DOI: 10.48305/jrrs.2023.41658.1031 Published by Vesnu Publications

This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 Unported License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

A Comparative Study of Electromyography Activity of Selected Lower Extremity Muscles in Badminton Players with Functional Ankle Instability during Single-Leg Landing: A Cross-Sectional Study

Reza Kowsari[1], Hooman Minoonajad[2], Mostafa Varmaziyar[1], Foad Seidi[2]

Original Article

Abstract

Introduction: Functional ankle instability is one of the most common sports injuries and causes disruption in neuromuscular control and intensity of muscle activity. Therefore, the aim of this study was to compare the electromyographic (EMG) activity of selected lower extremity muscles in badminton players with functional ankle instability in the feed forward and feedback phases during single leg landing with that of healthy players.

Materials and Methods: This cross-sectional study was conducted on 30 male badminton players (15 people with ankle functional instability and 15 people without ankle functional instability). First, their maximum voluntary contraction (MVC) was measured. Then, they stood on a platform of 30 cm height, and took several steps to reach the jumping place, from there they landed on one leg with the dominant leg, and the electrical activity of the selected muscles was recorded in a feedforward and feedback manner. Independent t-test and Man-Whitney U test were used to analyze the results.

Results: The independent t-test and Man-Whitney U test results showed that EMG activity in the feedforward phase in the tibialis anterior (P = 0.001), gastrocnemius (P = 0.001), and peroneus longus (P = 0.001) muscles, and in feedback phase in the tibialis anterior (P = 0.001), gastrocnemius (P = 0.001) and peroneus longus (P = 0.006) muscles were significantly higher in the group without functional ankle instability than the group with functional ankle instability.

Conclusion: Decreased activity of the lower extremity muscles in the ankle is one of the main reasons for ankle sprains. The EMG activity of the tibialis anterior, gastrocnemius, and peroneus longus muscles in the feedforward and feedback phases is lower in people with functional ankle instability compared to people without ankle instability. Therefore, there are many differences in the intensity of muscle activity between people with functional ankle instability and healthy people.

Keywords: Electromyography; Chronic ankle instability; Badminton athletes; Ankle muscles

Citation: Kowsari R, Minoonajad H, Varmaziyar M, Seidi F. **A Comparative Study of Electromyography Activity of Selected Lower Extremity Muscles in Badminton Players with Functional Ankle Instability during Single-Leg Landing: A Cross-Sectional Study.** J Res Rehabil Sci 2022; 18.

Received: 09.04.2022 Accepted: 17.06.2022 Published: 06.07.2022

Introduction

The ankle joint is highly susceptible to injury during sports and everyday activities (1). Ankle sprains account for approximately 20% of all sports-related injuries (2). Among athletes, damage to the external ligaments of the ankle is common, with 85% of sprains involving these ligaments (3-5). More than 70% of individuals experience symptoms for up to 18 months after a lateral ankle sprain (6), which can lead to chronic ankle instability (7). Initial symptoms include pain, muscle weakness, proprioceptive disorder, and recurrent ankle sprains (8), while individuals with chronic ankle instability often experience pain, instability, and a sense of emptiness in the ankle (9). Frequent ankle sprains can lead to ankle instability (4). Chronic ankle instability can be classified into the two categories of mechanical and functional instability (10). Mechanical ankle instability is associated with improper joint mechanics, measurable

1- MSc of Sports Injury and Corrective Exercise, Department of Health and Sports Medicine, School of Sport Sciences and Health, University of Tehran, Tehran, Iran
2- Associate Professor, Department of Health and Sport Medicine, School of Sport Sciences and Health, University of Tehran, Tehran, Iran
Corresponding Author: Foad Seidi; Associate Professor, Department of Health and Sport Medicine, School of Sport Sciences and Health, University of Tehran, Tehran, Iran; Email: foadseidi@ut.ac.ir

laxity, kinematic limitations, and synovial changes (11). Freeman et al. were the first to define functional ankle instability as the tendency of the foot to twist or give way (12) repeatedly. People with functional ankle instability may experience a long-term sense of instability and emptiness in the ankle, but no ligament laxity is observed in the joint (13). While mechanical and functional instability can occur concurrently (9), they are separate phenomena (14). Mechanical instability refers to joint movement beyond the normal physiological range, while functional instability refers to lack of voluntary control over joint movement within the physiological range (15). Research has shown that more than half of patients with chronic ankle instability experience functional instability without symptoms of mechanical instability (16).

Functional ankle instability is a common complication in 15-60% of cases following the primary sprain (4, 17-19). It can be caused by various factors such as balance (20-22), decreased activity of ankle muscles (23, 24), strength, proprioception (25, 26), and reflex delay of the peroneus longus muscle (27-29). This type of instability often causes athletes to avoid sports activities (30). It also creates instability in the ankle joint during dynamic movements, the most significant risk factor for ankle sprains (31). Research has shown that recruitment patterns and neuromuscular firing rates of people with functional ankle instability differ from those of healthy individuals (32, 33).

