Research Paper

A Single Session of Transcranial Direct Current Stimulation-imagery for Balance in Athletes With Chronic Ankle Instability

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ABSTRACT

Purpose: This study evaluated the combined effects of motor imagery practice (MIP) and transcranial direct current stimulation (tDCS) on static and dynamic balance in athletes with chronic ankle instability (CAI).

Methods: A randomized, double-blind design was used. Fourteen athletes (mean age, 24.5±2.62 years; 7 females) were randomly assigned to either a motor imagery-anodal tDCS group (MI-AtDCS) or a motor imagery-sham tDCS group. Participants completed a guided imagery procedure with an online tDCS over the dorsolateral prefrontal cortex (DLPFC). Static and dynamic balance were assessed pre-and post-intervention using the Biodex Balance System, which measured medial-lateral, anterior-posterior, and overall stability control.

Results: The motor imagery-anodal tDCS (MI-AtDCS) group demonstrated significant improvements in static and dynamic balance metrics ($P<0.05$), while the MI-tDCS group did not.

Conclusion: These results suggest that combining MIP with tDCS enhances motor control and balance, potentially through tDCS-induced increased neural excitability. This study provides preliminary evidence that MIP, integrated with tDCS, may augment rehabilitation protocols, thereby improving postural control and mitigating injury risk in athletes with CAI.

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Highlights

- Combined tDCS and MIP significantly improve dynamic and static balance in athletes with CAI.
- tDCS enhances CNS pathways, offering a novel approach for postural control rehabilitation.
- Anodal stimulation targeting the DLPFC shows acute effects on balance performance in single-session use.
- CNS-based interventions may reduce the risk of reinjury when integrated with traditional protocols.
- This study highlights the potential effect of tDCS-MIP as a complementary rehabilitation strategy for CAI.

Plain Language Summary

Athletes with chronic ankle instability (CAI) often experience challenges with balance, increasing their risk of injury. This study explored a novel approach to improve balance by combining motor imagery practice (MIP) (mentally rehearsing balance exercises) with transcranial direct current stimulation (tDCS), as a non-invasive technique in brain stimulation. The findings showed that a single session of this combined method significantly enhanced both dynamic and static balance in athletes with CAI compared to MIP alone. This suggests that targeting the brain's neural networks, alongside traditional physical therapy, can boost balance and reduce injury risks. Coaches and rehabilitation professionals are encouraged to consider integrating brain-focused techniques, such as tDCS, into training and recovery programs for athletes with similar conditions.

Introduction

An acute ankle sprain represents one of the most prevalent musculoskeletal injuries in physically active populations. Approximately one-third of those who sustain such sprains may develop chronic ankle instability (CAI), characterized by recurrent ankle sprains and a subjective sensation of the joint "giving way" [1]. This condition is commonly associated with functional deficits, including impaired balance, diminished proprioceptive acuity, and altered neuromuscular control [2]. A previous study identified static and dynamic balance as key variables commonly assessed and targeted in CAI rehabilitation [3]. The somatosensory system is critical in postural and balance control by integrating sensory input with the central nervous system (CNS). Mechanoreceptors and joint sensory information, transmitted by peripheral nerves to the CNS, are essential for maintaining balance [4]. CAI alters sensory receptors and proprioception, leading to impaired transmission of information to the cerebral cortex and resulting in balance deficits [5]. These impairments in postural control can reduce functional independence, limit daily activities, and negatively affect quality of life [6]. Therefore, restoring postural function is a central goal in rehabilitation programs for individuals with significant motor impairments [7]. Conventional rehabilitation for CAI primarily targets peripheral neuromuscular elements [8]. However, research has also linked reduced cortical activation to biomechanical impairments and a heightened likelihood of recurrent ankle sprains [9]. Integrating approaches that stimulate central neural pathways alongside peripheral neuromuscular interventions may enhance recovery outcomes in individuals with CAI. Techniques such as action observation and motor imagery (MI) have shown promise in promoting balance and improving postural control [10, 11].

