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RESEARCH **Open Access**

Is there a correlation among landing stability, ankle dorsiflexion range of motion, and ankle stiffness during single-leg landing?

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Abstract

Background Even though both landing stability and ankle dorsiflexion stiffness (ankle DR-stiffness) have been independently identified as risk factors associated with non-contact injuries, no study has specifically investigated the relationship between these two variables.

Methods Twenty male recreational athletes volunteered to participate in this study. Their ankle DF-ROM based on the weight-bearing lunge test, and landing stability based on the dynamic postural stability index (DPSI) and time to stabilization (TTS) were evaluated during a single-leg landing (SLL).

Results There was no statistically significant difference among ankle DF-ROM, ankle DF-stiffness, DPSI, and TTS during the SLL task ($p > .05$). Although a moderately positive relationship was observed between ankle DF-ROM and ankle DF-stiffness ($p = .177$; $r = .354$ [95% CI, -.153 to .653]) and a moderately negative relationship between ankle DF-ROM and TTS ($p = .163$; $r = -.375$ [95% CI, -.598 to .098]), these were not statistically significant.

Conclusion The findings indicate that ankle DF-stiffness as an independent variable, does not significantly affect landing stability based on the TTS and DPSI indexes. However, its interaction with other variables, such as sex, age, and the nature of the movement task, may influence landing stability. This study area warrants further research.

Keywords Ankle mobility, Time to stabilization, Postural stability, Injury prevention, Force plate

Background

The importance of landing stability for athletes in various jumping-based sports, such as volleyball and football, is widely recognized. Many injury prevention programs, including FIFA 11+, emphasize this critical aspect [1–3]. That is why it has garnered interest from researchers due to its potential role in reducing the risk of injuries. In this context, single-leg landing (SLL), which exerts significant and rapid impulse loads on the lower extremity—particularly the ankle—is frequently identified as a dynamic maneuver that aligns with common movement strategies in various sports and simulates the mechanisms of non-contact injuries [4–6]. Therefore, it seems logical to use a sport-specific SLL task to assess landing stability instead of a double-leg landing. Notably, it has been well established that performance demands and, consequently, research outcomes may vary across different movement tasks, and functional tests should be selected with care [7, 8]. Also, among the methods for measuring landing stability, the time to stabilization (TTS) and the dynamic postural stability index (DPSI) are two common and reliable approaches. These methods assess landing stability based on ground reaction forces, which are measured using a force plate [9, 10]. These dynamic stability

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measurements provide valuable insights into landing stability, reflecting an individual's movement performance capabilities.

The previous studies have been shown that various internal (e.g. Previous musculoskeletal-related injuries [11, 12], Sex [13], Foot posture [14], fatigue [15], and Hip muscles strength [16]) and external (e.g. Jump-landing direction [17], and Midsole of the shoes [18]) factors could affect the landing stability. Certainly, understanding and considering these factors is essential for developing targeted injury prevention strategies and training programs that improve landing stability and, consequently, enhance movement performance. The ankle dorsiflexion range of motion (Ankle DF-ROM) is considered as a crucial component of movement performance [7, 19], especially in sports that require a greater demand of the ankle DF-ROM. In this regard, some studies reported that restricting ankle DF-ROM [7, 19–21] affects the landing strategy, which causes movement faults and can raise the risk of lower extremity injuries, but its relationship to ankle DR-stiffness and landing stability was not clarified in these studies. There is evidence indicating that optimal ankle DR-stiffness is associated with a reduction in metabolic cost and [22] an improvement in jumping performance [23, 24].

In summary, despite the fact that both landing stability and ankle DR-ROM have been independently recognized as risk factors associated with non-contact injuries, no study has specifically investigated the relationship among these variables in relation to one another. Although, there are studies that have investigated the relationship between ankle DR-ROM and postural stability [25–29], but in these studies the Y-balance test or single-leg standing have been significantly used to assess the postural stability, or the participants were purposefully selected with limitations in ankle dorsiflexion.

Given the importance of utilizing evidence-based training programs by practitioners and coaches, the purpose of this study was to determine whether a correlation exists among landing stability, ankle DF-ROM, and ankle DF-stiffness during the SLL task? We hypothesized that a correlation would be present among the evaluated parameters, with participants exhibiting greater ankle DF-stiffness would have increased landing stability during the SLL task.