Individuals with functional ankle instability show different muscle activity to those without instability. During the feedforward stage, the tibialis anterior, gastrocnemius, and rectus femoris muscles show more activity, while the peroneus longus and biceps femoris muscles show less activity. In addition, the peroneus longus muscle activity decreases across all ranges in individuals with ankle instability (34). In the feedback phase, the electrical activity of the rectus femoris and tibialis anterior muscles is higher in individuals with ankle instability (35). The mechanics of the ankle, knee, and thigh joints are affected in individuals with functional ankle instability (36, 37). The decrease in dorsiflexion due to instability limits the ankle's ability to reach the closed-packed position, which is stable during landing and walking. This increases the risk of re-injury (38). Furthermore, individuals with chronic ankle instability exhibit different landing strategies to those of healthy individuals (39).

The ankle joint is particularly vulnerable during sports (40) that involve sudden direction changes and jumping movements, increasing the risk of injury by several times (41). Badminton is considered the fastest racket sport (42) and requires high levels of agility (43). Players must perform jumping activities, lunges, rapid changes of direction, and repetitive hand movements in different positions and the shortest possible time. Badminton became more popular after its inclusion in the 1992 Barcelona Olympic Games, with 200 million people playing it worldwide (44). However, with people's participation in badminton games, injuries in this field have also increased (45). Ankle sprains are the most commonly reported injury among badminton players (46), accounting for 33%-49% of all lower extremity injuries in players who regularly play this sport (47). Most ankle injuries in this sport occur when landing from a jump (48, 49). Therefore, ankle injury prevention and rehabilitation in badminton athletes can be critical.

Moreover, the prevalence of functional ankle instability is very high among adolescents (50). This damage can have a long-term effect until adulthood (51). Therefore, understanding its origin and prevention strategies in the adolescent population can be much more effective (50). In the present study, the electromyographic (EMG) activity of selected lower limb muscles in teenage badminton players with functional ankle instability was compared in the feedforward and feedback phases during single-leg landing with that of people without functional ankle instability.

Materials and Methods

The present research was both cross-sectional and semi-experimental. It is important to note that the process began by applying to 12 professional-level clubs in Tehran, Iran. Finally, 3 clubs in Tehran's Shiroudi Stadium and 1 in Tehran's Hijab Hall agreed to participate in the study.

The research participants were divided into 2 groups: athletes with functional ankle instability and those without. The statistical population of this research included male badminton players who were 15 to 18 years of age, had at least 3 years of sports experience, and worked professionally in this field. From among them, 30 people were selected as available samples and were non-randomly (purposefully) placed in 2 groups of 15 individuals. Using the GPower software (G*Power 3.1.9.2 freeware, University of Düsseldorf, Düsseldorf, Germany) and considering a statistical power of 0.8, a significance level of 0.05, and an expected effect size of 0.97 (52), a sample size of 17 people in each group was calculated. Due to the limitations of the laboratory and corona pandemic conditions, a total of 30 people, 15 in each group, were finally selected for participation in the study. The research data were collected and analyzed at the National Brain Mapping Laboratory.

The first group included athletes with functional ankle instability who scored 0 to 27 on the Cumberland Ankle Instability Tool (CAIT). The second group consisted of athletes without any problems related to functional instability of the ankle, and a CAIT score of higher than 27. The CAIT has 9 questions, with a validity of 0.83 and a reliability of 0.99, and the total score ranges from 0 to 30 (53). This questionnaire was designed by Hiller et al. in 2006. The Persian version of this questionnaire has also been investigated and it is considered a suitable tool for diagnosing functional ankle instability (54).

The inclusion and exclusion criteria of the study were based on the guidelines of the International Ankle Consortium (55). The inclusion criteria included the primary sprain occurring at least 12 months before the start of the trial, accompanied by inflammation (pain and swelling), followed by a break in physical activity for a day. A history of uncontrollable or unpredictable sprains (Ankle Giving-way), frequent sprains, or instability in the ankle, mainly when a person cannot focus on foot and ankle movements during activity due to physical or mental pressure (for example, during a football match) (9).

The exclusion criteria were a history of surgery on the musculoskeletal structures of the lower limb, a history of fracture in the lower limb, acute skeletal-muscular injury to the lower limb within the past 3 months that has impacted joint function, and disrupted physical activity for at least 1 day (41), lack of willingness to participate in the study, and mechanical instability, which is determined by the anterior ankle drawing test. During the anterior drawing ankle test, the examiner stands in front of the person being tested, with one hand placed behind the heel and the other on the tibia. It indicates mechanical instability if the heel can be pulled forward despite preventing the tibia from moving forward (56). Injuries, pain in the lower limb with a visual analogue scale (VAS) score above 4 during the research process, and unwillingness continue the research process were also grounds for exclusion from the study.

It is important to note that the athletes' participation was voluntary, and they were asked to sign an informed consent form before participating in the research. The study was conducted during the spring and summer of 2021 at the Brain Mapping Laboratory at Tehran University of Technology, Iran. An electromyography device [Motion Lab System MA400 (DTU), Motion Lab System, Baton Rouge, LA, USA,], was used during the study. Participants arrived at the laboratory at their scheduled times. Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) guidelines were followed for the determination of the location of surface electromyography electrodes. Before electrode placement, the approximate area was shaved and cleaned. The fat layer of the skin was then removed using alcohol and a cotton ball until the skin was visibly red.