MI, mental rehearsal of movements without physical execution, is an effective intervention for motor skill development and rehabilitation. Extensive research indicates repeated motor imagery practice (MIP) significantly benefits athletic performance and physical rehabilitation [12]. For instance, MIP has been shown to improve motor function in postural control tasks, such as weight shifting, by reducing the time required to execute the movement [13]. While physical training typically yields more pronounced improvements, MIP has proven effective at facilitating the acquisition of postural control skills and improving dynamic balance in unpredictable environments [14]. Additionally, MIP activates brain regions involved in gait planning, making it particularly valuable for populations with balance deficits, such as older adults and stroke survivors [15]. MIP enhances dynamic postural control and stabilizes movement by engaging neural pathways similar to those activated during physical exercise, particularly in the primary motor cortex (M1). Neuroimaging studies have demonstrated that MIP promotes activity-dependent plasticity, which is essential for motor learning, as it parallels the increases in neural excitability observed during physical training [16].

Transcranial direct current stimulation (tDCS) is another noteworthy non-invasive brain stimulation method that alters cortical excitability and facilitates motor learning. Anodal tDCS increases neural excitability and enhances interneuronal communication during motor tasks, facilitating learning. This stimulation improves performance on sequential and visuomotor tasks, reduces reaction times, and enhances functional abilities [17, 18]. Prior studies have shown that tDCS can augment motor learning, particularly in populations requiring rehabilitative care or skill acquisition. Similar improvements in balance and gait performance have been observed with tDCS interventions, comparable to those observed with physical exercises [19]. Recently, tDCS has been combined with various therapeutic modalities, such as physical therapy, virtual reality, and mindfulness, to optimize functional outcomes by facilitating neuroplasticity [20, 21].

Using anodal tDCS over the right dorsolateral prefrontal cortex (DLPFC) during MI has enhanced Mu desynchronization, a neural marker of motor execution and imagery [22]. This suggests that anodal tDCS can augment the neuroplastic effects of MIP, thereby enhancing performance. For instance, Yavari et al. reported that the simultaneous application of tDCS and mindfulness training led to significant improvements in self-control and emotion regulation among skilled badminton players, with the combined approach proving more effective than mindfulness alone [23]. Similarly, Matsumoto et al. found greater performance improvements in sequential tasks when MIP was paired with anodal tDCS than either intervention alone [24]. While prior research has explored the individual effects of MIP and tDCS on motor performance, the integrated application of these two approaches—especially with stimulation targeting the DLPFC—remains underexplored in the context of balance regulation among athletes experiencing CAI. Given the DLPFC's involvement in executive functioning, attentional processes, and motor coordination, it is a potentially valuable neural target for enhancing MIP outcomes via tDCS-induced modulation [25, 26]. Moreover, effective balance regulation is a key component in the rehabilitation of individuals with CAI. Nonetheless, the neural mechanisms underlying cognitive-motor integration achieved through the combined use of MIP and DLPFC-targeted stimulation remain insufficiently understood. To address this, the present study investigates whether a single session of anodal tDCS over the right DLPFC can amplify the effects of MIP on both static and dynamic balance in physically active individuals with CAI.

