

Original Article

Alterations in Ankle Eversion-to-Inversion Muscle Strength and Postural Control in Individuals with Chronic Lateral Ankle Instability

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Abstract

Objective: This study examined alterations in ankle eversion/inversion strength and postural control in chronic lateral ankle instability (CLAI). **Methods:** Twenty-three CLAI patients and 14 matched controls underwent isokinetic strength testing at 30°/s, 60°/s, and 90°/s (peak torque/body weight: PT/BW). Postural control was assessed via center-of-pressure (COP) trajectory length and peripheral area during eyes-open and eyes-closed single-leg stance. **Results:** The CLAI group demonstrated significantly lower eversion PT/BW across all angular velocities versus controls ($p < 0.05$). Inversion PT/BW was not significantly different for the group effect ($p > 0.05$). The eversion-to-inversion strength ratio was consistently lower in CLAI ($p < 0.05$). No between-group differences in COP metrics occurred during eyes-open stance ($p > 0.05$). However, with eyes closed, the CLAI group exhibited significantly longer COP trajectory [107.52 (94.90, 118.70) cm vs. 93.75 (83.09, 95.25) cm] and larger peripheral area [8.34 (5.73, 12.90) cm² vs. 5.92 (5.05, 6.88) cm²] ($p < 0.05$). **Conclusions:** CLAI is characterized by eversion muscle weakness and an impaired eversion-to-inversion strength ratio. Postural control deficits manifest primarily under visual deprivation, suggesting proprioceptive impairment, though visual input enables partial compensation during eyes-open conditions.

Keywords: Ankle Joint, Chronic Lateral Ankle Instability, Eversion Muscle Strength, Inversion Muscle Strength, Peak Torque/Body Weight Ratio

Introduction

Ankle sprains are among the most prevalent lower limb sports-related injuries, particularly in physically active populations such as athletes and military personnel¹. In the

United States, approximately 2 million acute ankle sprains occur annually, affecting about 2 to 7 cases per 1,000 individuals¹. A high recurrence rate is associated with acute ankle sprains, contributing to the onset and progression of chronic lateral ankle instability (CLAI)². Previous studies have reported that approximately 40% of individuals with acute lateral ankle sprains develop CLAI³, with some studies indicating a progression rate of up to 70%⁴. Multiple factors contribute to the development of CLAI, including inadequate or inappropriate management following the initial injury⁵, weakening of peri-ankle musculature⁶, and impairments in proprioception and balance control⁷. CLAI may result in persistent symptoms such as ankle swelling, pain, limited range of motion, and decreased athletic performance, all of which can significantly diminish quality of life.

The authors have no conflict of interest.

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Edited by: G. Lyritis

Accepted 20 October 2025



In recent years, advances in sports and rehabilitation medicine have focused increasing attention on the pathophysiological mechanisms and therapeutic strategies for CLAI. Restoration of peripheral ankle muscle strength and proprioceptive function has emerged as a primary objective in treatment protocols. However, discrepancies persist in the literature regarding the specific patterns of muscular impairment in individuals with CLAI, particularly concerning eversion and inversion muscle strength⁸. For instance, Bosien et al. reported significant weakness in eversion strength among individuals with CLAI⁹. However, Park et al. emphasized the role of inversion muscle strength deficits in the condition⁸. Proprioceptive deficits, a common finding in individuals with CLAI, are critical contributors to impaired postural stability. Current research exploring postural control in this population remains limited, especially with respect to the role of visual input in modulating balance^{10,11}.

This study aims to investigate the specific characteristics of ankle eversion and inversion muscle strength, as well as postural control, in individuals with chronic lateral ankle instability (CLAI). The findings are intended to support clinical decision-making and facilitate the evaluation of treatment outcomes. The researchers hypothesize that: (1) eversion muscle strength and the eversion-to-inversion muscle strength ratio are significantly lower in individuals with CLAI compared to healthy controls; and (2) postural control is impaired in individuals with CLAI, particularly under visual deprivation, but may improve with the availability of visual input.

