International Journal of Medical, Pharmacy and Drug Research (IJMPD)
Article DOI: https://dx.doi.org/10.22161/ijmpd.9.4.1

Peer-Reviewed Journal Int. J. Med. Phar. Drug Re., 9(4), 2025
ISSN: 2456-8015

Dynamic Stabilization Challenges in Sport Training: How Ankle Instability Compromises Lower Extremity Balance

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Received: 02 Sep 2025; Received in revised form: 01 Oct 2025; Accepted:05 Oct 2025; Available online: 13 Oct 2025

***Abstract*—** *Lateral ankle instability impairs neuromuscular coordination in athletes, yet evidence quantifying its functional deficits in sports majors remains fragmented. This study pioneers a comparative analysis of metrics between stable and unstable ankle groups to establish rehabilitation benchmarks. Eighteen physical education majors (CAIT-screened) were stratified into Stable (SBG, n=12) and Unstable (USBG, n=12) groups. Eight standardized tests evaluated three functional domains: dynamic balance (YBT, hurdle test), static balance (eyes-closed/unipedal stance), and explosive power (vertical/standing jumps). SPSS 20 analyzed between-group differences through independent ANOVA (a=.05) with the LSD method. SBG demonstrated superior performance in dominant-side explosive tests versus non-dominant limbs (p<.05) and USBG unstable limbs (p<.05). USBG healthy limbs matched SBG non-dominant performance in power metrics. Static balance tests greater stability in SBG non-dominant limbs compared to USBG unstable limbs (p<.05). Dynamic evaluation shows that the USBG does not perform well in complex motion modes. Chronic ankle instability alters lower extremity kinetic chains through compromised neuromuscular control and force transfer efficiency. Rehabilitation protocols should prioritize proprioceptive training and multiplanar strength development to restore functional symmetry in sports-specific movements.*

Keywords*— *dynamic equilibrium, lateral ankle injury, static balance.

I. INTRODUCTION

Lower extremity skills are essential for playing many sports, particularly in performing actions such as spiking in volleyball, stop-jumping shooting in basketball, and cross-over in soccer [1]. Lower extremity balance is crucial in net and contact sports and is essential for completing movements involved in various strategies and tactics. Athletes with more vital lower extremities can perform movements more efficiently and comfortably [2].

Lower extremity balance is essential in sports training and for performing daily life activities such as walking, running, jumping, tiptoeing, and climbing stairs. Lower extremity joints include the hip joint, knee joint, ankle joint, and toe joint, among which the ankle joint is the most crucial. The articular surfaces of the lower tibia, fibula, and trochlea of the talus form the ankle joint. Also known as the articulus talocruralis [3], the ankle joint includes the seven tarsal bones, the metatarsal bones of the foot, the tibia, and the fibula; this joint is an essential structure of the human body that rotates at different angles to maintain balance when an individual moves forward, walks, runs, and jumps. In particular, the ankle joint maintains balance when the body moves uphill, downhill, or suddenly turns or stops. Although the ankle joint is smaller than the knee and hip joints, it is crucial to maintaining body balance, thereby enabling a person to stand still. Therefore, the ankle joint is the foundation for body stability.

The Cumberland Ankle Instability Tool (CAIT) [4] was used to select participants for this study. The effects of recovering ankle injuries on lower extremity balance were analyzed by assessing participants' dynamic balance, static balance, and strength using experimental data. This study hopes to shed light on the effects of ankle sprains so that students and athletic training teams can give ankle injuries the attention they deserve. The researchers compared lower extremity balance, proprioception, and lower extremity activity between ankles that recovered from the injury and ankles that had never been injured. The comparison results can be used as a reference to prevent potential ankle injuries more effectively, which may help reduce the fear associated with injuries and decreased athleticism caused by ankle injuries.

II. METHOD

2.1 Research participants

This study recruited research participants from students at the School of Sports and Physical Education, Huizhou University, based on the severity of their functional ankle stability measured using the CAIT. A total of 130 questionnaires were distributed in this experiment, and 106 valid responses were included after excluding random responses, invalid responses such as the same answers for all items, or missing data. The respondents with valid responses were categorized into the stable group (SBG) or the unstable group (USBG) based on their CAIT scores, with a higher score indicating higher stability; a score ≤24 indicates an unstable ankle joint, and a score >24 indicates a healthy ankle. Subsequently, 12 and 12 respondents were randomly selected from the SBG and USBG to participate in the study experiments. The 24 participants were matched according to sex, age, height, and weight.

