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An Examination Of Gluteal Complex Strength And Unipedal Equilibrium In Runners With Persistent Ankle Instability: A Cross-Sectional Investigation

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Abstract
Purpose: *This investigation sought to delineate the association between gluteal complex musculature strength and single-leg stance equilibrium capabilities in runners afflicted with chronic ankle instability (CAI), in contrast to a cohort of healthy runners.*
Methods: *The study cohort comprised 16 participants diagnosed with CAI and 18 healthy runners. Hip Stability Isometric Test (Hip SIT) and Star Excursion Balance Test (SEBT) protocols were employed for participant assessment. Statistical analyses were executed to ascertain disparities in Hip SIT and SEBT scores between the two groups and to elucidate correlations between muscular strength and equilibrium capacity.*
Results: *No statistically significant variations were observed in Hip SIT and SEBT (F, PM, PL) scores when comparing the CAI and healthy runner cohorts (P=.729; P=.636; P=.675; P=.401). Correlation analysis indicated an absence of significant relationships between Hip SIT and SEBT-F or SEBT-PL (r=.151,P>.05; r=.277,P>.05). However, a moderate correlation was identified between Hip SIT and SEBT-PM (r=.344,P<.05).*
Conclusion: *This study furnishes fundamental insights for the development of rehabilitative and training regimens tailored for runners experiencing ankle instability. The findings underscore the critical role of gluteal complex strength in specific facets of equilibrium maintenance. Future scholarly endeavors should consider augmenting sample sizes and integrating additional variables to enrich the comprehension of rehabilitation program design aimed at mitigating recurrence and fostering recuperation in individuals with chronic ankle instability.*
Key words: *CAI, SEBT, Hip-SIT*

I. INTRODUCTION

The prevalence of musculoskeletal (MSK) symptoms continues to rise due to population aging, changing lifestyles, and increased screen time leading to VDT (Visual Display Terminal) syndrome. While regular visits to healthcare providers are recommended for managing MSK disorders, access issues and time constraints often result in inadequate treatment and chronicity. Although various consumer-grade wearable devices (e.g., TENS units, massage tools, heat stimulators) have been developed, most provide only superficial relief and fall short in addressing the root causes of MSK symptoms.

Recent studies report that up to 37% of individuals experience plantar fasciitis at some point in their lives (Khired et al., 2022). Repeated impact on the plantar fascia can result in cumulative stress on the calcaneus, gradual degradation of the heel pad, and onset of pain, joint cartilage degeneration, and arthritis. MSK fatigue and pain impair physical equilibrium and gait performance, disrupt neuromuscular signaling, and contribute to muscle weakness, joint deformity (Park et al., 2018), and postural imbalance. During warmer seasons, increased use of low-profile footwear exacerbates plantar fasciitis, while excessive pronation heightens plantar loading, further aggravating symptoms (Kim et al., 2014).

The arch-shaped slippers used in this study differ from conventional models that often induce excessive muscle contractions leading to discomfort and fatigue. Instead, these slippers promote natural activation of medial lower leg muscles critical for knee stability during daily activities. Furthermore, the design aims to minimize mediolateral sway in joint ROM and reduce GRF during gait.

Thus, the objective of this study was to evaluate the efficacy of arch-structured slippers in preventing lower limb MSK disorders by analyzing their effects on gait-related joint ROM, GRF, and muscle activation.

I. INTRODUCTION

Ankle sprains represent one of the most prevalent musculoskeletal injuries within athletic populations, exhibiting a high incidence rate.1) Despite this frequent occurrence, the transitional process from acute ankle sprain to chronic instability remains incompletely elucidated.2,3) The pathophysiology of ankle sprains encompasses alterations in proprioception, impairment of postural control, and diminished strength of the peroneal muscles.4) These elements collectively compromise the ability to maintain balance and stability during dynamic movements, a critical attribute for runners.

