

The impact of ankle sprain injury on jumping performance, ankle dorsiflexion, and dynamic balance among adolescents

Nezir Eğdemir

Dissertação para obtenção do Grau de Mestre em
Ciências do Desporto
(2^o ciclo de estudos)

Orientador: Professor Doutor Henrique Pereira Neiva
Coorientador: Professor Doutor Diogo Luís Sequeira Torgal Marques

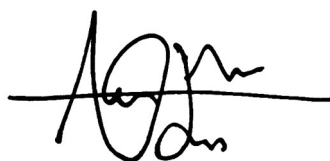
junho de 2025

Declaração de Integridade

Eu, Nezir Eđdemir, que abaixo assino, estudante com o número de inscrição M11486 de Ciências do Desporto da Faculdade de Ciências Sociais e Humanas, declaro ter desenvolvido o presente trabalho e elaborado o presente texto em total consonância com o **Código de Integridades da Universidade da Beira Interior**.

Mais concretamente afirmo não ter incorrido em qualquer das variedades de Fraude Académica, e que aqui declaro conhecer, que em particular atendi à exigida referenciação de frases, extratos, imagens e outras formas de trabalho intelectual, e assumindo assim na íntegra as responsabilidades da autoria.

Universidade da Beira Interior, Covilhã 06/06/2025

A handwritten signature in black ink, appearing to be 'Nezir Eđdemir', written over a horizontal line.

Dedication

To my mother and my sisters.

Acknowledgements

Many thanks for the guidance of Professor Henrique Neiva and Professor Diogo Marques.

Abstract

The ankle is one of the most injured joints in children and adolescents. Some reasons are related to their physical growth, including the development of muscle mass, sports movement skills, and hormonal factors. Considering the high rates of ankle sprain injuries among adolescents, it is important to understand how a previous injury can impact their physical performance. This study aimed to i) analyze the impact of ankle sprain injury on jumping performance, ankle dorsiflexion range of motion, and dynamic balance among adolescents, and ii) identify the factors associated with ankle sprain injury. Forty-eight adolescents (24 male and 24 female) aged between 11 and 16 were selected based on regularly practicing physical exercise. Participants included those with previous ankle sprain injuries and those without. At the time of the study, all participants were uninjured and healthy. Participants completed an injury-related questionnaire and a double-leg jump-landing test, ankle dorsiflexion test, and Y-balance test. The results showed that twenty-three participants reported previous ankle sprain injury, while twenty-five had no previous recordings of ankle injuries. Ankle-injured participants were older than the non-ankle-injured participants ($p < 0.01$, effect size = 0.73) and presented higher ground contact times ($p = 0.03$, effect size = 0.56) and lower stiffness ($p = 0.04$, effect size = 0.52) in the double-leg jump-landing test. Finally, a higher chronological age increased the odds of ankle sprain injury 1.89 times in adolescents. This study showed that age significantly predicted ankle sprain injury among adolescents. Furthermore, even after recovery from ankle-sprain injury, changes in jumping and landing biomechanics were observed, with longer jumping times and lower joint stiffness being observed in the ankle-injured participants.

Keywords

Ankle sprain injury; adolescent; Y-balance test; Ankle dorsiflexion test; double-leg jump-landing test

Table of Contents

Acknowledgements	vii
Abstract	ix
Keywords	ix
List of Tables	xiii
List of Acronyms	xv
Introduction	1
Methods	3
Study Design	3
Participants	3
Procedures	4
Injury-related data questionnaire	4
Double-leg jump-landing test	4
Ankle dorsiflexion test	4
Y-Balance test	5
Statistical analysis	6
Results	7
Test-retest reliability analysis	7
General characteristics of the participants and injury-related data	8
Differences in jumping performance, ankle dorsiflexion, and dynamic balance between adolescents with and without previous ankle sprain injury	10
Factors associated with ankle sprain injury in adolescents	12
Discussion	13
Chronological age as a predictor of ankle injury	13
Double-jump landing test	14
Ankle dorsiflexion test	15
Y-Balance test	16
Limitations of the study	17

Practical implications	19
Conclusion	20
References	22

List of Tables

Table 1	Test-retest reliability data.	7
Table 2	Characteristics of the participants.	9
Table 3	Differences in jumping performance, ankle dorsiflexion, and dynamic balance between adolescents with and without previous ankle sprain injury.	11
Table 4	Factors associated with ankle sprain injury.	12

List of Acronyms

ACL	Anterior Cruciate Ligament
ANT, PM, PL	Anterior, Posteromedial, Posterolateral
BMI	Body Mass Index
CI	Confidence Interval
CV	Coefficient of Variation
ICC	Intra-Class Correlation Coefficient
OR	Odds Ratio
PHV	Peak Height Velocity
RSI	Reactive Strength Index
SD	Standard Deviation
SEBT	Star Excursion Balance Test
SPSS	Statistics Package for the Social Sciences
YBT-LQ	Y-Balance Test Lower Quarter

Introduction

Children and adolescents are more susceptible to ankle sprains than adults, attributable to developmental characteristics such as muscle mass, proficiency in executing sports movements, and hormonal influences (Santos et al., 2022). Consequently, the ankle ranks as one of these individuals' most frequently injured joints. Ankle sprain is a medical condition where ankle ligaments are torn (Faizullin & Faizullina, 2015). The ankle joint connects the talus, the tibia, and the fibula bones. It is a synovial hinge joint with one plane of motion, and the main movements can be described as plantar flexion (where the toes are pushed in the downward direction) and dorsiflexion (the movement where the toes are lifted) (Faizullin & Faizullina, 2015). Ankle dorsiflexion is particularly associated with squat depth and is essential in walking, running, squatting, and landing (Pacheco et al., 2021). Although a significant public health problem, the prognostic factors are largely unknown (Pacheco et al., 2021).

