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The effects of a tDCS-mindfulness program on selective attention in skilled badminton players

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Abstract

Background: This study addresses the challenge of enhancing selective attention in skilled badminton players, a critical cognitive skill for optimal performance, by investigating the combined effects of transcranial direct current stimulation (tDCS) and mindfulness training.

Aim: The present study was conducted to investigated the effects of a tDCS-mindfulness program on selective attention in skilled badminton players.

Materials and Methods: Thirty-six male badminton players (mean age= 23.78±3.09 years) were selected based on exclude and include criteria and randomly divided into three groups of 12, A-tDCS-Mindfulness, sham-tDCS-Mindfulness (five sessions), and control. The Edinburgh Hand Test was used to determine the dominant hemisphere of the brain. The Computerized Stroop Test was used to measure selective attention capacity. Nonparametric Wilcoxon, Kruskal-Wallis and Mann-Whitney U tests were used.

Results: The results showed that the within-group changes in both A-tDCS and sham-tDCS mindfulness groups, it was able to have a significant improvement on the Stroop test score and time of interference. In the comparison between groups effect, it was also found that there is a significant difference in time and score between the three groups, and respectively, the A-tDCS mindfulness, sham-tDCS mindfulness and the control group had the best performance. Based on the results of the present research, it was found that the presentation of A-tDCS mindfulness can be more effective on the time and score of selective attention of badminton players.

Conclusion: Results suggest that the use of tDCS along with mindfulness can improve selective attention in badminton players.

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1. Introduction

Badminton has gained widespread popularity across various social classes due to its elegance, precision, timing, and agility in the execution of various skills [1]. As with other sports, it is imperative that athletes must meet their physical, physiological, psychological, and skill requirements. Success in badminton, as in any sport, depends on a multifaceted approach, as reliance on one-dimensional preparation, such as physical conditioning, alone cannot guarantee exceptional performance in both training and competition. Researchers have delineated the diverse needs of badminton players and categorized them into technical, tactical, physiological, and psychological facets. These aspects are broadly classified into two overarching categories: physical and psychological [2]. In the physical realm, preparation includes aspects related to physical and technical ability, as well as overall readiness. The psychological dimension addresses the psychological needs, tools, skills, and overall mental enhancement of athletes. Addressing athletes' cognitive needs and potential challenges is a complex issue.

In recent decades, coaches and athletes of various skill levels have increasingly emphasized the impact of psychological factors and skills on competition and training [3]. Researchers assert that psychological skills contribute significantly to athletic performance [4]; Weinberg and Gould (2014) highlight the central role of psychological factors as the primary cause of variability in executive function in professional athletes [5].

The importance of attention in athletic performance has long been recognized [6]. Attention and its role to the execution of athletic skills is an integral aspect of high-level athletic performance. Athletes who strive to outperform their competitors and achieve victory inevitably rely on and are required to use attention. By its very nature, selective attention focuses on a feature or aspect of a skill that is critical to its accurate execution [7]. In sports like badminton, athletes need to focus their attention within precise boundaries to execute skills accurately, such as positioning the shuttle accurately behind the net or delivering both short and long serves effectively. Mastery in these sports demands specialized attentional skills, particularly selective attention, which is essential for both performance execution and the ongoing learning process in athletes [8].

Transcranial direct current stimulation (tDCS) has become an increasingly utilized tool in sports science, particularly for its potential to influence neural processes that impact cognition, behavior, and overall performance. The method involves applying a low-intensity direct current (typically 1 to 4 mA) between two electrodes– a cathode and an anode– positioned on the skin either inside or outside the skull. This current has been shown to penetrate the skull, affecting neural tissues and blood vessels and potentially enhancing neuroplasticity and cognitive flexibility [9, 10]. Research underscores that the effects of tDCS, such as the magnitude and duration of physiological adaptations, are contingent upon variables like the current's intensity and duration of exposure [11, 12]. By altering neural excitability and connectivity, tDCS can produce significant physiological and behavioral adaptations, making it valuable in both daily activities and targeted athletic training.

In tandem with tDCS, mindfulness-based interventions have gained traction among athletes and coaches as a complementary cognitive enhancement strategy. Rooted in ancient Eastern traditions, particularly Hinduism and Buddhism, mindfulness was initially intended as a means to transcend suffering and cultivate self-awareness [13]. Mindfulness practice fosters a present-centered, non-judgmental awareness that can mitigate the tendency to judge experiences as “good” or “bad”, ultimately reducing internal conflict and enabling greater psychological resilience [14, 15].

Empirical evidence supports the efficacy of mindfulness in sports contexts, where it has been associated with enhanced mental skills and performance outcomes. For instance, research on athletes with disabilities, specifically disabled basketball players, found that while mindfulness training had minimal effects on body image, it substantially improved mental skills such as visualization, anxiety control, and concentration. Notably, it led to measurable enhancements in performance metrics, including significant gains in free throw accuracy [16]. Additional studies report that mindfulness practice contributes to improved working memory [17], reduction in anxiety, stress, and depressive symptoms [18], and development of effective emotional coping mechanisms [19].