2.2 Research method

The 12 participants from the SBG and 12 from the USBG were subject to the following experiments (Table 2).

Table 1: Demographic data of the research participants (N = 24).

	Height	Weight	Age	CAIT
SBG N=12	172.56±6.09	65.89±7.51	22.44±1.51	29±0.71
USBG N=12	174.33±4.24	70.33±6.58	21.33±1.41	17.22±2.54

Table 2: Experimental type and content

Type	Content
Dynamic balance tests	Y-balance test—lower quarter, hurdle step test, and single-leg drop test
Static balance tests	Balance error scoring system test, eye-closed single-leg stance test, and static balance single-leg stance test
Power tests	Single-leg counter movement jump test and single-leg standing long-jump test

This study obtained parameters related to dynamic balance, static balance, and lower extremity power of the participants and analyzed the parameters by using one-way analysis of variance in SPSS 20 (IBM, Armonk, New York); the significance level was set at a = .05. Finally, post hoc analysis was performed using the least significant difference test.

2.3 Experimental procedure

2.3.1 Dynamic balance test

Y-balance test—lower quarter (YBT)

The participants were asked to remove their shoes and socks during the Y-balance test. At the same time, the length of their lower extremities was measured (from the anterior superior iliac spine on one side to the center of the medial malleolus on the same side). The participants had to place one leg on a platform and align their hallux toward the red starting line on the platform for measurements with their hands on their hips. They were asked to try to move their other leg forward, backward and inward, and backward and outward as much as possible to push the test plate before returning their leg to the starting line. The participants drove the plate toward each direction three times, and the furthest distance was recorded (with a precision of up to 0.5 cm). Afterward, the participants switched their legs to perform the same procedure as their other legs, and the results were recorded [5].

Hurdle step test (HST)

In this test, the subjects stand with their feet together and their toes touching the test board. The experimenter then adjusts the height of the test cord to ensure that it is the same height as the subject's tibial tuberosity. Subsequently, the participants held the test rod with both hands and placed it on their shoulders and parallel to the ground. They then slowly lifted one leg to cross over the hurdle and placed their sole on the ground while keeping their center of gravity on the other leg and maintaining their balance. They finished the test by returning their leg to its starting position slowly. The participants completed the hurdle step test three times for each leg, and the scores of the two legs were recorded separately [6, 7].

Overall lower quarter：

$$\frac{(\text{Anterior} + \text{Posteromedial} + \text{Posterolateral})}{3 \times \text{Limb Length}} \times 100$$

Single-leg drop test (SLDT)

The participants were asked to stand on a 28-cm-high step on the leg that was not tested and then jump forward from the step and try their best, landing vertically down on a mark with the other leg. They were required to maintain their balance for at least 2 seconds in the landing position. The participants completed each leg's single-leg drop test thrice [8].

Table 3: BESS test evaluation.

Age	Excellent	Above average	Average	Below average	Poor
20~29	0~5	6~7	8~14	15~17	18~23
30~39	0~4	5~7	8~15	16~18	19

Table 4: Seconds-scores conversion table

Scores	1	2	3	4	5
Time (s)	3-5	6-17	18-41	42-98	<98

.2.3.2 Static balance test

Balance error scoring system test

The balance error scoring system (BESS) test assesses the double-leg stance on the ground, single-leg stance on the ground (non-dominant leg, NDL), tandem stance on the ground (center of gravity on NDL), double-leg stance on foam, single-leg stance on foam (NDL), and tandem stance on foam (center of gravity on NDL). In this test, the participants were asked to maintain each position for 20 seconds with their eyes closed and hands on their hips (iliac spine) during the test. The hip of the nonsupporting leg should be bent at ≥60°, and the participants were required to maintain balance in the process [9, 10].