Materials and Methods

Research Participants

Individuals with CLAI

Inclusion criteria were as follows: (1) A history of at least two ipsilateral ankle inversion sprains, with the first sprain occurring at least 12 months prior to enrollment in this study and no recurrence within the preceding three months¹²; (2) Presence of pain, swelling, or a feeling of “instability” in the affected ankle; (3) A score less than or equal to 25 points on the Cumberland Ankle Instability Tool (CAIT)¹³, as a fully validated local-language CAIT version is unavailable, we took “Forward and Back-Translation” to ensure the understanding and validity of the scale: A Chinese sports medicine expert proficient in English translated the original English version of CAIT into Chinese. Subsequently, an independent bilingual translator who was not familiar with the original scale translated the Chinese version back into English. The research team compared the back-translated version with the original version, discussed and modified the ambiguous items until consensus was reached; (4) Willingness to participate in the study and provision of signed informed consent.

Exclusion criteria were as follows: (1) Prior lower limb surgery or significant traumatic injury; (2) Bilateral ankle instability; (3) Neurological disorders affecting

lower limb function, weight-bearing capacity, or balance; (4) Active ankle swelling or pain that precluded completion of isokinetic muscle strength or plantar pressure testing; (5) Ankle instability caused by other foot and ankle pathologies.

Between August 2023 and December 2024, a total of 30 individuals with CLAI were screened. Among them, 3 were excluded due to a history of lower limb trauma or surgery, two due to bilateral ankle joint instability, and 2 due to current ankle symptoms that prevented completion of tests. Ultimately, 23 participants met the inclusion criteria and were enrolled in this study to form the CLAI group (Figure 1). The cohort included 19 males and 4 females, aged 20 to 38 years, with a mean age of 24.48 ± 4.75 years, and a mean body mass index (BMI) of 22.70 ± 1.11 kg/m².

Healthy Controls

A total of 14 healthy individuals, matched to the participants in the CLAI group for age and sex, were recruited to form the control group. Inclusion criteria for the control group included absence of lower limb joint pain, movement disorders, previous trauma or surgical history, and no history of ankle sprain.

Statistical Indicators

Main indicators: eversion-to-inversion strength ratio at 60°/s

Secondary indicators: trajectory length of center of pressure (COP) during eyes-closed single-leg stance, gender, age, BMI, tested limb, IPAQ-S score, Tegner score

Testing Process

Subject tests on limb selection

Strength-testing limb is the affected limb for CLAI group. In isokinetic strength testing and postural-control section, dominant/non-dominant of the designated limb in the control group was matched to that in the CLAI group. The dominant limb was determined by the ‘fall-back test’. During the test, the subject stands relaxed with feet together while a tester stands behind them. Without warning, the tester applies a brief, gentle push to the subject’s upper back, just enough to disrupt their balance. The subject’s instinctive response—specifically, the leg they first step backward with to regain stability—is identified as their stability-dominant limb.

Assessment of Postural Control Ability

Postural control ability was assessed using the FeetMapping plantar pressure measurement system (FANGYUE MEDICAL, Hunan, China), which recorded the total length of the plantar center of pressure (COP) trajectory in cm and the peripheral area in cm². The testing plate of the pressure measurement system is 60.5 cm in length 46.5 cm in width, with an effective sensing area of 30.5 cm × 36.5 cm. It contains 2,288 sensors and