Chronic Ankle Instability (CAI) is a common affliction among many runners,5) characterized by recurrent sensations of the ankle "giving way" during physical activities. This condition frequently arises when an initial ankle sprain fails to heal adequately, leading to protracted instability. CAI often presents with symptoms such as pain, swelling, and persistent discomfort, significantly impacting an individual's athletic performance and overall quality of life. The etiology of CAI is multifaceted, involving both mechanical instability (ligamentous laxity) and functional instability resulting from neuromuscular dysfunction. Functional instability was initially described by Freeman et al. (1965),6) who reported a deficit in postural control during single-leg stance due to proprioceptive dysfunction.7)

Recently, the role of hip musculature, particularly hip stabilizing muscles, has garnered considerable attention in relation to ankle instability. The hip external rotators, abductors, and extensors, collectively referred to as the gluteal complex, play a pivotal role in aligning the lower extremity and conferring stability upon the ankle joint.8,9,10) Weakness or dysfunction of these muscles can induce compensatory movements due to a loss of postural control and exacerbate instability by augmenting the load imposed on the ankle during single-leg stance.11,12) Previous studies have demonstrated that strengthening hip musculature can positively influence ankle stability and functional improvement.11,12,13) However, these studies typically measured hip muscle strength in isolation.

In daily life and sports scenarios, muscles are utilized in a synergistic, rather than isolated, manner. Consequently, Almeida$^{10)}$ developed the Hip Stability Isometric Test (Hip-SIT) as a functional method to assess hip muscle strength. In this study, we adopted a distinct approach, considering the integrated function of the gluteal complex, to gain a more profound understanding of the correlation between the gluteal complex and ankle instability, diverging from prior research.8—13)

The primary objectives of this investigation were twofold: 1) to ascertain whether disparities exist in gluteal complex strength and postural control capabilities between individuals with chronic ankle instability and healthy counterparts, and 2) to determine the correlation between gluteal complex strength and postural control during single-leg stance. Specifically, we hypothesized that a correlation exists between gluteal complex strength and postural control, and that the CAI group would exhibit diminished strength in stabilizing muscles and reduced postural control. By comprehending these relationships, we aim to contribute to the formulation of ankle injury prevention strategies that account for both proximal and distal factors in the mechanism of ankle injury occurrence.

II. MATERIALS AND METHODS

2.1 Participants

This cross-sectional study enrolled 16 runners diagnosed with chronic ankle instability and 18 healthy runners. The design of this study adhered to the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) guidelines (Figure 1).14) Participants were restricted to adult males and females aged between 20 and 40 years. The diagnostic criteria for chronic ankle instability were based on the recommendations of the International Ankle Consortium$^{15)}$ and included the following:

- A history of at least two ankle sprains within the preceding six months.
- Experience of ankle "giving way" sensations or instability.
- Cumberland Ankle Instability Tool (CAIT) score of 24 points or less.
- Identification of Functional Ankle Instability (IdFAI) score of 11 points or more.
- Ankle Instability Instrument (AII) score of 5 points or more.

Healthy runners were defined as individuals with no prior history of ankle injuries. Participants with pain or injuries in the lower extremities other than ankle sprains, or neurological disorders that could induce pain during testing, were excluded. All participants had experienced their last injury at least one year prior and engaged in regular exercise at least twice a week.16) Informed consent was obtained from all participants via a questionnaire prior to their involvement.

We performed all tests in the same sequence for each participant: 1) Leg length, 2) SEBT, 3) Hip SIT.

2 Experimental procedure

2.2.1. Assessment of Balance Capability

Star Excursion Balance Test (SEBT): The SEBT was utilized to evaluate the single-leg stance postural control ability of the study participants. The SEBT involves reaching with the foot in three distinct directions: Anterior (F), Posterolateral (PL), and Posteromedial (PM). The selection of these directions is substantiated by prior research focusing on individuals with CAI and lower extremity injuries.17,18,19) Prior to the SEBT, participants received instruction on the execution method and performed four practice trials for each direction, as recommended by Gribble et al. (2008), before commencing the actual measurements.20) The average value of three repeated measurements was used. Assessors were blinded to the affected and unaffected ankle sides for the CAI group's SEBT.

