixed-ANOVA 2 × 2 × 2 for interference time in Stroop task.

Source	Type III Sum of Squares	*df*	Mean Square	*F*	*Sig.*	Partial Eta Squared
Test	846.09	1	846.09	3.47	.07	.07
Test×Group1	31.51	1	31.51	0.13	.72	.003
Test×Group2	4253.34	1	4253.34	17.42	.0001*	.28
Test×Group1×Group2	810.84	1	810.84	3.32	.07	.07
Error (Test)						
Group1	6716.76	1	6716.76	7.14	.01*	.14
Group2	7158.76	1	7158.76	7.61	.008*	.15
Group1×Group2	46.76	1	46.76	0.05	.82	.001
Error (Group)	10740.708	44	244.107			

Note: Group1 is athlete/non athlete and group2 is real stimulation/Sham.
*: Significant at $p \leq 0.01$

As shown in table 4, the main effect of group 1 (p = .01), group 2 (p = .008) and interactive effect of test × group2 (p = .0001) is significant. For further investigation, the significant effect of interaction, two independent t-tests were used to examine the difference between the real stimulation group and Sham stimulation once in the pretest ($t_{(46)} = .52$, $p = .61$) and again in the post-test ($t_{(46)} = -4.35$, $p = .0001$). Also, two dependent t-tests were used to examine the difference between the pretest and post-test once in the real stimulation group ($t_{(46)} = 4.55$, $p = .0001$) and again in the Sham stimulation group ($t_{(46)} = -1.5$, $p = .15$). Based on the mean values obtained for both groups in the post-test, it was determined that subjects receiving the real stimulation compared to those receiving Sham stimulation (Regardless of athleticity) had a better performance. Also, with regard to the mean values, it was found that the group receiving stimulation experienced improvements in their performance from pre-test to post-test. Figure 2 shows an overview of the performance of the groups (athlete and non-athlete) and intervention (real and Sham stimulation) in interference time.

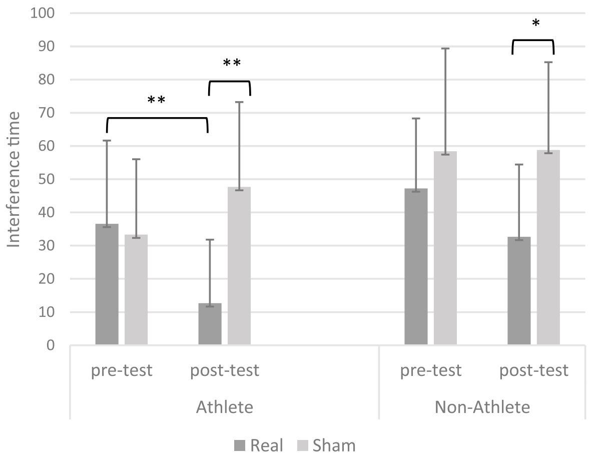

Fig. 2. Comparison of two groups of athlete and non-athletes in real and Sham stimulation conditions in pre and post- tests (interference time)

*: Significant at $p < .05$
**: Significant at $p < .01$

DISCUSSION

This study aimed to investigate the effect of tDCS on inhibitory and interference control in athletes and non-athletes**.** Data analysis showed that transcranial direct current stimulation on DLPFC contributed to the improvement of the inhibition score in the athlete group, which is consistent with the results of Chen et al. (2021) and Friehs et al. (2021). In the present study, there was a significant difference between the types of stimulation (real/Sham) on the inhibitory control variable, which is contrary to cubillo et al's (2010) finding. The results of their research showed that those who had ADHD in their childhood and whose behavioral symptoms persisted have a significant pattern of parietal and frontal malfunctions during the inhibitory control tasks. Constant attention is usually affected severely when there is prolonged and repetitive presentation of stimuli, resulting in considerable reduction in the individual's level of vigilance, and gradually their responses will vary greatly (Barkley, 1997; Verbruggen, Liefooghe, Notebaert, & Vandierendonck, 2006). Therefore, the inconsistent findings could be attributed to the studied samples. Participants in Cubillo et al's (2010) study were adults with ADHD, while the participants in the current study were healthy people with complete attention and vigilance. Another reason explaining the inconsistent findings may be related to the nature of the tasks. The Go/No Go test measures mostly the motor aspect of an inhibitory control, while the Stroop test measures selective inhibition. We also found that there is a significant difference between the type of stimulation and the inhibition score, which is inconsistent with the findings of Nejati et al. (2017). This inconsistency could be attributed to the interval between stimulation sessions. The interval between stimulation sessions in this study was 24 hours, while it was 72 hours in Nejati et al. (2017). According to Sergeant, Oosterlaan, & van der Meere,

(1999) in presenting stimuli with long intervals, while the chances for distraction or behaviors non-relevant to the test increase, the cognitive load of the test also increases and the individual is obliged to allocate more resources to the process for giving a response, based on the delay aversion model5. Conners, Epstein, Angold, & Klaric, (2003) and Hervey et al. (2006) also provided evidence that by increasing the intervals of stimuli, the number of elimination errors and commitment of the affected individuals increased significantly.