For each muscle, 3 electrodes were attached to the skin at a distance of 2 centimeters from each other (between the centers of the electrodes). A reference electrode was installed on the bony landmark adjacent to the muscle. The exact location of the recording electrodes was determined by touching the bony landmarks and isometric contraction in the direction of the desired muscle fibers using the SENIAM guide (57). The tibialis anterior muscle electrodes were installed at one-third of the distance between the head of the fibula and the inner ankle. Peroneus longus electrodes were installed at one-third of the distance between the head of the fibula and the outer ankle. The external gastrocnemius electrodes were installed at one-third of the distance between the head of the fibula and the heel (58). To reduce motion noises, the cables of the electromyography device were fixed on the body using masking tape. It is worth mentioning that this research used the F-RG electrode model (Skintact, Germany).

First, the subjects' maximum voluntary contraction (MVC) was measured. The participant was asked to have maximum isometric contraction 3 times in 15 seconds, and all signals were recorded (59). Before the tests, an accelerometer (ADXL203CE; SparkFun Electronics, USA) was connected to the subject's feet. The participant was placed on a platform with a height of 30 cm. Then, to reach the platform's edge, the participant was asked to take 2 steps at a slow pace. Upon reaching the desired location, the subject landed on the dominant leg. At the same time, the electrical activity of the selected muscles was recorded as feedforward (200 milliseconds before the foot hits the ground) and feedback (200 milliseconds after the foot hits the ground). This process was repeated 5 times; from among which, 3 signals with less noise were selected and their average was calculated. It should be noted that the moment the foot hit the ground was detected using an accelerometer.

Data were collected from electromyography at a sampling frequency of 1000 Hz (60). These signals underwent pre-amplification (61) 10 times and were filtered between 20 and 500 Hz (61). To compare participants and normalize data, the obtained values were divided by each muscle's MVC. Muscle activity was expressed as a percentage of the MVC (%MVC). The accelerometer signal was checked to determine the onset moment, and the EMG signals were segmented accordingly. The root mean square (RMS) value of each segment was calculated (61, 62). All devices were calibrated and checked by the operator of the brain mapping laboratory before starting work.

The data analysis in this study was carried out using the SPSS software (version 27; IBM Corp., Armonk, NY, USA). The normal distribution of data was checked using the Shapiro-Wilk test, while the homogeneity of variances was assessed using Lune's test. The independent t-test and Yeoman-Whitney test were utilized to analyze the data in the two groups, one with ankle functional instability and the other without. Additionally, intragroup comparison was conducted using the Wilcoxon test. The significance level was set at 0.05. The GPower software was used to perform the power test.

Results

All eligible participants thoroughly completed all the steps of the study, and there were no dropouts (dropout rate = 0%). Figure 1 shows the research process and number of participants involved.

The age, height, and weight of the participants are presented in table 1.

During the feedforward phase, it was found that the peroneus longus muscle did not follow a normal distribution in either group, and the tibialis anterior muscle only followed a normal distribution in the group with ankle instability (P = 0.001). Moreover, the external gastrocnemius muscle in the group without ankle instability did not follow a normal distribution (P = 0.009). In the feedback phase, the data distribution for the anterior tibialis and external gastrocnemius muscles did not follow a normal distribution in the group without ankle instability (P = 0.008). Therefore, non-parametric statistics (Mann-Whitney U test) were employed to compare the two groups in the feedforward phase for all three muscles and in the feedback phase for the anterior tibialis and external gastrocnemius muscles. Furthermore, non-parametric statistics (Wilcoxon test) were used to compare the two phases in the group with ankle instability for the tibialis anterior and peroneus longus muscle, and the group without ankle instability for all three muscles. The dependent variables in this study were the feedforward and feedback activity of three muscles, the tibialis anterior, peroneus longus, and external gastrocnemius. Table 2 provides descriptive information.

The comparison of the activity level of the selected muscles in the feedforward phase between the two groups is presented in table 3.

