Research Article

Immediate Effect of Dual-Task Training on Brain Electrical Activity, Functional Disability, and Pain Severity in Athletes with Chronic Ankle Instability

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Running title: Effect of dual-task training on brain electrical activity

Abstract
Background: Chronic ankle instability (CAI) induces a disorder of the central nervous system, in which brain waves play an important role in regulating these factors. The aim of this study was to investigate the immediate effect of dual-task training (neuromuscular and cognitive) on brain electrical activity, pain severity, and foot and ankle disability index (FADI) in athletes with CAI.
Methods: This study a single-blind randomized control trial (RCT). Participants were 44 young male and women athletes (N=27 male: N=17 women) with CAI who were randomly divided into two groups; dual-task training group and control group. The immediate effect of dual-task training was performed for 30 minutes. Outcome measures were brain electrical activity (electroencephalography Medina Teb Company, Iran was employed), pain severity (10-centimeter visual analog scale) and disability.
Results: The results indicated that dual-task training significantly improved brain electrical activity and reduced pain severity. Significant reductions in pain were observed ($P < 0.001$, $\eta^2 = 0.493$), along with decreased theta wave activity at O1 and O2 ($P < 0.001$, $\eta^2 = 0.837$; $P < 0.001$, $\eta^2 = 0.898$). In contrast, alpha and beta wave activities significantly increased at both O1 and O2 electrodes (beta: $P \leq 0.001$, $\eta^2_p = 0.702$ and 0.898).

Conclusion: The findings of this study indicate that dual-task training has an immediate effect on enhancing brain electrical activity in the O1 and O2 regions and reducing pain severity. Based on these acute findings, physiotherapists and sports rehabilitation practitioners may consider incorporating dual-task training as a complementary approach aimed at improving central nervous system function.
Keywords: Neuromuscular rehabilitation; Ankle instability; Postural; Electroencephalography

Introduction

Lateral ankle sprains are among the most common musculoskeletal injuries affecting both athletes and the general population engaged in daily physical activities (1). In the United States, ankle sprains result in approximately two million emergency department visits annually, with nearly 75% classified as lateral ankle sprains (2). Lateral ankle sprains are highly prevalent among athletes, accounting for approximately 15–17% of all sports-related injuries at the professional and collegiate levels (3). Following such injuries, one of the most clinically significant and persistent sequelae is chronic ankle instability (CAI). It has been reported that approximately one in three individuals develops CAI after sustaining a lateral ankle sprain (4).

The symptoms of chronic ankle instability include recurrent ankle sprains, persistent ankle pain, episodes of the ankle "giving way" during sports participation and activities of daily living, and a reduced quality of life (5). In addition, chronic ankle instability is associated with multiple functional impairments, including decreased ankle function, impaired balance, and deficits in ankle joint proprioception (6). Recent evidence suggests that following initial damage to the lateral ankle ligaments, alterations occur within the central nervous system, leading to disruptions in motor planning and neuromuscular control in affected individuals (7). Zhang et al. (2023) compared brain electrical activity between individuals with chronic ankle instability (CAI) and healthy controls and reported significant differences in brainwave power, particularly an increase in theta-band activity within central cortical regions (8). Similarly, Shaw et al. (2024) demonstrated that alterations in the central nervous system following injury contribute to attentional and memory impairments in patients with CAI (9). Neurophysiological evidence further indicates that increased theta activity and reduced beta-band activity in the cerebellar region are associated with balance dysfunction (10). Impaired balance and proprioceptive deficits are recognized as key factors contributing to the progression and persistence of chronic ankle instability (11). Despite the chronic nature of this condition, athletes with CAI frequently report persistent ankle pain during or following physical activity (4). Brain wave activity within the occipital–cerebellar regions of the central nervous system plays a critical role in postural control and balance regulation (1). Moreover, electroencephalography-based neurophysiological studies suggest that chronic ankle instability is not solely a peripheral musculoskeletal disorder but is also associated with central alterations in brain electrical activity (2).