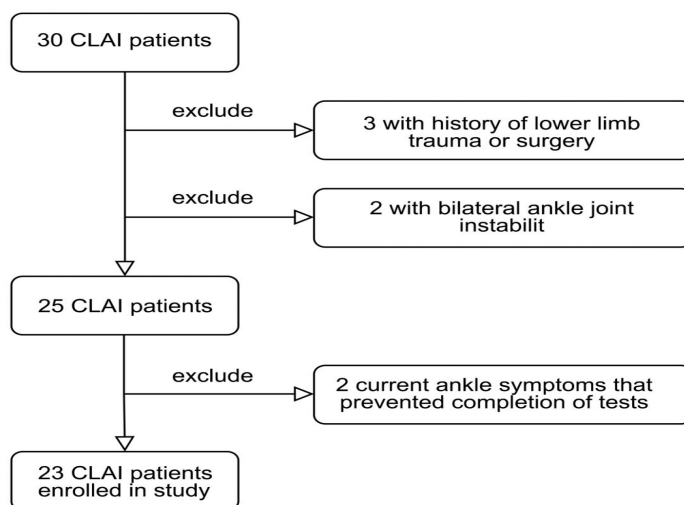


Figure 1. Inclusion flowchart for patients in the CLAI group.



Figure 2. Assessment of plantar pressure: Pre-test positioning.



Figure 3. Isokinetic muscle strength testing setup.

operates using the piezoresistive method and the sampling frequency is 140Hz.

Testing procedure: After completing system calibration and connection, participants were instructed to stand barefoot on the designated area of the pressure plate in a standardized position: heels close together, toes approximately 30° apart, arms at the sides, and gaze directed forward (Figure 2). In the CLAI group, participants were asked to lift the unaffected limb with the knee flexed at approximately 30° , maintaining balance on the affected limb. In the control group, the designated limb was lifted similarly, and balance was maintained on the other limb. All participants kept their arms at their sides and attempted to maintain a stable center of gravity. Upon observing stable single-leg stance, the examiner initiated the data acquisition sequence. The system recorded plantar pressure variations for 16 seconds during the single-leg stance and transmitted the data to a connected computer. The accompanying software automatically calculated the total COP trajectory length and the peripheral area. The peripheral area, or more standard name “ellipse area”, was defined as the 90% envelope area of the COP trajectory path, according to system specifications. Posturography was performed on the same limb defined under the section Subject tests on

limb selection (affected limb in CLAI; dominance-matched limb in controls).

Isokinetic Muscle Strength Test

Isokinetic testing is considered the gold standard for evaluating muscle strength and is widely used in clinical and research settings¹⁴. In this study, the isokinetic assessment of ankle eversion and inversion muscle strength was conducted using the Isoforce muscle strength testing system (TUR GmbH, Berlin, Germany), following completion of the postural control ability assessment¹⁵. Testing was performed in the concentric isokinetic mode at three angular velocities: $30^\circ/s$, $60^\circ/s$, $90^\circ/s$. The range of motion was set from 20° of inversion to 10° of eversion. Physical end-range stops were applied to ensure participant safety and consistency. Gravity correction was performed with the foot in a relaxed neutral position (0°). The dynamometer was calibrated according to the manufacturer's specifications prior to the study.

Testing procedure: Participants were seated in the testing chair with the hip flexed at 80° and the knee at 20° flexion. A support pad was placed below the distal femur, and the thigh was stabilized with a securing strap. The chair and dynamometer were adjusted so that the foot rested on

Table 1. General characteristics of study participants.

Group	Sex (Number of Cases)		Age (Years)	BMI (kg/m ²)	Side (Number of Cases)				IPAQ-S	Tegner scores
	Male	Female			Left	Right	Dominant side	Non-dominant side		
CLAI group	18	5	24.48±4.75	22.70±1.11	6	17	16	7	3958.91±627.03	6.48±0.51
Control group	9	5	24.29±4.98	22.52±1.16	6	8	9	5	4011.21±993.24	6.50±0.52
t / χ^2 value	0.862		0.117	0.492	1.117		0.111		-0.197	-0.125
P value	0.353		0.907	0.626	0.291		0.739		0.845	0.901

BMI: Body Mass Index. IPAQ-S: International Physical Activity Questionnaires scores.