The evidence indicates that ankle sprain injuries account for 16%-40% of all sports-related injuries (Fong et al., 2007; Halabchi & Hassabi, 2020). A study of Australian basketball players reported that over half of the total time lost from an injury was due to an ankle injury (McKay et al., 2001). The relatively high rates of ankle sprains create a compelling reason to investigate this injury and examine its impact on a typical group of athletes. The most common type of ankle sprain involves lateral ligament injuries, accounting for an estimated 85% of all ankle sprains (Halabchi & Hassabi, 2020). Lateral ankle sprains usually occur during a rapid shift of the body's center of mass over the landing or weight-bearing foot (Halabchi & Hassabi, 2020). The ankle rolls outward, whilst the foot turns inward, causing the lateral ligament to stretch and tear. When a ligament tears or is overstretched, the previous elasticity and resilience rarely return to normal (Halabchi & Hassabi, 2020).

Studies have determined several risk factors for lateral ankle sprains. For example, Halabchi & Hassabi (2020), list a previous history of an ankle sprain, being overweight, ankle joint laxity, and impaired balance as the risk factors. There are also different risk factors for ankle sprain in males and females (Mason et al., 2022). Injury risk factors in males include a previous ankle sprain, higher weight and body mass index, poor dynamic balance performance, and lower hip strength. Lower specific ankle strength was the only risk factor identified for ankle sprains in females.

Alongside an injury-related survey, standard physical tests are commonly selected to assess performance in ankle-injured individuals, including dynamic balance, ankle

dorsiflexion range of motion, and double-leg jump-landing tests (González-Fernández et al., 2022; Konor et al., 2012; Rowell & Relph, 2021). A number of studies have found that poor dynamic balance ability is significantly related to an increased risk of ankle injuries in different activities (Hrysomallis, 2007). A standard test used to assess dynamic balance is the Y-Balance test (Plisky et al., 2009). Moderate to high-quality evidence demonstrates that the Y-Balance test is a reliable dynamic neuromuscular control test, with important applicability in injured individuals (Plisky et al., 2021). Ankle dorsiflexion measurement is also important for clinical and research use (Plisky et al., 2021). A weight-bearing lunge where the foot is firmly planted on the ground replicates the ankle's position during functional activities, such as squatting, jump landing, or stair climbing (Adillón et al., 2022). Finally, a double-leg jump-landing test can identify asymmetrical lower extremity biomechanics following injuries. As the jumping test simultaneously analyses the injured and uninjured lower segments of both legs, this test can provide important insights regarding the jumping and landing biomechanics.

Despite the established procedures noted in the literature, research on ankle-injured Portuguese adolescents remains limited. Therefore, in order to gain a broader understanding of the physical performance differences among adolescents with and without a previous history of ankle sprain injury, this study aimed to analyze the impact of ankle sprain injury on jumping performance, ankle dorsiflexion range of motion, and dynamic balance among adolescents. Furthermore, a second aim was to identify the factors associated with ankle sprain injury among adolescents.

Methods

Study Design

In a cross-sectional study design, adolescents with and without a previous history of ankle sprain injury were recruited to perform a battery of tests in two sessions, separated by 48 hours. In session one, the participants answered an injury-related data questionnaire and performed anthropometric measurements, including standing and sitting height (Stadiometer SECA 213, Germany), body mass (TANITA BC-601, Japan), and leg length (calculated as standing height minus sitting height (Hawkes et al., 2020)). Sitting height was measured from the seated position (back and buttocks placed on the stadiometer) to the top of the head (Oliveira-Santos et al., 2016). Body mass index (BMI) was calculated as the body mass divided by the standing height squared. In addition, all participants were familiarized with the tests to be performed in the second session: the double-leg jump-landing, ankle dorsiflexion, and dynamic balance. Two researchers and two sport-related professionals with certified training supervised all tests and collected the data.

Participants

Forty-eight adolescents (ages 11 to 16) volunteered to participate in this study. The study was disseminated in sports clubs, associations, and schools in Covilhã, Portugal. The participants were recruited based on the following criteria: i) male or female adolescents (according to the World Health Organization, adolescence ranges from 10 to 19 years of age (Singh et al., 2019), ii) regular practice of physical exercise in sports clubs in the last 12 months (at least, three training sessions per week and one game in the weekend), iii) with and without a previous history of ankle sprain injury, iv) no ankle sprain injury in the past four weeks, and v) physically fit to perform the tests without any medical restriction. All participants provided informed consent signed by their legal guardians, authorizing their participation in the study. The study was approved by the Scientific Committee of the Department of Sport Sciences, University of Beira Interior (UBI) (project M11486), and followed the recommendations of the Declaration of Helsinki.

Procedures

Injury-related data questionnaire

An ankle sprain injury was defined as trauma that disrupted the ligaments and structures of the ankle and occurred during or as a result of participation in a game or training, required medical consultation, and caused (Owoeye et al., 2023; Trojian & McKeag, 2006) the chronological age based on the date of data collection), iii) regular practice of exercise in the last 12 months, iv) type of sport practiced, v) time of the last ankle sprain injury (< 1 year, 1-2 years, and > 2 years), vi) ankle injured (left or right) vii) time-loss (1-6 days, 7-27 days, and \geq 28 days), viii) injury mechanism (contact or no contact), and ix) injury occurrence (training or game).