Recently, researchers in the field of rehabilitation have emphasized that effective management of chronic ankle instability (CAI) requires the implementation of multifaceted intervention protocols that address all dimensions of rehabilitation to achieve optimal clinical outcomes (12). In this context, dual-task exercises have emerged as a novel, evidence-based approach in rehabilitation. These exercises involve the simultaneous performance of a motor task and a cognitive task, such as neuromuscular or balance-related activities combined with cognitive challenges (13). For instance, balance exercises performed under progressively increasing cognitive demands, such as counting backward while maintaining postural stability, have been described in the literature (14). Dual-task training is considered particularly relevant as it closely simulates the real-life conditions encountered by athletes with CAI during sports participation and activities of daily living. Moreover, research grounded in cognitive load theory suggests that when two tasks are performed concurrently, the central nervous system exhibits increased neural activity, and under more demanding conditions, cognitive load is elevated in both the left and right cerebral hemispheres (15). Rehabilitation protocols for chronic ankle instability should simultaneously target the musculoskeletal and nervous systems. A multimodal approach that enhances coordination between the central nervous system and musculoskeletal function may improve brain electrical activity, reduce functional disability, alleviate pain, and improve functional outcomes such as FADI scores. To test this, we conducted a randomized controlled trial to examine the effects of integrating dual-task training into a multidimensional rehabilitation program for athletes. We hypothesized that immediate dual-task training would alter brain electrical activity patterns, reduce pain severity, and improve FADI scores compared with a control group. This study provides evidence to inform the design of rehabilitation strategies that address both neural and musculoskeletal components.

Methods

Study design and participants

This study was designed as a single-blind, randomized controlled clinical trial. A total of 44 male and female young athletes with chronic ankle instability, aged 18–25 years, participated in the study. Participants were voluntarily recruited and randomly allocated into two groups—the dual-task training group and the control group—using random number generation software. the minimum required sample size was calculated using G*Power software version 3.1.9.2. The effect size was set at 0.80 based on Cohen's conventional criteria for a large effect size and supported by findings from previous studies with similar methodologies and outcome measures. The significance level was considered at $\alpha = 0.05$, and the statistical power was set at 0.95 (16). A total of 108 male and female athletes with chronic ankle instability were initially screened for eligibility. Of these, 47 participants were excluded for failing to meet the predefined inclusion and exclusion criteria. An additional 17 participants were excluded due to noncompliance with the rehabilitation protocol. Ultimately, 44 individuals who met all criteria were included in the study as the final sample. The dual-task training group consisted of 22 participants (9 females, 13 males), while the control group included 22 participants (8 females, 14 males) (Figure 1).

Participants were included in the study based on specific, evidence-based criteria. Inclusion criteria required a history of lateral ankle sprain within the past 12 months, accompanied by symptoms such as pain, swelling, or limitation in physical activity lasting at least one day. Participants were also required to engage in regular physical activity, defined as participation in sports at least three times per week for a minimum of 30 minutes per session. Additional inclusion criteria included a score of less than 24 on the Cumberland Ankle Instability Tool (CAIT) and less than 5 on the Ankle Instability Questionnaire (AIQ). Furthermore, participants were required to report at least two episodes of ankle "giving way" or instability within the six months preceding the evaluation. These criteria were established based on evidence and guidelines from the International Ankle Consortium [18, 17]. Participants were excluded from the study if they presented with severe structural abnormalities of the lower limbs, experienced significant musculoskeletal pain within the six months prior to study initiation, had a history of serious injuries to other parts of the lower limbs, or a history of fractures or surgical interventions in the lower extremities. Individuals with medical conditions that could potentially influence study outcomes or the implementation of the intervention, such as diabetes, mild brain injury, or other relevant disorders, were also excluded. Additionally, female participants were excluded if they were in the menstruation phase at the time of testing. [20, 19]. All inclusion and exclusion criteria were reviewed and approved by an orthopedic specialist prior to study initiation. In addition, participants received a comprehensive explanation of the study objectives and methodology, and written informed consent was obtained from all volunteers. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (2008), and ethical approval was obtained from the university's ethics committee (Ethics Code: IR.BASU.REC.1404.032).

