©Journal of Sports Science and Medicine (2025) **24,** 332-340
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2025.332

Research article

Effects of Different Intervention Methods on Postural Control in Athletes with Chronic Ankle Instability: A Randomized Controlled Trial

Xiaoya Zhang [1]†, Jianxin Wu [1]†, Dun Liang [2], Bin Ruan [1] and Qi Gao [1]✉
[1] School of Sports Medicine and Rehabilitation, Beijing Sport University, Beijing, China
[2] Shenzhen Prevention and Treatment Center for Occupational Diseases, Shenzhen, Guangdong Province, China
† These authors are regarded as co-first authors.

Abstract
This study aimed to evaluate the impacts of a 4-week transcranial direct current stimulation (tDCS), balance training (BT), and an integrated program combining tDCS with BT on static and dynamic postural control in athletes suffering from chronic ankle instability (CAI); as well as to explore whether the combined program produces superior effects compared to either single intervention. Forty athletes with CAI were randomized into four groups: tDCS group, sham tDCS (s-tDCS) group, tDCS + BT group, and s-tDCS + BT group. Twenty minutes of 2 mA anodal or sham tDCS was applied either independently or in conjunction with a 20-minute progressive hop-to-stabilization balance (PHSB) training program over 12 supervised sessions spanning 4 weeks. Primary outcomes were the total score of the Balance Error Scoring System (BESS) and the composite reach distance (COMP) in the Y-Balance Test (YBT). Secondary outcome measures included error scores of single-limb and tandem stance on firm and foam surfaces, as well as mean normalized reach distances in the anterior (ANT), posteromedial (PM), and posterolateral (PL) directions. Compared to baseline measures, the tDCS, tDCS + BT, and s-tDCS + BT groups scored fewer errors on posttest measures for single-leg stance on a firm surface (Sfi), single-leg stance on a foam surface (Sfo), tandem stance on a firm surface (Tfi), tandem stance on a foam surface (Tfo), and the total BESS ($p < 0.05$). Additionally, both the tDCS + BT and the s-tDCS + BT groups showed greater PM, PL, and COMP in posttest measures compared to pretest measures ($p < 0.05$). However, no significant differences were found among the tDCS group, the tDCS + BT group, and the s-tDCS + BT group in the posttest measures ($p > 0.05$). tDCS, BT, and the combination of these two interventions can significantly improve static postural stability in athletes with CAI. However, only intervention methods incorporating BT were effective in enhancing dynamic stability. The combined program offered no additional benefits.

Key words: Ankle injuries, postural balance, transcranial direct current stimulation, exercise therapy.

Introduction

Chronic ankle instability (CAI), characterized by recurrent sprains, is the most frequent long-term consequence following an initial ankle sprain (Delahunt et al., 2010), leading to the discontinuation of exercise in 20% to 40% of affected individuals (Ekstrand and Tropp, 1990). Individuals with CAI often demonstrate impaired postural control, whether in static or dynamic postural control (Docherty et al., 2006; Olmsted et al., 2002; Ross and Guskiewicz, 2004; Vikram et al., 2012; Wikstrom et al., 2007). These deficits may predispose individuals to repetitive trauma and exacerbation of ankle instability, thereby escalating the susceptibility to joint degeneration and arthritis (Hershkovich et al., 2015; Wikstrom and Brown, 2014). Therefore, it is imperative to optimize the rehabilitation plan to minimize postural deficits among CAI populations to the greatest extent possible.

Transcranial direct current stimulation (tDCS) is a non-invasive neurophysiological technique that employs weak currents (1-2 mA) to modulate the activity of brain neurons and alter cortical excitability (Auvichayapat and Auvichayapat, 2011). As an adjunctive therapy for movement disorders, it has been widely used in the treatment of various clinical neurological conditions (Lefaucheur et al., 2017). However, in the field of musculoskeletal injury rehabilitation, research on tDCS remains in the exploratory stage. Bruce et al. (Bruce et al., 2020) and Ma et al. (Ma et al., 2020) respectively showed that tDCS combined with eccentric training or short-foot exercises could significantly improve dynamic postural stability in patients with CAI, thereby highlighting its potential therapeutic benefits. Despite these findings, consensus regarding the optimal stimulation parameters for enhancing treatment outcomes has yet to be reached, thus leaving the protocol for achieving maximal therapeutic benefits undefined. Balance training (BT), performed in a weight-bearing position, has been extensively utilized in rehabilitation due to its proven efficacy in reestablishing neuromuscular control, thereby addressing poor postural control and repairing ankle joint injuries. BT has been a crucial element of the clinical rehabilitation protocol for CAI (Taube et al., 2008). Patients with CAI who undergo BT exhibit positive neural adaptations, which are associated with enhanced balance performance (Chung et al., 2023). However, the effectiveness of combining BT with tDCS has yet to be established in CAI individuals.

The primary purpose of this prospective, randomized, sham-controlled study is to examine the effects of a 4-week tDCS intervention, BT, and a combined tDCS and BT program on static and dynamic postural control in athletes with CAI. The secondary purpose is to explore whether the combined program yields superior effects compared to single-type interventions. We hypothesized that: (1) tDCS, BT, and the combination of both interventions would be effective in improving both static and dynamic postural control in CAI athletes; (2) the combined intervention would yield superior efficacy in postural control compared to tDCS or BT alone.

Received: 27 February 2025 / Accepted: 01 May 2025 / Published (online): 01 June 2025

Methods

Study design and randomization

This randomized controlled trial received approval from the Sports Science Experiment Ethics Committee of Beijing Sport University (2022058H), registered in Chinese Clinical Trial Registry, and conducted in compliance with the principles outlined in the Declaration of Helsinki. Participants were randomly assigned to four groups (G1: tDCS group, G2: s-tDCS group, G3: tDCS + BT group, G4: s-tDCS + BT group) in a 1:1:1:1 ratio using a random number generator in Microsoft Excel. The randomization process was performed by SW, an independent study coordinator who was not involved in participant screening. The sham stimulation protocol can effectively facilitate single blinding, and blinding was maintained for the assessors and statisticians involved in the study.

Participants

Earlier research that combined tDCS with exercise and examined similar outcome measures, such as static and dynamic balance, reported effect sizes (η^2_p = 0.096-0.154), which correspond to f values ranging from 0.33 to 0.43 (Bruce et al., 2020; McKeon et al., 2008; Xiao et al., 2022). Thus, to determine the required sample size, we utilized G*Power software (version 3.1) with the following parameters: a power of 0.90, a significance level of 0.05, and an effect size of 0.40. The software suggested that each group should have at least 7 participants. To account for an attrition rate of up to 25% and to avoid underestimating the sample size, a total of 40 participants were recruited (See Table 1).