Eye-closed single-leg stance test (ECT)

In this test, the participants removed their shoes and socks and placed both hands on their hips or crossed their arms in front of their bodies. Next, the participants were instructed to lift their nonsupporting leg off the ground while ensuring it did not affect the supporting leg. The participants practiced for 1 minute before the actual test, and the timer started after the nonsupporting leg was lifted off the ground. For safety reasons, the researchers stood behind the participants to prevent them from losing their balance and getting injured. The timer was stopped when the hands of the participants left their hip, the supporting leg rotated, moved, or hopped in any direction, or the nonsupporting leg touched the supporting leg. The time the participants remained balanced while standing on one leg was recorded. The participants repeated the test three times for both legs, and the longest time was selected for comparisons. Table 4 converted seconds to scores [11].

Static balance single-leg stance test (SBT)

In this test, the participants removed their shoes and placed their hands on their hips. Next, they put their nonsupporting leg on the inner side of the knee joint of their supporting leg and lifted the heel of their supporting leg to maintain their balance on their forefoot. The timer started as soon as the heel of their supporting leg was lifted off the ground. For safety reasons, the researchers stood behind the participants to prevent them from losing their balance, falling backward, and getting injured. The timer was stopped when the hands of the participants left their hip, the supporting leg rotated, moved, or hopped in any direction, the nonsupporting leg stopped touching the knee joint of the supporting leg, or the heel of the supporting leg touched the ground. The time the participants remained balanced while standing on one leg was recorded. The participants repeated the test thrice for both legs, and the longest time was selected [12].

2.3.3 Power test

Single-leg counter movement jump test (CMJ)

In this test, the participants stood on the ground on one leg and recorded their standing reach height. Afterward, the participants were asked to squat rapidly and swing their arms swiftly backward beyond their hip to perform a countermovement jump as high as possible. They were required to reach their fingertip, which was coated with chalk powder beforehand, leave a mark on the wall at the highest point they could get by touching it with this fingertip, and then land on both feet. The distance between the highest chalk mark and the ground was recorded as the total jump height, and the precision was up to 1 cm [13, 14].

Table 5: Summary results of the power tests.

	SBG		USBG		F	Post hoc
	DL(A)	NDL(B)	HL(C)	USL(D)		
CMJ* (cm)	26.51±1.10	23.30±0.96	23.16±4.17	21.59±3.64	5.40	A>B, A>C, A>D
SLJ* (cm)	218.60±7.60	212.90±5.82	213.38±9.05	207.75±7.32	3.18	A>D

Note:* indicates statistical significance (p<.05)

Single-leg standing long-jump test (SLJ)

The participants stood on one leg in this test and placed their soles behind the starting line. Then, they were asked to quickly bend their knees while swinging their arms backward behind their hips, perform a countermovement jump forward as far as possible, land on both their feet and maintain this position so that the jump distance could be measured. The distance from the starting line to the heel was recorded closer to the starting line, and the precision was up to 1 cm [15].

III. RESULTS

3.1 Lower extremity power test

The power test results are presented in Table 5. In CMJ, the dominant leg (DL) results were significantly superior to the non-dominant leg (NDL) results in the SBG ($p < .05$); DL results in the SBG were significantly superior to both the healthy leg (HL) results ($p < .05$) and unstable leg (USL) results ($p < .05$) in the USBG. In SLJ, DL results in the SBG were significantly superior to USL results in the USBG ($p < .05$).

3.2 Results of the lower extremity dynamic balance test

The results of the lower extremity dynamic balance test are presented in Table 6. For the YBT, DL was significantly superior to USL ($p < .05$), NDL was significantly superior to USL ($p < .05$), and within the SBG, DL results were significantly superior to NDL ($p < .05$). In HST, DL was significantly superior to USL ($p < .05$); within the USBG, HL were significantly superior to USL ($p < .05$); and NDL were significantly superior to USL. All the participants passed SLDT, meaning the two groups performed similarly in this test.

Table 6: Summary results of the dynamic balance tests.

	SBG		USBG		F	Post hoc
	DL(A)	NDL(B)	HL(C)	USL(D)		
YBT* (%)	108.46±4.12	103.96±5.52	100.38±6.96	95.81±4.19	9.24	A>C, A>D, B>D
HST* (times)	3±0.0	3±0.0	2.88±0.35	2.5±0.54	5.31	A>D, B>D, C>D

Note:* indicates statistical significance (p<.05)

3.3 Results of the lower extremity static balance test results

In ECT, DL was significantly superior to both HL ($p < .05$) and USL ($p < .05$), NDL was significantly superior to USL ($p < .05$), and within the USBG, HL was significantly superior to USL ($p < .05$). For the SBT, DL were significantly superior to both the HL ($p < .05$) and USL ($p < .05$), and NDL were significantly superior to USL ($p < .05$).