Furthermore, mindfulness has shown positive impacts on self-efficacy, pain management [20], mental skill acquisition [21], and overall athletic performance [22]. Together, tDCS and mindfulness training offer a dual approach to enhancing selective attention and cognitive flexibility in athletes. By combining the neurological benefits of tDCS with the psychological robustness fostered through mindfulness, this integrative program could provide a comprehensive framework to improve selective attention and performance in skilled badminton players.

Previous studies underscore the effectiveness of both mindfulness and tDCS in enhancing mental skills, each showing unique benefits for athletes through separate interventions. For instance, research by Amir Asadi Mowalu, Abul Maali, and Saber (2020) evaluated both mindfulness and tDCS protocols, indicating that each approach positively impacted specific cognitive and performance-related variables [23]. However, findings on the comparative efficacy of these techniques remain inconsistent, with some studies reporting more substantial outcomes with tDCS, while others found mindfulness to be more advantageous [24, 25]. Notably, limited research has explored the potential synergistic effects of combining tDCS and mindfulness, suggesting an area ripe for further investigation.

Badran et al. (2017) explored the combined application of mindfulness and tDCS, reporting promising outcomes in enhancing mindfulness skills [26]. Additionally, other research has demonstrated that combining these two techniques yields synergistic effects, such as improved sleep quality in diabetic patients [27]. Further findings in the context of depression suggest that while the independent use of mindfulness and tDCS individually had positive effects, their combined application resulted in significantly greater improvements than either technique alone [28]. However, despite these promising findings, there is limited research examining the concurrent use of mindfulness and tDCS specifically within athletic contexts.

The emerging interest in pairing tDCS with other cognitive enhancement strategies highlights the potential for this combined approach to benefit athletes by positively impacting both psychological resilience and performance metrics. However, there remains a notable gap in studies that assess the simultaneous application of these two techniques on athletic performance, particularly in sports requiring high cognitive engagement and selective attention, such as badminton. Skilled badminton players, who rely on swift decision-making and precise attentional control, may benefit from interventions that address both cognitive and psychological demands. Addressing this research gap, the present study seeks to evaluate whether the simultaneous use of mindfulness and tDCS can positively influence selective attention in skilled badminton players. By examining the impact of this integrative approach, we aim to provide badminton athletes with targeted insights that could support their cognitive development and enhance key mental skills essential to their sport.

2. Materials and Methods

The current research is a semi-experimental study using a pretest-posttest randomized-group design.

2.1. Participation

The study's statistical population comprised skilled male badminton players from Tehran, each with at least five years of continuous training experience. From this population, 36 participants aged between 18 and 30 were selected based on specific inclusion and exclusion criteria. These participants were randomly divided into three groups: the A-tDCS-Mindfulness (n=12), sham-tDCS-Mindfulness (n=12), and control (n=12). Although a sample size of 12 was set for each group following guidelines from previous studies, an initial invitation was extended to 15 participants per group to mitigate the effects of any noncompliance with the study’s criteria.

The include criteria for this study specified male badminton players aged 18 to 30, with at least five years of experience and right-handedness to account for brain hemisphere dominance. Additional requirements included the absence of musculoskeletal injuries, neurological disorders, skull fractures, previous head or spinal surgeries, vertigo, chronic headaches, and no history of psychotropic medication use. Exclusion criteria were comprehensive, disqualifying any individuals with a history of epilepsy or those currently using medications such as antiepileptics, antidepressants, antipsychotics, benzodiazepines, or L-dopa. Participants were also excluded if they had previous tDCS exposure, engaged in meditation or related cognitive interventions, or presented with investigator-determined hearing or vision impairments. Moreover, individuals with orthopedic issues, fractures, or any metal implants— particularly in the head— were deemed ineligible for participation.

Exclude criteria for this study included a participant’s unwillingness to continue cooperation, scoring within the moderate, high, or very high ranges on the DASS-21 Anxiety, Depression, and Stress Questionnaire, and missing more than one training session. Participants were also excluded if undisclosed underlying conditions were identified, infectious diseases emerged during the study, or if unexpected events outside the laboratory led to prolonged absence. Additional grounds for exit included failure to record data accurately or the occurrence of errors in program execution or equipment functionality.

2.2. Instrument

2.2.1. Informed consent form and demographic information

The informed consent form for this study was developed in alignment with the ethical guidelines set by the Research Ethics Department of the Faculty of Sports and Health Sciences at Tehran University and was completed by all participants prior to study commencement. Additionally, demographic data— including height, weight, sports history, medical background, and psychological health status— were collected from each participant.

2.2.2. Edinburgh test

The Edinburgh Manual Excellence Scale is a short and simple 10-item questionnaire that assesses manual excellence in 10 one-handed skills, such as writing, drawing, throwing, using scissors, brushing, using a knife, using a spoon, sweeping, matching, and opening a can lid. In this scale, individuals indicate their hand preference for each action by selecting one of the following options: always use right hand (10+), usually use right hand (5+), always use left hand (-10), usually use left hand (-5), and no difference in use of right or left hand (0) [28]. Alipour and Harris (2007) reported an internal consistency coefficient of 0.92 for the items of this questionnaire in the Iranian population in their study [29].