All participants were recruited from Beijing Sport University and required to reach at least the national second-level athletes standard in China, and actively practicing and/or matching at least 3 times per week for 2 hours. Only patients with unilateral ankle sprains were included in the study. More inclusion criteria aligned with the guidelines proposed by the International Ankle Consortium (Gribble et al., 2014). (1) a history of at least one significant ankle sprain, that led to interruption of physical activity for more than one day within the last year; (2) having experienced at least 2 episodes of the ankle "giving way" and/or recurrent in the past 6 months before enrollment; (3) the initial sprain and the most recent injury should have occurred at least 12 months and 3 months before study enrollment, respectively; (4) score ≤ 24 on the Cumberland Ankle Outcome Score (CAIT).Exclusion criteria included any history of prior surgeries or fractures in the lower extremity (Gribble et al., 2014), acute injury to the musculoskeletal structures of lower extremity joints within the previous 3 months (Gribble et al., 2014), chronic musculoskeletal conditions known to induce postural control deficits (Uzlaşır et al., 2021), currently undergoing rehabilitation treatment, having previously received transcranial electrical stimulation therapy, or being inappropriate for electrical stimulation (Rossi et al., 2009).

Test protocols

Balance Error Scoring System (BESS)

The BESS was originally developed for the assessment of postural stability in people with concussion (Wilkins et al., 2004). Currently, its application has gone beyond the original test purpose and scope. It has been widely utilized to evaluate postural stability in diverse populations and has demonstrated good reliability and validity in static balance measurement (Bell et al., 2011). The BESS assessment protocol involves participants standing barefoot on two types of surfaces (firm and foam) while adopting three distinct stances (double-limb, single-limb, and tandem) (Docherty et al., 2006). The foam stance was conducted using a medium-density Airex balance pad measuring 50.8 × 41.7 × 6.4 cm. The test was only administered on the injured side of patients with CAI, and the order of conditions was determined through a random allocation process. Participants were asked to place their hands on the iliac crests, close their eyes, keep their heads upright, and stay as still as possible for a duration of 20 seconds. Each trial is scored by counting errors and at most one error is recorded every two seconds. The maximum error score for each condition is 10, and the total number of errors for the entire test is 60. If they cannot maintain a stable posture for at least 5 seconds with the designated 20-second time frame, it will be scored 10 (Shamshiri et al., 2020). Errors involve taking hands away from the iliac crests, opening their eyes, losing balance or falling during a step, moving the hip into abduction or flexion greater than 30 degrees, raising the forefoot or heel off the test surface, or remaining outside the proper testing posture for over 5 seconds (Riemann et al., 1999). Participants will be given one opportunity for practice, followed by a single formal trial for each of six conditions. After each participant's trial is completed, the pad will be rotated 90 degrees to prevent unevenness caused by repeated pressure. The test is administered by a panel of three raters, and the median value of the three ratings is considered as the ultimate score for this particular condition.

Y-Balance Test (YBT)

The YBT is a widely recognized method for assessing dynamic postural stability, demonstrating high interrater reliability (ICC 0.81 - 1.00) and intrarater reliability (ICC 0.85 - 0.91) (Plisky et al., 2021). To conduct the assessment, the YBT utilizes a testing kit (FMS, Chatham, VA, USA). A verbal and visual demonstration of the testing procedure was given to each subject by an examiner (SW).

Table 1. Participant demographics (mean ± standard deviation) in four groups.

	G1	G2	G3	G4	F	*p*
n(M/F)	9(5/4)	9(5/4)	9(5/4)	9(5/4)		
Age, y	20.56 ± 1.67	20.78 ± 1.48	20.00 ± 1.00	19.78 ± 0.97	1.135	0.350
Height, cm	173.69 ± 9.84	173.02 ± 8.45	174.87 ± 7.81	172.23 ± 5.39	0.173	0.914
Mass, kg	63.63 ± 14.67	66.06 ± 12.61	66.94 ± 9.57	62.91 ± 9.78	0.237	0.870
CAIT, score	17.89 ± 4.54	19.00 ± 3.67	17.33 ± 4.18	18.67 ± 2.24	0.361	0.781

G1, tDCS group; G2, sham tDCS group; G3, tDCS with balance training group; G4, sham tDCS with balance training group; tDCS, transcranial direct current stimulation; CAIT, Cumberland Ankle Instability Tool; M, male; F, female.

Participants practiced once and then completed 3 successful test trials for 3 directions while barefoot. They were required to stand with test foot on the starting point and utilize contralateral limb to push the indicator block as far as possible in each direction (Wilson et al., 2018). They should touch the block lightly to avoid providing extra support for maintaining equilibrium and back to the starting point while keeping both hands on their hips (DeJong et al., 2020). The test was only administered on the injured side and the testing order was applied in the following sequence: anterior (ANT), posteromedial (PM), and posterolateral (PL). Participants were deemed to have failed if they lost balance, lifted their stance foot, shifted weight onto the reach foot, were unable to execute a controlled return, failed to touch the measuring tape, or moved hands off hips (Ness et al., 2015). Leg length was measured in centimeters on the injured limb from the anterior superior iliac spine to the ipsilateral medial malleolus. The mean of the normalized reach distances in each direction and a composite (COMP) reach distance were calculated (Anguish and Sandrey, 2018; Hale et al., 2007).

Interventions

Participants in G1 and G2 were required to rest for 20 minutes following electrical stimulation to avoid any potential influence from physical activity. To prevent the loosening of electrode pads caused by BT or impedance changes due to sweating, which could compromise the efficacy of tDCS, participants in G3 and G4 performed 20 minutes of BT after receiving electrical stimulation. Regardless of group allocation, all participants underwent 3 sessions per week, totaling 12 supervised intervention sessions. Intervention was performed at the Sport Medical Rehabilitation Center of Beijing Sport University.

Transcranial direct current stimulation

tDCS was administered using a constant-current device (StarStim 32, Neuroelectrics, Spain) via two saline-soaked circular sponge surface electrodes (25 cm^2) placed on the scalp. The tDCS procedure was conducted with the participant seated, as this position was conducive to maintaining stable electrode contact and ensuring the effectiveness of stimulation. The anode electrode was positioned at the lower extremity motor cortex (Cz), while the cathode electrode was placed over the right orbital region (Fp2) (Needle et al., 2017). During the anodal tDCS procedure, the current intensity was gradually increased to 2 mA during the first 30 seconds, maintained for 19 minutes, and then gradually decreased to 0 mA over the last 30 seconds (Ma et al., 2020). During the sham tDCS procedure, the current was gradually increased to 2 mA over a 30-second period and then immediately turned off. The stimulation impedance maintained below 10 kΩ. Any discomfort should be promptly reported to the staff, who would determine whether to continue based on the actual circumstances and the participant's consent. Prior to the formal tDCS session, participants were informed about the potential adverse reactions and acceptable levels of this intervention.

Balance training

BT refers to the progressive hop-to-stabilization balance (PHSB) training program proposed by McKeon (McKeon et al., 2008). This program included five practice contents, and each practice contained seven difficulty levels. Each training session lasted for 20 minutes. Before progressing to the next level, participants were required to demonstrate error-free completion of the task.