IV. DISCUSSION

4.1 The lower extremity power test

The results of the single-leg countermovement jump test and single-leg standing long-jump test revealed that the DL of the participants in the SBG was more substantial than their NDL and the HL and unstable leg of the participants in the USBG. People tend to power with their DL, making the DL more dynamic and powerful than the NDL. Most people use their DL or rely on it to exert force when playing sports or performing daily activities. Therefore, based on the theory of use and disuse perspective and the usually more frequent training and development of the DL, the DL generally has greater power than the NDL. In the USBG, the HL had greater power than the unstable leg, and the average power of the HL of the participants in the USBG was similar to that of the NDL participants in the SBG. The injured unstable leg of the participants in the USBG was weaker than the HL [16]. Therefore, the injury on the unstable leg of the participants in the USBG might have affected the power of their HL.

4.2 The lower extremity dynamic balance test

4.2.1 Differences in results between the stable and USBGs

The Y-balance and hurdle step test results showed that the SBG was superior to the USBG. Ankle injury affects the stability and proprioception of the lower extremity [17]. The muscular strength of an injured leg is lower than that of a leg that has never been injured [18], indicating that past ankle injuries affect the power of the lower extremities, which affects balance. Therefore, the lower extremity dynamic balance is correlated with lower extremity injuries [19, 20, 21]. The mean and standard deviation values obtained in the hurdle step test reveal that the results of the SBG were superior to those of the USBG. Participants in the USBG had past lower extremity injuries, which still affected their hip, knee, and ankle joints. During the hurdle step test, participants in the SBG, who had never injured their lower extremity or ankle joint, exhibited excellent activity and stability in their hip, knee, and ankle joints.

4.2.2 Differences in results between the DL of the participants in the SBG and the HL of the participants in the USBG

The Y-balance and hurdle step tests revealed that the average DL performance of the SBG was superior to the HL performance of the USBG. The SBG's average DL performance in the Y-balance test was superior to the USBG's average HL performance. The post hoc analysis showed that the SBG's DL performance differed nonsignificantly from the USBG's HL performance in the hurdle step test; however, the mean and the standard deviation values still revealed a certain level of difference between the two groups, with the SBG's DL performance being superior to the USBG's HL performance. Accordingly, the HL of the participants in the USBG was weaker than the DL of the participants in the SBG because the previous ankle injury on one leg among those in the USBG may have affected the posture control, strength, joint movement, and proprioception of the other leg. Based on the observation of the average performance of both groups in the hurdle step test, this study inferred that the performance of the HL of the participants in the USBG was affected by the unstable leg, which reduced the activity of the hip, knee, and ankle joints of the HL and ultimately reduced its stability and power.

4.2.3 Differences in results between the NDL of the participants in the SBG and the unstable leg of the participants in the USBG

The Y-balance and hurdle step tests revealed that, on average, the NDL performance of the SBG was superior to the unstable leg performance of the USBG. This suggested that the NDL of the participants in the SBG was more substantial than the unstable leg of the participants in the USBG. This study inferred that the unstable leg of the participants in the USBG was affected by previous ankle injuries with incomplete recovery in terms of flexibility, balance, lower extremity control, and lower extremity proprioception, resulting in poorer function [22, 23, 24]. Some participants even trained for games with ankle injuries. Neglecting the current ankle injury could result in repeated ankle injuries, increase the load on the ankle joints, and worsen the injury. Consequently, the functions of the ankle joint remain unstable, and the ankle cannot effectively heal and recover [25].

We found that in the SBG, the participant's DL had superior results to their NDL. The posture control, strength, joint movement, and proprioception of the DL with an uninjured ankle are more efficient than those of the NDL with an uninjured ankle [26]. The DL usually bears higher loads during daily activities, which trains the DL daily. The human body needs to exert force to perform daily activities. If the DL exerts a more vital force, the NDL automatically exerts a weaker force and bears a lower load during daily activities. Because the NDL lacks effective loading and training, the difference in the strength between the DL and the NDL increases with time.