Double-leg jump-landing test

We followed the procedures described in previous research to conduct the double-leg jump-landing test (Goerger et al., 2015; Lisman et al., 2021; Rowell & Relph, 2021). The participants started the test atop a 30 cm high box with feet shoulder-width apart. They were then instructed to: i) jump forward off the box and not vertically, ii) land with both feet at the same time in the middle of a jump mat (Chronojump Boscossystem, Barcelona, Spain) positioned in front of the box at a distance equal to their leg length, and iii) perform a vertical jump as high as possible immediately after landing. After two warm-up trials, participants performed three trials with the maximal intended effort, interspersed with 15 seconds of rest. The jump height, ground contact time, flight time, reactive strength index (calculated as jump height divided by the ground contact time), power, stiffness, and take-off velocity were measured through the jump mat connected to a laptop and averaged for further analysis.

Ankle dorsiflexion test

The ankle dorsiflexion range of motion was measured using the weight-bearing lunge test facing a wall, following the procedures described in previous research (Konor et al., 2012). After assuming a standing position with the heel in contact with the ground (barefoot), the knee aligned with the second toe, and the great toe 10 cm away from the wall, the participants were instructed to lunge forward until their knee touched the wall.

The participants were allowed to place two fingers from each hand on the wall to maintain balance. Every time they reached the wall with their knees, the foot progressed 1 cm away until they could not touch the wall with the knee without lifting the heel. When the knee could not touch the wall, the foot progressed in smaller increments toward the wall until the knee could reach the wall while maintaining the heel on the ground. The maximal ankle dorsiflexion range of motion was defined as the maximum distance of the great toe from the wall to the nearest 0.1 cm while maintaining contact between the wall and knee without lifting the heel from the ground. After three warm-up trials, participants performed three trials with the maximal intended effort, and the average between the testing trials was calculated for further analysis.

Y-Balance test

The dynamic balance was measured following the Y-Balance test protocol, as described in previous research (Gonell et al., 2015; González-Fernández et al., 2022). The Y-Balance test requires a kit (Perform Better, West Warwick, Rhode Island) of three connected cylindrical tubular plastic bars marked in half-centimeter increments. Each bar has a moveable indicator plate, which the participant pushes with their foot/toes without bearing weight on the indicator, while keeping their hands on their hips. After standing on one foot (barefoot) in the center of the platform (leg under evaluation) with the most distal end of the longest toe at the starting line, the participants were instructed to reach with the free limb in the anterior, posteromedial, and posterolateral directions, all designated in relation to the supporting foot. After six warm-up trials, the participants performed three consecutive trials on both legs, and in each one, they were instructed to push the indicator as far as possible while maintaining balance (hands on the waist were allowed). The trial was discarded and repeated if the participant: i) lost balance from leaving the starting position until returning, ii) was unable to maintain the starting position for at least one second after returning, iii) lifted the heel of the foot placed on the platform, iv) lost foot contact with the distance indicator while the distance was in motion (e.g., kicking the indicator), v) placed the free foot on the ground, or vi) released hands from the hips. The average of three successful trials in each direction was analyzed. Furthermore, a composite reach distance in each leg was calculated as the sum of the three reach directions (maximum values) divided by three times the leg length, multiplied by 100.

Statistical analysis

The statistical analysis was conducted in SPSS (v29, IBM Corporation, USA) and Excel (v24, Microsoft, Washington, USA). Descriptive statistics (means with standard deviations or frequency distribution) were calculated for all variables. The intraclass correlation coefficient (ICC (2,k): two-way random effects, absolute agreement, multiple measurements) and coefficient of variation (CV) with the respective 95% confidence intervals (CI) analyzed the test-retest reliability. ICC values were interpreted as poor (< 0.50), moderate ($0.50-0.75$), good ($0.75-0.90$), or excellent (> 0.90) (Koo & Li, 2016). CV values were interpreted as poor ($> 10\%$), moderate ($5-10\%$), or good ($< 5\%$) (Kilgallon et al., 2022). The normality of the data was checked and confirmed through the Kolmogorov-Smirnov test, while the homoscedasticity was inspected and confirmed through Levene's test. Independent samples T-test compared the differences (anthropometrics, jumping performance, ankle dorsiflexion, and balance) between adolescents with and without a previous ankle sprain injury. Hedge's g effect size analyzed the magnitude of the differences, which were interpreted as small ($0.20 - 0.49$), medium ($0.50 - 0.79$), and large (≥ 0.80) (Sullivan & Feinn, 2012). A binary logistic regression with the odds ratio (OR) and 95% CI explored the relationship between physical characteristics (independent variables: sex, age, jumping variables, ankle dorsiflexion variables, and dynamic balance variables) and ankle sprain injury (dependent variable). A p -value lower than 0.05 was considered the threshold to determine statistically significant differences.

Results

Test-retest reliability analysis

Table 1 presents the test-retest reliability data for the variables collected during the tests. In the double-leg jump-landing test, almost all variables presented excellent ICC and 95% CI values, except the ground contact time, power, and stiffness variables, whose lower limit of 95% CI was considered good. The CV and 95% CI values were considered good for almost all variables, except the reactive strength index and stiffness variables, whose upper limit of 95% CI was considered poor, as it exceeded 10% (11.62% and 14.63%, respectively). All variables presented excellent ICC and CV values in the ankle dorsiflexion test. Finally, in the Y-balance test, the ICC and respective 95% CI values varied between good to excellent in the right leg and moderate to excellent in the left leg. The CV and respective 95% CI values varied between moderate and good in both legs (no variable exceeded 10%).

Table 1. Test-retest reliability data.