Data analysis

Data analysis was conducted using SPSS version 24.0 (IBM Corp, Armonk, NY, USA). The Shapiro-Wilk (S-W) test was utilized to assess the normality of the variables, while the Levene test was applied to evaluate the homogeneity of variances. As the data met these assumptions, parametric tests were applied for further analyses. To assess the differences between groups in terms of demographics (age, height, weight, and CAIT score), a one-way ANOVA was employed. Separate 4 (groups) × 2 (times) repeated-measures ANOVA were conducted to evaluate changes in dependent variables attributable to different interventions. The independent variables were group (G1 vs. G2 vs. G3 vs. G4) and time (Pre vs. Post). Post-hoc comparisons were conducted using the Bonferroni correction method. Mean and SDs were calculated for all continuous variables. Effect sizes were quantified using partial eta squared (η^2_p), where values less than 0.01, between 0.01 and 0.06, and greater than or equal to 0.14 represent small, medium, and large effect sizes, respectively (Fritz et al., 2012). The level of statistical significance was established at $p < 0.05$.

Results

No side effects or adverse events were reported. Study procedures and the number of subjects at each stage were presented in Figure 1. No significant differences were found in demographic characteristics, baseline BESS scores, and YBT scores between the groups ($p > 0.05$) (See Table 1).

Balance Error Scoring System

Since the double-limb stance resulted in 0 points, this study focused on single-limb and tandem stances on firm and foam surfaces, as well as the total BESS score. We observed significant group × time interactions for single-leg stance on a firm surface (Sfi) ($F = 3.958$, $p = 0.017$, $\eta^2_p = 0.217$), single-leg stance on a foam surface (Sfo) ($F = 4.632$, $p = 0.008$, $\eta^2_p = 0.303$), tandem stance on a foam surface (Tfo) ($F = 9.189$, $p < 0.001$, $\eta^2_p = 0.463$) and total BESS ($F = 12.521$, $p < 0.001$, $\eta^2_p = 0.540$) scores, but not for tandem stance on a firm surface (Tfi) ($p > 0.05$). Compared to baseline measures, G1, G3, and G4 scored fewer errors on posttest measures for Sfi (G1: $F = 12.100$, $p = 0.001$, $\eta^2_p = 0.274$; G3: $F = 16.900$, $p < 0.001$, $\eta^2_p = 0.346$; G4: $F = 10.000$, $p = 0.003$, $\eta^2_p = 0.238$), Sfo (G1: $F = 21.993$, $p < 0.001$, $\eta^2_p = 0.407$; G3: $F = 49.485$, $p < 0.001$, $\eta^2_p = 0.607$; G4: $F = 29.086$, $p < 0.001$, $\eta^2_p = 0.476$), and the total BESS (G1: $F = 24.071$, $p < 0.001$, $\eta^2_p = 0.429$; G3: $F = 74.187$, $p < 0.001$, $\eta^2_p = 0.699$; G4: $F = 44.232$, $p < 0.001$, $\eta^2_p = 0.580$). G3 and G4 also showed a significant decrease in Tfi (G3: $F = 11.757$, $p = 0.002$, $\eta^2_p = 0.269$; G4: $F = 4.452$, $p = 0.043$, $\eta^2_p = 0.122$) and Tfo (G3: $F = 29.594$, $p < 0.001$, $\eta^2_p = 0.480$; G4: $F = 27.077$, $p < 0.001$, $\eta^2_p = 0.458$) scores, while this change was not observed in G1 (*p*

> 0.05). Moreover, significant differences were observed among groups on posttest measures of Sfi, Sfo, Tfi, and total BESS scores ($p < 0.05$). However, post-hoc comparisons indicated that no significant differences existed between G1, G3, and G4 ($p > 0.05$), with the inter-group differences primarily attributed to G2. (See Table 2).

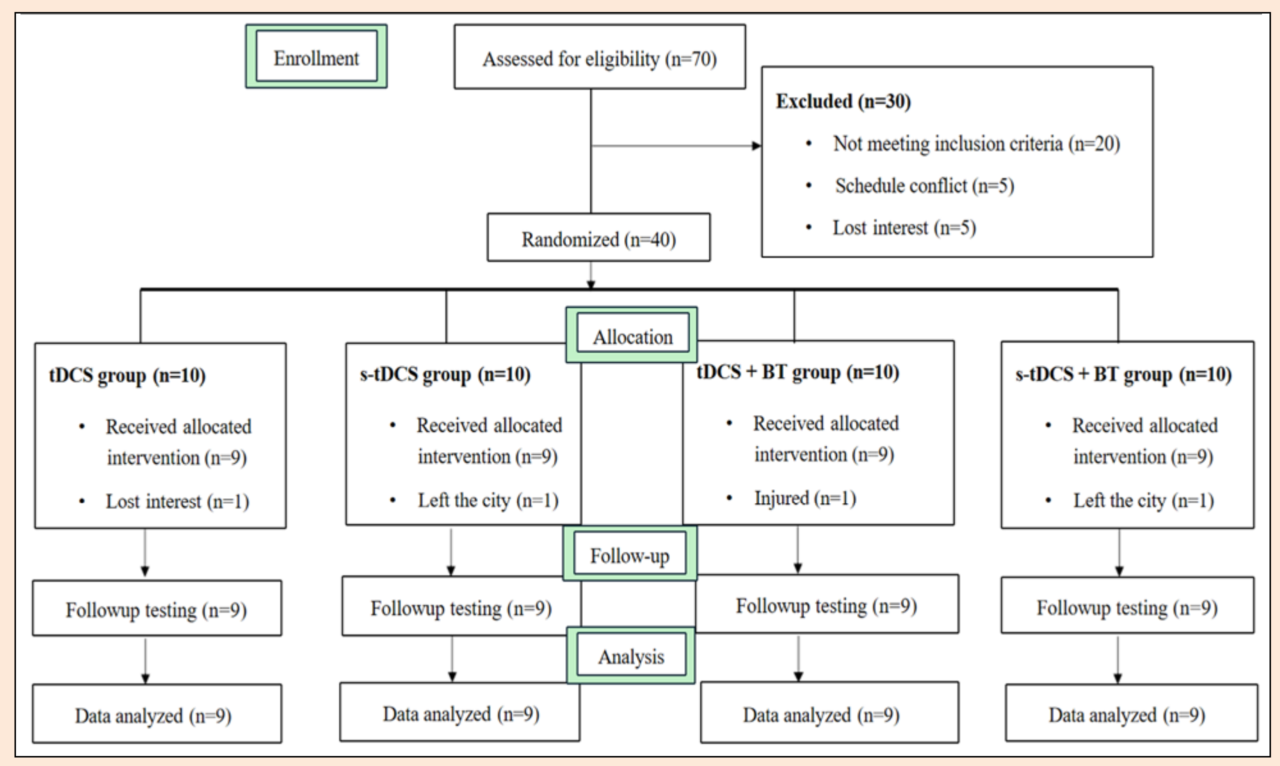

Figure 1. **CONSORT diagram of study procedures.**

Table 2. **Descriptive statistics (mean ± standard deviation) for the Balance Error Scoring System at two assessment points in four groups.**