4.2.4 Differences in results between the HL and the unstable leg of the participants in the USBG

A comparison of the Y-balance test results between the healthy and unstable legs of the participants in the USBG revealed no significant correlation between the healthy and unstable legs. Still, the HL had a slightly superior result than the unstable leg. The hurdle step test results revealed that the HL had a superior result than the unstable leg. Injuries limited the activity of the unstable leg's hip, knee, and ankle joints, reducing the muscular strength and control of the lower extremity. Although injuries on the unstable leg also affected the HL, the effect on the unstable leg was more significant. Thus, lower extremity injuries can easily affect the lower extremity balance, reducing sporting ability, performance, and ability to score in games.

4.3 The lower extremity static balance test

4.3.1 Differences in results between the stable and USBGs

Table 7: Summary of results of the static balance tests.

	SBG		USBG		F	Post hoc
	DL(A)	NDL(B)	HL(C)	USL(D)		
BESS		2.10±0.88		3.13±0.64		
ECT*	4±0.00	3.60±0.52	3.13±0.64	2.50±0.54	16.17	A>C, A>D, B>C, B>D, C>D
SBT*(s)	30.40±17.22	24.40±14.07	13.5±6.39	8.38±4.66	5.82	A>C, A>D, B>D

Note:* indicates statistical significance (p<.05)

The results of the static balance tests are presented in Table 7. The results of the SBG were superior to those of the USBG. In particular, the SBG outperformed the USBG for both legs in the eye-closed single-leg stance and static balance single-leg stance tests. The eye-closed single-leg stance test required participants to rely on proprioception and muscular strength to balance their body without visual support [17]. Therefore, a higher score indicated higher proprioception and muscular strength. The static balance single-leg stance test required participants to rely on the strength of their ankle joint and their motor control skills, with participants who could stand longer achieving a higher score. The significantly different performance between the groups may be attributable to the past injuries of participants in the USBG, which reduced their lower extremity strength in terms of proprioception and control.

4.3.2 Differences in results between the DL of the participants in the SBG and the HL of the participants in the USBG

The results of the eye-closed single-leg stance and static balance single-leg stance tests revealed that the average DL performance of the SBG was significantly higher than the average HL performance of the USBG. The muscular strength, proprioception, and motor control of the DL of the participants in the SBG were superior to those of the HL of their USBG counterparts. This may be because the USBG had past ankle injuries that continued to affect their lower extremity stability in the HL even after the injured leg recovered.

4.3.3 Differences in results between the NDL of the participants in the SBG and the unstable leg of the participants in the USBG

The results of the BESS, eye-closed single-leg stance and static balance single-leg stance tests demonstrated that the average NDL performance of the SBG was superior to that of the average unstable leg performance of the USBG. In the BESS test, with a higher score indicating weaker lower extremity balance, the USBG's BESS test score for the unstable leg was higher than the SBG's for the NDL. Therefore, the SBG had superior lower extremity balance in the NDL than the USBG did in the unstable leg.

4.3.4 Differences in results between the HL and the unstable leg of the participants in the USBG

In the USBG, the HL performed better than the unstable leg. The results of the eye-closed single-leg stance and static balance single-leg stance tests for the HL were also superior to those of the unstable leg. The eye-closed single-leg stance test required participants to close their eyes; thus, they could not use visual support and only relied on their lower extremity strength, proprioception, and posture control. Therefore, the USBG had greater lower extremity strength, proprioception, and posture control in the HL than in the unstable leg. The static balance single-leg stance test required participants to rely on their ankle joint strength and posture control, and the results demonstrated that the group's ankle joint strength and posture control in the HL were superior to those in the unstable leg.

V. CONCLUSION

The participants' past ankle injuries might have caused their joints to remain unstable despite recovering. Such joint instability affects the lower extremity balance, the activity of the hip, knee, and ankle joints, the surrounding muscular strength, proprioception, and posture control. These past injuries could also affect the lower extremity stability in the HL and thus undermine the sporting ability, sporting performance, and ability to score in games. Therefore, people with unstable ankle joints due to sprains should increase training on the nerves and muscles surrounding the joints even after recovery from the sprains and avoid compensatory movements.

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