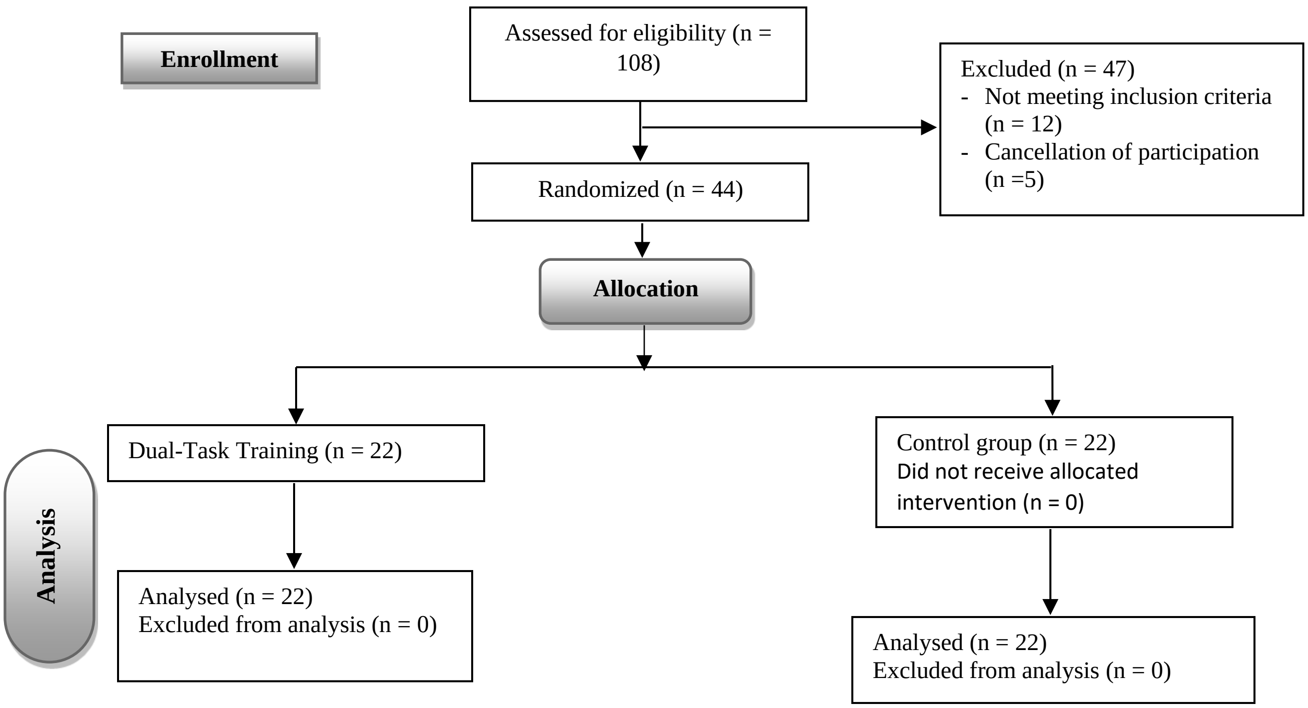

Figure 1. The subjects' CONSORT flow diagram.

Brain electrical activity

To assess brain electrical activity in athletes with chronic ankle instability (CAI), a 19-channel electroencephalography (EEG) system (Medina Teb Company, Iran) was employed. EEG signals were recorded using Neurosees software by a clinical neurology specialist with approximately 14 years of experience. Participants were instructed to abstain from caffeine and smoking on the night prior to testing to minimize potential effects on brain activity. Before placing the EEG cap, participants' hair was washed and thoroughly dried. The right and left earlobes were cleaned with alcohol, and conductive gel was applied prior to attaching the reference and ground electrodes. After fitting the EEG cap, the neurology specialist ensured electrode impedance was maintained below 10 Ω. During testing, participants initially stood with weight evenly distributed on both feet; the test then proceeded starting with the injured leg. Athletes were instructed to maintain balance for 20 seconds while EEG signals were recorded. If a participant shifted the non-tested foot to the ground or lost balance entirely, the trial was stopped and repeated. A rest period of 5 minutes was provided between each trial. Each test was performed three times, and the mean values were used for statistical analysis. Raw EEG data were stored within the recording software and subsequently imported into EEGLAB for preprocessing. The data were filtered using a 48–52 Hz notch filter to eliminate electrical noise. Artifacts caused by eye blinking and muscle activity were identified and removed by an experienced specialist. The power of theta (4–8 Hz), alpha (8–13 Hz), and beta and hight beta (14–25 Hz) frequency bands was analyzed at the occipital electrode site O1 and O2. Given the critical role of visual input in postural control and balance regulation, occipital EEG activity recorded from O1/O2 was analyzed to examine visual processing–related contributions to balance performance and specifically, growing evidence demonstrates that postural control under dual-task conditions extends beyond sensorimotor regions and includes visual cortical involvement (23,21,22) (Figure 2).