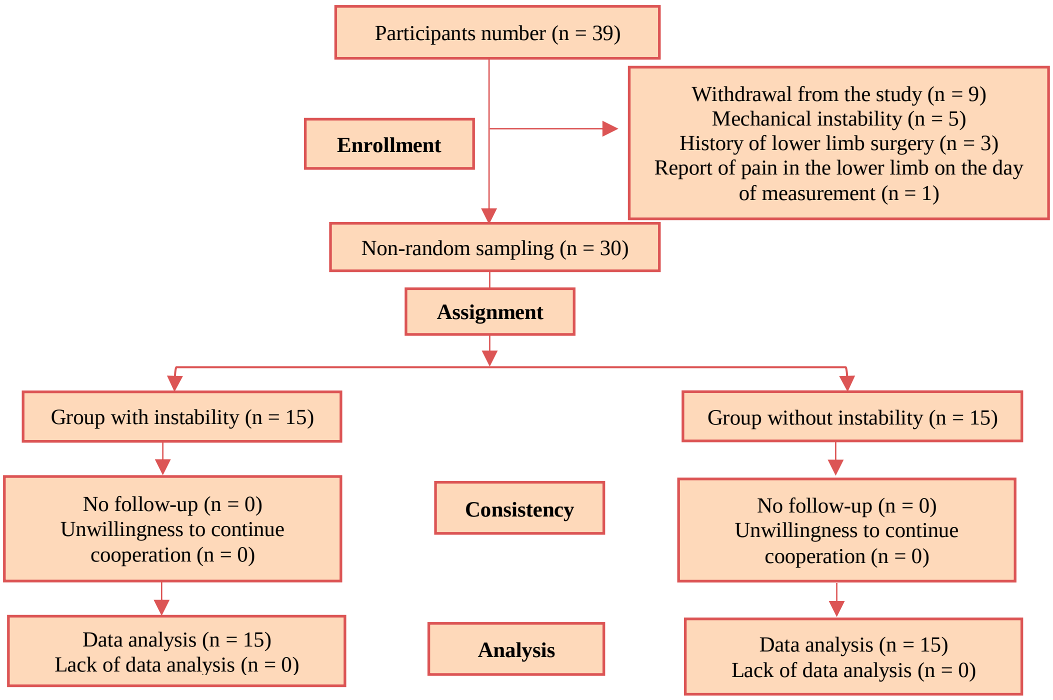

Figure 1. Diagram of the exclusion of participants in different stages of the study

Table 1. Descriptive statistics test results of anthropometric characteristics of the participants

Variable	Group with instability (n = 15) (mean ± SD)	Group without instability (n = 15) (mean ± SD)	P-value of comparison between groups
Age (years)	16.10 ± 1.20	16.27 ± 1.19	0.92
Height (cm)	175.00 ± 6.05	176.00 ± 4.80	0.95
Weight (kg)	66.10 ± 3.96	63.18 ± 1.18	0.61
Body mass index (kg.m^2)	21.59 ± 1.09	20.42 ± 1.15	0.53

SD: Standard deviation

As can be seen in table 3, the results of the Mann-Whitney U test indicate that during the feedforward phase, individuals without functional ankle instability had significantly higher EMG activity in the tibialis anterior, external gastrocnemius, and peroneus longus muscles compared to those with functional ankle instability. Tables 4 and 5 compare the activity levels of these muscles in the feedback phase for the tibialis anterior, external gastrocnemius, and peroneus longus muscles using the Mann-Whitney U test and independent t-test, respectively.

According to the results of the independent t-test and Mann-Whitney U test (Tables 4 and 5), during the feedback phase, people without functional ankle instability had significantly higher EMG activity in the tibialis anterior, external gastrocnemius, and peroneus longus muscles ($P < 0.050$). The power test indicated that the current study had a sufficient sample size.

Discussion

The present study compared the EMG activity of the anterior tibialis, peroneus longus, and external gastrocnemius muscles in badminton players with and without functional ankle instability during single-leg landing. The study evaluated the feedforward and feedback phases to assess muscle activity differences between the study groups (with and without ankle instability). The results indicated significant differences in the electrical activity of the tibialis anterior, peroneus longus, and external gastrocnemius muscles in feedforward and feedback landing modes.

In another study, women with functional ankle instability were compared to women without this condition. The results showed a decrease in the activity of the peroneus longus and an increase in the activity of the external gastrocnemius muscle during the feedforward phase. During the feedback phase, an increase was observed in the activity of the tibialis anterior and rectus femoris muscles (24). However, in the present study, a reduction was only observed in the activity of the peroneus longus muscle. This difference may be due to the gender of the participants and the type of task studied. The previous study analyzed muscle activity in women who landed on two legs, one on a flat surface and the other on an inclined surface, while the present research was conducted on men who landed on one foot on a flat surface. This could explain the differences observed in the activity levels of the external gastrocnemius and tibialis anterior muscles between the two studies.

A study compared the activity of muscles in people with functional ankle instability while walking 4.8 km on a treadmill to those without instability. The results showed that the anterior tibialis muscle had more activity 100 milliseconds before the heel hit the ground in the group with instability compared to the control group (63). However, the peroneus longus and gluteus medius muscles had more activity in the feedforward phase in the group with instability, which contradicts the findings of the present study.

Table 2. The mean and standard deviation of the activity of selected muscles in the feedforward and feedback phases according to the maximum percentage of voluntary contraction

Muscles	Activity type ((%MVC)	Group with instability (mean ± SD)	Group without instability (mean ± SD)	P-value of between group comparison
Tibialis anterior	Feedforward activity	2.35 ± 0.87	29.22 ± 8.57	0.001*
	Feedback activity	2.90 ± 1.22	27.89 ± 5.19	0.001*
	P-value of intragroup comparison	0.330	0.720	
Peroneus longus	Feedforward activity	4.83 ± 2.09	60.97 ± 8.09	0.001*
	Feedback activity	17.24 ± 4.99	34.38 ± 16.95	0.001*
	P-value of intragroup comparison	0.005*	0.008*	
Gastrocnemius	Feedforward activity	4.10 ± 2.15	36.48 ± 7.21	0.001*
	Feedback activity	3.75 ± 0.73	42.83 ± 18.65	0.001*
	P-value of intragroup comparison	0.570	0.210	