2.2.3. Depression, Anxiety, and Stress Scale (DASS-21)

This scale is a condensed adaptation of the original 42-item questionnaire, now comprising 21 items after the removal of certain elements. It encompasses 8 items that assess depression (D), 7 items that evaluate anxiety (A), and 6 items pertaining to stress (S), thereby measuring these psychological factors in both normal and clinical populations. Responses are collected using a Likert scale, with values ranging from 0 (not at all) to 3 (very much). Sahebi et al. (2004) reported satisfactory internal consistency for this test, which was found to be nearly equivalent to that of the original DASS version developed by Lovibond and Lovibond in 1995 [30]. In a normative sample of 717 individuals, internal consistency values were determined to be 0.81 for the depression subscale, 0.73 for the anxiety subscale, and 0.81 for the stress subscale [31].

2.2.4. Stroop task

Stroop task consists of two distinct phases designed to assess selective attention and cognitive inhibition. In the first phase, participants are introduced to a training session where colored circles (blue, yellow, red, or green) are displayed periodically on the screen. Each circle color corresponds to a specific key on the laptop keyboard. Participants are instructed to press the key that matches the color of the circle. This phase serves solely as a training exercise to familiarize participants with the task mechanics, and it does not influence the final assessment outcomes. The second phase involves the main task. During this phase, 96 Persian color words are presented randomly on the screen, comprising 48 congruent words and 48 incongruent words. Congruent words appear when the color of the text matches the meaning of the word (e.g., the word "red" displayed in red color), while incongruent words appear when the color of the text differs from the word’s meaning (e.g., the word "red" displayed in blue color). Participants are instructed to focus solely on the color of the word and press the corresponding key, ignoring the actual meaning of the word. Each stimulus remains on the screen for 2 seconds, with an 800-millisecond interval between consecutive stimuli, allowing for quick and continuous response assessment. The outputs of the Stroop task are two key measurements: the interference score and the interference time. The interference score is calculated by subtracting the number of correctly identified incongruent stimuli from the number of correctly identified congruent stimuli. A higher interference score indicates greater difficulty in inhibiting automatic reading of the word's meaning. The interference time is derived by subtracting the average response time to incongruent stimuli from the average response time to congruent stimuli, providing insight into the participant's processing speed under different cognitive demands. The validity and reliability of this adapted version of the Stroop test for measuring selective attention in Iranian populations have been previously confirmed by Zarghi et al. (2011). Their research supports the use of this instrument for effectively assessing cognitive inhibition and attention control within this context [32].

2.2.5. tDCS device

The device used in the present study was the Active DAS system. It generates a maximum current of 4 milliamperes and includes two electrodes: an anode (positive) and a cathode (negative). These electrodes are placed within sponge pads measuring 35 cm². After the pads are soaked in a conductive solution (9% sodium chloride), which enhances conductivity and prevents overheating, they are positioned on specific areas of the scalp. A constant electrical current is then delivered across the skull to the brain. The device allows control over current intensity, duration of stimulation, and electrode size.

2.3. Procedure

First, the required approvals were obtained from the Research Ethics Committee of the Faculty of Health and Sports Sciences at the University of Tehran, under the research ethics code IR.UT.SPORT.REC.1401.049. Participants were randomly assigned to one of three groups: A-tDCS-Mindfulness, sham-tDCS-Mindfulness, and a control group, with 12 participants in each group. One week before the commencement of the interventions and the sessions, all participants completed a pre-test that included the Stroop task.

Next, to initiate the training programs for the A-tDCS-Mindfulness group, subjects listened to a mindfulness-related audio file through a high-quality sound system while simultaneously receiving tDCS at a current of 1.5 mA at point F8, according to the 10-20 brain system division and based on previous brain mapping studies. In accordance with a previous study by Badran et al. 2017, all tDCS-related instructions were set [26]. The mindfulness program consisted of five recorded sessions, developed based on the Mindful Sport Performance Enhancement (MSPE) intervention by Kaufman, Glass, and Arnkoff (2009). Each session comprised a series of structured practices. The sequence of practices, following the setup of the equipment, adhered to the model proposed by Kaufman et al. (2009) [33]. Adjustments were made to fit the recorded format, including shortening the duration of exercises, eliminating at-home practice, and repeating the content from Sessions 2 and 3 in Sessions 4 and 5. This was done using 5 x 5 cm square sponge pads, with the cathode electrode placed over the left orbit for a duration of 30 minutes. In the sham-tDCS-Mindfulness intervention group, all conditions mirrored those of the A-tDCS-Mindfulness group, but the electric current was discontinued after 30 seconds without informing the participant. Both groups followed their exercise schedules for five consecutive days, with a 24-hour interval between interventions. It is important to note that the implementation of the interventions ensured consistency across participants in terms of time (between 9:00 a.m. and 1:00 p.m.), confirmed the completion of breakfast, and controlled sleeping and waking conditions the night before, which were extensively monitored by self-report to ensure that subjects received at least seven to eight hours of adequate sleep.