Materials and Methods

The current study utilized a double-blind, randomized clinical trial with a pre-test-post-test design and a control (sham) group. Fourteen right-handed athletes (mean age: 24.5±2.62 years; seven females) who had sustained an ankle sprain more than a year prior and reported experiencing at least two episodes of ankle "giving way" on the same side were recruited for the study [27], and physician-diagnosed CAI were randomly selected based on predefined inclusion criteria. Participants were recruited from the Faculty of Sport Sciences and Health at the University of Tehran. Before initiating the intervention, all subjects completed written informed consent for voluntary participation and submitted demographic, sports, and medical history data. Participants were excluded if they had a history of seizures, any neurological or psychiatric conditions, previous lower limb surgery or fractures, or if they were concurrently involved in other intervention programs. The Ethics Committee of the Faculty of Sport Sciences and Health at the University of Tehran approved the study protocol. Baseline assessments were conducted using the Biodex Balance System (BBS), in which participants performed both static and dynamic balance tests to establish pre-intervention balance metrics. Participants were then randomly assigned to one of two groups: The anodal stimulation group (MI + AtDCS) or the imagery sham stimulation group (MI + StDCS), each consisting of seven individuals. The intervention included an MI session and tDCS targeting the DLPFC. All experimental procedures, including the intervention and subsequent assessments, were conducted at the laboratory of the Faculty of Sport Sciences and Health. Participants were randomly allocated to the experimental or control group using a computer-generated random number sequence. The study was double-blind, with both the participants and the assessors unaware of group assignments. After the intervention, post-test assessments were performed to evaluate dynamic and static balance using the BBS. The BBS was selected due to its high reliability and validity in assessing both static and dynamic balance. Given the study's focus on balance performance in athletes with CAI and to ensure methodological clarity and control, a single outcome measure was used. This allowed for a focused evaluation of the intervention's effectiveness without introducing confounding variability from multiple assessment tools.

Study design

This experiment employed a randomized, double-blind design with placebo control involving sham and anodal stimulation. Participants were randomly allocated into two groups: imagery anodal stimulation (MI-AtDCS) and imagery sham stimulation (MI-StDCS), with seven participants in each group.

tDCS

A tDCS device (ActivaDose) was used to administer the stimulation protocol. For electrode placement, a 5×5 cm saline-soaked sponge served as the anodal electrode and was positioned over the left DLPFC (F3), The cathodal electrode, identical in size, was positioned on the right forehead. The stimulation protocol involved delivering a direct current of 1.5 mA for a single 15-minute session [23]. For the sham condition, the device delivered the current for 60 seconds before turning off to mimic stimulation without maintaining active current flow, thereby ensuring participant blinding to the condition.

MI

The MI exercise program consisted of a guided imagery procedure tailored to balance tasks. Participants were first instructed to visualize, step by step, the process of maintaining static balance as assessed during the pre-test using the BBS, while focusing on executing the task positively. This visualization lasted approximately two minutes, followed by a one-minute rest period, and was repeated twice. After completing the static balance imagery phase, the participants engaged in the dynamic balance imagery procedure, which followed the same protocol as the static balance exercise. The total imaging and rest duration for static and dynamic balance exercises were 12 minutes [13]. Before the guided imagery exercises began, participants received tDCS stimulation for an initial three-minute period without performing any specific activity, allowing them to adapt to the stimulation protocol.

Assessments

The BBS is reliable for evaluating static and dynamic balance in clinical and athletic populations. The BBS measures participants' ability to maintain stability on a fixed platform during static balance assessments. Dynamic balance assessments require participants to respond to multi-directional platform tilts, thereby evaluating functional stability and proprioception [28]. These metrics are essential for identifying balance deficits that may increase injury risk and monitoring improvements following interventions. The BBS has demonstrated high test, re-test reliability for dynamic balance measurements in injured and non-injured athletes [29]. This study used the BBS (manufactured in the USA, 2018) to measure static and dynamic balance. Postural maintenance time during each assessment was set at 30 s, followed by a 60-s rest period. These durations were selected based on previously established protocols to ensure adequate time for balance evaluation while minimizing fatigue [30]. Three indices—overall stability, anterior-posterior stability, and medial-lateral stability—were used to assess balance. Each test was repeated three times, with the average values recorded for analysis.

Statistics

Data analysis was conducted using paired-sample t-tests to evaluate within-group difference measurements. For between-group comparisons, analysis of covariance (ANCOVA) was performed to adjust for baseline differences. To summarize the data, descriptive statistics were computed for all variables, including Means±SD. Data were analyzed using SPSS software, version 26.0 with statistical significance at P<0.05.

Results

All 14 participants (n=14) completed the study protocol. Table 1 presents a summary of their demographic information. No statistically significant differences were observed between the groups regarding age, body weight, or height.

Table 2 presents the descriptive statistics for static and dynamic balance measures, reported separately for the pre-test and post-test phases. Table 2 summarizes the descriptive statistics of static and dynamic balance outcomes for each group at pre- and post-intervention stages.