Methods

Participants

This study was designed as a cross-sectional study. According to G. Power software version 3.1.0 (Franz Faul, University of Kiel, Germany), based using a Pearson statistical test and assuming a power of 0.80, an effect size of 0.7 [30], and two-tailed alpha level of 0.05, twenty recreational male athletes were required for this study (Age, 23.53 ± 2.23 years; Mass, 75.51 ± 10.98 kg; Height, 179.86 ± 8.92 cm) who were selected based on certain criteria. The faculty's board of physical education and Sports Sciences invited people to join the study for one month starting from January 10, 2024. The inclusion criteria were to be physically active, between the ages of 18 and 25, and have a body mass index between 18 and 24. Participants were excluded if they had a musculoskeletal injury within the past two months or a lower-extremity injury within the past six months, had any neurological or pathological conditions, had a lower-limb surgery or fracture within the past year, or were unwilling to cooperate.

The ethical committee of Allameh Tabataba'I university obtained approval before the test, and all participants gave their consent in writing.

Procedures

In this study, participants were referred to the sports biomechanics laboratory on one occasion and completed a one-hour testing session. In order to prevent the influence of footwear differences, they were instructed to wear comfortable sports clothing without shoes. The evaluation focused on the participants' ankle joint stiffness and landing stability, as measured by the DPSI and TTS indexes during the SLL task. Each participant performed the single-leg landing (SLL) on a force plate (60 cm × 50 cm, Kistler, 9260AA6, Switzerland) for two trials, with a one-minute rest interval between trials; the average of the two trials was used for analysis. Simultaneous recordings of kinematic data (120 Hz) and force plate data (1200 Hz) were collected during each trial to calculate the Ankle DF-stiffness. Prior to the test, participants were instructed to perform a 5-min warm-up consisting of general lower extremity stretching and weight-bearing exercises under the supervision of a corrective exercise expert.

The ankle dorsiflexion range of motion (Ankle DF-ROM) measurement

The weight-bearing lunge test was conducted to functionally assess the ankle dorsiflexion range of motion in a weight-bearing position (Fig. 1); First, the subject was instructed to assume a lunge position with the evaluated leg in front, one palm placed against the wall, and perpendicular to the floor. Next, they were asked to bring their knee closer to the wall without lifting their heel off the ground. If the knee did not touch the wall or if the heel lifted, the subject was directed to move their leg forward and repeat the test until their knee made contact with the wall without lifting the heel. Finally, the examiner measured the distance between the wall and the big

Fig. 1 The subject's ankle dorsiflexion ROM was measured using the weight-bearing lunge test-distance from wall to big toe (A)

toe using a tape measure. It is important to note that each centimeter was considered equivalent to 2° of ankle dorsiflexion range of motion [31].

The dynamic postural stability measurement based on DPSI and TTS indexes

The dynamic postural stability of the subjects was assessed during SLL task. The participants were instructed to stand with their feet shoulder-width apart on a 30-cm-high step, positioned at a distance equal to half their height from the force plate. They were then instructed to land on the force plate using an arm swing with their dominant leg while maintaining balance (Fig. 2); The dominant leg was defined as the preferred landing leg, typically chosen unconsciously.

The dynamic postural stability index (DPSI) and its directional components were calculated using a custom MATLAB script (v9.9.0, Natick, Massachusetts). This method assesses mean square deviations to evaluate fluctuations around zero in the ground reaction force (GRF) across three directions. The DPSI integrates elements from the APSI, MLSI, and VSI. The calculation of the Dynamic Postural Stability Index (DPSI) score along with its three directional components, was performed by analyzing the initial three seconds of the ground reaction force following the point of initial contact, defined

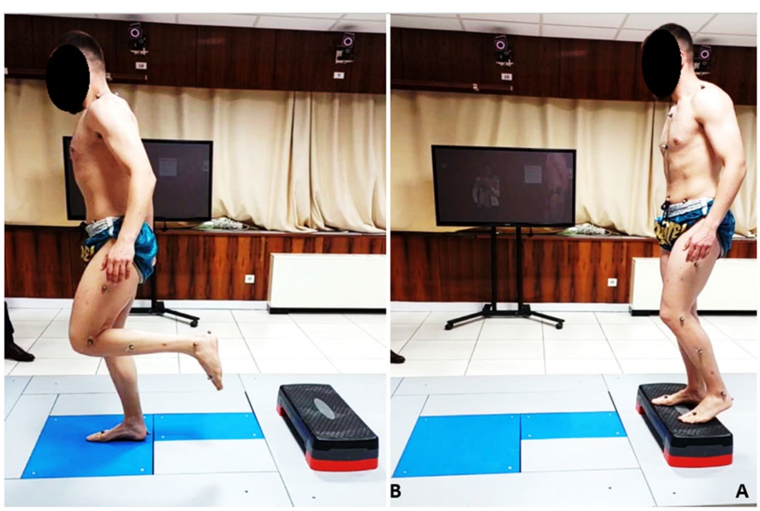

Fig. 2 The subject is performing the single-leg landing (SLL) task on the force plate

as the moment when the vertical ground reaction force exceeded 5% of the participant's body weight [32].