Variables	ICC (2,k)	95% CI	CV (%)	95% CI
Double-leg jump-landing test				
Height	0.98	0.97 – 0.99	6.14	4.89 – 7.38
Ground contact time	0.91	0.86 – 0.95	7.20	5.53 – 8.87
Flight time	0.98	0.97 – 0.99	3.10	2.46 – 3.74
RSI	0.95	0.91 – 0.97	9.28	6.94 – 11.62
Power	0.91	0.86 – 0.95	7.54	5.66 – 9.42
Stiffness	0.93	0.89 – 0.96	12.11	9.59 – 14.63
Take-off velocity	0.98	0.97 – 0.99	3.10	2.46 – 3.74
Ankle dorsiflexion test				
Left	1.00	0.99 – 1.00	2.35	1.75 – 2.94
Right	1.00	0.99 – 1.00	2.01	1.44 – 2.58
Y-Balance test left leg				
Anterior direction	0.83	0.72 – 0.90	5.87	4.91 – 6.83
Posteromedial direction	0.78	0.65 – 0.87	7.63	6.45 – 8.81
Posterolateral direction	0.88	0.80 – 0.93	4.96	4.04 – 5.89
Y-Balance test right leg				
Anterior direction	0.90	0.84 – 0.94	5.78	4.77 – 6.79
Posteromedial direction	0.91	0.85 – 0.94	4.99	3.94 – 6.05
Posterolateral direction	0.92	0.87 – 0.95	5.35	4.59 – 6.11

CI, confidence intervals; CV, coefficient of variation; RSI, reactive strength index.

General characteristics of the participants and injury-related data

Table 2 presents the characteristics of the participants and injury-related data. Twenty-three participants had a history of a previous ankle sprain injury, and twenty-five had no previous history of ankle sprain injury. The ankle-injured participants were significantly older than the non-ankle-injured participants (p -value = 0.007, g = 0.734, medium effect size). No significant differences were noted for height, body mass, leg length, and BMI (all $p > 0.05$ and g varying between 0.134 and 0.476, small effect size). All participants practiced exercise regularly in the past 12 months and were basketball players (100%). Almost half reported that their last ankle sprain injury occurred between one and two years ago. The remaining half indicated that the injury occurred less than one year (~25%) or more than two years ago (~25%). Nearly 70% of the participants indicated that the ankle most injured was the right. Regarding the time lost due to ankle injury, almost 45% indicated between 1-6 days, followed by 7-27 days (~35%) and ≥ 28 days (22%). The injury mechanism was nearly equal between contact and non-contact (~50% vs. ~50%), while the injury occurrence was higher in games than in training (60% vs. 40%).

Table 2. Characteristics of the participants.

Variables	Ankle Injury (13 female and 10 male)	No Ankle Injury (11 female and 14 male)
Anthropometric data		
Age (years), mean \pm SD	14.62 \pm 1.12	13.74 \pm 1.24*
Standing height (cm), mean \pm SD	166.28 \pm 11.28	164.52 \pm 11.58
Sitting height (cm), mean \pm SD	85.24 \pm 5.43	82.54 \pm 6.25
Body mass (kg), mean \pm SD	59.66 \pm 9.72	55.22 \pm 10.15
Leg length (cm), mean \pm SD	81.04 \pm 7.01	81.98 \pm 6.78
BMI (kg/h ²), mean \pm SD	21.48 \pm 2.07	20.32 \pm 2.67
Injury-related data		
Regular exercise practice (last 12 months), n (%)	23 (100)	25 (100)
Time of the last ankle sprain injury		
< 1 year, n (%)	6 (26.1)	0 (0)
1-2 years, n (%)	11 (47.8)	0 (0)
> 2 years, n (%)	6 (26.1)	0 (0)
Ankle injured		
Left, n (%)	7 (30.4)	0 (0)
Right, n (%)	16 (69.6)	0 (0)
Time-loss		
1-6 days, n (%)	10 (43.5)	0 (0)
7-27 days, n (%)	8 (34.8)	0 (0)
\geq 28 days, n (%)	5 (21.7)	0 (0)
Injury mechanism		
Contact, n (%)	11 (47.8)	0 (0)
No contact, n (%)	12 (52.2)	0 (0)
Injury occurrence		
Training, n (%)	9 (39.1)	0 (0)
Game, n (%)	14 (60.9)	0 (0)

BMI, body mass index; SD, standard deviation; *denotes statistical significance (p -value < 0.01).

Differences in jumping performance, ankle dorsiflexion, and dynamic balance between adolescents with and without previous ankle sprain injury

Table 3 presents the physical performance differences between adolescents with and without a previous ankle sprain injury. Ankle-injured participants presented significantly higher ground contact times (p -value = 0.028, g = 0.558, medium effect size) and lower stiffness (p -value = 0.038, g = 0.518, medium effect size) in the double-leg jump-landing test than non-ankle-injured participants. No significant differences were denoted for the remaining physical performance variables.

Table 3. Differences in jumping performance, ankle dorsiflexion, and dynamic balance between adolescents with and without previous ankle sprain injury.

	Ankle Injury (13 female and 10 male)	No Ankle Injury (11 female and 14 male)	<i>p</i> - <i>value</i>	Effect size (<i>g</i>)
Double-leg jump-landing test				
Height (cm)	32.03 ± 8.88	29.52 ± 8.70	0.164	0.281
Ground contact time (ms)	370.09 ± 70.93	333.09 ± 59.50	0.028	0.558
Flight time (ms)	506.88 ± 67.19	485.43 ± 72.80	0.148	0.301
RSI (m/s)	0.89 ± 0.23	0.90 ± 0.22	0.452	0.035
Power (W)	850.06 ± 165.87	898.25 ± 143.46	0.143	0.307
Stiffness (N/m)	5997.97 ± 2252.23	7233.41 ± 2431.86	0.038	0.518
Take-off velocity (m/s)	2.49 ± 0.33	2.38 ± 0.36	0.148	0.300
Ankle dorsiflexion test				
Left (cm)	10.28 ± 3.14	9.85 ± 2.72	0.306	0.145
Right (cm)	10.20 ± 2.90	9.99 ± 2.76	0.396	0.075
Y-Balance test left leg				
Anterior direction (cm)	61.41 ± 6.13	59.85 ± 5.49	0.180	0.263
Posteromedial direction (cm)	77.49 ± 8.90	79.01 ± 7.32	0.260	0.184
Posterolateral direction (cm)	84.62 ± 9.26	82.05 ± 7.17	0.143	0.307
Composite reach distance (%)	98.17 ± 8.58	94.68 ± 7.35	0.068	0.431
Y-Balance test right leg				
Anterior direction (cm)	60.51 ± 8.91	59.29 ± 6.24	0.292	0.156
Posteromedial direction (cm)	81.90 ± 10.30	81.80 ± 8.88	0.486	0.010
Posterolateral direction (cm)	80.86 ± 10.11	80.56 ± 8.82	0.457	0.031
Composite reach distance (%)	96.68 ± 7.83	94.91 ± 8.61	0.232	0.210

RSI, reactive strength index.