Table 3 presents changes in static and dynamic balance scores across three items (two different directions: antro-posterior and medio-lateral, and overall). A paired t-test revealed a statistically significant change (P<0.05) in the scores on three BBT items in the active group. In contrast, no significant differences were detected in the sham group.

Table 1. Demographic characteristics of two groups

Group	Variables	Min	Max	Mean±SD
MI-AtDCS	Age (y)	23	30	25.57±2.299
	Weight (kg)	58.0	78.0	66±7.2342
	Height (cm)	165.0	181.0	173.714±6.0198
MI-StDCS	Age (y)	20	27	23.43±2.637
	Weight (kg)	62.0	80.0	70.571±6.4254
	Height (cm)	165.0	182.0	175±7.0711

PHYSICAL TREATMENTS

Abbreviations: tDCS: Transcranial direct current stimulation; MI-AtDCS: Motor imagery-anodal tDCS; MI-StDCS: Motor imagery-sham tDCS.

Table 4 presents a comparison of post-test scores between groups.

Discussion

This study aimed to examine the combined effects of MIP and tDCS on both dynamic and static balance in athletes diagnosed with CAI. Pre- and post-intervention assessments were conducted using the BBS. The intervention involved a single session of either anodal or sham tDCS in conjunction with MIP. Results indicated significant enhancements in both dynamic and static balance within the active stimulation group, as reflected by improvements in the anterior-posterior index, medial-lateral index, and overall stability index. Conversely, participants in the sham tDCS-MIP group exhibited no notable improvements, suggesting that MIP alone may not be sufficient to produce balance gains in athletes with CAI.

The effectiveness of tDCS in improving balance has been previously demonstrated in healthy populations [31, 32] and clinical groups [33, 34]. For example, a study combining tDCS with virtual reality training reported improved fatigue, balance, and walking ability in patients with multiple sclerosis [22]. The effects of tDCS on dynamic balance in CAI have also been investigated in non-athletic populations [21]. These studies found improvements in dynamic balance following a

Table 2. Descriptive statistics of the static and dynamic balance (n=7)

Group	Variables		Stages	Mean±SD
MI-AtDCS	Static balance	Overall	Pre	3.686±1.278
			Post	1.929±1.021
		Antro-posterior	Pre	4.143±1.898
			Post	2.029±0.801
		Medio-lateral	Pre	4.114±1.616
			Post	1.886±1.241
	Dynamic balance	Overall	Pre	4.271±1.108
			Post	3.371±1.247
		Antro-posterior	Pre	3.814±0.961
			Post	2.577±1.77
		Medio-Lateral	Pre	1.6±0.282
			Post	1±0.27

Group	Variables		Stages	Mean±SD
MI-StDCS	Static balance	Overall	Pre	4.414±1.085
			Post	3.943±1.35
		Antro-posterior	Pre	4.143±1.185
			Post	4.057±1.104
		Medio-lateral	Pre	3.8±0.909
			Post	3.529±0.815
	Dynamic balance	Overall	Pre	4.443±0.854
			Post	4.757±0.834
		Antro-posterior	Pre	3.729±0.745
			Post	3.714±0.749
		Medio-lateral	Pre	1.8±0.435
			Post	1.786±0.805

Abbreviations: tDCS: Transcranial direct current stimulation; MI-AtDCS: Motor imagery-anodal tDCS; MI-StDCS: Motor imagery-sham tDCS.

Table 3. Paired samples test

Group	Variables		t	df	Sig
MI-AtDCS	Static balance	Overall	7.481	6	0.001*
		Antro-posterior	4.137	6	0.006*
		Medio-lateral	10.782	6	0.001*
	Dynamic balance	Overall	4.347	6	0.005*
		Antro-posterior	3.423	6	0.014*
		Medio-lateral	4.938	6	0.003*
MI-StDCS	Static balance	Overall	2.244	6	0.066
		Antro-posterior	0.849	6	0.429
		Medio-lateral	2.321	6	0.059
	Dynamic balance	Overall	-1.637	6	0.153
		Antro-posterior	0.11	6	0.916
		Medio-lateral	0.085	6	0.935

Abbreviations: tDCS: Transcranial direct current stimulation; MI-AtDCS: Motor imagery-anodal tDCS; MI-StDCS: Motor imagery-sham tDCS.