These ground reaction forces, measured in Newton units, were normalized with respect to the subject's body weight. It is important to note that elevated values of stability indices and DPSI scores are indicative of poorer dynamic postural stability. Previous research endeavors have highlighted the robustness of this methodology, showing favorable test–retest reliability as evidenced by Intraclass Correlation Coefficients (ICCs) ranging between 0.86 and 0.90, and Standard Error of Measurement (SEM) values falling within the range of 0.028 to 0.06 [9, 33].

Also, the TTS was calculated from the time of initial landing contact until they stabilized within 5% of their bodyweight for 2 s. For instance, if a subject's initial contact occurred at 1.7 s and stabilization to within 5% of their bodyweight occurred at 2.4 s, TTS of 0.7 s was recorded [34, 35].

The ankle dorsiflexion stiffness (Ankle DF-stiffness) Measurement

In general, stiffness is defined as the ratio of changes in force to changes in length. In the human body, it reflects the potential to resist deformation caused by the ground reaction force. In the present study, ankle joint stiffness was calculated using the torsional-spring model, which is the ratio of the peak sagittal plane joint moment (i.e., the joint rotatory force) to the peak sagittal plane joint angular displacement between the initial landing contact and maximum joint flexion during SLL task [36]: Kjoint (Nm/θ) = ΔMjoint/ Δθjoint.

In the current formula, ΔM_joint represents the change in joint torque from the initial contact of the foot with the force plane to the maximum knee flexion, while Δθ_joint denotes the change in angular displacement of the joint between the initial landing contact and maximum knee flexion.

Statistical analysis

Based on the Shapiro–Wilk test, the data distribution was found to be non-normal. Consequently, a Spearman correlation coefficient statistical test was employed to assess the relationships among ankle DF-ROM, ankle DF-stiffness, DPSI, and TTS during the SLL task. All analyses were conducted using SPSS software Version 22.0 (Microsoft Corp., Redmond, WA), and the significance level was set at 0.05.

Results

The mean and median values of ankle DF-ROM, ankle DF-stiffness, DPSI, and TTS measurements of the participants can be found in Table 1. The results of the Spearman correlation coefficient test indicated that there is no statistically significant difference among ankle DF-ROM, ankle DF-stiffness, DPSI, and TTS during the SLL task ($p > 0.05$). Although there was a moderately positive relationship between ankle DF-ROM and ankle DF-Stiffness ($p = 0.177$; $r = 0.354$ [95% CI, -0.153 to 0.653]) and a moderately negative relationship between ankle DF-ROM and TTS ($p = 0.163$; $r = -0.375$ [95% CI, -0.598 to 0.098]), these were not statistically significant (Table 2).

Table 1 Median (Interquartile range) and Mean (SD) values of measured parameters of the participants during SLL task[a]

Variables	Median (Interquartile range)	Mean ± SD
Ankle DF-ROM (°)	30.00 (24.00 – 31.50)	28.30 ± 6.53
Ankle DF-Stiffness (Nm·kg – 1·deg. – 1)	2.711 (2.344 – 3.413)	3.02 ± 1.29
DPSI	.156 (.154—.157)	.16 ± .01
TTS (s)	.815 (.710—.999)	.96 ± .419

Abbreviations: DF-ROM Dorsiflexion range of motion, *DPSI* Dynamic postural stability index, *TTS* Time to stabilization, *SLL* Single leg-landing

[a] Data are presented as mean ± SD

Discussion

The results of the current study did not support our hypothesis that the ankle DF-ROM and ankle DF-stiffness could significantly affect landing stability during the SLL; We indicated that there was no correlation among ankle DF-ROM, ankle DF-stiffness, DPSI, and TTS during the SLL task. Despite the existence of a moderately positive correlation between the ankle DF-ROM and ankle DF-stiffness, and a moderately negative correlation between the ankle DF-ROM and TTS, these correlations were not statistically significant.