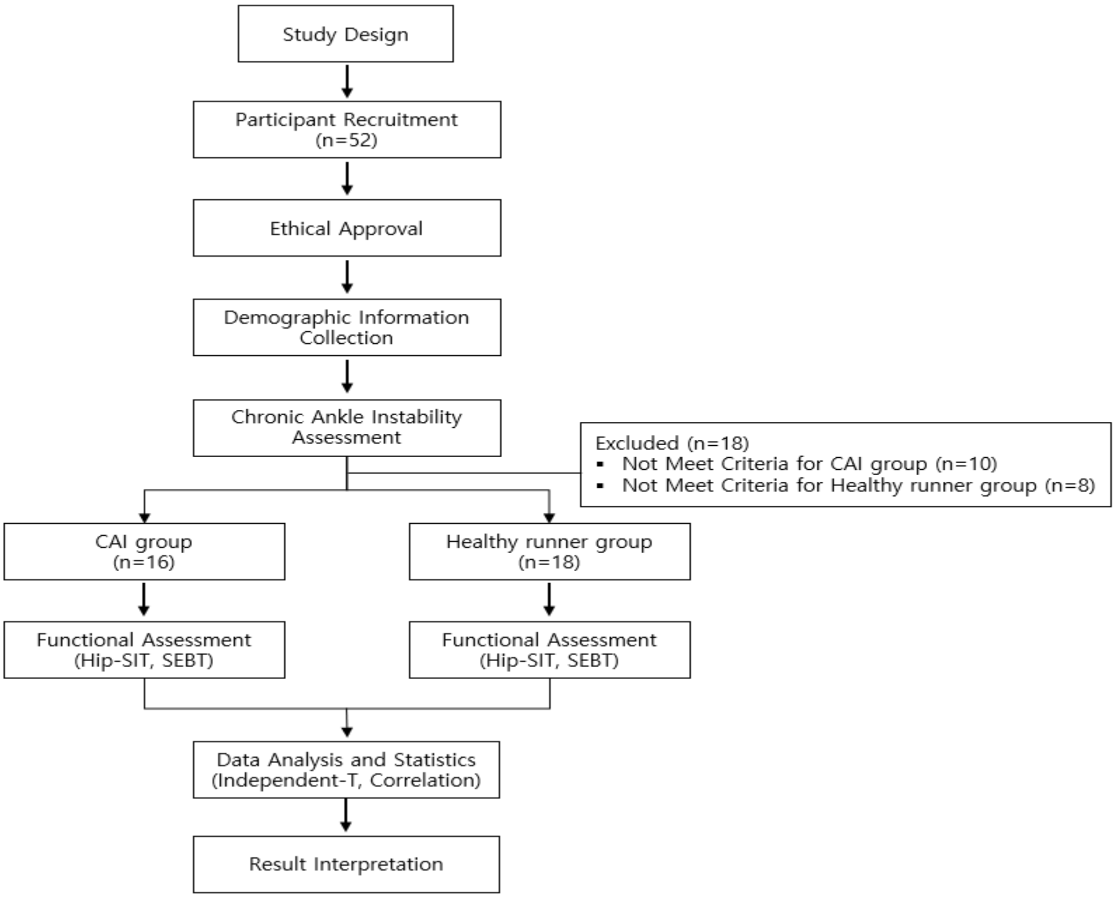

Figure 1. **General characteristics of the subjects**

Participants positioned the second toe of the testing foot at the center point, designated as the starting position. Participants, with hands placed on their iliac crests, lightly touched the farthest point on the line with the most distant part of their foot and then returned to the starting position. The vertical distance to the farthest reach point from the center was measured (Figure 2). Failures in measurement occurred under the following conditions: 1) hands detaching from the iliac crest, 2) movement of the testing foot (toes or heel), 3) inability to return to the starting position from the reach point, or 4) loss of balance.

The maximum reach distance (cm) for each direction was recorded, and the reach distance was normalized to leg length (from the anterior superior iliac spine to the distal end of the medial malleolus).21) To compute a composite score, all maximum reach distances were summed, and the total was divided by three times the leg length, then multiplied by 100. Previous studies have reported excellent intra-rater reliability (ICC = 0.85-0.92) and inter-rater reliability (ICC = 0.88-0.92) for this testing methodology.22,23)

2.2.2. Hip Strength Measurement

Hip Stability Isometric Test (HipSIT): The strength of the hip extensors, abductors, and external rotators was assessed using a digital dynamometer (Manual Muscle Tester 01165, Lafayette Instrument Company, USA). Previous research has reported excellent intra-rater reliability (ICC = 0.96-0.99) and inter-rater reliability (ICC = 0.96-0.98) for this testing method.10) The placement of the handheld dynamometer was based on parameters established in the literature. Strength data were normalized to each participant's body mass (strength/body mass). Participants' maximal strength of the hip stabilizing muscles was measured, and straps were employed in all tests to mitigate assessor influence. Participants were instructed to press against the dynamometer as forcefully as possible for 5 seconds. They performed one practice trial, rested for 30 seconds, and then executed the measured trials. If calibration was confirmed, the value was discarded, and a new assessment was performed after 20 seconds. The average value of three repeated measurements was used.10)

Assessors were blinded to the affected and unaffected ankle sides for the CAI group's Hip SIT.