*Significant difference P<0.05.

Table 4. Tests of between-subjects effects

Variables		Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Static balance	Overall	5.909	1	5.909	16.451	0.002	0.599
	Antro-posterior	14.403	1	14.403	42.021	0.000	0.793
	Medio-lateral	12.203	1	12.203	110.438	0.000	0.909
Dynamic balance	Overall	5.214	1	5.214	17.407	0.002	0.613
	Antro-posterior	5.515	1	5.515	12.704	0.004	0.536
	Medio-lateral	0.905	1	0.905	5.916	0.033	0.35

PHYSICAL TREATMENTS

Note: After adjusting for the pre-test effect, ANCOVA showed significant differences between the anodal and sham groups ($P<0.05$). Therefore, the results indicated improvement in the anodal group's medio-lateral, anteroposterior, and overall scores for static and dynamic balance.

4-week protocol of anodal tDCS applied to the primary motor cortex (M1). However, the consistency of these results varies across studies, with some demonstrating significant improvements and others showing minimal or no effects. Possible factors contributing to this inconsistency include differences in stimulation parameters (e.g. electrode placement, stimulation duration, and intensity), population characteristics (e.g. age, baseline motor function), and specific protocols used (e.g. exercise combinations). Similarly, significant improvements in dynamic balance and proprioception were observed when high-definition tDCS was combined with short-foot exercises, using a 4-week stimulation protocol targeting the Cz region [35].

Contrary to the aforementioned results, recent research involving a single application of cerebellar tDCS in healthy participants did not yield significant enhancements in either static or dynamic balance. The discrepancy between the results could be attributed to differences in the stimulation site and balance assessment tools (e.g. Y-balance test versus BBS). Various tDCS protocols have been employed in studies aimed at improving balance and postural control. Depending on the targeted cortical region, electrical stimulation of the motor cortex (M1), cerebellum, or frontal areas, such as the DLPFC, has shown potential for enhancing balance and postural control [36-38].

Most tDCS studies have focused on motor-specific areas, such as the motor cortex and cerebellum, to influence balance and posture. In our study, the anodal electrode was placed over F3 to stimulate the DLPFC, aiming to improve cognitive performance and postural control. However, the DLPFC has been primarily recognized for its role in cognitive functions, but it has been considered to affect motor functions in some studies. Fujita demonstrated hyperactivation of the DLPFC, indicated by increased blood flow, during dual-task posture control [39]. Similarly, an fMRI study reported increased DLPFC activity among the brain regions involved in proprioceptive stimulation, contributing to balance performance and postural control [40]. The application of tDCS to the DLPFC has been shown to improve functional mobility and balance in patients with Parkinson's disease [41]. Researchers attributed this improvement to the DLPFC's role in visuospatial processing, which enhances balance and mobility [42]. Another proposed mechanism is that anodal stimulation targeting F3 (DLPFC) directly and indirectly influences the premotor region through interneuronal connections with the prefrontal cortex. Additionally, tDCS over the DLPFC has been widely used to enhance cognitive functions, including attention and working memory [43, 44].

The DLPFC is a densely interconnected brain region believed to play a key role in integrating sensory inputs with cognitive processes [45]. Evidence from neuroimaging and repetitive transcranial magnetic stimulation studies has highlighted the DLPFC's involvement in higher-order cognitive functions, including attention regulation and working memory [46, 47]. A recent investigation employed a combined MI and tDCS intervention to enhance mobility and reduce fall risk among older adults [48]. This protocol involved six sessions of prefrontal tDCS targeting a cortical region analogous to the one stimulated in the current study.