		G1	G2	G3	G4	F	*p* value	ES (η^2_p)
Sfi	Pre	1.78 ± 1.48	1.56 ± 1.33	2.11 ± 1.90	1.22 ± 0.97	0.591	0.626	0.052
	Post	0.56 ± 0.73	1.67 ± 1.23	0.67 ± 1.12	0.11 ± 0.33	4.579	0.009‡	0.300
					(Effect)	Interaction	Group	Time
	p value	0.001*	0.754	0.000*	0.003*	0.017†	0.321	0.000†
	ES (η^2_p)	0.274	0.003	0.346	0.238	0.271	0.102	0.460
Tfi	Pre	1.00 ± 1.66	0.78 ± 1.09	1.56 ± 1.51	1.11 ± 1.27	0.492	0.691	0.044
	Post	0.33 ± 0.50	0.78 ± 0.97	0.11 ± 0.33	0.22 ± 0.44	2.049	0.127	0.161
					(Effect)	Interaction	Group	Time
	p value	0.123	1.000	0.002*	0.043*	0.132	0.970	0.001†
	ES (η^2_p)	0.073	0.000	0.269	0.122	0.159	0.008	0.284
Sfo	Pre	3.89 ± 1.90	4.78 ± 1.72	4.56 ± 2.13	4.44 ± 1.51	0.385	0.764	0.035
	Post	1.67 ± 1.12	3.89 ± 1.45	1.22 ± 0.83	1.89 ± 0.78	10.762	0.000‡	0.502
					(Effect)	Interaction	Group	Time
	p value	0.000*	0.070	0.000*	0.000*	0.008†	0.068	0.000†
	ES (η^2_p)	0.407	0.099	0.607	0.476	0.303	0.197	0.738
Tfo	Pre	2.11 ± 1.05	2.67 ± 1.87	3.78 ± 1.56	3.33 ± 1.50	2.082	0.122	0.163
	Post	1.22 ± 0.67	3.11 ± 1.45	1.22 ± 0.67	0.89 ± 0.78	10.215	0.000‡	0.489
					(Effect)	Interaction	Group	Time
	p value	0.068	0.351	0.000*	0.000*	0.000†	0.106	0.000†
	ES (η^2_p)	0.101	0.027	0.480	0.458	0.463	0.172	0.512
Total	Pre	8.78 ± 4.30	9.78 ± 4.92	12.00 ± 4.50	10.11 ± 2.67	0.933	0.436	0.080
	Post	3.78 ± 1.72	9.44 ± 3.58	3.22 ± 1.72	3.33 ± 1.23	16.169	0.000‡	0.603
					(Effect)	Interaction	Group	Time
	p value	0.000*	0.746	0.000*	0.000*	0.000†	0.107	0.000†
	ES (η^2_p)	0.429	0.003	0.699	0.580	0.540	0.171	0.766

*Indicates $p < 0.05$ between the pretest and posttest within each group and for each condition; †Indicates $p < 0.05$ for the interaction effect, group effect, or time effect; ‡Indicates $p < 0.05$ between four groups at pretest or posttest. ES: effect size; G1, tDCS group; G2, sham tDCS group; G3, tDCS with balance training group; G4, sham tDCS with balance training group; tDCS, transcranial direct current stimulation; Sfi, single-leg stance on a firm surface; Tfi, tandem stance on a firm surface; Sfo, single-leg stance on a foam surface; Tfo, tandem stance on a foam surface.

Table 3. Descriptive statistics (mean ± standard deviation) for the Y-Balance Test at two assessment points in four groups.

		G1	G2	G3	G4	F	*p* value	ES (η^2_p)
ANT	**Pre**	66.22 ± 4.66	61.27 ± 7.63	68.68 ± 7.65	65.31 ± 3.93	2.220	0.105	0.172
	Post	65.13 ± 6.63	62.97 ± 7.01	72.19 ± 5.26	68.59 ± 2.89	4.550	0.009‡	0.299
					(Effect)	**Interaction**	**Group**	**Time**
	***p* value**	0.507	0.301	0.038*	0.051	0.184	0.024†	0.029†
	ES (η^2_p)	0.014	0.033	0.128	0.114	0.138	0.252	0.141
PM	**Pre**	111.87 ± 9.37	103.59 ± 9.45	106.86 ± 5.62	110.56 ± 9.21	1.722	0.182	0.139
	Post	113.48 ± 4.06	105.05 ± 9.71	116.30 ± 3.80	119.12 ± 6.75	7.784	0.000‡	0.422
					(Effect)	**Interaction**	**Group**	**Time**
	***p* value**	0.587	0.622	0.003*	0.006*	0.111	0.007†	0.001†
	ES (η^2_p)	0.009	0.008	0.244	0.210	0.169	0.312	0.287
PL	**Pre**	117.36 ± 6.46	111.11 ± 11.60	111.17 ± 7.05	116.95 ± 4.31	1.782	0.170	0.143
	Post	120.78 ± 4.25	110.70 ± 11.85	118.10 ± 3.91	123.08 ± 6.74	4.749	0.008‡	0.308
					(Effect)	**Interaction**	**Group**	**Time**
	***p* value**	0.101	0.842	0.002*	0.005*	0.064	0.033†	0.000†
	ES (η^2_p)	0.082	0.001	0.268	0.223	0.200	0.235	0.330
COMP	**Pre**	111.84 ± 8.00	105.42 ± 10.95	107.88 ± 7.06	110.93 ± 8.70	1.003	0.404	0.086
	Post	113.40 ± 7.87	106.50 ± 10.34	115.35 ± 5.47	117.69 ± 8.22	3.141	0.039‡	0.227
					(Effect)	**Interaction**	**Group**	**Time**
	***p* value**	0.441	0.594	0.001*	0.002*	0.053	0.154	0.000†
	ES (η^2_p)	0.019	0.009	0.304	0.264	0.210	0.149	0.358

*Indicates $p < 0.05$ between the pretest and posttest within each group and for each condition; †Indicates $p < 0.05$ for the interaction effect, group effect, or time effect; ‡Indicates $p < 0.05$ between four groups at pretest or posttest. ES: effect size; G1, tDCS group; G2, sham tDCS group; G3, tDCS with balance training group; G4, sham tDCS with balance training group; tDCS, transcranial direct current stimulation; ANT, anterior reach; PM, posteromedial reach; PL, posterolateral reach; COMP, composite reach.