To sustain the effects of tDCS, it was essential to ensure that the observed positive outcomes during the initial days were predominantly linked to the stimulation on the first day, with any subsequent improvements reflecting cumulative benefits from repeated exposure to tDCS. This approach aligns with previous findings that highlight the importance of consistent, repeated application to maximize the effects of tDCS [34]. Therefore, to maintain consistency and facilitate the integration of tDCS effects, a mindfulness program was designed with five sessions, spaced 24 hours apart, following the structure outlined by Kaufman et al. (2018) [35]. After completing the five-session training program, all participants took part in a post-test to evaluate the overall impact of the intervention.

2.4. Statistic

A combination of descriptive and inferential statistical methods was used to analyze the statistical data. Descriptive statistics were used to present the conditions of subjects in different groups, while inferential statistics were used to test hypotheses. In the descriptive section, the mean and standard deviation of the measured variables were reported along with demographic information. In the inferential section, the normality of the data was first assessed using the Shapiro-Wilk statistical test. Following the nonparametric test, since the normality of the data was not confirmed, the Wilcoxon, Kruskal-Wallis and Mann-Whitney U tests were used to report within-group and between-group differences. All analyses were performed using SPSS version 25 statistical software, with a significance level of $\alpha < 0.05$.

3. Results

A total of 36 badminton players with a mean age of 23.78 years and a mean experience of 4.53 years participated in this study. Descriptive demographic statistics and measured variables are shown in Table 1.

In order to assess the assumptions for the use of parametric statistics, the Shapiro-Wilk test was used to test the normality of the data distribution. The results indicated a deviation from normality. Consequently, non-parametric tests, such as the Wilcoxon and Kruskal-Wallis, were used to analyze the data.

First, the nonparametric Wilcoxon statistical test was used to assess within-group differences (Table 2). The results of the within-group changes showed a significant difference between the pre- and post-test scores for the two interference scores and the selective attention time in both the A-tDCS-Mindfulness and the sham-tDCS-Mindfulness groups. Conversely, no significant difference was observed in the control group.

The nonparametric Kruskal-Wallis test was used to examine the differences between the groups (Table 3).

Table 1. Mean and Standard deviation of all variables

Variables \ Groups	A-tDCS-Mindfulness		sham-tDCS-Mindfulness		Control	
	M	**SD**	**X**	**SD**	**X**	**SD**
Age (year)	22.67	2.535	24.25	3.519	24.42	3.118
High (cm)	178.58	1.832	177.00	6.150	177.58	5.054
Wight (kg)	77.25	1.712	74.58	4.400	73.00	2.892
BMI	24.227	.658	23.83	1.336	23.183	1.324
History of Badminton (year)	4.83	1.030	5.17	2.406	3.92	.669
DASS-21	2.17	2.329	.67	1.303	.83	1.586
Interference score (Pre)	5.08	1.165	5.50	1.314	5.25	1.357
Interference score (Post)	1.50	.798	2.00	1.044	4.08	.900
Interference time (Pre)	61.58	6.999	64.42	6.557	63.17	5.828
Interference time (Post)	41.83	5.424	49.58	9.229	62.50	7.392

The results showed a significant difference between the three groups in both the interference score and the interference time of the Stroop test ($P < 0.05$). For post hoc determination, the Mann-Whitney U test was used, which showed a significant difference in the interference time results between the A-tDCS mindfulness group and the other two groups, as well as between the sham-tDCS mindfulness group and the control group. In addition, the ranking of means showed that the A-tDCS-Mindfulness, sham-tDCS-Mindfulness, and control groups had the best interference score and time, respectively.

Table 2. Examining within-group changes in two Interference Score and time across three groups using Wilcoxon test

Variables \ Groups	A-tDCS-Mindfulness		sham-tDCS-Mindfulness		Control	
	Z	**Sig**	**Z**	**Sig**	**Z**	**Sig**
Interference score	-3.074	0.002	-3.114	0.002	-1.897	0.058
Interference time	-3.065	0.002	-3.063	0.002	-0.949	0.342

Table 3. Examining between-group changes in two Interference Score and Time across three groups using Kruskal-Wallis test

Variables	Kruskal-Wallis H	Df	Sig
Interference score	23.082	2	0.001
Interference time	21.364	2	0.001

4. Discussion

The present study was conducted to investigate the effects of a tDCS-Mindfulness program on the selective attention of skilled badminton players. The results showed that the within-group changes in both A-tDCS-Mindfulness and sham-tDCS-Mindfulness groups, it was able to have a significant effect on the score and time of interference, but no significant difference was observed in the control group. In the comparison between groups effect, it was also found that there is a significant difference in time and score between the three groups, and respectively, the A-tDCS mindfulness, sham-tDCS mindfulness and the control group had the best performance.