Figure 2. Brain electrical activity

Data analysis

Continuous EEG data were imported from EDF files and preprocessed before analysis. Raw signals were bandpass-filtered between 1 and 42.5 Hz, and a 50 Hz notch filter was applied to remove line noise. Independent component analysis (ICA) was used to identify and remove up to two artifact components (e.g., ocular or cardiac), with a maximum of 30 components estimated. Power spectral density (PSD) was computed using Welch's FFT on channels Fz, Cz, C3, C4, Pz, P3, P4, POz, O1, and O2, covering Theta (4–8 Hz), Alpha (8–12 Hz), Beta (13–30 Hz) bands. For recordings shorter than the default Welch window length, segment length and overlap were adjusted to maintain valid PSD estimates.

Foot and ankle disability questionnaire (FADI)

Activities of daily living and sports-related activities. It consists of 34 items, including 4 items specifically addressing pain. The daily activities subscale contains 22 items, while the sports subscale comprises 8 items. Participants respond to each item based on their experiences over the past week, using a 5-point scale: 4 = no functional impairment, 3 = mild functional impairment, 2= moderate functional impairment, 1 = severe functional impairment, and 0 = inability to perform the activity. The total possible score is 120, with lower scores indicating greater levels of foot and ankle disability (23).

Assessment pain severity

Pain severity was measured using a 10-centimeter visual analog scale (VAS). Participants were asked to rate their pain over the past week. A score of 0 represented no pain, 1–3 indicated mild pain, 4–6 indicated moderate pain, and 7–10 indicated severe pain. The VAS has demonstrated good internal consistency, with reliability estimates ranging from 0.85 to 0.95 (24).

Immediate effects of dual-task training

Each athlete performed neuromuscular exercises combined with a cognitive load for 30 minutes. The neuromuscular component included five movements: (1) bending over the injured leg on an unstable surface, (2) standing on tiptoes, (3) single-leg balance with eyes open and closed, (4) high-knee walking in a runner's knee position, and (5) jumping and landing. During these exercises, a cognitive load was simultaneously introduced (6) Toe walk. Four-digit numbers were played randomly through a loudspeaker, and participants were instructed to recite the numbers backward while performing the exercises. Additionally, two-digit numbers were presented for arithmetic operations (multiplication and division), which participants were required to solve while maintaining balance. The 30-minute training session was structured so that the cognitive load increased progressively: at the beginning of the session, participants performed backward recall of two-digit numbers, which gradually progressed to three- and four-digit numbers by the end of the session. This dual-task approach was designed to challenge both neuromuscular control and cognitive processing concurrently. The control group, after completing the pretest, spent 30 minutes in the laboratory performing their personal activities. They did not engage in the training exercises and did not observe the dual-task training group (Figure 3) (26,25).