Y-Balance Test

There were no significant group × time interactions found for ANT, PM, PL, and COMP (p > 0.05); however, there was a significant main effect of time (ANT: F = 5.235, p = 0.029, η^2_p = 0.141; PM: F = 12.889, p = 0.001, η^2_p = 0.287; PL: F = 15.741, p < 0.001, η^2_p = 0.330; COMP: F = 17.832, p < 0.001, η^2_p = 0.358). No significant changes were found in either G1 or G2 across all directions between the pretest and posttest measures (*p* > 0.05). Both G3 and G4 exhibited significantly greater PM (G3: F = 10.347, p = 0.003, η^2_p = 0.244; G4: F = 8.506, p = 0.006, η^2_p = 0.210), PL (G3: F = 11.712, p = 0.002, η^2_p = 0.268; G4: F = 9.167, p = 0.005, η^2_p = 0.223), and COMP (G3: F = 13.995, p = 0.001, η^2_p = 0.304; G4: F = 11.460, p = 0.002, η^2_p = 0.264) reach distances in the posttest compared to the pretest. Only G3 revealed a farther ANT reach distance after 4 weeks of intervention (F = 4.692, p = 0.038, η^2_p = 0.128). Also a significant main effect of group was observed (ANT: F = 3.598, p = 0.024, η^2_p = 0.252; PM: F = 4.846, p = 0.007, η^2_p = 0.312; PL: F = 3.281, p = 0.033, η^2_p = 0.235). Consistent with the main effect finding, significant differences were observed among groups on posttest measures (*p* < 0.05). However, post-hoc comparisons indicated that no significant differences existed between G1, G3, and G4 in terms of ANT, PM, PL, and COMP (p > 0.05), with the inter-group differences primarily attributed to G2 (See Table 3).

Discussion

Static postural control

After a 4-week intervention with BT, or the combination of tDCS and BT, CAI athletes exhibited significant reductions in the total BESS score and error scores for Sfi, Sfo, Tfi, and Tfo. These findings collectively suggest an enhancement in static balance ability, which aligns with prior research outcomes. Following a 4- to 6-week BT program, subjects with CAI or FAI demonstrated significant improvements in static postural control, as evaluated by the center of pressure excursion, BESS, and time-to-boundary (Bernier and Perrin, 1998; Hall et al., 2018; McKeon et al., 2008; Mettler et al., 2015; Rozzi et al., 1999). BT could diminish proprioceptive deficits associated with ligamentous injury to the ankle (Freeman et al., 1965). However, a systematic review highlights a paucity of evidence supporting the effectiveness of BT in improving instrumental postural control among patients with CAI (McKeon and Hertel, 2008). The potential reasons for this outcome include: the measurement instruments may lack the sensitivity to detect improvements from BT in patients with CAI, and static single-limb standing may not provide sufficient challenges to elicit discernible changes.

In the current study, we found that after 4 weeks of tDCS, patients with CAI demonstrated significant improvements in Sfi, Sfo, and total BESS scores. tDCS, either as a standalone intervention or in conjunction with other therapeutic approaches, has been shown to enhance balance in adults with neurological disorders (Beretta et al., 2022). CAI patients experience diminished somatosensory input, leading to a greater reliance on visual cues. During the closed-eye test, the lack of visual input exacerbates the reduced proprioceptive information from the lower extremities, resulting in higher balance error scores (Kwon, 2018). Anodal tDCS can positively affect cortical excitability and thus address the maladaptive neuroplasticity following joint instability (Jeffery et al., 2007; Nitsche and Paulus, 2001). This improvement in neural plasticity may contribute to more efficient neural processing of sensory information relevant to balance, such as proprioceptive and vestibular cues, and enhance the generation of appropriate motor responses for maintaining balance. It has been shown that tDCS can enhance the long-term potentiation effects in the motor cortex, promoting the formation of new synaptic connections and strengthening existing ones (Monte-Silva et al.,2013). Additionally, it could enhance the balance within asymmetric neural networks between brain hemispheres and modify the functional connectivity of various brain regions involved in both direct and indirect pathways of postural control (Beretta et al., 2022). These mechanisms likely contribute to the observed improvements in the static balance ability of CAI athletes in our study following a 4-week tDCS intervention.

Dynamic postural control

We found that both tDCS combined with BT and BT alone significantly improved PM, PL, and COMP reach distances, compared to tDCS or sham tDCS alone, neither of which resulted in any significant changes. These improvements indicate a substantial enhancement in dynamic postural control. BT is beneficial for enhancing dynamic postural control among patients with CAI (Anguish and Sandrey, 2018; Burcal et al., 2019; Hale et al., 2007; McKeon et al., 2008). Specifically, participants in the BT group exhibited significant improvements in PM and PL reach distances of the Star Excursion Balance Test compared to their pretest measurements (Cruz-Diaz et al., 2015; McKeon et al., 2008). These enhancements might be attributed to the diminished restrictions on the sensorimotor system resulting from BT (McKeon et al., 2008). A significant improvement in COMP was observed following BT in the present study. However, the increase in ANT was observed only in the tDCS combined with BT group, with a moderate effect size ($\eta^2_p = 0.128$). Given that this direction is primarily associated with reductions in dorsiflexion mobility and posterior talar glide (Vicenzino et al., 2006), and no significant differences were found among different interventions in this study, we should cautiously conclude that tDCS combined with BT may improve ANT reach distance in CAI athletes.

No significant changes were observed in any direction in the tDCS group after 4 weeks of intervention. This result diverges from prior research findings, which indicated that anodal tDCS applied to the leg area of the primary motor cortex enhances dynamic performance in young adults (Kaminski et al., 2016; Hou et al., 2022). However, to date, for patients with CAI, tDCS has been combined with other forms of training, including eccentric training (Bruce et al., 2020) and short-foot exercises (Ma et al., 2020). tDCS over leg motor enhances the excitability of the motor cortex and modifies the firing strategies of motor units (Dutta et al., 2015), and enhances locomotor adaptation aftereffects (Kaski et al., 2012). This suggests that tDCS has the potential to serve as an effective adjunctive rehabilitation treatment to enhance postural control. The reason tDCS alone did not positively affect YBT results in CAI athletes in this study may be attributed to the multifaceted nature of dynamic postural stability. This function relies on the integration of multiple sensory inputs (e.g., proprioceptive, vestibular, visual) and motor outputs. In the absence of complementary effects from other training modalities, tDCS alone might have been insufficient to effectively coordinate and optimize the complex neuromuscular processes required for maintaining dynamic balance in CAI patients. When tDCS was combined with BT, a significant increase in the reach distance could be observed, which also indirectly verified this reason.