When examining the effects of tDCS on performance enhancement, multiple studies have reported positive outcomes, including significant improvements in peak power and reductions in heart rate among cyclists [36], increases in selective attention [37], improvements in balance and performance in basketball players [9], and overall enhancement of athletic performance [36]. Similarly, mindfulness programs have been well-documented for their positive impact on both functional and cognitive skills in athletes, enhancing cognitive focus, reducing stress, and improving mental resilience. Several studies have directly compared the effects of mindfulness and tDCS. While both protocols have demonstrated effectiveness in targeted performance measures, findings are mixed regarding which approach might offer superior results [38]. For instance, some studies suggest that tDCS yields more pronounced improvements in specific physical performance metrics, while others favor mindfulness for its comprehensive benefits on mental clarity and stress reduction [24]. However, few studies have investigated the potential synergistic effects of combining tDCS with mindfulness. This gap highlights the need to explore how concurrent use of both interventions might produce unique or amplified benefits, particularly in domains like selective attention, where both methods independently show promise but may, when combined, address complementary aspects of cognitive and athletic enhancement.

The results of the present study showed that use of tDCS and mindfulness, compared to the mindfulness group with sham-tDCS and the control group, had better performance in score and time interference of the Stroop test. The effect of tDCS-mindfulness on attention or selective attention did not exist or was not found. The closest study was related to Badran et al. (2017) who investigated the effect of tDCS-mindfulness on improving mindfulness ability, the results were very promising and it had led to further increase in the mindfulness ability of the subjects [26].

In reviewing the results of the present research, we can point out the effects of using tDCS as a treatment method and adjunctive therapy. tDCS is considered a "neuromodulator" in which a weak electric current is passed through the electrodes placed on the scalp and leads to specific changes in the polarity of the desired cortex [39], and nerve depolarization and cortical-spinal excitability increase. tDCS not only exerts a neuromodulatory effect on the stimulated region, but also modulates distal regions connected to the stimulated region [40]. In fact, it may affect the performance of athletes by creating and influencing neuroplasticity, which is the ability of the central nervous system (CNS) to change in response to experience, use, or environmental demands, and is known to be a neural substrate for skill acquisition and recovery from brain injury [41]. Increasing synaptic flexibility can include short-term strengthening lasting 5 to 20 minutes and long-term strengthening lasting 30 minutes, hours, or days [42]. It has been shown that tDCS can induce neuroplasticity in vitro [43].

In this regard, two theories have been proposed for the basis of the response of corticospinal output neurons following the initial protocols for the use of tDCS, including Gating and Homeostatic Plasticity. Gating occurs concurrently with motor training (i.e., tDCS while training), while homeostatic plasticity involves modulating the resting state of neurons prior to training (i.e., tDCS applied before motor training). The Gating theory describes the immediate appearance and influx of calcium ions into the corticospinal neurons of interest, leading to disinhibition of intracortical inhibitory circuits. Gate theory is obtained concurrently with movement training and has been shown to facilitate motor performance tasks such as hand performance measured by maximal force tests, movement speed, reaction time and speed-accuracy trade-off. The second case is the principle of isostatic flexibility, whereby the resting state of corticospinal neurons before training (increasing/ decreasing the level of excitability following the low/ high level of synaptic activity) changes due to changes in the activity of the postsynaptic glutamate receptor [44].

These changes, together with the main intervention (mindfulness), are a contributing factor that can lead to an increase in the synergistic effects of the training protocol. Mindfulness has been shown to positively impact cognitive function through mechanisms involving attention regulation, emotional regulation, and enhanced awareness of the present moment. One key mechanism is improved attentional control, as mindfulness trains individuals to maintain focus and resist distractions, thereby strengthening executive functions [45]. Studies suggest that mindfulness meditation activates brain regions associated with attention, such as the prefrontal cortex and anterior cingulate cortex, leading to enhanced cognitive control and a greater ability to regulate thoughts and emotions [46].

Additionally, mindfulness reduces activity in the default mode network (DMN)— a brain network associated with mind-wandering and self-referential thinking— thus promoting a focused and present-centered state of mind [47]. These neurological adjustments contribute to improved self-regulation and emotional balance, fostering an optimal mental state for tasks requiring high levels of focus and control.

Besides this, another effect of using tDCS together with other interventions is to reduce the duration of the treatment or intervention period [48]. This case is very important because in sports, and especially in championship sports, most athletes do not seek to improve their performance or their physical or mental problems, and the existence of training programs and interventions with long sessions raises this concern among researchers. It is possible to demand this long time from athletes due to their busy lives and careers, and sometimes during pre-season training or before competition, there is a need for interventions that are highly effective in a short period of time. Therefore, the design of shortened programs using tDCS may be a solution. For example, mindfulness was used in the current research, its main program consists of 6 weeks and one session each week, the program used in the current research was modified according to the research needs and was implemented in five half-hour sessions on five consecutive days. In order to make the desired changes in the main protocol after the correspondence with Drs. Kaufman and Glass and the sources introduced by Dr. Glass, it was stated that although the main designed program includes 6 sessions of 90 to 60 minutes, but according to the needs of the athlete, research requirements and the diagnosis of the researcher and expert, the length of each session, the interval of presentation of sessions (presentation frequency) and also the number of sessions can be changed [49]; based on this, the mentioned changes were made in the main protocol designed by Kaufman et al. (2018) [35], and the mindfulness program used in the present study was designed, whose sessions were shortened and continuously combined with tDCS interventions.