The Hip SIT was performed with both legs positioned at 45° of hip flexion and 90° of knee flexion. Participants performed the movement by lifting the knee of the upper leg to achieve 20° of hip abduction, with their heels in contact. The dynamometer was positioned 5 cm superior to the line of the knee joint, laterally. After assuming the position, participants were requested to exert maximal force by lifting their knee within the range where their heels remained in contact (Figure 3).

2.3 Data Analysis

All statistical analyses in this study were conducted using SPSS 25.0 statistical software, computing the mean and standard deviation for each measured variable. The sample size determination criteria were calculated using G-power based on previous research.24) Following normality testing, independent t-tests were employed to compare the mean values for demographic characteristics, body mass-normalized Hip SIT, and leg length-normalized SEBT for each group. Additionally, Spearman correlation analysis was performed to ascertain the relationship between Hip SIT and SEBT. The statistical significance level was set at $p<.05$.

III. RESULT

The general characteristics of the participants are summarized in Table 1. No statistically significant differences were observed between the Chronic Ankle Instability (CAI) group (n=16) and the healthy group (n=18) in terms of age, weight, height, and leg length (P>.05). However, significant differences were found between the CAI group and the healthy group in Cumberland Ankle Instability Tool (CAIT), Identification of Functional Ankle Instability (IdFAI), and Ankle Instability Instrument (AII) scores (P<.001).

Table 1. General characteristics of the subjects

	Mean (SD)		
	CAI (n=16)	Healthy (n=18)	P
Age	31 (2.4)	30 (3.8)	.481
Mass, kg	67.4 (13.6)	69.9 (12.2)	.584
Height, cm	167.5 (6.8)	171.3 (7.5)	.135
Leg length, cm	83.6 (3.9)	84.6 (4.5)	.500
CAIT	16.7 (5.6)	29.6 (0.6)	.000**
IdFAI	17.75 (4.8)	1.1 (1.5)	.000**
AII	7.5 (0.8)	0.3 (0.7)	.000**

SD, standard deviation. CAI, Chronic ankle instability. * Statistical significance was assessed using independent samples t-tests: P < .05. **, P <.001. CAIT, Cumberland Ankle Instability Tool. IdFAI, Identification of Functional Ankle Instability. AII, Ankle Instability Instrument

The Hip SIT and SEBT results for the CAI group and the healthy group are summarized in Table 2. No statistically significant differences were observed in Hip SIT results between the two groups (P=.729). SEBT measurements (F, PM, PL) also did not show significant differences between the two groups (SEBT-F: P=.636, SEBT-PM: P=.675, SEBT-PL: P=.401).

Table 2. Comparison of Hip stability isometric test (Hip SIT) and Star excursion balance test (SEBT) Between CAI and Healthy Runners

	Mean (SD)		
	CAI (n=16)	Healthy (n=18)	P
Hip SIT (Nm/kg)	0.41 (0.07)	0.42 (0.11)	.729
SEBT-F (%)	68.04 (7.92)	69.26 (6.83)	.636
SEBT-PM (%)	109.28 (7.42)	110.66 (10.95)	.675
SEBT-PL (%)	105.83 (11.70)	101.99 (14.28)	.401

SD, standard deviation. CAI, Chronic ankle instability. * Statistical significance was assessed using independent samples t-tests: P < .05. Hip SIT, Hip stability isometric test. SEBT-F, Star excursion balance test forward side. SEBT-PM, Star excursion balance test posterior-medial side. SEBT-PL, Star excursion balance test posterior-lateral side.

The correlations between Hip SIT and SEBT measurements are summarized in Table 3. No significant correlation was observed between Hip SIT and SEBT Anterior (SEBT-F) or SEBT Posterolateral (SEBT-PL) (r=.151,P>.05; r=.277,P>.05). However, a moderate correlation was found between Hip SIT and SEBT Posteromedial (SEBT-PM) (r=.344,P<.05).25) Furthermore, a strong positive correlation was observed between SEBT-PM and SEBT-PL (r=.695,P<.001).