Combination intervention

Regarding the results of static and dynamic balance, no intergroup differences were found in this study. Specifically, tDCS alone, BT alone, and the combination of these two produced comparable effects.This finding diverges from our hypothesis and previous research Previous studies have indicated that combining tDCS with other interventions may offer greater benefits for postural control compared to using only one type of intervention. Bruce et al. revealed that a 4-week tDCS in conjunction with eccentric training improved the dynamic postural stability index by enhancing neural drive to stabilizing muscles in patients with CAI (Bruce et al., 2020). Jafarzadeh et al. additionally noted that combining 2 weeks of tDCS with physical training led to more significant enhancements in dynamic stability, as measured by the Biodex Balance System (Jafarzadeh et al., 2019). In older adults at high risk of falling, the combination of bilateral cerebellar and primary motor cortex anodal tDCS along with postural training led to significant enhancements in postural control and balance. However, neither the 2-week regimen of postural training by itself nor the standalone application of bilateral cerebellar anodal tDCS resulted in comparable levels of improvement (Yosephi et al., 2018). Additionally, high-definition tDCS combined with short-foot exercise resulted in significantly greater improvement in the performance on the YBT in CAI individuals (Ma et al., 2020). However, a combination of 4-week anodal tDCS with foot core exercise did not affect static balance in healthy young adults. Perhaps because of the stimulus target effect (Xiao et al., 2022). Although the structural and functional alterations in the motor cortex may influence balance, the motor cortex's role in postural control is not as crucial as that of the cerebellum, the primary balance regulation center (Takakusaki, 2017). This perspective is supported by the findings of Yosephi (Yosephi et al., 2018). Additionally, a meta-analysis indicated no significant difference between tDCS alone and its combination with another intervention in treating neurological disorders (Beretta et al., 2022), which supports our findings. These discrepancies could be attributed to methodological variations in study design, leading to divergent outcomes. Another potential reason could be the high motor abilities of the subjects in this study, which may have caused a ceiling effect, thereby making further improvements in balance ability challenging.

Study limitations

Firstly, we did not conduct a longer follow-up after the intervention, which could provide valuable insights into the long-lasting impacts of different interventions targeting postural control for individuals with CAI. Secondly, all participants were collegiate athletes competing at the national level or higher. Despite experiencing recurrent ankle sprains, their adaptability and athletic abilities may partially compensate for the postural impairments, making it challenging to discern changes in their postural control. Finally, the paper failed to include posturography as a measurement tool, which is widely regarded as the gold standard for assessing postural control. Future studies should consider integrating posturography to achieve more precise and reliable observations of changes in postural control.

Conclusion

Four weeks of tDCS, BT, and the combination of these two interventions significantly improved static postural stability in athletes with CAI. However, only intervention methods incorporating BT were effective in enhancing dynamic stability. Notably, the combined program did not offer additional benefits over the individual interventions.

Acknowledgements

We are grateful to Wanrongyu Su for his valuable suggestions and assistance provided during the experimental design process and the subsequent experimental tests, and to Anran Dong, Jianjun Zhao, Xuefang Liu, and Hao Chang for their assistance in data collection. We also thank all the athletes for their time and effort. This research was supported by Beijing high-grade, precision and advanced disciplines project. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author who was an organizer of the study.

References

Anguish, B. and Sandrey, M.A. (2018) Two 4-week balance-training programs for chronic ankle instability. *Journal of Athletic Training* **53**, 662-671. https://doi.org/10.4085/1062-6050-555-16

Auvichayapat, P. and Auvichayapat, N. (2011) Basic knowledge of transcranial direct current stimulation. *Journal of the Medical Association of Thailand* **94**, 518-527.

Bell, D.R., Guskiewicz, K.M., Clark, M.A. and Padua, D.A. (2011) Systematic review of the balance error scoring system. *Sports Health* **3**, 287-295. https://doi.org/10.1177/1941738111403122

Beretta, V.S., Santos, P.C.R., Orcioli-Silva, D., Zampier, V.C., Vitório, R. and Gobbi, L.T.B. (2022) Transcranial direct current stimulation for balance rehabilitation in neurological disorders: A systematic review and meta-analysis. *Ageing Research Reviews* **81**, 101736. https://doi.org/10.1016/j.arr.2022.101736

Bernier, J.N. and Perrin, D.H. (1998) Effect of coordination training on proprioception of the functionally unstable ankle. *Journal of Orthopaedic and Sports Physical Therapy* **27**, 264-275. https://doi.org/10.2519/jospt.1998.27.4.264

Bruce, A.S., Howard, J.S., VAN Werkhoven, H., McBride, J.M. and Needle, A.R. (2020) The effects of transcranial direct current stimulation on chronic ankle instability. *Medicine and Science in Sports and Exercise* **52**, 335-344. https://doi.org/10.1249/MSS.0000000000002129

Burcal, C.J., Jeon, H., Gonzales, J.M., Faust, M.E., Thomas, A.C., Hubbard-Turner, T. J. and Wikstrom, E.A. (2019) Cortical measures of motor planning and balance training in patients with chronic ankle instability. *Journal of Athletic Training* **54**, 727-736. https://doi.org/10.4085/1062-6050-450-17

Chung, S., Rodriguez, A., Alijanpour, E. and McCann, R.S. (2023) Effects of a single balance training session on neural excitability in individuals with chronic ankle instability. *Journal of Sport Rehabilitation* **32**, 847-854. https://doi.org/10.1123/jsr.2023-0024

Cruz-Diaz, D., Lomas-Vega, R., Osuna-Pérez, M. C., Contreras, F.H. and Martínez-Amat, A. (2015) Effects of 6 weeks of balance training on chronic ankle instability in athletes: a randomized controlled trial. *International Journal of Sports Medicine* **36**, 754-760. https://doi.org/10.1055/s-0034-1398645

DeJong, A.F., Mangum, L.C. and Hertel, J. (2020) Ultrasound imaging of the gluteal muscles during the Y-Balance Test in individuals with or without chronic ankle instability. *Journal of Athletic Training* **55**, 49-57. https://doi.org/10.4085/1062-6050-363-18

Delahunt, E., Coughlan, G.F., Caulfield, B., Nightingale, E.J., Lin, C.W. and Hiller, C.E. (2010) Inclusion criteria when investigating insufficiencies in chronic ankle instability. *Medicine and Science in Sports and Exercise* **42**, 2106-2121. https://doi.org/10.1249/MSS.0b013e3181de7a8a

Docherty, C.L., Valovich McLeod, T.C., and Shultz, S.J. (2006) Postural control deficits in participants with functional ankle instability as measured by the balance error scoring system. *Clinical Journal of Sport Medicine* **16**, 203-208. https://doi.org/10.1097/00042752-200605000-00003

Dutta, A., Krishnan, C., Kantak, S.S., Ranganathan, R. and Nitsche, M.A. (2015) Recurrence quantification analysis of surface electromyogram supports alterations in motor unit recruitment strategies by anodal transcranial direct current stimulation. *Restorative Neurology and Neuroscience* **33**, 663-669. https://doi.org/10.3233/RNN-140469

Ekstrand, J. and Tropp, H. (1990) The incidence of ankle sprains in soccer. *Foot & Ankle* **11**, 41-44. https://doi.org/10.1177/107110079001100108

Freeman, M.A., Dean, M.R. and Hanham, I.W. (1965) The etiology and prevention of functional instability of the foot. *Journal of Bone and Joint Surgery* **47**, 678-685. https://doi.org/10.1302/0301-620X.47B4.678