Factors associated with ankle sprain injury in adolescents

Table 4 presents the binary logistic results. Chronological age was the only variable significantly associated with ankle sprain injuries (OR = 1.891; 95% CI: 1.111 – 3.291; $p = 0.019$). Specifically, higher chronological age increases the odds of ankle sprain injury 1.89 times in adolescents.

Table 4. Factors associated with ankle sprain injury.

Independent Variables	<i>p-value</i>	Odds Ratio	95% CI
Sex			
Men		1	
Women	0.387	1.655	0.528 – 5.182
Age (years)	0.019	1.891	1.111 – 3.219
Double-leg jump-landing test			
Height (cm)	0.323	1.034	0.967 – 1.106
Ground contact time (ms)	0.062	1.009	1.000 – 1.018
Flight time (ms)	0.291	1.005	0.996 – 1.013
RSI (m/s)	0.901	0.852	0.068 – 10.687
Power (W)	0.281	0.998	0.994 – 1.002
Stiffness (N/m)	0.081	0.977	0.952 – 1.003
Take-off velocity (m/s)	0.292	2.516	0.452 – 13.995
Ankle dorsiflexion test			
Left (cm)	0.603	1.054	0.864 – 1.285
Right (cm)	0.787	1.029	0.838 – 1.262
Y-Balance test left leg			
Anterior direction (cm)	0.353	1.049	0.948 – 1.161
Posteromedial direction (cm)	0.512	0.976	0.908 – 1.049
Posterolateral direction (cm)	0.281	1.040	0.968 – 1.118
Composite reach distance (cm)	0.139	1.059	0.982 – 1.142
Y-Balance test right leg			
Anterior direction (cm)	0.576	1.022	0.947 – 1.103
Posteromedial direction (cm)	0.971	1.001	0.943 – 1.063
Posterolateral direction (cm)	0.912	1.003	0.944 – 1.067
Composite reach distance (cm)	0.456	1.027	0.957 – 1.103

CI, confidence intervals; RSI, reactive strength index.

Discussion

The current study aimed to analyze the impact of ankle sprain injury on jumping performance, ankle dorsiflexion range of motion, and dynamic balance among adolescents, and to identify the factors associated with ankle sprain injury. The main findings showed that i) ankle-injured participants were older than the non-ankle-injured participants, ii) ankle-injured adolescents presented higher ground contact times and lower stiffness in the double-leg jump-landing test than the non-ankle-injured participants, and iii) a higher chronological age increased the odds of ankle sprain injury 1.89 times in adolescents.

These findings align with existing literature suggesting that age and developmental stage play a critical role in injury susceptibility during adolescence, a period marked by rapid physical growth and neuromuscular changes (Lopez-Valenciano et al., 2023). The observed differences in jumping biomechanics, even after injury resolution, may reflect underlying deficits in neuromuscular control or strength that persist beyond clinical recovery.

Chronological age as a predictor of ankle injury

Ankle sprain injured participants were statistically significantly older than non-injured participants, at a significance level of $p < 0.01$. Ankle sprain injured participants had a mean age of 14.62 ± 1.12 years compared to an uninjured participant mean age of 13.72 ± 1.24 years.

A key statistically significant predictor of ankle injury found in this study was higher chronological age ($p = 0.019$), with an Odds Ratio of 1.89 (95% CI 1.111-3.219). This result derives solely from participant responses from the injury-related data questionnaire.

One of the criteria for inclusion in the study was regular sporting activity for a period at least twelve months prior to assessment. This requirement of regular sports participation means that the older participants will have been exposed to similar potential injury activities over the twelve-month period prior to the study as the uninjured participants. This however potentially excluded injured adolescents who had ceased intense sporting activity as a result of injury.

Adolescence is a period of change in the body and its biomechanical structures, and requires an adaptation in motor control of the voluntary movements of the limbs and their joints. The period of time of the maximum growth in height is known as Peak Height Velocity (PHV), also known informally as a growth spurt (Lopez-Valenciano et al., 2023). It is seen as a key indicator of adolescence and puberty. PHV generally occurs earlier in girls (around 10-12 years old) than in boys (around 12-15 years old). Adolescence is also associated with an increase in muscle mass and strength. This is associated with a comparative lack of coordination of the body, and this period of development has been associated with an increased risk of balance injury (Lopez-Valenciano et al., 2023).

It is also worth considering that the accumulation of repetitive stress on the ankle joint over time, especially in sports like basketball, could contribute to the higher prevalence of injuries among older adolescents. As athletes grow older, the intensity and competitive demands of their sport often increase, potentially exposing them to higher mechanical loads and greater injury risks. This cumulative exposure to sport-specific demands may exacerbate the vulnerability of developing musculoskeletal structures.

The participants in this study potentially fall within the period of PHV. Therefore, this suggests there may be some influence associated with increased injury rates during this key period. Girls typically undergo PHV earlier than boys, and because both the girls and boys in this study are statistically of a similar age, we may expect that at the time of testing, girls and boys were potentially at a different stage of PHV. Future research could benefit from exploring the relationship between PHV timing, specific stages of biological maturity, and ankle injury risk, as well as including maturity offset or skeletal age assessments alongside chronological age to provide a more nuanced understanding of developmental risk factors.