Table 3. Correlation Between Hip stability isometric test (Hip SIT) and Star excursion balance test (SEBT)

	Correlation Coefficients (r)			
	Hip SIT	SEBT-F	SEBT-PM	SEBT-PL
Hip SIT		.151	.344*	.277
SEBT-F	.151		.569**	.371*
SEBT-PM	.344*	.569**		.695**
SEBT-PL	.277	.371*	.695**	

* Statistical significance was assessed using Spearman Correlation: P < .05. **, P <.001. Hip SIT, Hip stability isometric test. SEBT-F, Star excursion balance test forward side. SEBT-PM, Star excursion balance test posterior-medial side. SEBT-PL, Star excursion balance test posterior-lateral side.

Statistical significance was assessed using Spearman Correlation: P<.05. **, P<.001. Hip SIT, Hip stability isometric test. SEBT-F, Star excursion balance test forward side. SEBT-PM, Star excursion balance test posterior-medial side. SEBT-PL, Star excursion balance test posterior-lateral side.

IV. DISCUSSION

This study investigated the correlation between gluteal complex strength and postural control during single-leg stance in runners with chronic ankle instability (CAI) and healthy runners. A key finding was the moderate correlation (r=.344,P<.05) between the SEBT PM side measurement and the Hip SIT test. This suggests that the gluteal complex may play a crucial role in balance capabilities in specific directions. Particularly, balance performance in the SEBT PM direction may be more significantly influenced by ankle instability and hip stability.17,26—28) These findings underscore the importance of strengthening hip musculature as a critical component in the management of ankle instability.

The independent t-test results revealed no statistically significant differences in Hip SIT and SEBT measurements between the CAI group and the healthy group (P>.05). This suggests an absence of clear distinctions between the CAI group and the healthy group in terms of gluteal complex strength and single-leg stance postural control. Although self-reported scales (CAIT, AII, IdFAI) were used to exclude "copers" (individuals with CAI who functionally adapt) to minimize limitations due to functional adaptation,15) it is possible that the differences between the two groups were not clearly evident due to limitations in the sample size and composition of the study. This may indicate that the CAI group had functionally adapted, and such adaptation could have diminished the observed differences in Hip SIT and SEBT measurements. This is supported by the research of Gribble et al. (2009),28) which confirmed that CAI may not necessarily be directly linked to hip muscle weakness.

The correlation between the SEBT PM side measurement and the Hip SIT test suggests that the gluteal complex may play a crucial role in balance capabilities in specific directions. Specifically, the gluteal complex, comprising the hip external rotators, abductors, and extensors, plays a vital role in aligning the lower extremity and providing stability to the ankle joint.8,9,10) This implies that strengthening hip muscles can contribute to improving ankle instability.13,27,29) Conversely, no significant correlation was observed with SEBT F and PL measurements. This suggests that various factors, such as the characteristics of the measurement direction and the contribution of hip muscles, may have influenced the results.21,24,27) A more in-depth understanding of the functional role of hip muscles necessitates diverse measurement methods and complementary analyses. This is supported by the study of Ayotte NW et al. (2007),11) which reported that hip muscle activation is critical for balance capabilities in specific directions in patients with CAI. It also aligns with the findings of Gribble et al. (2012),8) who confirmed that hip muscles can influence SEBT measurement outcomes.

A limitation of this study is that the generalizability of the results may be restricted due to the limited sample size and composition of the participants. Future research should include a larger number of participants and a more diverse range of study subjects. Furthermore, the SEBT and Hip SIT tests employed may have limitations in assessing the coordination of specific muscle groups and hip stability. Variables such as measurement accuracy, participant posture during measurement, and fatigue could also have influenced the results. More detailed data collection is required in future studies to clarify these differences. For instance, additional research incorporating assessments of running mechanisms through 3D motion analysis and functional tests (e.g., hopping tests) is warranted.4) Lastly, as a cross-sectional study, it was challenging to establish clear cause-and-effect relationships. Future longitudinal follow-up studies or experimental approaches could yield more definitive conclusions.30)

V. CONCLUSION

This study evaluated the correlation between gluteal complex strength (Hip SIT) and single-leg stance postural control (SEBT) in runners with chronic ankle instability (CAI) and healthy runners. The primary finding was a moderate correlation between the SEBT PM side measurement and the Hip SIT test, suggesting that the gluteal complex may play a crucial role in balance capabilities in specific directions. This provides important foundational data for the development of rehabilitation and training programs for runners with ankle instability. Future research, by expanding sample sizes and considering a wider range of variables, will enable the design of more accurate and comprehensive rehabilitation programs based on a more thorough understanding.

Moving forward, such programs can more effectively support the prevention of recurrence and foster recovery in patients with chronic ankle instability.

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