the foot pedal, ensuring that the rotational axis of the dynamometer was aligned with the center of the calcaneus and that the hip, knee, and ankle were in a straight line. The foot was firmly secured to the pedal using the stabilizing strap (Figure 3). Prior to the formal test, participants completed 10 warm-up repetitions at an angular velocity of 120°/s to become familiarized with the concentric contraction mode and the inversion/eversion movement pattern. Submaximal practice repetitions (3-5 trials at 50-70% effort) at each testing angular velocity was completed as well. The formal tests then involved five consecutive maximal-effort repetitions through the full range of motion. Testing was conducted sequentially at angular velocities of 90°/s, 60°/s, and 30°/s, with a two-minute rest interval between each set to minimize fatigue. All testing procedures were performed by the same examiner to ensure consistency. The examiner was blinded to group and standardized verbal encouragement (e.g., “very good!” “Keep pushing!” “Push as hard as you can!”) was used. To standardize results across individuals, peak torque values were normalized to body weight and expressed as peak torque-to-body weight (PT/BW in Nm·kg⁻¹). Isokinetic testing used the same limb defined under the section Subject tests on limb selection.

Statistical Analysis

All statistical analyses were performed using SPSS software (version 22.0; IBM, Armonk, NY USA). Age, BMI, International Physical Activity Questionnaires scores (IPAQ-S) and Tegner scores are presented as mean ± standard deviation as data met assumptions of normality with Shapiro–Wilk test and homogeneity of variance with Levene test, and between-group differences were analyzed using independent

samples *t*-tests. Differences in sex, limb laterality (left/right), and limb dominance (dominant/non-dominant) were analyzed using the chi-squared (χ^2) test. As the total COP trajectory length and peripheral area did not meet the assumptions of normality with Shapiro–Wilk test, these data are expressed as medians, and differences between and within groups were analyzed using the Mann–Whitney U test. Eversion muscle strength, inversion muscle strength, and the eversion-to-inversion muscle strength ratio met assumptions of normality with Shapiro–Wilk test and homogeneity of variance with Levene test; thus, repeated measures analysis of variance (ANOVA) was applied. When appropriate, Bonferroni correction was used for pairwise comparisons. The assumption of sphericity was checked with Mauchly’s test, and if violated, the Greenhouse–Geisser correction was applied. A *p*-value of < 0.05 was considered statistically significant.

Results

General characteristics of participants

The CLAI group included 23 participants, and the control group included 14 participants. There were no statistically significant differences between the two groups in terms of sex, age, BMI, or side of the test limb (left/right or dominant/non-dominant), IPAQ-S scores, Tegner scores (*p* > 0.05) (Table 1).

Postural Control Assessment Results

During single-leg stance with eyes open, the total COP trajectory length in the CLAI group was greater than in the control group, although this difference did not

Table 2. Total length of COP trajectory during single-leg stance with eyes open and eyes closed (cm).

	Eyes Open	Eyes Closed	Z value	P value
CLAI group	66.78 (57.58, 76.15)	107.52(94.90, 118.70)	-4.198	<0.0001
Control group	59.44 (53.16, 78.40)	93.75 (83.09, 95.25)	-3.233	0.001
Z value	-0.720	-2.991		
P value	0.471	0.003		

Table 3. Peripheral area of COP trajectory during single-leg stance with eyes open and eyes closed (cm²).

	Eyes Open	Eyes Closed	Z value	P value
CLAI group	1.72 (1.01, 3.26)	8.34 (5.73, 12.90)	-4.197	<0.0001
Control group	1.86 (1.48, 2.12)	5.92 (5.05, 6.88)	-3.296	0.001
Z value	-0.344	-2.772		
P value	0.730	0.006		

Table 4. Eversion muscle PT/BW (Nm/Kg).

	30°/s	60°/s	90°/s	F (2,34) value	P value
CLAI group	0.33±0.12	0.31±0.10 a	0.30±0.09 a	6.90	0.003
Control group	0.49±0.08	0.44±0.07 a	0.46±0.07	27.02	<0.001
F(1,35) value	20.80	18.65	35.58		
P value	<0.001	<0.001	<0.001		

Note: (a) vs 30°/s, $p < 0.05$; (b) vs 60°/s, $p < 0.05$; All pairwise comparisons were corrected using Bonferroni correction.

reach statistical significance ($p > 0.05$). In contrast, under eyes-closed conditions, the CLAI group demonstrated a greater COP trajectory length compared to the control group ($p < 0.05$). Within-group comparisons revealed that in both the CLAI and control groups, the COP trajectory length was significantly greater during eyes-closed trials than during eyes-open trials ($p < 0.05$) (Table 2).