The current study investigated the acute effects of tDCS in athletes with CAI. Consistent with the findings, Weigie studied the effects of a one-session of anodal tDCS and reported improvements in intrinsic foot muscle activation and static balance [49]. Similarly, tDCS has been shown to enhance muscle strength, foot sensation, and static balance in other studies [50]. In contrast, the present study found that MIP alone did not significantly improve balance in athletes with CAI. This aligns with prior research reporting the limited efficacy of standalone MIP interventions [51]. It should be noted that the intervention in the present study consisted of only a single MIP session. MI activates brain regions typically involved during task performance, but its effects may require multiple sessions to elicit significant improvements [52]. The underlying mechanism of MIP is attributed to weak neuromuscular activation in the muscles involved in the imagined activity. This facilitated neural pathway improves muscle function and motor performance [53]. Neuromodulation techniques such as tDCS can enhance the effects of MIP by altering the resting membrane potential and increasing neural pathway activity [54]. The present study used tDCS and MIP to strengthen the stimulation effect. tDCS is presumed to influence the resting membrane potential during stimulation, thereby facilitating motor activity by modulating neural excitability [55].

This study is the first attempt to evaluate the impact of a single-session tDCS intervention combined with MIP in individuals with CAI. The results support the efficacy of CNS-targeted strategies in addressing balance impairments in athletes with CAI, even following a single exposure. Although the current investigation focused on immediate, short-term outcomes, prior studies have reported prolonged effects resulting from repeated tDCS sessions, including sustained increases in cortical excitability elicited by motor cortex stimulation. The present results highlight the synergistic influence of tDCS and MIP on balance regulation in this population. These findings underscore the value of examining acute responses and lay the foundation for future research to optimize CNS-based rehabilitation strategies for balance enhancement.

Conclusion

The results of this study suggest that the simultaneous use of MIP and tDCS leads to significant enhancements in both static and dynamic balance among athletes with CAI. In contrast to conventional rehabilitation approaches targeting peripheral neuromuscular mechanisms, integrating brain stimulation techniques, such as tDCS, introduces a novel strategy for engaging CNS pathways. This approach enhances motor function and postural control, addressing the neural aspects of balance deficits. Although the study has limitations, including a small sample size and the inability to isolate the effects of tDCS alone, the results suggest that CNS-based interventions may serve as valuable adjuncts to traditional rehabilitation protocols. These findings provide a foundation for future research to optimize postural control and minimize re-injury risk in athletes with CAI.

Limitations

This study has some limitations. The effects of tDCS alone were not assessed, making it impossible to isolate the individual contributions of tDCS and MIP. The limited sample size may limit the generalizability of these findings; therefore, further studies with larger participant groups are essential to confirm and extend these results. Additionally, the quality or success of MIP was not quantitatively assessed using a specific instrument, which may have influenced the intervention's efficacy.

Recommendations for future studies

Future studies should consider employing multi-session protocols to examine the sustained effects of combining tDCS and MIP in athletes with CAI. Increasing sample sizes would also improve the generalizability of findings. Moreover, investigating the isolated effects of each intervention could help clarify their individual contributions to balance improvements.

Policy implications

Integrating tDCS-based interventions into rehabilitation protocols for athletes with CAI could improve treatment outcomes by addressing the central nervous system's contribution to balance dysfunction. Sports organizations and rehabilitation centers may consider adopting this novel approach to reduce the risk of recurrent injuries, improve postural control, and enhance athletic performance. Policies supporting research funding for non-invasive neuromodulation techniques could accelerate advancements in rehabilitation science and promote evidence-based clinical practices. Moreover, incorporating tDCS and MIP into professional training programs for sports medicine practitioners could facilitate the broader adoption of CNS-based therapies in athletic rehabilitation.

Ethical Considerations

Compliance with ethical guidelines

All stages of the research were approved by the approval of the Ethics Committee of the Faculty of Sport Sciences and Health at the University of Tehran, Tehran, Iran (Code: IR.UT.SPORT.REC.1401.033).

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Authors' contributions

All authors equally participated in the preparation and development of this manuscript.

Conflict of interest

The authors declared no conflict of interest.

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