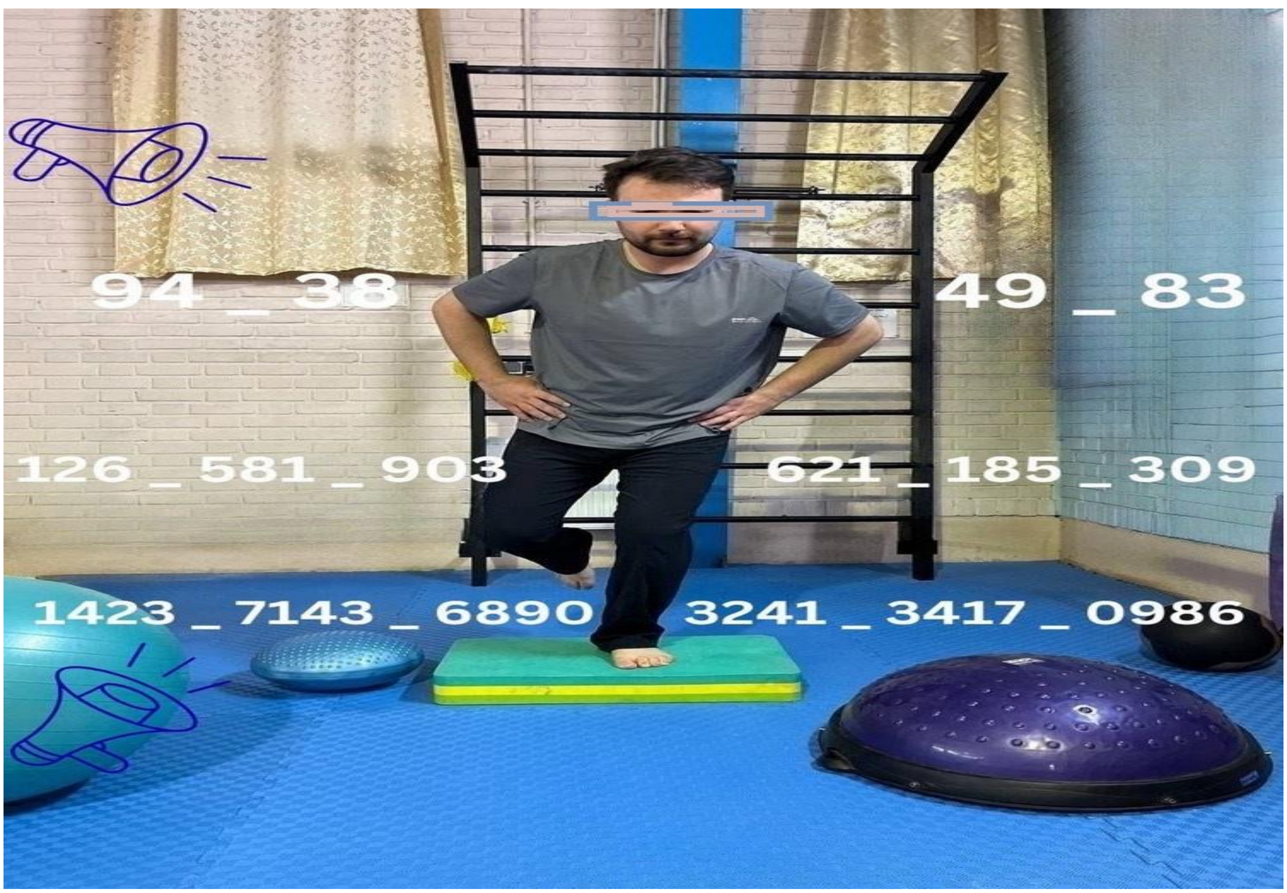

Figure 2. Immediate effects of dual-task training

Statistical analysis:

The Shapiro–Wilk test was used to assess the normality of demographic variables and dependent measures, including brain electrical activity, foot and ankle disability, and pain intensity ($P \geq 0.05$). Within-group changes from pre-test to post-test were evaluated using paired t-tests, while between-group differences were examined using one-way analysis of covariance (ANCOVA) Assumptions of ANCOVA, including normality of residuals and homogeneity of regression slopes, were checked met and to control for the increased risk of type I error associated with multiple comparisons across eight dependent variables (six EEG bands, pain intensity, and FADI score), Bonferroni correction was applied. Accordingly, the adjusted significance threshold was set at $\alpha = 0.00625$.

effect sizes were interpreted using partial η^2 (η^2_p) according to conventional benchmarks: 0.01 = small, 0.06 = medium, and 0.14 = large (Cohen, 1988). All statistical analyses were performed using SPSS version 20 with a significance level set at 0.05.