Previous studies have also used brief examples of mindfulness and reported its usefulness, such as the research by Mackenzie et al. (2006) in which four 30-

minute mindfulness sessions led to significant improvements in symptoms of occupational depression, relaxation, and life satisfaction in nurses [50]. Therefore, based on the recent findings, it can be stated that the mindfulness program and the simultaneous use of tDCS may have promising results in improving the selective attention ability of badminton athletes.

Among the limitations of the present study, we can mention the lack of investigation and comparison of the effects of tDCS and mindfulness alone and the number of samples. In the end, based on the results of the current research, it can be said that the tDCS-mindfulness program in the prefrontal areas can be beneficial for increasing and improving the selective attention of athletes, which the researcher called E-mindfulness for this type of intervention. Future research could explore the long-term effects of a tDCS-mindfulness program on selective attention and athletic performance among badminton players, as well as its effectiveness across other sports to determine if certain disciplines benefit more from combined cognitive interventions. Examining variations in tDCS protocols, such as intensity and timing, could help optimize selective attention outcomes, while neuroimaging studies (e.g., EEG) could shed light on the synergistic mechanisms between tDCS and mindfulness. Additionally, comparing the program's impact on novice versus skilled players may offer insights for tailoring cognitive training to different expertise levels.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design. Conceptualization, M.Y.K., E.A., R.R., H.G.Z., Y.M.T.; methodology, M.Y.K., E.A.; investigation, M.Y.K., E.A., R.R., H.G.Z., Y.M.T.; writing - original draft preparation, M.Y.K.; writing - review and editing, E.A., Y.M.T.; visualization, M.Y.K.; supervision, E.A., R.R., H.G.Z., Y.M.T.; project administration, E.A., R.R., H.G.Z., Y.M.T.

Ethical considerations

The author has completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc.

The study was conducted in accordance with the Declaration of Helsinki, and study protocol was approved by the Research Ethics Committees of Faculty of Sports and Health Sciences -Tehran University (IR.UT.SPORT.REC.1401.049). Written informed consent has been obtained from the participant(s) to publish this paper.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

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References

[1] Brahms BV. B*adminton Handbook*. Meyer & Meyer Sport. 2014.

[2] Omosegaard B. *Physical Training for Badminton*. International Badminton Federation. 1996.

[3] Chang C, Putukian M, Aerni G, Diamond A, Hong G, Ingram Y, et al. "Mental health issues and psychological factors in athletes: Detection, management, effect on performance and prevention: American Medical Society for Sports

Medicine Position Statement—Executive Summary". *British Journal of Sports Medicine*. 2020; 54(4): 216-20. https://doi.org/10.1097/JSM.0000000000000817.

[4] Birrer D, Röthlin P, Morgan G. "Mindfulness to enhance athletic performance: Theoretical considerations and possible impact mechanisms". *Mindfulness*. 2012; 3(3): 235-46. https://doi.org/10.1007/s12671-012-0109-2.

[5] Weinberg RS, Gould D. *Foundations of Sport and Exercise Psychology*. 6th ed. Human Kinetics. 2014.

[6] Moran A. "The state of concentration skills training in applied sport psychology". *Concentration Skills Training in Sport*. 2003: 8(12): 7-19.

[7] Moran AP. T*he Psychology of Concentration in sport Performers: A Cognitive Analysis*. Psychology Press. 2016.

[8] Moran A. *Attention in Sport. Advances in applied sport psychology*. Routledge. 2008.

[9] Veldema J, Engelhardt A, Jansen P. "Does anodal tDCS improve basketball performance? A randomized controlled trial". *European Journal of Sport Science*. 2022; 22(2): 126-35. https://doi.org/10.1080/17461391.2020.1862306.

[10] Hamner J, Villamar MF, Fregni F, Taylor JA. "Transcranial direct current stimulation (tDCS) and the cardiovascular responses to acute pain in humans". *Clinical Neurophysiology*. 2015; 126(5): 1039-46. https://doi.org/10.1016/j.clinph.2014.08.019.

[11] Cavaleiro C, Martins J, Goncalves J, Castelo-Branco M. "Memory and cognition-related neuroplasticity enhancement by transcranial direct current stimulation in rodents: A systematic review". *Neural Plasticity*. 2020. https://doi.org/10.1155/2020/4795267.

[12] Paulus W. "Transcranial electrical stimulation (tES–tDCS; tRNS, tACS) methods". *Neuropsychological Rehabilitation*. 2011; 21(5): 602-17. https://doi.org/10.1080/09602011.2011.557292.

[13] Hạnh N. *The Miracle of Mindfulness: A Manual on Meditation*. Beacon Press (MA). 1987.

[14] Nyklíček I. "Mindfulness, emotion regulation, and well-being". E*motion Regulation and Well-Being*. 2011: 101-18. https://doi.org/10.1007/978-1-4419-6953-8_7.

[15] Kabat-Zinn J. "Mindfulness". *Mindfulness*. 2015; 6(6): 1481-3. https://doi.org/10.1007/s12671-015-0456-x.