In a single-leg stance with eyes open, the peripheral area of the COP trajectory was slightly smaller in the CLAI group compared to the control group, but the difference was not statistically significant ($p > 0.05$). Under eyes-closed conditions, the CLAI group exhibited a significantly larger peripheral area than the control group, with a statistically significant difference ($p < 0.05$). Within-group comparisons showed that the peripheral area during eyes-closed stance was significantly larger than during eyes-open stance in both groups ($p < 0.05$) (Table 3).

Isokinetic Muscle Strength Test Results

At all tested angular velocities (30°/s, 60°/s, and 90°/s), the eversion PT/BW in the CLAI group was significantly lower than that observed in the control group, with statistically significant differences ($p < 0.05$) (Table 4). Group Effects: $F(1, 35) = 25.60$, $p < 0.001$, partial $\eta^2 = 0.42$; Velocity Effects: $F(1.44, 50.53) = 16.86$, $p < 0.001$, partial $\eta^2 = 0.33$; Group×Velocity Effects: $F(1.44, 50.53) = 3.69$, $p = 0.06$, partial $\eta^2 = 0.10$. Within-Subjects Effects partial $\eta^2 = 0.33$; Between-Subjects Effects partial $\eta^2 = 0.42$. (Eversion muscle PT/BW pairwise comparisons see to Supplementary Table S1).

For inversion muscle PT/BW, values in the CLAI group were lower than those in the control group at angular velocities of 30°/s and 60°/s; however, these differences were not statistically significant ($p > 0.05$). At 90°/s, the inversion PT/BW in the CLAI group was significantly lower

Table 5. Inversion muscle PT/BW (Nm/Kg).

	30°/s	60°/s	90°/s	F (2,34) value	P value
CLAI group	0.70±0.24	0.60±0.22 a	0.51±0.19 ab	31.81	<0.001
Control group	0.78±0.11	0.64±0.07 a	0.62±0.09 a	16.65	<0.001
F(1,35) value	1.28	0.49	4.26		
P value	0.265	0.487	0.047		

Note: (a) vs 30°/s, $p < 0.05$; (b) vs 60°/s, $p < 0.05$. All pairwise comparisons were corrected using Bonferroni correction.

Table 6. Eversion-to-inversion muscle strength ratio.

	30°/s	60°/s	90°/s	F(2,34) value	P value
CLAI group	0.49±0.10	0.54±0.11 a	0.62±0.14 ab	15.25	<0.001
Control group	0.63±0.040	0.68±0.05	0.75±0.05 ab	6.82	<0.001
F(1,35) value	26.12	18.48	10.46		
P value	<0.001	<0.001	0.003		

Note: (a) vs 30°/s, $p < 0.05$; (b) vs 60°/s, $p < 0.05$. All pairwise comparisons were corrected using Bonferroni correction.

than in the control group, with a statistically significant difference ($p < 0.05$) (Table 5). Group Effects: $F(1, 35) = 1.74$, $p = 0.20$, partial $\eta^2 = 0.05$; Velocity Effects: $F(1.61, 56.41) = 62.52$, $p < 0.001$, partial $\eta^2 = 0.64$; Group×Velocity Effects: $F(1.61, 56.41) = 2.19$, $p = 0.13$, partial $\eta^2 = 0.06$; Within-Subjects Effects partial $\eta^2 = 0.64$; Between-Subjects Effects partial $\eta^2 = 0.05$. (Inversion muscle PT/BW pairwise comparisons see to Supplementary Table S2).