MVC: Maximal voluntary contraction; SD: Standard deviation
*$P < 0.05$

Table 3. The results of the Mann-Whitney U test in the comparison of the average activity of selected muscles of the lower limbs between the two groups

Variable	Muscle	Group	Activity rate (%MVC) (mean ± SD)	df	Z-score	P-value
Feedforward activity	Tibialis anterior	With instability	2.35 ± 0.87	28	3.90	0.001*
		Without instability	29.22 ± 8.57			
	Peroneus longus	With instability	4.83 ± 2.09	28	3.94	0.001*
		Without instability	60.97 ± 8.09			
	External gastrocnemius	With instability	4.10 ± 2.15	28	3.92	0.001*
		Without instability	36.48 ± 7.21			

MVC: Maximal voluntary contraction; SD: Standard deviation; df: Degree of freedom
*P < 0.05

Moreover, during the feedback phase, 200 milliseconds after the heel hit the ground, the gluteus medius muscle was more active in the last 50% of the stance phase, and the first 25% of the swing phase, but this muscle's activity did not show a significant change in the present study. The difference in the activity investigated, and the possible effect of fatigue caused by prolonged walking in the study by Koldenhoven et al. may be the reasons for the inconsistency in the findings of the studies.

Kim et al. conducted a study (64) on 1,000 athletes who had functional ankle instability and 100 healthy athletes. They measured the electromyography of the lower body muscles 200 milliseconds before the foot hit the ground during a jump-landing task. The results showed that more activity was recorded for the peroneus longus muscle at the beginning and end of the movement in people with instability, and less activity was recorded in the middle, which contradicts the findings of the present study. Additionally, the gastrocnemius muscle showed more significant activity in all activity ranges for people with instability. In contrast, the tibialis anterior muscle showed the same amount of activity in both groups, which is inconsistent with the present research. It is worth noting that in the study by Kim et al., both men and women participated, and the jump-landing task was evaluated, while in the present study, only landing was assessed. Furthermore, in the study by Kim et al., the participants underwent a 10-minute warm-up and performed 10 jumps and landings to the sides before the main task, which may explain the differences in the results of the two studies.

A study by Tretriluxana et al. (65) on 40 volleyball and basketball players (20 players in each group) showed that people with functional ankle instability had shorter activity in the peroneus longus, tibialis anterior, and gluteus medius muscles 200 milliseconds before foot impact than people without instability. This finding is consistent with the results of the present study. The research by Li et al. (24) and Tretriluxana et al. (65) has also shown lower activity in the peroneus longus muscle, which is critical for lateral ankle stability, in subjects with functional ankle instability compared to subjects without it. This study shows that people with functional ankle instability may have different neuromuscular control in the forward phase than healthy people.

Limitations

The research was conducted on male badminton players in the Tehran league. It is important to note that due to variations in weather, skill levels, sports facilities, and other factors, the findings of this study cannot be generalized to other cities or countries. Additionally, the gender differences between male and female players suggest that the results of this research may not be applicable to women.

Recommendations

The research findings indicate that individuals with ankle instability have different muscle activity in the tibialis anterior, gastrocnemius, and peroneus longus muscles to that of healthy individuals.

Table 4. The results of the Mann-Whitney U test for the comparison of the average activity of selected lower limb muscles between the two groups

Variable	Muscle	Group	Activity rate (%MVC) (mean ± SD)	df	Z-score	P-value
Feedback activity	Tibialis anterior	With instability	2.90 ± 1.22	28	3.98	0.001*
		Without instability	27.89 ± 5.19			
	External gastrocnemius	With instability	3.75 ± 0.73	2	3.92	0.001*
		Without instability	42.83 ± 18.65			

MVC: Maximal voluntary contraction; SD: Standard deviation; df: Degree of freedom
*P < 0.05

Table 5. Results of independent t-test in the comparison of the average activity of selected lower limb muscles between the two groups

Variable	Muscle	Group	Activity rate (%MVC) (mean ± SD)	df	Z-score	P-value
Feedback activity	Peroneus longus	With instability	17.24 ± 4.99	28	3.07	0.006*
		Without instability	34.38 ± 18.65			

MVC: Maximal voluntary contraction; SD: Standard deviation; df: Degree of freedom
*P < 0.05

To prevent ankle sprains and control instability, future studies should consider using various protocols, such as exercises based on virtual reality, to improve the activity of these specific muscles.

Conclusion

The present study revealed that individuals with functional ankle instability had different neuromuscular control to that of healthy individuals, as evident from the differences in muscle activity during the feedforward and feedback phases. This difference in neuromuscular control can result in frequent sprains, making it a crucial factor to consider. Additionally, the functional instability of the ankle affects the feedback phase, feedforward activity, and commands from the central nervous system before landing. Therefore, addressing this issue and considering its impact on landing tasks is imperative to prevent frequent ankle sprains.

Acknowledgments

The authors would like to express their gratitude to all badminton players who participated in the present study and to their coaches and team physicians.