Results

The demographic characteristics of the participants are presented in Table 1. Data normality was assessed using the Shapiro-Wilk test, which indicated a normal distribution for all variables in both groups ($P>0.05$). Independent samples t - tests were used to compare demographic variables and baseline (pre-test) values of the dependent variables between the two groups, and no significant differences were observed ($P>0.05$; Table 1). Therefore, considering the normality of the data distribution, paired t-test and analysis of covariance were used to analyze the data. A Significance level of statistical results was considered in ($P<0.05$) and was used to analyses the data. The results of the paired t-test indicated significant differences between the pre- and post-test for the (dual-task training group) brain electrical activity O1 indices—theta, alpha, and beta waves ($P<0.001$). In contrast, no significant changes were observed in the control group ($P \geq 0.05$). The results of the ANCOVA test indicated a medium effect size, significant difference in the increase in Beta Wave Power O1 between the (Dual-Task training group and Control group) ($P \leq 0.001$, $\eta^2_p = 0.702$). Similarly, alpha wave power showed an initial difference ($P = 0.017$, $\eta^2_p = 0.181$), which did not retain significance after correction (adjusted $P>= 0.006$). Moreover, the analysis of the covariance test indicated a large effect size, significant difference in the decreased in Theta Wave Power O1 between the (Dual-Task training group and Control group) ($P \leq 0.001$, $\eta^2_p = 0.838$). The results of the paired t-test indicated significant differences between the pre- and post-test for the (dual-task training group) brain electrical activity O2 indices—theta, alpha, and beta waves ($P<0.001$). In contrast, no significant changes were observed in the control group ($P \geq 0.05$). The results of the ANCOVA test indicated a large effect size, significant difference in the increase in Beta Wave Power O2 between the (Dual-Task training group and Control group) ($P \leq 0.001$, $\eta^2_p = 0.898$). Similarly, the results of the ANCOVA test indicated a small effect size significant difference in the alpha wave power O2 between the (Dual-Task training group and Control group) ($P = 0.021$, $\eta^2_p = 0.162$), which was no longer significant after correction (adjusted $P>0.006$). Moreover, the ANCOVA test indicated a medium effect size, significant difference in the decreased in Theta Wave Power O2 between the (Dual-Task training group and Control group) ($P \leq 0.001$, $\eta^2_p = 0.838$) (Table 2).

The results of the paired t-test exhibited significant differences between the pre- and post-test for the (dual-task training group) Pain ($P<0.001$). In contrast, no significant changes were observed in the control group ($P \geq 0.05$). The results of the ANCOVA test indicated a medium effect size significant difference in the Pain intensity between the (Dual-Task training group and Control group) ($P \leq 0.001$; η^2_p:0.493). No significant within-group changes in lower limb and ankle functional disability were observed from pre-test to post-test in either the control group or the dual-task exercise group ($P \geq 0.05$). Similarly, ANCOVA adjusting for pre-test scores, revealed no significant between-group differences in leg and ankle disability following the intervention ($P \geq 0.05$, $\eta^2_p = 0.055$) (Table 2). Only comparisons with $P < .00625$ were considered statistically significant, based on Bonferroni correction. Given the number of outcome variables and repeated comparisons, we acknowledge the increased risk of Type I error, even with Bonferroni correction. To mitigate this, we have focused the interpretation on the strongest and most consistent effects, particularly those with both high statistical significance and large effect sizes. Although several comparisons yielded large effect sizes ($\eta^2_p > 0.80$), these values should be interpreted with caution. The magnitude of partial eta squared may be influenced by the study design (pre–post repeated measures), relatively low within-group variability, and the homogeneous nature of the sample. Therefore, these large statistical effects may not directly correspond to equally large clinical effects.

Table 1: Demographic characteristics of the participants and independent t-test (N=27 male: N=17 women).