[16] Abbasi F, Badami R, Jalali D. The effect of mindfulness and acceptance training on body image concerns, mental skills and free throw shooting performance in male basketball players with wheelchairs". *Positive Psychology Research*. 2018; 4(2): 25-40. https://doi.org/10.22108/ppls.2018.108925.1333.

[17] Hunter MA, Lieberman G, Coffman BA, Trumbo MC, Armenta ML, Robinson CS, et al. "Mindfulness-based training with transcranial direct current stimulation modulates neuronal resource allocation in working memory: A randomized pilot study with a nonequivalent control group". *Heliyon*. 2018; 4(7). https://doi.org/10.1016/j.heliyon.2018.e00685.

[18] Gallego J, Aguilar-Parra JM, Cangas AJ, Langer ÁI, Mañas I. "Effect of a mindfulness program on stress, anxiety and depression in university students". *The Spanish Journal of Psychology*. 2014; 17: E109. https://doi.org/10.1017/sjp.2014.102.

[19] Weinstein N, Brown KW, Ryan RM. "A multi-method examination of the effects of mindfulness on stress attribution, coping, and emotional well-being". *Journal of Research in Personality*. 2009; 43(3): 374-85. https://doi.org/10.1016/j.jrp.2008.12.008.

[20] Ahn H, Zhong C, Miao H, Chaoul A, Park L, Yen IH, et al. "Efficacy of combining home-based transcranial direct current stimulation with mindfulness-based meditation for pain in older adults with knee osteoarthritis: A randomized controlled pilot study". *Journal of Clinical Neuroscience*. 2019; 70: 140-5. https://doi.org/10.1016/j.jocn.2019.08.047.

[21] Kee YH, Wang CJ. "Relationships between mindfulness, flow dispositions and mental skills adoption: A cluster analytic approach". *Psychology of Sport and Exercise*. 2008; 9(4): 393-411. https://doi.org/10.1016/j.psychsport.2007.07.001.

[22] Anderson SA, Haraldsdottir K, Watson D. "Mindfulness in athletes". *Current Sports Medicine Reports*. 2021; 20(12): 655-60. https://doi.org/10.1249/JSR.0000000000000919.

[23] Amir Asadi Moalavo A, Abolmaali Al-Hosseini K, Saber S. (2021). "Investigating the effectiveness of mindfulness training and transcranial direct current stimulation (tDCS) on improving working memory in adolescents". *Medical Journal of Mashhad University of Medical Sciences.* 64(5).

https://civilica.com/doc/1465350. [in Persian]

[24] vaghef l, soltani Margani F, Bafandeh Gharamaleki H. "Effectiveness of Transcranial Direct Current Stimulation (TDCS) on attention in people with depression". S*tudies in Medical Sciences*. 2020; 31(2): 98-106. https://doi.org/10.5812/ijpbs-142498.

[25] Seyfaddini Zarandi E, Mahmoud S, Bagherzade F, Moghadas Tabrizi Y, Akoochakian M. "The effect of mindfulness interval and transcrinal direct current stimulation on injury anxiety and performance in elite fencers". *Journal of Applied Psychological Research*. 2021; 12(1): 247-63. https://doi.org/10.22059/japr.2021.305625.643566.

[26] Badran BW, Austelle CW, Smith NR, Glusman CE, Froeliger B, Garland EL, et al. "A double-blind study exploring the use of transcranial direct current stimulation (tDCS) to potentially enhance mindfulness meditation (E-Meditation)". *Brain Stimulation: Basic, Translational, and Clinical Research in Neuromodulation*. 2017; 10(1): 152-4. https://doi.org/10.1016/j.brs.2016.09.009.

[27] Mohammadi R, Javanmard GH, Alipour A, Zare H. "The incremental effect of combining Mindfulness-based Relaxation (MBR) trainings and transcranial electrical stimulation (tCES) on decreasing depression, anxiety, and stress in patients with diabetes 2". *Journal of Modern Psychological Researches*. 2020; 15(59): 109-26. https://doi.org/20.1001.1.27173852.1399.15.59.7.9.

[28] Mahdiloo A, Moheb N, Alivandi Vafa M. "Effectiveness of combination of transcranial direct current stimulation and mindfulness-based group cognitive therapy on depression reduction in nonclinical populations". *Studies in Medical Sciences*. 2021; 32(5): 354-64. http://umj.umsu.ac.ir/article-1-5292-en.html.

[29] Alipour A, Harris MA. "Investigating the reliability and validity of the Edinburgh Hand Excellence Questionnaire in Iran". *Virtual*. 2007; 1(1): 117-33.

[30] Sahebi A, Asghari MJ, Salari RS. "Validation of depression anxiety and stress scale (DASS-21) for an Iranian population". *Iranian Psychologists*. 2005; 1(4).

[31] Fotohi Ardakani R, Mostofi H. "The effectiveness of short-term behavioral activation therapy on reducing depression in students with clinical symptoms of depression". J*ournal of Psychology New Ideas*. 2021; 10(14): 1-9. http://jnip.ir/article-1-609-en.html.