Double-jump landing test

Double-jump landing test measures seven components of the activity using a model of the lower limbs and joints as a compressible spring (Brazier et al., 2014). Five of the measurements did not show any significant differences between ankle-injured and uninjured groups (jump height, flight time, reactive strength index (RSI), power and take-off velocity). However, there was statistically significant increase in ground contact times ($p = 0.028$) and a statistically significant reduction in Stiffness ($p = 0.038$). These results from the double-leg jump-landing test indicated that those with a history of ankle injuries had longer ground contact times, suggesting that their second jump is less

responsive than that of those uninjured. Additionally, the injured participants demonstrated lower stiffness, implying that the muscle and tendon groups in the injured individuals may lack the elasticity of their uninjured counterparts (Brazier et al., 2014). This finding supports the hypothesis that even after an ankle sprain has healed, athletes may exhibit residual deficits in their neuromuscular function, particularly in their ability to absorb and transfer forces effectively during dynamic movements like jumping and landing. This may increase the risk of reinjury or secondary injuries if not properly addressed through rehabilitation.

The JUMP-ACL study (Goerger et al., 2015) analyzed the differences in lower limb biomechanics for uninjured participants and those with previous anterior cruciate ligament (ACL) injuries. They found that injury and reconstructive surgery caused an alteration of the movement patterns that could be measured using a double-jump landing test. Traditional post-injury physical therapy did not restore pre-injury movement patterns. The present study is concerned with injuries to the ankle joint rather than the knee ACL, but it shows that ankle sprain injury can also have a long-term change in the biomechanics of the ankle joint.

These findings highlight the importance of developing targeted rehabilitation protocols that focus not only on restoring ankle range of motion and strength but also on retraining neuromuscular control and landing mechanics. Addressing these deficits early in the rehabilitation process may help prevent long-term functional limitations.

In our study, the physical therapy status of participants with previous ankle injury was not noted, but the injured-related data questionnaire revealed the long-term change in movement patterns in the ankle aligned with the results of the JUMP-ACL study.

Ankle dorsiflexion test

The ankle dorsiflexion test showed no statistically significant differences between the injured and uninjured individuals. Thus, the current results indicate that ankle dorsiflexion tests had a minimal impact to differentiate the effects of ankle injury on performance among adolescents. The ankle dorsiflexion results may be compared to previous studies (Adillón et al., 2022), who presented ankle joint dorsiflexion reference values for adolescent basketball players. The results did not differentiate laterally between left and right limbs, or between previously injured and never injured participants. However, the values agree extremely well with those obtained in this study.

All groups combined yielded a result of 10.68 ± 2.44 cm (Adillón et al., 2022). One possible explanation for the lack of significant differences is that dorsiflexion range may recover more effectively than dynamic stability or neuromuscular control following an ankle sprain. Additionally, dorsiflexion deficits may not persist long-term in adolescents compared to adults due to the greater plasticity of musculoskeletal tissues during growth.

Y-Balance test

The Y-Balance test results showed no significant differences between the injured and uninjured groups, suggesting that the Y-Balance test may not be indicated to differentiate the effects of ankle injury within adolescents. These results can be compared to those of a study looked for predictors of future lower extremity injury (Plisky et al., 2006). A significant predictor of lower limb injury was found arising from the measurements of a Y-Balance test. A difference of ≥ 4 cm between right and left anterior direction meant that participants were 2.7 times more likely to sustain a lower extremity injury. In a wide-ranging study of Y-Balance test studies up to 2019 (Plisky et al., 2021), the evidence for reach asymmetries as an injury risk identifier was one of the aspects analyzed. They found that in the published literature, both anterior direction reach asymmetry and posteromedial/posterolateral direction reach asymmetry had been investigated across several populations (sex, activity, and competition level). The asymmetry threshold across these studies was typically ≥ 4 cm (Plisky et al., 2006). Plisky et al., (2021) also found that a composite reach distance of less than 94% of leg length was 3 times more likely to have a lower extremity injury. In contrast, in this study, although the composite reach distance in the injured cohort is less than that of the previously injured cohort, this does not reach a statistically significant level ($p = 0.232$).

This finding suggests that while the Y-Balance test has predictive validity in identifying injury risk in certain populations, its sensitivity in detecting long-term functional deficits post-ankle sprain among adolescents may be limited. Therefore, it may not be an ideal standalone assessment for evaluating recovery in this age group. Future studies could explore combining the Y-Balance test with other dynamic tasks, such as cutting or single-leg hop tests, to improve its diagnostic utility.

Limitations of the study

Including more detailed rehabilitation questions into the injury related data questionnaire could possibly be beneficial for the further contributing to the understanding of rehabilitation options. For example, asking about specific rehabilitation protocols followed, duration of rehabilitation, adherence to exercises, and any ongoing maintenance programs could provide valuable insights into factors influencing recovery and reinjury risk.

Given that approximately 74% of the injured participants were injured over one year before the study, a history of rehabilitation already performed by the injured participants could generate statistically useful data. This time gap between injury occurrence and testing could also introduce variability in the participants' recovery status, as some adolescents may have returned to full function while others could still be experiencing residual deficits.

Furthermore, the additional data of the participants chronological age at time of injury could possibly statistically place them within the typical adolescent PHV “growth spurt” associated with proneness to injury (Lopez-Valenciano et al., 2023). Future studies could improve on this by collecting data on biological maturation markers (e.g., maturity offset or skeletal age) in addition to chronological age, as this would allow a more precise understanding of how growth phases impact injury risk.