Authors' Contribution

Design and ideation of the study: Foad Seidi, Hooman Minoonejad, and Reza Kowsari
Support and executive and scientific services of the study: Foad Seidi, Hooman Minoonejad, Reza Kowsari, and Mostafa Varmaziyar,
Providing study equipment and samples: Reza Kowsari and Mostafa Varmaziyar
Data collection: Reza Kowsari and Mostafa Varmaziyar
Analysis and interpretation of the results: Reza Kowsari and Mostafa Varmaziyar
Specialized statistical services: Reza Kowsari
Handwritten editing: Foad Seidi, Hooman Minoonejad, Reza Kowsari, and Mostafa Varmaziyar
Expert evaluation of handwriting in terms of scientific concepts: Foad Seidi, Hooman Minoonejad, Reza Kowsari, and Mostafa Varmaziyar
Approval of the final manuscript for submission to the journal office: Foad Seidi, Hooman Minoonejad,Reza Kowsari, and Mostafa Varmaziyar
Maintaining the integrity of the process of conducting the study from the beginning to publication and responding to the comments of the referees: Foad Seidi, Reza Kowsari, Mostafa Varmaziyar, and Hooman Minoonejad.

Funding

This article was based on the data extracted from the MSc. thesis by Mr. Reza Kowsari (Ethics Code: IR.UT.SPORT.REC.1400.015) under the supervision of Dr. Foad Seidi and the advice of Dr. Hooman Minoonejad in the Department of Health and Sports Medicine, School of Sport Sciences and Health, Tehran University. Tehran University funded the project and did not interfere in data collection, analysis and reporting, manuscript preparation, and final approval of the study for publication.

Conflict of Interest

The authors did not have any conflicts of interest. Dr. Foad Seidi, and Dr. Hooman Minoonjad were the supervisor and advisor of this project, respectively, and Mr. Mostafa Varmaziyar assisted in data collection and manuscript drafting.

References

1. Fong DT, Hong Y, Chan LK, Yung PS, Chan KM. A systematic review on ankle injury and ankle sprain in sports. Sports Med 2007; 37(1): 73-94.
2. Fu SN, Hui-Chan CW. Modulation of prelanding lower-limb muscle responses in athletes with multiple ankle sprains. Med Sci Sports Exerc 2007; 39(10): 1774-83.
3. Diamond JE. Rehabilitation of ankle sprains. Clin Sports Med 1989; 8(4): 877-91.
4. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. J Athl Train 2002; 37(4): 364-75.
5. Delahunt E, Remus A. Risk factors for lateral ankle sprains and chronic ankle instability. J Athl Train 2019;

54(6): 611-6.
6. Santilli V, Frascarelli MA, Paoloni M, Frascarelli F, Camerota F, De NL, et al. Peroneus longus muscle activation pattern during gait cycle in athletes affected by functional ankle instability: A surface electromyographic study. Am J Sports Med 2005; 33(8): 1183-7.
7. Feger MA, Hart JM, Saliba S, Abel MF, Hertel J. Gait training for chronic ankle instability improves neuromechanics during walking. J Orthop Res 2018; 36(1): 515-24.
8. Gerber JP, Williams GN, Scoville CR, Arciero RA, Taylor DC. Persistent disability associated with ankle sprains: A prospective examination of an athletic population. Foot Ankle Int 1998; 19(10): 653-60.
9. Hertel J, Corbett RO. An updated model of chronic ankle instability. J Athl Train 2019; 54(6): 572-88.
10. Rowe PL, Bryant AL, Paterson KL. Current ankle sprain prevention and management strategies of netball athletes: a scoping review of the literature and comparison with best-practice recommendations. BMC Sports Sci Med Rehabil 2021; 13(1): 113.
11. Simpson JD, Stewart EM, Macias DM, Chander H, Knight AC. Individuals with chronic ankle instability exhibit dynamic postural stability deficits and altered unilateral landing biomechanics: A systematic review. Phys Ther Sport 2019; 37: 210-9.
12. Freeman MA, Dean MR, Hanham IW. The etiology and prevention of functional instability of the foot. J Bone Joint Surg Br 1965; 47(4): 678-85.
13. Geerinck A, Beaudart C, Salvan Q, Van Beveren J, D'Hooghe P, Bruyere O, et al. French translation and validation of the Cumberland Ankle Instability Tool, an instrument for measuring functional ankle instability. Foot Ankle Surg 2020; 26(4): 391-7.
14. Brown C, Padua D, Marshall SW, Guskiewicz K. Individuals with mechanical ankle instability exhibit different motion patterns than those with functional ankle instability and ankle sprain copers. Clin Biomech (Bristol, Avon) 2008; 23(6): 822-31.
15. Tropp H, Odenrick P, Gillquist J. Stabilometry recordings in functional and mechanical instability of the ankle joint. Int J Sports Med 1985; 6(3): 180-2.
16. Lin CI, Houtenbos S, Lu YH, Mayer F, Wippert PM. The epidemiology of chronic ankle instability with perceived ankle instability- a systematic review. J Foot Ankle Res 2021; 14(1): 41.
17. Santos MJ, Liu H, Liu W. Unloading reactions in functional ankle instability. Gait Posture 2008; 27(4): 589-94.
18. Richie DH, Jr. Functional instability of the ankle and the role of neuromuscular control: A comprehensive review. J Foot Ankle Surg 2001; 40(4): 240-51.
19. Delahunt E. Neuromuscular contributions to functional instability of the ankle joint. J Bodyw Mov Ther 2007; 11(3): 203-13.
20. Ross SE, Guskiewicz KM, Yu B. Single-leg jump-landing stabilization times in subjects with functionally unstable ankles. J Athl Train 2005; 40(4): 298-304.
21. Ganesh GS, Chhabra D, Mrityunjay K. Efficacy of the star excursion balance test in detecting reach deficits in subjects with chronic low back pain. Physiother Res Int 2015; 20(1): 9-15.
22. Olmsted LC, Carcia CR, Hertel J, Shultz SJ. Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. J Athl Train 2002; 37(4): 501-6.
23. Munn J, Beard DJ, Refshauge KM, Lee RY. Eccentric muscle strength in functional ankle instability. Med Sci Sports Exerc 2003; 35(2): 245-50.
24. Li Y, Ko J, Walker MA, Brown CN, Schmidt JD, Kim SH, et al. Does chronic ankle instability influence lower extremity muscle activation of females during landing? J Electromyogr Kinesiol 2018; 38: 81-7.
25. Hubbard TJ, Kaminski TW. Kinesthesia is not affected by functional ankle instability status. J Athl Train 2002; 37(4): 481-6.
26. Boyle J, Negus V. Joint position sense in the recurrently sprained ankle. Aust J Physiother 1998; 44(3): 159-63.
27. Vaes P, Duquet W, Van Gheluwe B. Peroneal reaction times and eversion motor response in healthy and unstable ankles. J Athl Train 2002; 37(4): 475-80.
28. Konradsen L, Ravn JB. Ankle instability caused by prolonged peroneal reaction time. Acta Orthop Scand 1990; 61(5): 388-90.
29. Ebig M, Lephart SM, Burdett RG, Miller MC, Pincivero DM. The effect of sudden inversion stress on EMG activity of the peroneal and tibialis anterior muscles in the chronically unstable ankle. J Orthop Sports Phys Ther 1997; 26(2): 73-7.
30. Ryan L. Mechanical stability, muscle strength and proprioception in the functionally unstable ankle. Aust J