To our knowledge, this is the first study to investigate the relationship between ankle DF-ROM, DR-stiffness, and landing stability during SLL task. The importance of landing stability in the movement performance of athletes as well as injury prevention has been shown [1, 2]. In this regard, various studies have investigated the relationship between various factors affecting landing stability so that they can provide valuable information for sports experts to design effective training programs to improve landing performance [12–16, 18]. Previous studies suggested that limitations in the ankle DF-ROM could affect the landing biomechanics, which may expose the athlete to an increased risk of injuries [7, 19]. Furthermore, a positive correlation has been shown between limited ankle DF-ROM and ankle joint stiffness, which causes an increase in ground reaction forces and subsequently increases the stress on the skeletal structure and the risk of injury [37]. However, it is reported that increasing or

Table 2 Correlation (r) among Ankle dorsiflexion ROM, Ankle dorsiflexion stiffness, Dynamic postural stability index, and Time to stabilization during the single leg landing (SLL)[a]

Variables	Ankle DF-ROM	Ankle DF-Stiffness	DPSI	TTS
Ankle DF-ROM	1	.354 (-.153 to .673)	.259 (-.270 to .664)	-.375 (-.597 to .098)
***p*-value**	-	.177	.270	.163
Ankle DF-Stiffness	-	1	-.036 (-.451 to .371)	.086 (-.363 to .549)
***p*-value**	-	-	.880	.719
DPSI	-	-	1	.009 (-.445 to .449)
***p*-value**	-	-	-	.970

[a] Data are presented as r (95% CI)

Abbreviations: DF-ROM Dorsiflexion range of motion, *DPSI* Dynamic postural stability index, *TTS* Time to stabilization, *SLL* Single leg-landing

decreasing ankle joint stiffness does not necessarily affect landing biomechanics and it would affected more by the demands of the task [8]. For the first time, we've shown that ankle DF-stiffness, as an independent variable, didn't affect landing stability based on the TTS and DPIS indexes, which is in line with the previous study, which found that ankle stiffness doesn't affect landing strategy; Basically, it should be noted that landing stability may be affected by several factors simultaneously; therefore, the results of the present study cannot definitively describe that there is no correlation between landing stability and ankle DF-stiffness. Thus, the ankle DF-stiffness interaction with other parameters such as sex, age, and nature of the movement task may affect landing stability, which requires more research in this field, and these notes must be considered in research studies and the design of exercise programs.

Notably, it should be mentioned that the limitation at ankle DF-ROM was not defined as an inclusion criterion in this research, and the subjects have been randomly selected. As most of the participants in the present study were subjects with normal ankle DF-ROM, we recommend that a study be conducted in a targeted manner to investigate the relationship between limited ankle DF-ROM and landing stability and also its interaction with other variables. Also, considering that in previous studies there was a difference in the results related to ankle dorsiflexion limitation and ankle joint stiffness, we assume that there is a difference between these two parameters in landing stability as well.

We acknowledge that the current study had limitations that should be considered. First, most of the subjects randomly selected for this study had a normal ankle DF-ROM, which may have influenced the results of the correlation analysis. Second, the participants were healthy male recreational athletes, which limits the generalizability of the findings to a broader population, including athletes with injuries or those at risk of injury. Comparisons with injured subjects would provide valuable insights for readers seeking to understand these relationships. Additionally, gender differences may significantly impact landing biomechanics and stiffness. Finally, we did not assess leg, knee, and hip stiffness, nor did we evaluate joint stiffness in other movement planes, which could offer further insights into the correlation between stiffness and landing stability.

Conclusion

In summary, we determined the relationship among landing stability, ankle dorsiflexion range of motion, and ankle stiffness during single-leg landing; The findings of the current study indicated ankle DF-stiffness as an independent variable couldn't affect landing stability based on the TTS and DPSI indexes, although it is essential to evaluate the interaction of this factor with other parameters, such as sex, age, and the nature of the movement task, in future research, as these may influence landing stability.

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Authors' contributions
M.H: Writing- Original draft preparation, Conceptualization, Methodology, Data capture, Data analysis.M.B: Writing- Original draft preparation, Investigation, Data capture.F.B: Conceptualization, Methodology, Scientific editing.

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

Declarations

Ethics approval and consent to participate
A study description was provided for all participants prior to the experiment. All participants signed the informed consent. The study protocol was approved by ethical committee of Allameh Tabataba'I University, Iran. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication
It is worth noting that written informed consent for publication has been obtained from the patient shown in Figure 1

Competing interests
The authors declare no competing interests.

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