The eversion-to-inversion muscle strength ratio was significantly reduced in the CLAI group compared to the control group at angular velocities of 30°/s, 60°/s, and 90°/s ($p < 0.05$) (Table 6). Group Effects: $F(1, 35) = 24.50$, $p < 0.001$, partial $\eta^2 = 0.41$; Velocity Effects: $F(1.70, 59.40) = 29.14$, $p < 0.001$, partial $\eta^2 = 0.45$; Group×Velocity: $F(1.70, 59.40) = 0.17$, $p = 0.81$, partial $\eta^2 = 0.005$; Within-Subjects Effects partial $\eta^2 = 0.454$; Between-Subjects Effects partial $\eta^2 = 0.41$. (Eversion-to-inversion muscle strength ratio pairwise comparisons see to Supplementary Table S3).

Discussion

The pathogenesis of CLAI is generally considered to involve two mechanisms: mechanical instability caused by ligament injury and functional instability caused by biomechanical dysfunction following repeated sprains. In 2019, Hertel further categorized the pathological mechanisms of CLAI into three major categories: mechanical abnormalities, sensory deficits, and motor impairments¹⁶. However, in clinical practice, distinguishing

mechanical instability from functional instability remains challenging. Gehring et al. observed motor dysfunction even in individuals with mechanical instability, while more recent evidence has identified mechanical damage to ligaments in cases typically classified as functional instability^{17,18}. Both functional and mechanical characteristics are often considered within the broader clinical construct of CLAI.

The underlying cause of impaired postural control in individuals with CLAI remains uncertain, but altered sensory information processing is considered a contributing factor. Postural control depends on the body's ability to maintain balance and stability, requiring not only appropriate efferent responses but also the integration of input feedback from visual, vestibular, and somatosensory systems. Static single-leg stance is a widely accepted method for assessing postural control ability, and force plate analysis of COP trajectory during such tasks is commonly employed in both clinical and research settings^{10,19}. In this study, the total length of the COP trajectory and the peripheral area—two standard metrics derived from the COP trace—were used to quantify postural control performance¹⁹.

The findings indicated no statistically significant difference in COP trajectory length or peripheral area between the CLAI group and control groups under eyes-open conditions. However, when visual input was removed (eyes closed), the CLAI group demonstrated significantly greater trajectory lengths and peripheral areas, indicating impaired postural control. These results suggest that individuals with CLAI may rely heavily on visual input to

compensate for underlying sensory or motor deficits. Although intrinsic postural control ability in the CLAI group appeared compromised, the provision of visual information enabled performance at levels comparable to healthy individuals. These findings are consistent with the results of a meta-analysis by Song et al., which reported that individuals with CLAI demonstrate reduced reliance on local somatosensory input and increased dependence on visual feedback during static single-leg tasks in order to approximate normal balance performance²⁰.

Ankle joint stability is maintained through the coordinated function of the inversion and eversion muscle groups, with the eversion group (such as peroneus longus muscle and peroneus brevis muscle) playing a key role in resisting inversion forces preventing sprains. Wilkerson et al. emphasized that co-activation of inversion and eversion muscle groups contributes significantly to dynamic ankle stability, and the eversion-to-inversion muscle strength ratio has been proposed as an important indicator in evaluating individuals with CLAI, a perspective supported by the current findings²¹. In this study, the eversion muscle PT/BW in the CLAI group was lower than in the control group across all angular velocities, with statistically significant differences. In contrast, inversion muscle PT/BW values were not significantly different between groups at 30°/s and 60°/s, with a significant reduction observed only at 90°/s in the CLAI group, and the group effect for inversion was not significantly different. Notably, the eversion-to-inversion muscle strength ratio was significantly reduced in the CLAI group at all tested velocities. These results indicate that eversion muscle weakness and imbalance between eversion and inversion muscle strength are important characteristics of CLAI. Findings from Cho et al. demonstrated reduced eversion strength and eversion-to-inversion strength ratio in individuals with CLAI compared to healthy controls, aligning with the presents results²². A lower eversion-to-inversion ratio may compromise dynamic ankle stability and increase the risk of recurrent injuries. Pearce et al. emphasized the importance of strengthening peroneal muscles in rehabilitation strategies for CLAI to restore ankle joint stability, an approach further supported by the current data²³. However, variability in findings across studies may be attributed to differences in inclusion criteria, joint positioning during testing²⁴, angular velocity, contraction modes, and testing protocols. Lentell et al.²⁵ reported no significant reduction in peroneal strength among individuals with CLAI and questioned the role of muscle weakness as a primary contributor. In contrast, other studies have suggested that deficits in inversion strength may be more closely associated with the development of CLAI^{8,21}. Further research is warranted to clarify the specific patterns of peri-ankle muscle strength impairment in CLAI and to explore their relationship with the progression and recurrence of instability.