Physiother 1994; 40(1): 41-7.
31. Arnold BL, Linens SW, de la Motte SJ, Ross SE. Concentric evertor strength differences and functional ankle instability: A meta-analysis. J Athl Train 2009; 44(6): 653-62.
32. Corbin DM, Hart JM, McKeon PO, Ingersoll CD, Hertel J. The effect of textured insoles on postural control in double and single limb stance. J Sport Rehabil 2007; 16(4): 363-72.
33. Feger MA, Donovan L, Hart JM, Hertel J. Lower extremity muscle activation in patients with or without chronic ankle instability during walking. J Athl Train 2015; 50(4): 350-7.
34. Wikstrom EA, Cain MS, Chandran A, Song K, Regan T, Migel K, et al. Lateral ankle sprain and subsequent ankle sprain risk: A systematic review. J Athl Train 2021; 56(6): 578-85.
35. Miranda JP, Silva WT, Silva HJ, Mascarenhas RO, Oliveira VC. Effectiveness of cryotherapy on pain intensity, swelling, range of motion, function and recurrence in acute ankle sprain: A systematic review of randomized controlled trials. Phys Ther Sport 2021; 49: 243-9.
36. Dolan P, Kenny I, Glynn L, Campbell M, Warrington GD, Cahalan R, et al. Risk factors for acute ankle sprains in field-based, team contact sports: a systematic review of prospective etiological studies. Phys Sportsmed 2022; 1-14. [Online ahead of print].
37. Mason J, Kniewasser C, Hollander K, Zech A. Intrinsic risk factors for ankle sprain differ between male and female athletes: A systematic review and meta-analysis. Sports Med Open 2022; 8(1): 139.
38. Lee HM, Oh S, Kwon JW. Effect of plyometric versus ankle stability exercises on lower limb biomechanics in taekwondo demonstration athletes with functional ankle instability. Int J Environ Res Public Health 2020; 17(10).
39. de RR, Russo G, Lena F, Giovannico G, Neville C, Turolla A, et al. The effect of manual therapy plus exercise in patients with lateral ankle sprains: A critically appraised topic with a meta-analysis. J Clin Med 2022; 11(16).
40. Herzog MM, Kerr ZY, Marshall SW, Wikstrom EA. Epidemiology of ankle sprains and chronic ankle instability. J Athl Train 2019; 54(6): 603-10.
41. Smith MD, Vicenzino B, Bahr R, Bandholm T, Cooke R, Mendonca LM, et al. Return to sport decisions after an acute lateral ankle sprain injury: introducing the PAASS framework-an international multidisciplinary consensus. Br J Sports Med 2021; 55(22): 1270-6.
42. Pathmanathan C, Jayakody J, Perera M, Weerarathna W, Nirosha S, Indeewari D, et al. Physical fitness factors of school badminton players in Kandy district. Euro J Sports Exerc Sci 2015; 4(2): 14-25.
43. N Chandrakumar, C Ramesh. Effect of ladder drill and SAQ training on speed and agility among sports club badminton players. Int J Appl Res 2015;1(12):527-529. 2023.
44. Sudaryono MD, Pradjoko D. Sports, nationalism, and achievement: Indonesian badminton in the 1992 barcelona olympics. In Dissecting History and Problematizing the Past in Indonesia. Nova Science Publishers, Inc. 2021. p. 73-84. 2023.
45. Palmer D, Cooper DJ, Emery C, Batt ME, Engebretsen L, Scammell BE, et al. Self-reported sports injuries and later-life health status in 3357 retired Olympians from 131 countries: a cross-sectional survey among those competing in the games between London 1948 and PyeongChang 2018. Br J Sports Med 2021; 55(1): 46-53.
46. Park SH. Effects of Neuromuscular Training on Muscle Activity and Balance Ability in Badminton Club Members with Chronic Ankle Instability. J Kor Phys Ther 2016; 28(4): 243-8.
47. Herbaut A, Delannoy J, Foissac M. Do French and Chinese regular badminton players experience the same injuries? Proceedings of the 23rd Annual Congress of the European College of Sport Science; 2018 July 4-7; Dublin, Ireland. 2018.
48. Herbaut A, Delannoy J. Fatigue increases ankle sprain risk in badminton players: A biomechanical study. J Sports Sci 2020; 38(13): 1560-5.
49. Herbaut A, Delannoy J, Foissac M. Injuries in French and Chinese regular badminton players. Sci Sports 2018; 33(3): 145-51.
50. Donovan L, Hetzel S, Laufenberg CR, McGuine TA. Prevalence and Impact of chronic ankle instability in adolescent athletes. Orthop J Sports Med 2020; 8(2): 2325967119900962.
51. Hershkovich O, Tenenbaum S, Gordon B, Bruck N, Thein R, Derazne E, et al. A large-scale study on epidemiology and risk factors for chronic ankle instability in young adults. J Foot Ankle Surg 2015; 54(2): 183-7.
52. Delavar A. Theoretical and practical foundations of research in humanities and social sciences. 9th ed. Tehran, Iran: Roshd Publications; 2011. [In Persian]. 2023.
53. Hiller CE, Refshauge KM, Bundy AC, Herbert RD, Kilbreath SL. The Cumberland ankle instability tool: A