The present study also showed that bilateral electric stimulation of the dorsolateral prefrontal cortex in subjects with real stimulation compared with those stimulated by Sham (regardless of athleticity) increases the speed (reduction of interference time) in the Stroop task. This finding is similar with the results of Nejati et al. 2017) in terms of reaction time. The transcranial direct current stimulation enhances the processing capacity of the information (Gandiga, Hummel, & Cohen, 2005; Nejati et al. 2017). The results also show reduction of interference time in the real stimulation group compared to Sham stimulation group in both athletes and non-athletes. Recent studies using fMRI have shown that anodal transcranial stimulation increases the cortical-spinal excitability of 4 localized stimulated regions and farther regions, which can be due to interactions between these regions. Therefore, the location of the electrode can make a vital contribution to the spatial distribution and the path of electrical current, which can play a decisive role in effectiveness of stimulation. Therefore, the reasons for the inconsistency between this finding with that of Nejati et al. (2015) could be attributed to the type of subjects and the location of stimulation. On the other hand, this present finding is inconsistent with Frings, Brinkmann, Friehs, & van Lipzig, (2018). They applied single session stimulation for investigating the effect of tDCS of DLPFC on interference control. Their results showed single-session stimulation disrupt the interference processing. Once brain imaging studies recently indicated the activation of both left and right brain areas improves Stroop task performance) Hyodo, Kyutoku, Suwabe, Byun, Ochi, Soya, 2016), therefore, the reason of this inconsistency could be attributed to the stimulated areas of the brain. In Frings et al. study the stimulation was on left DLPFC, whereas in this study, we stimulated both of left and right DLPFC.

Another finding of the present study was that bilateral electric stimulation of the dorsolateral prefrontal cortex increased the performance of the athletes compared with non-athletes in terms of the time of interference in the Stroop task. This finding was consistent with the findings of the Gomes and Dias 2016) and Nejati et al. (207). Nejati et al. evaluated the interference control by the Stroop test and concluded that the anodal stimulation of the left prefrontal cortex and the cathodal stimulation of the right prefrontal cortex lead to improvement in the accuracy and the duration of response in the Stroop task. Recent studies using brain imaging have proven that activating both left and right brains contributes to the optimal performance of the Stroop task (Hyodo et al., 2016). One of the conclusions reached is that exercise can affect the various aspects of perceptual and cognitive functions. The benefit of exercise for executive control functions, such as the planning and execution of simultaneous tasks, has also been indicated (Heyn, Abreu, & Ottenbacher, 2004). It has also been found that in skilled and experienced athletes, irrelevant signals do not interfere with the performance on the original tasks (Ford, Hodges, & Williams, 2005). Various studies have examined the effect of sports exercises on the decision of athletes in team sports, and have concluded that joining the team's exercises and competitions improves the skill of prediction and decision-making in athletes. These results confirm that in their course of sports exercises, athletes acquire extensive knowledge of special neuro-cognitive patterns, and in similar sports conditions (e.g., computer neuro-cognitive tests), they have higher perceptual abilities compared to non-athlete subjects because of the efficient utilization of this knowledge (Baker, Cote, & Abernethy, 2003). These results justify the –better performance of athletes over non-athletes in this regard.

The findings of this study provide an important insight related to use of tDCS for improving inhibition and interference control, but the study is not without limitations. First, the sample size was rather small in each group. The future research can conduct on this topic with large sample to able for better comparing between groups. Second, in this study we select a specific set up of tDCS, as previous research (Tremblay, Lepage, Latulipe-Loiselle, Fregni, Pascual-Leone, & Théoret, 2014) were indicated different finding by various set up and configuration of tDCS, therefore, next research can select other possible set up and configuration of tDCS to able to compare their results together and attain valid finding in this area. Third, we did not test verifying if the participants identified the condition they were allocated to and only limited ourselves to self-reporting. It was recommended future research test this concern to further validate their work. Last, the applied tasks in this research (Stroop task, Go/NoGo task) are not sport-specific ecological tasks in which the inhibition and interference are applied as processes that are underlay performance. Therefore, it is recommended to other researcher to work on this area applying sport-specific ecological tasks for finding more valid results.

CONCLUSION

Since this study confirmed the effectiveness of transcranial direct current stimulation on inhibitory control and interference control in athletes, it is recommended that along with physical exercises, athletes, coaches and sports managers may improve athletic performance in sports fields using transcranial direct current stimulation which is non-invasive, inexpensive, and safe.

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CONFLICT OF INTEREST

The authors in this study state that they have no conflict of interests with the content of the present study.

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