Variables	Dull-Task Training	Control group	P
Age	21.35±2.51	21.64±3.08	**0.751**
Height	172.32±5.34	171.28±5.11	**0.286**
Weight	71.30±10.52	70.23±10.03	**0.485**
BMI	22.32±2.41	21.14±2.44	**0.523**
Theta wave O1	2.97±0.17	2.91±0.28	**0.658**
Alpha wave O1	2.05±0.09	2.02±0.19	**0.267**
Beta wave O1	1.31±0.22	1.34±0.25	**0.425**
Theta wave O2	3.12±0.21	3.10±0.26	**0.346**
Alpha wave O2	2.24±0.34	2.22±0.28	**0.665**
Beta wave O2	1.25±0.27	1.26±0.20	**0.287**
FADI	69.18±8.11	70.91±10.48	**0.395**
Pain	4.31±0.83	4.61±0.84	**0.215**

FADI; Foot and ankle disability index

Table 2. Results of the brain electrical activity, foot and ankle disability and pain severity

Indices	Group	Pretest	Posttest	Between-groups difference η^2 (P value) Control vs Dul-task training
Theta wave O1	Dul-task training	2.97±0.17	2.08±0.20[a]	0.838 L (<0.001)*
	Control	2.91±0.28	2.93±0.27	
Alpha wave O1	Dul-task training	2.05±0.09	2.06±0.52[a]	0.191 S (0.007)*
	Control	2.02±0.19	2.03±0.34	
Beta wave O1	Dul-task training	1.31±0.22	2.21±0.41 [a]	0.702 M (<0.001)*
	Control	1.34±0.25	1.41±0.52	
Theta wave O2	Dul-task training	3.12±0.21	2.29±0.29 [a]	0.794 M (<0.001)*
	Control	3.10±0.26	3.11±0.31	
Alpha wave O2	Dul-task training	2.24±0.34	2.26±0.19 [a]	0.181 S (0.004)*
	Control	2.22±0.28	2.22±0.23	
Beta wave O2	Dul-task training	1.25±0.27	2.29±0.41 [a]	0.898 L (<0.001)*
	Control	1.26±0.20	1.27±0.31	
FADI	Dul-task training	69.18±8.11	72.96±9.41	0.055 (P≥0.05)
	Control	70.91±10.48	71.13±8.39	
Pain	Dul-task training	4.31±0.83	3.59±0.54 [a]	0.498 M (<0.001)*
	Control	4.61±0.84	5.04±0.68	

*Indicates significant difference between study groups ($p < 0.05$), η^2 shows partial Eta squared, and [a] is $p<0.05$ for pretest vs. posttest.

Discussion

This randomised controlled clinical trial investigated the effect of acute dual-task training on brain electrical activity during balance on the injured leg, pain severity and FADI in athletes with CAI. We hypothesized that after immediate rehabilitation, brain electrical activity would power brain waves and reduce self-reported pain. A fteracute dual-task training, this led toa reduction in self-reported painand changes in beta brain wave power, including a decrease in theta brain wave power during single-leg balance. Therefore, the hypothesis proposed in this clinical trial was supported within the context of an inactive control condition. The findings of our study are consistent with previous similar clinical trials (25,27). Therefore, we suggest that dual-task training may have clinical relevance for improving central nervous system function in both male and female athletes, within the limitations of an inactive control group. It is worth noting that CAI is common in both male and female athlete groups (28). Meanwhile, we selected this research on male and female athletes with CAI**.**

Researchers have suggested that sensory dysfunction following lateral ankle sprains may contribute to the development of CAI (29). In contrast, more recent evidence indicates that CAI may not be solely a musculoskeletal disorder, but rather a neurophysiological condition associated with asymmetries in neural processing (30). Previous studies have reported that neuroimaging findings in individuals with chronic ankle instability (CAI) indicate a reduction in motor cortex representation (31). Additionally, CAI has been associated with microstructural alterations in white matter and a decrease in gray matter volume (30). These neural changes appear to be closely related to impairments in proprioception and balance (32). More recently, researchers have suggested that rehabilitation protocols should consider the recovery capacity of the central nervous system as a key factor in mitigating such damage (31). Emerging evidence indicates that individuals with balance disorders exhibit disrupted neural coordination, as reflected by alterations in brain wave activity. Specifically, increased theta wave activity—typically associated with drowsiness and reduced levels of consciousness—has been observed in the occipital regions (O1 and O2). Conversely, beta wave activity, which is commonly linked to complex motor tasks and cognitive processing such as mathematical problem solving, appears to be reduced (33). Appropriate modulation of brain wave activity appears to induce adaptive changes within the central nervous system (34). Rosen et al. (2020) proposed that individuals with chronic ankle instability (CAI) may exhibit substantial cognitive impairments, which contribute to asymmetries in brain wave activity (20). Motor–cognitive dual-task exercises have been suggested as a potential approach for improving neurophysiological dysfunctions associated with CAI (25). Such exercises may effectively simulate the demands encountered by athletes with this condition during real-world sporting and daily activities (26). Research grounded in cognitive load theory has reported that simultaneous performance of two tasks elicits greater central nervous system activity, with increased cognitive engagement across both the left and right cerebral hemispheres under challenging conditions (27). This heightened neural engagement may facilitate improved processing of complex information, faster responses to injury-related situations, and enhanced automatic motor control (1). Accordingly, immediate dual-task protocols that integrate neuromuscular and cognitive demands may be applied prior to sport participation, as they appear to influence central nervous system function and proprioceptive performance.