While Bonferroni corrections were applied to control for Type I error within sets of pairwise comparisons for each individual outcome, no further alpha adjustment

was performed across the different outcome families. This approach increases the risk of inflation of the family-wise error rate. Therefore, the findings regarding these individual outcomes, particularly those with p-values approaching the significance threshold (e.g., p-values between .01 and .05), should be interpreted as exploratory rather than confirmatory and considered in the context of the entire pattern of results, including effect sizes and their confidence intervals. Future studies with pre-specified primary outcomes could employ stricter alpha correction procedures (e.g., Bonferroni-Holm) to confirm these observations.

The findings of the present study, while not directly testing rehabilitation outcomes, carry important implications for clinical practice. The identified isokinetic strength deficits, particularly in eversion peak torque and the eversion-to-inversion strength ratio across velocities, suggest a potential target for intervention. A logical progression in rehabilitation may involve implementing targeted strengthening of the peroneal muscles through their full range of motion at varying velocities, as deficits were consistent regardless of speed. Furthermore, as dynamic joint stability is a complex interplay between strength and neuromuscular control, our findings support the integration of such strength training with challenging proprioceptive and neuromuscular training paradigms. This combined approach, directly addressing the deficits quantified here, could be considered for developing more effective prevention and rehabilitation programs for individuals with CLAI. Future research should directly investigate the efficacy of rehabilitation protocols designed based on these specific biomechanical profiles.

This study has several limitations. First, the sample size was relatively small and primarily composed of young people, predominantly male, and that limits the generalizability of the conclusions. Second, due to the limited sample size, the study did not examine the relationship between ankle periarticular muscle strength and postural control ability in individuals with CLAI. Future research with a larger and more diverse sample is warranted to explore the potential correlation between muscle strength deficits and balance control impairments in this population. Third, this study is that it did not use validated patient-reported outcome measures such as the Foot and Ankle Ability Measure (FAAM) and its sport subscale (FAAM-Sport) to more comprehensively capture the participants' perceived functional limitations and quality of life impacts. Future studies should integrate these tools to provide a more comprehensive functional assessment. Fourth, we could not find relevant research literature on Isoforce for ankle tasks, so we are unable to provide reliability data for ankle inversion/eversion with this system. Fifth, many balance studies use 20 to 30 seconds, but the time for the single-leg standing balance test in our system is fixed at 16 seconds. Therefore, there may be significant differences in the test results compared with other literature. This point should be

taken into consideration when applying the conclusions of this study. Sixth, the constant speed tests in this study were conducted in a fixed order from high speed to low speed, although this design is based on safety and fatigue reduction, it cannot completely rule out the possibility of learning effects as a potential confounding factor. However, the lack of significant interaction between groups and speed suggests that any potential order effects may have affected both groups equally, thus unlikely to alter our main conclusion about group differences. Future studies could further validate these findings by using randomized or balanced test orders. Seventh, because a validated language version of the CAIT is unavailable, we conducted forward–back translation by bilingual clinicians, resolved discrepancies by consensus. We recognize the absence of a formally validated local version as a limitation.