The study covered a subset of ages within the accepted range of adolescence (Singh et al., 2019). Given the finding of significant age differences within this study, it could be of interest to widen the range of ages to the full adolescent age range. Additionally, including pre-adolescent and post-adolescent participants in future research could help clarify whether the trends observed in this study are unique to mid-adolescence or extend across different developmental stages.

The study represents a single point in the development of the participants. A follow up study of the same cohort, if it were possible, could provide further information regarding injury resolution and to the rehabilitation of adolescents. Longitudinal research designs would allow for the monitoring of biomechanical changes over time and could help determine whether deficits observed post-injury persist, resolve, or worsen with time. Furthermore, it would provide insights into the long-term effectiveness of rehabilitation programs.

Another limitation is the exclusive focus on basketball players, which may limit the generalizability of findings to adolescents engaged in other sports with different movement patterns and demands. Future studies could consider recruiting participants from a broader range of sports to enhance the external validity of the results.

Practical implications

The results of this study may contribute to refining the rehabilitation of adolescents with a history of ankle sprain. Implementing the double-jump landing test with a particular emphasis on analyzing the ground contact time and stiffness variables can be important to understand how the previous injury impacted the jumping and landing biomechanics after recovery. These analyses can have important benefits for adolescents, as they will help prescribe specific and individualized exercise plans to improve the ability to generate force rapidly and, eventually, improve the range of motion necessary to perform the motor task successfully.

Furthermore, the study highlights the importance of regular biomechanical assessments post-injury, not only to track progress but also to identify lingering deficits that may not be evident through standard clinical tests. Coaches, physiotherapists, and strength and conditioning professionals should collaborate to monitor these variables over time, especially during the return-to-sport phase, to optimize performance and minimize reinjury risk.

Additionally, it is recommended that age-appropriate training loads and injury prevention strategies be tailored for adolescents. For example, younger athletes may benefit from foundational movement skill development, while older adolescents might require more advanced neuromuscular and strength training to match their increased physical demands and competitive levels.

Finally, educational programs for adolescents, coaches, and parents on the long-term consequences of ankle sprains and the importance of comprehensive rehabilitation can play a key role in injury prevention. Emphasizing adherence to rehabilitation programs and the integration of sport-specific training could enhance functional recovery and promote long-term joint health.

Conclusion

This study demonstrated that chronological age increased the probability of ankle sprain injury 1.89 times in adolescents. Furthermore, the performance on the ankle dorsiflexion and Y-Balance tests could not detect differences between adolescents with and without previous ankle sprain injury. Conversely, the double-leg jump-landing test outcomes indicated decreased muscle and ligament elasticity due to prolonged ground contact time and reduced stiffness. These findings suggest that the injury may have a lasting or permanent effect on the individual, making it essential to further investigate muscle and ligament elasticity to evaluate the chronicity of the injury and the potential effectiveness of treatments.

References

- Adillón, C., Gallegos, M., Treviño, S., & Salvat, I. (2022). Ankle Joint Dorsiflexion Reference Values in Non-Injured Youth Federated Basketball Players: A Cross-Sectional Study. *International Journal of Environmental Research and Public Health*, *19*(18), 11740. <https://doi.org/10.3390/ijerph191811740>
- Brazier, J., Bishop, C., Simons, C., Antrobus, M., Read, P. J., & Turner, A. N. (2014). Lower Extremity Stiffness: Effects on Performance and Injury and Implications for Training. *Strength & Conditioning Journal*, *36*(5), 103–112. <https://doi.org/10.1519/ssc.0000000000000094>
- Faizullin, I., & Faizullina, E. (2015). Effects of balance training on post-sprained ankle joint instability. *The International Journal of Risk & Safety in Medicine*, *27* Suppl 1, S99–S101. <https://doi.org/10.3233/JRS-150707>
- Fong, D. T.-P., Hong, Y., Chan, L.-K., Yung, P. S.-H., & Chan, K.-M. (2007). A Systematic Review on Ankle Injury and Ankle Sprain in Sports: *Sports Medicine*, *37*(1), 73–94. <https://doi.org/10.2165/00007256-200737010-00006>
- Goerger, B. M., Marshall, S. W., Beutler, A. I., Blackburn, J. T., Wilckens, J. H., & Padua, D. A. (2015). Anterior cruciate ligament injury alters preinjury lower extremity biomechanics in the injured and uninjured leg: The JUMP-ACL study. *British Journal of Sports Medicine*, *49*(3), 188–195. <https://doi.org/10.1136/bjsports-2013-092982>
- Gonell, A. C., Romero, J. A. P., & Soler, L. M. (2015). Relationship Between the Y Balance Test Scores and Soft Tissue Injury Incidence In a Soccer Team. *International Journal of Sports Physical Therapy*, *10*(7), 955–966.
- González-Fernández, F. T., Martínez-Aranda, L. M., Falces-Prieto, M., Nobari, H., & Clemente, F. M. (2022). Exploring the Y-Balance-Test scores and inter-limb asymmetry in soccer players: Differences between competitive level and field