Chronic musculoskeletal conditions such as CAI are commonly associated with pain and functional limitations (35). Although pain intensity has received relatively limited attention in the CAI literature, pain may persist even in the absence of ongoing peripheral nociceptive input, potentially as a result of synaptic plasticity and neural network remodeling at multiple levels of the nervous system—a phenomenon often referred to as pain centralization (36). Previous studies have reported that approximately 60% of individuals with CAI experience increased pain intensity following physical activity or sports participation (35). More recent evidence suggests that pain intensity in individuals with CAI is associated with fear of movement, CAI severity scores, and functional performance (37). Pain is a psychological factor that has been shown to impair cognitive functioning within the brain (35). Attention to pain intensity is therefore considered an important component in the rehabilitation of individuals with chronic ankle instability (CAI). Alshahrani et al (2024) Pain has been reported to negatively affect ankle proprioception and sensorimotor function and is also believed to contribute to muscle weakness and functional disability, underscoring the clinical relevance of pain intensity in CAI rehabilitation (38). Dual-task exercises that simultaneously incorporate neuromuscular and cognitive demands may modulate attentional focus toward external performance, potentially engaging similar mechanisms within the central nervous system (39). One potential benefit of this rehabilitation protocol is its capacity to enhance cognitive functioning within the central nervous system. Neuromuscular training primarily aims to improve motor control through the retraining of muscle activation patterns, strengthening of functional movements, and optimization of motor strategies (1). In contrast, although cognitive training does not directly target the peripheral nervous system, it may enhance central processing and central nervous system efficiency, thereby indirectly facilitating efferent neural pathways and improving proprioceptive function (34).

limitations

activity using advanced neuroimaging techniques is warranted. Second, EEG recordings were limited to static balance tasks, which may not fully reflect neural control during dynamic or sport-specific activities. Although fatigue was accounted for, the single-session design, relatively short intervention duration, and lack of an active control group limit the generalizability of the findings. Third, the unequal gender distribution and lack of analyses stratified by gender, as well as the lack of correction for multiple comparisons, should also be considered. Fourth, despite the observation of large effect sizes, particularly for theta wave activity, these findings should be interpreted with caution. The magnitude of partial eta squared may be influenced by methodological factors such as the repeated-measures design, reduced within-group variability, and the relatively homogeneous sample. Furthermore, the present study assessed only acute responses following a single session; therefore, the clinical relevance and long-term implications of these findings remain uncertain. Finally, the long-term durability of the observed effects was not assessed. Future studies should include multi-session designs, dynamic tasks, appropriate statistical corrections, and longer follow-up periods

Conclusion

The results of this study indicate that dual-task training can enhance brain electrical activity in the O1 and O2 regions and reduce pain intensity. Given that improvements in several outcome measures were observed with large effect sizes, incorporating these exercises into daily rehabilitation routines may promote central nervous system function in individuals with chronic ankle instability (CAI). Therefore, dual-task training may serve as a valuable complementary component within rehabilitation protocols for CAI.

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Authors' contributions

MA and AY contributed equally to this work. Both authors were involved in the study design, acquisition of data, statistical analysis, interpretation of the results, and drafting and revising the manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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