[32] Zarghi A, Zali A, Tehranidost M, Zarindast MR, Khodadadi SM. "Application of cognitive computerized test in assessment of neuro-cognitive domain". *Pajoohandeh Journal*. 2011; 16(5): 341-245. https://doi.org/10.5555/20123217319.

[33] Kaufman KA, Glass CR, Arnkoff DB. "Evaluation of Mindful Sport Performance Enhancement (MSPE): A new approach to promote flow in athletes". *Journal of Clinical Sport Psychology*. 2009; 3(4): 334-56. https://doi.org/10.1123/jcsp.3.4.334.

[34] Rodriguez-Ugarte MdlS, Iáñez E, Ortiz-Garcia M, Azorín JM. "Effects of tDCS on real-time BCI detection of pedaling motor imagery". *Sensors*. 2018; 18(4): 1136. https://doi.org/10.3390/s18041136.

[35] Kaufman KA, Glass, CR, Pineau TR. *Mindful sport Performance Enhancement: Mental Training for Athletes and Coaches*. Washington DC: American Psychological Association. 2018.

[36] Okano AH, Fontes EB, Montenegro RA, Farinatti PdTV, Cyrino ES, Li LM, et al. "Brain stimulation modulates the autonomic nervous system, rating of perceived exertion and performance during maximal exercise". *British Journal of Sports Medicine*. 2015; 49(18): 1213-8. https://doi.org/10.1136/bjsports-2012-091658.

[37] Jacoby N, Lavidor M. "Null tDCS effects in a sustained attention task: The modulating role of learning". *Frontiers in Psychology*. 2018; 9: 476. https://doi.org/10.3389/fpsyg.2018.00476.

[38] Bayat Mokhtari L, Aghayousefi A, Zare H, Nejati V. "The considering of the impact of transcranial direct current stimulation (tDCS) and phonological awareness training on improvement of the visual aspect function of the working memory in children with dyslexia". *Neuropsychology*. 2017; 3(8): 51-68. https://doi.org/20.1001.1.24765023.1396.3.8.3.0.

[39] Nitsche MA, Paulus W. "Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans". *Neurology*. 2001; 57(10): 1899-901. https://doi.org/10.1212/WNL.57.10.1899.

[40] Lang N, Nitsche M, Paulus W, Rothwell JC, Lemon RN. "Effects of transcranial direct current stimulation over the human motor cortex on corticospinal and transcallosal excitability". *Experimental Brain Research*. 2004; 156: 439-43. https://doi.org/10.1007/s00221-003-1800-2.

[41] Classen J, Liepert J, Wise SP, Hallett M, Cohen LG. "Rapid plasticity of human cortical

movement representation induced by practice". *Journal of Neurophysiology*. 1998; 79(2): 1117-23. https://doi.org/10.1152/jn.1998.79.2.1117.

[42] Bliss TV, Collingridge GL. "A synaptic model of memory: long-term potentiation in the hippocampus". *Nature*. 1993; 361(6407): 31-9. https://doi.org/10.1038/361031a0.

[43] Sale MV, Ridding MC, Nordstrom MA. "Factors influencing the magnitude and reproducibility of corticomotor excitability changes induced by paired associative stimulation". *Experimental Brain Research*. 2007; 181: 615-26. https://doi.org/10.1007/s00221-007-0960-x.

[44] Kidgell DJ, Pearce AJ. *Principles of Exercise Neuroscience*. Cambridge Scholars Publishing. 2020.

[45] Zeidan F, Johnson SK, Diamond BJ, David Z, Goolkasian P. "Mindfulness meditation improves cognition: Evidence of brief mental training". *Consciousness and Cognition*. 2010; 19(2): 597-605. https://doi.org/10.1016/j.concog.2010.03.014.

[46] Tang YY, Hölzel BK, Posner MI. "The neuroscience of mindfulness meditation". *Nature Reviews Neuroscience*. 2015; 16(4): 213-25. https://doi.org/10.1038/nrn3916.

[47] Brewer JA, Worhunsky PD, Gray JR, Tang YY, Weber J, Kober H. "Meditation experience is associated with differences in default mode network activity and connectivity". *Proceedings of the National Academy of Sciences*. 2011; 108(50): 20254-9. https://doi.org/10.1073/pnas.1112029108.

[48] Meron D, Hedger N, Garner M, Baldwin DS. "Transcranial direct current stimulation (tDCS) in the treatment of depression: systematic review and meta-analysis of efficacy and tolerability". *Neuroscience & Biobehavioral Reviews*. 2015; 57: 46-62. https://doi.org/10.1016/j.neubiorev.2015.07.012.

[49] Ivtzan I. *Handbook of Mindfulness-based Programmes: Mindfulness Interventions from Education to Health and Therapy*. Routledge, 2019.

[50] Mackenzie CS, Poulin PA, Seidman-Carlson R. "A brief mindfulness-based stress reduction intervention for nurses and nurse aides". *Applied Nursing Research*. 2006; 19(2): 105-9. https://doi.org/10.1016/j.apnr.2005.08.002.