report of validity and reliability testing. Arch Phys Med Rehabil 2006; 87(9): 1235-41.
54. Haji-Maghsoudi M, Naseri N, Nouri-Zadeh S, Jalayi S. Evidence of reliability for Persian version of the “Cumberland Ankle Instability Tool (CAIT)" in Iranian Athletes with lateral Ankle Sprain. J Rehab 2016; 16(4): 304-11. [In Persian].
55. Gribble PA, Delahunt E, Bleakley CM, Caulfield B, Docherty CL, Fong DT, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. J Athl Train 2014; 49(1): 121-7.
56. Kikumoto T, Akatsuka K, Nakamura E, Ito W, Hirabayashi R, Edama M. Quantitative evaluation method for clarifying ankle plantar flexion angles using anterior drawer and inversion stress tests: A cross-sectional study. J Foot Ankle Res 2019; 12: 27.
57. Konrad P. The ABC of EMG: A practical introduction to kinesiological electromyography. Scottsdale, AZ: Noraxon U.S.A. Inc.; 2006.
58. Sacco IC, Gomes AA, Otuzi ME, Pripas D, Onodera AN. A method for better positioning bipolar electrodes for lower limb EMG recordings during dynamic contractions. J Neurosci Methods 2009; 180(1): 133-7.
59. Roman-Liu D, Bartuzi P. Influence of type of MVC test on electromyography measures of biceps brachii and triceps brachii. Int J Occup Saf Ergon 2018; 24(2): 200-6.
60. Contarli N, Cankaya T. Effect of the Pes Planus on Vertical Jump Height and Lower Extremity Muscle Activation in Gymnasts. Turkish Journal of Sport and Exercise 2022; 24(1): 81-9.
61. Gilmore KL, Meyers JE. Using surface electromyography in physiotherapy research. Aust J Physiother 1983; 29(1): 3-9.
62. McManus L, De VG, Lowery MM. Analysis and biophysics of surface EMG for physiotherapists and kinesiologists: Toward a common language with rehabilitation engineers. Front Neurol 2020; 11: 576729.
63. Koldenhoven RM, Feger MA, Fraser JJ, Saliba S, Hertel J. Surface electromyography and plantar pressure during walking in young adults with chronic ankle instability. Knee Surg Sports Traumatol Arthrosc 2016; 24(4): 1060-70.
64. Kim H, Son SJ, Seeley MK, Hopkins JT. Altered movement strategies during jump landing/cutting in patients with chronic ankle instability. Scand J Med Sci Sports 2019; 29(8): 1130-40.
65. Tretriluxana J, Nanbancha A, Sinsurin K, Limroongreungrat W, Wang HK. Neuromuscular control of the ankle during pre-landing in athletes with chronic ankle instability: Insights from statistical parametric mapping and muscle co-contraction analysis. Phys Ther Sport 2021; 47: 46-52.