Fritz, C.O., Morris, P.E. and Richler, J.J. (2012) Effect size estimates: current use, calculations, and interpretation. *Journal of Experimental Psychology - General* **141**, 2-18. https://doi.org/10.1037/a0024338

Gribble, P.A., Delahunt, E., Bleakley, C., Caulfield, B., Docherty, C., Fourchet, F., Fong, D.T., Hertel, J., Hiller, C., Kaminski, T., McKeon, P., Refshauge, K., van der Wees, P., Vicenzino, B. and Wikstrom, E. (2014) Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. *British Journal of Sports Medicine* **48**, 1014-1018. https://doi.org/10.1136/bjsports-2013-093175

Hale, S.A., Hertel, J. and Olmsted-Kramer, L.C. (2007) The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. *The Journal of Orthopaedic and Sports Physical Therapy* **37**, 303-311. https://doi.org/10.2519/jospt.2007.2322

Hall, E.A., Chomistek, A.K., Kingma, J.J. and Docherty, C.L. (2018) Balance- and strength-training protocols to improve chronic ankle instability deficits, part I: assessing clinical outcome measures. *Journal of Athletic Training* **53**, 568-577. https://doi.org/10.4085/1062-6050-385-16

Hershkovich, O., Tenenbaum, S., Gordon, B., Bruck, N., Thein, R., Derazne, E., Tzur, D., Shamiss, A. and Afek, A. (2015) A large-scale study on epidemiology and risk factors for chronic ankle instability in young adults. *Journal of Foot and Ankle Surgery* **54**, 183-187. https://doi.org/10.1053/j.jfas.2014.06.001

Hou, J., Nitsche, M.A., Yi, L., Kong, Z. and Qi, F. (2022) Effects of transcranial direct current stimulation over the primary motor cortex in improving postural stability in healthy young adults. *Biology* **11**, 1370-1383. https://doi.org/10.3390/biology11091370

Jafarzadeh, A., Ehsani, F., Yosephi, M.H., Zoghi, M. and Jaberzadeh, S. (2019) Concurrent postural training and M1 anodal transcranial direct current stimulation improve postural impairment in patients with chronic low back pain. *Journal of Clinical Neuroscience* **68**, 224-234. https://doi.org/10.1016/j.jocn.2019.07.017

Jeffery, D.T., Norton, J.A., Roy, F.D. and Gorassini, M.A. (2007) Effects of transcranial direct current stimulation on the excitability of the leg motor cortex. *Experimental Brain Research* **182**, 281-287. https://doi.org/10.1007/s00221-007-1093-y

Kaminski, E., Steele, C.J., Hoff, M., Gundlach, C., Rjosk, V., Sehm, B., Villringer, A. and Ragert, P. (2016) Transcranial direct current stimulation (tDCS) over primary motor cortex leg area promotes dynamic balance task performance. *Clinical Neurophysiology* **127**, 2455-2462. https://doi.org/10.1016/j.clinph.2016.03.018

Kaski, D., Quadir, S., Patel, M., Yousif, N. and Bronstein, A.M. (2012) Enhanced locomotor adaptation aftereffect in the "broken escalator" phenomenon using anodal tDCS. *Journal of Neurophysiology* **107**, 2493-2505. https://doi.org/10.1152/jn.00223.2011

Kwon, Y.U. (2018) Static postural stability in chronic ankle instability, an ankle sprain and healthy ankles. *International Journal of Sports Medicine* **39**, 625-629. https://doi.org/10.1055/a-0608-4552

Lefaucheur, J.P., Antal, A., Ayache, S.S., Benninger, D.H., Brunelin, J., Cogiamanian, F., Cotelli, M., De Ridder, D., Ferrucci, R., Langguth, B., Marangolo, P., Mylius, V., Nitsche, M.A., Padberg, F., Palm, U., Poulet, E., Priori, A., Rossi, S., Schecklmann, M., Vanneste, S., Ziemann, U., Garcia-Larrea, L. and Paulus, W. (2017) Evidence-based guidelines on the therapeutic use of transcranial direct current stimulation (tDCS). *Clinical Neurophysiology* **128**, 56-92. https://doi.org/10.1016/j.clinph.2016.10.087

Ma, Y., Yin, K., Zhuang, W., Zhang, C., Jiang, Y., Huang, J., Manor, B., Zhou, J. and Liu, Y. (2020) Effects of combining high-definition transcranial direct current stimulation with short-foot exercise on chronic ankle instability: a pilot randomized and double-blinded study. *Brain Sciences* **10**, 749-763. https://doi.org/10.3390/brainsci10100749

McKeon, P.O. and Hertel, J. (2008) Systematic review of postural control and lateral ankle instability, part II: Is balance training clinically effective? *Journal of Athletic Training* **43**, 305-315. https://doi.org/10.4085/1062-6050-43.3.305

McKeon, P.O., Ingersoll, C.D., Kerrigan, D.C., Saliba, E., Bennett, B.C. and Hertel, J. (2008) Balance training improves function and postural control in those with chronic ankle instability. *Medicine and Science in Sports and Exercise* **40**, 1810-1819. https://doi.org/10.1249/MSS.0b013e31817e0f92

Mettler, A., Chinn, L., Saliba, S.A., McKeon, P.O. and Hertel, J. (2015) Balance training and center-of-pressure location in participants with chronic ankle instability. *Journal of Athletic Training* **50**, 343-349. https://doi.org/10.4085/1062-6050-49.3.94

Monte-Silva, K., Kuo, M.F., Hessenthaler, S., Fresnoza, S., Liebetanz, D., Paulus, W. and Nitsche, M.A. (2013) Induction of late LTP-like plasticity in the human motor cortex by repeated non-invasive brain stimulation. *Brain Stimulation* **6**, 424-432. https://doi.org/10.1016/j.brs.2012.04.011

Needle, A.R., Lepley, A.S. and Grooms, D.R. (2017) Central nervous system adaptation after ligamentous injury: a summary of theories, evidence, and clinical interpretation. *Sports Medicine* **47**, 1271-1288. https://doi.org/10.1007/s40279-016-0666-y

Ness, B.M., Taylor, A.L., Haberl, M.D., Reuteman, P.F. and Borgert, A.J. (2015) Clinical observation and analysis of movement quality during performance on the star excursion balance test. *International Journal of Sports Physical Therapy* **10**, 168-177.

Nitsche, M.A. and Paulus, W. (2001) Sustained excitability elevations induced by transcranial DC motor cortex stimulation in humans. *Neurology* **57**, 1899-1901. https://doi.org/10.1212/WNL.57.10.1899

Olmsted, L.C., Carcia, C.R., Hertel, J. and Shultz, S.J. (2002) Efficacy of the Star Excursion Balance Tests in detecting reach deficits in subjects with chronic ankle instability. *Journal of Athletic Training* **37**, 501-506.