Conclusion

Individuals with CLAI demonstrate eversion muscle weakness and a reduced eversion-to-inversion muscle strength ratio, indicating that insufficient eversion muscle strength may associate with the pathophysiology of CLAI. Postural control ability in this population is notably impaired under conditions of reduced visual input (eyes closed), suggesting that deficits in proprioceptive function may contribute to balance instability. However, the ability to utilize visual information enables partial compensation for these deficits, allowing individuals with CLAI to achieve near-normal postural control under eyes-open conditions.

Ethics approval

The study was conducted in accordance with the Declaration of Helsinki (as was revised in 2013). The study was approved by Ethics Committee of the Beidaihe Rest and Recuperation Center of the Joint Logistics Support Force of PLA (No. BL20-25-005-02).

Consent to participate

Written informed consent was obtained from all participants.

Authors' contributions

Wei-Chuang Cai: Conception and design of the research, Acquisition of data, Writing of the manuscript. Xiao-Bing Cai: Conception and design of the research, Analysis and interpretation of the data. Yue-Zhen Liang: Acquisition of data, Analysis and interpretation of the data. Wen-Shuang Cao: Acquisition of data, Critical revision of the manuscript for intellectual content. Zhi-Ning Zhang: Statistical analysis, Critical revision of the manuscript for intellectual content. Wen-Zhen Shao: Statistical analysis, Critical revision of the manuscript for intellectual content. Yong Zhang: Analysis and interpretation of the data, Statistical analysis, Critical revision of the manuscript for intellectual content. All authors read and approved the final version of the manuscript.

Acknowledgements

We are particularly grateful to all the people who have given us help on our article.

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Supplementary Table S1. Eversion muscle PT/BW pairwise comparisons.

Groups	Subgroups	mean difference	95% CI up	95% CI low	t	p	Cohen's d
CLAI group	30°/s vs 60°/s	0.02	0.01	0.04	4.00	0.002	0.22
	30°/s vs 90°/s	0.03	0.01	0.06	3.18	0.012	0.33
	60°/s vs 90°/s	0.01	-0.01	0.03	1.22	0.64	0.12
Control group	30°/s vs 60°/s	0.06	0.04	0.08	7.00	<0.001	0.69
	30°/s vs 90°/s	0.03	-0.01	0.07	2.21	0.12	0.30
	60°/s vs 90°/s	-0.03	-0.05	0.003	-2.27	0.09	-0.25

Supplementary Table S2. Inversion muscle PT/BW pairwise comparisons.

Groups	Subgroups	mean difference	95% CI up	95% CI low	t	p	Cohen's d
CLAI group	30°/s vs 60°/s	0.10	0.06	0.15	5.42	<0.001	0.45
	30°/s vs 90°/s	0.19	0.13	0.25	8.04	<0.001	0.90
	60°/s vs 90°/s	0.09	0.056	0.13	5.63	<0.001	0.44
Control group	30°/s vs 60°/s	0.14	0.08	0.20	5.67	<0.001	1.49
	30°/s vs 90°/s	0.16	0.08	0.24	5.16	<0.001	1.63
	60°/s vs 90°/s	0.02	-0.03	0.07	1.15	0.79	0.28

Supplementary Table S3. Eversion-to-inversion muscle strength ratio pairwise comparisons.

Groups	Subgroups	mean difference	95% CI up	95% CI low	t	p	Cohen's d
CLAI group	30°/s vs 60°/s	-0.05	-0.10	-0.01	-3.24	0.01	-0.51
	30°/s vs 90°/s	-0.13	-0.20	-0.07	-5.63	<0.001	-1.14
	60°/s vs 90°/s	-0.08	-0.13	-0.03	-4.21	<0.001	-0.62
Control group	30°/s vs 60°/s	-0.05	-0.10	0.01	-2.09	0.13	-1.06
	30°/s vs 90°/s	-0.12	-0.19	-0.04	-3.71	0.002	-2.62
	60°/s vs 90°/s	-0.07	-0.13	-0.01	-2.88	0.02	-1.49