Plisky, P., Schwartkopf-Phifer, K., Huebner, B., Garner, M.B. and Bullock, G. (2021) Systematic review and meta-analysis of the y-balance test lower quarter: reliability, discriminant validity, and predictive validity. *International Journal of Sports Physical Therapy* **16**, 1190-1209. https://doi.org/10.26603/001c.27634

Riemann, B.L., Guskiewicz, K.M. and Shields, E.W. (1999) Relationship between clinical and forceplate measure of postural stability. *Journal of Sport Rehabilitation* **8**, 71-82. https://doi.org/10.1123/jsr.8.2.71

Ross, S.E. and Guskiewicz, K.M. (2004) Examination of static and dynamic postural stability in individuals with functionally stable and unstable ankles. *Clinical Journal of Sport Medicine* **14**, 332-338. https://doi.org/10.1097/00042752-200411000-00002

Rossi, S., Hallett, M., Rossini, P.M., Pascual-Leone, A. and Safety of TMS Consensus Group (2009) Safety, ethical considerations, and application guidelines for the use of transcranial magnetic stimulation in clinical practice and research. *Clinical Neurophysiology* **120**, 2008-2039. https://doi.org/10.1016/j.clinph.2009.08.016

Rozzi, S.L., Lephart, S.M., Sterner, R. and Kuligowski, L. (1999) Balance training for persons with functionally unstable ankles. *Journal of Orthopaedic and Sports Physical Therapy* **29**, 478-486. https://doi.org/10.2519/jospt.1999.29.8.478

Shamshiri, A., Rezaei, I., Sinaei, E., Heidari, S. and Ghanbari, A. (2020) Normative data for the Balance Error Scoring System in Iranian adults. *Journal of Sport Rehabilitation* **30**, 408-413. https://doi.org/10.1123/jsr.2019-0482

Takakusaki, K. (2017) Functional neuroanatomy for posture and gait control. *Journal of Movement Disorders* **10**, 1-17. https://doi.org/10.14802/jmd.16062

Taube, W., Gruber, M. and Gollhofer, A. (2008) Spinal and supraspinal adaptations associated with balance training and their functional relevance. *Acta Physiologica (Oxford, England)* **193**, 101-116. https://doi.org/10.1111/j.1748-1716.2008.01850.x

Uzlaşır, S., Özdıraz, K.Y., Dağ, O. and Tunay, V.B. (2021) The effects of stroboscopic balance training on cortical activities in athletes with chronic ankle instability. *Physical Therapy in Sport* **50**, 50-58. https://doi.org/10.1016/j.ptsp.2021.03.014

Vicenzino, B., Branjerdporn, M., Teys, P. and Jordan, K. (2006) Initial changes in posterior talar glide and dorsiflexion of the ankle after mobilization with movement in individuals with recurrent ankle sprain. *The Journal of Orthopaedic and Sports Physical Therapy* **36**, 464-471. https://doi.org/10.2519/jospt.2006.2265

Vikram, M., Sundaraganesh, K., Justine, M., Kurup, M. and Leonard, J.H. (2012) Evaluation of postural control impairment using Balance Error Scoring System among athletes with ankle injury: an effective tool in daily clinical practice. *La Clinica Terapeutica* **163**, 383-386.

Wilkins, J.C., Valovich McLeod, T.C., Perrin, D.H. and Gansneder, B.M. (2004) Performance on the Balance Error Scoring System decreases after fatigue. *Journal of Athletic Training* **39**, 156-161.

Wilson, B.R., Robertson, K.E., Burnham, J.M., Yonz, M.C., Ireland, M.L. and Noehren, B. (2018) The relationship between hip strength and the Y balance test. *Journal of Sport Rehabilitation* **27**, 445-450. https://doi.org/10.1123/jsr.2016-0187

Wikstrom, E.A., Tillman, M.D., Chmielewski, T.L., Cauraugh, J.H. and Borsa, P.A. (2007) Dynamic postural stability deficits in subjects with self-reported ankle instability. *Medicine and Science in Sports and Exercise* **39**, 397-402. https://doi.org/10.1249/mss.0b013e31802d3460

Wikstrom, E.A. and Brown, C.N. (2014) Minimum reporting standards for copers in chronic ankle instability research. *Sports Medicine* **44**, 251-268. https://doi.org/10.1007/s40279-013-0111-4

Xiao, S., Wang, B., Yu, C., Shen, B., Zhang, X., Ye, D., Deng, L., Xu, Y., Zhou, J. and Fu, W. (2022) Effects of intervention combining transcranial direct current stimulation and foot core exercise on sensorimotor function in foot and static balance. *Journal of Neuroengineering and Rehabilitation* **19**, 98-110. https://doi.org/10.1186/s12984-022-01077-5

Yosephi, M.H., Ehsani, F., Zoghi, M. and Jaberzadeh, S. (2018) Multi-session anodal tDCS enhances the effects of postural training on balance and postural stability in older adults with high fall risk: primary motor cortex versus cerebellar stimulation. *Brain Stimulation* **11**, 1239-1250. https://doi.org/10.1016/j.brs.2018.07.044

Key points

- The total BESS score significantly decreased in the tDCS group, the tDCS + BT group, and the s-tDCS + BT group following four weeks of intervention. These findings suggest that both individual and combined interventions utilized in this study can significantly improve static postural stability in athletes with CAI.
- The YBT composite reach distance showed a significant increase only after the implementation of the BT intervention. The application of tDCS alone did not influence the dynamic stability in athletes with CAI.
- The integrated program combining tDCS with BT did not provide significant additional benefits compared to the individual interventions.

AUTHOR BIOGRAPHY

Xiaoya ZHANG
Employment
PhD student, School of Sports Medicine and Rehabilitation, Beijing Sport University, Beijing, China
Degree
MSc
Research interests
Musculoskeletal injury prevention and rehabilitation, particularly with respect to chronic ankle instability
E-mail: hanbingxy@sina.com

Jianxin WU
Employment
PhD student, School of Sports Medicine and Rehabilitation, Beijing Sport University, Beijing, China
Degree
MSc
Research interests
The prevention of musculoskeletal injuries and their rehabilitation.
E-mail: wujianxin128@gmail.com

Dun LIANG
Employment
Shenzhen Prevention and Treatment Center for Occupational Diseases, Shenzhen, Guangdong Province, China
Degree
BSci
Research interests
Sports injuries, sports training, and physiotherapy
E-mail: oliondun@gmail.com

Bin RUAN
Employment
PhD student, School of Sports Medicine and Rehabilitation, Beijing Sport University, Beijing, China
Degree
MSc
Research interests
Musculoskeletal injury prevention and rehabilitation
E-mail: ruanbing@bsu.edu.cn

Qi GAO
Employment
School of Sports Medicine and Rehabilitation, Beijing Sport University, Beijing, China
Degree
PhD
Research interests
Sports medicine, sports injuries and rehabilitation
E-mail: fevok@sina.com

✉ **Qi Gao**
No.48, Xinxi Road, Haidian District, Beijing, China 100084