- positions. *BMC Sports Science, Medicine and Rehabilitation*, 14(1), 45.
<https://doi.org/10.1186/s13102-022-00438-w>
- Halabchi, F., & Hassabi, M. (2020). Acute ankle sprain in athletes: Clinical aspects and algorithmic approach. *World Journal of Orthopedics*, 11(12), 534–558.
<https://doi.org/10.5312/wjo.v11.i12.534>
- Hawkes, C. P., Mostoufi-Moab, S., McCormack, S. E., Grimberg, A., & Zemel, B. S. (2020). Leg length and sitting height reference data and charts for children in the United States. *Data in Brief*, 32, 106131.
<https://doi.org/10.1016/j.dib.2020.106131>
- Hrysomallis, C. (2007). Relationship between balance ability, training and sports injury risk. *Sports Medicine (Auckland, N.Z.)*, 37(6), 547–556.
<https://doi.org/10.2165/00007256-200737060-00007>
- Kilgallon, J., Cushion, E., Joffe, S., & Tallent, J. (2022). Reliability and validity of velocity measures and regression methods to predict maximal strength ability in the back-squat using a novel linear position transducer. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 17543371221093189. <https://doi.org/10.1177/17543371221093189>
- Konor, M. M., Morton, S., Eckerson, J. M., & Grindstaff, T. L. (2012). Reliability of three measures of ankle dorsiflexion range of motion. *International Journal of Sports Physical Therapy*, 7(3), 279–287.
- Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*, 15(2), 155–163. <https://doi.org/10.1016/j.jcm.2016.02.012>
- Lisman, P., Wilder, J. N., Berenbach, J., Jiao, E., & Hansberger, B. (2021). The Relationship between Landing Error Scoring System Performance and Injury in Female Collegiate Athletes. *International Journal of Sports Physical Therapy*, 16(6), 1415–1425. <https://doi.org/10.26603/001c.29873>

- Lopez-Valenciano, A., Ayala, F., De Ste Croix, M. B. A., Barbado, D., Moreno-Perez, V., Sanz-Rivas, D., & Fernandez-Fernandez, J. (2023). The Association Between Chronological Age and Maturity Status on Lower Body Clinical Measurements and Asymmetries in Elite Youth Tennis Players. *Sports Health: A Multidisciplinary Approach*, 15(2), 250–259. <https://doi.org/10.1177/19417381221083319>
- Mason, J., Kniewasser, C., Hollander, K., & Zech, A. (2022). Intrinsic Risk Factors for Ankle Sprain Differ Between Male and Female Athletes: A Systematic Review and Meta-Analysis. *Sports Medicine - Open*, 8(1), 139. <https://doi.org/10.1186/s40798-022-00530-y>
- McKay, G. D., Goldie, P. A., Payne, W. R., & Oakes, B. W. (2001). Ankle injuries in basketball: Injury rate and risk factors. *British Journal of Sports Medicine*, 35(2), 103–108. <https://doi.org/10.1136/bjism.35.2.103>
- Oliveira-Santos, J., Santos, R., Moreira, C., Abreu, S., Lopes, L., Agostinis, C., & Mota, J. (2016). Ability of Measures of Adiposity in Identifying Adverse Levels of Inflammatory and Metabolic Markers in Adolescents. *Childhood Obesity*, 12(2), 135–143. <https://doi.org/10.1089/chi.2015.0124>
- Owoeye, O. B. A., Paz, J., & Emery, C. A. (2023). Injury severity at the time of sport-related ankle sprain is associated with symptoms and quality of life in young adults after 3–15 years. *Annals of Medicine*, 55(2), 2292777. <https://doi.org/10.1080/07853890.2023.2292777>
- Pacheco, J., Guerra-Pinto, F., Araújo, L., Flora, M., Alçada, R., Rocha, T., Diniz, P., & Consciência, J. G. (2021). Chronic ankle instability has no correlation with the number of ruptured ligaments in severe anterolateral sprain: A systematic review and meta-analysis. *Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA*, 29(11), 3512–3524. <https://doi.org/10.1007/s00167-021-06610-y>

- Plisky, P. J., Gorman, P. P., Butler, R. J., Kiesel, K. B., Underwood, F. B., & Elkins, B. (2009). The reliability of an instrumented device for measuring components of the Star Excursion Balance Test. *North American Journal of Sports Physical Therapy*, 4(2), 92.
- Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star Excursion Balance Test as a Predictor of Lower Extremity Injury in High School Basketball Players. *Journal of Orthopaedic & Sports Physical Therapy*, 36(12), 911–919. <https://doi.org/10.2519/jospt.2006.2244>
- Plisky, P., Schwartkopf-Phifer, K., Huebner, B., Garner, M. B., & Bullock, G. (2021). Systematic Review and Meta-Analysis of the Y-Balance Test Lower Quarter: Reliability, Discriminant Validity, and Predictive Validity. *International Journal of Sports Physical Therapy*, 16(5), 1190–1209. <https://doi.org/10.26603/001c.27634>
- Rowell, S., & Relph, N. (2021). The Landing Error Scoring System (LESS) and Lower Limb Power Profiles in Elite Rugby Union Players. *International Journal of Sports Physical Therapy*, 16(5), 1286–1294. <https://doi.org/10.26603/001c.27632>
- Santos, T. R. T., Silva, E. I., Leite, M. M. D. A. G., Pinho, G. B., Marcati, M. M., & Bittencourt, N. F. N. (2022). Entorse no tornozelo em jovens atletas: Um estudo retrospectivo de 2 anos em um clube multiesportivo. *Revista Brasileira de Ortopedia*, 57(06), 1001–1008. <https://doi.org/10.1055/s-0042-1742340>
- Singh, J. A., Siddiqi, M., Parameshwar, P., & Chandra-Mouli, V. (2019). World Health Organization Guidance on Ethical Considerations in Planning and Reviewing Research Studies on Sexual and Reproductive Health in Adolescents. *Journal of Adolescent Health*, 64(4), 427–429. <https://doi.org/10.1016/j.jadohealth.2019.01.008>

Sullivan, G. M., & Feinn, R. (2012). Using Effect Size—Or Why the P Value Is Not Enough. *Journal of Graduate Medical Education*, 4(3), 279–282.
<https://doi.org/10.4300/JGME-D-12-00156.1>

Trojian, T. H., & McKeag, D. B. (2006). Single leg balance test to identify risk of ankle sprains. *British Journal of Sports Medicine*, 40(7), 610–613.
<https://doi.org/10.1136/bjism.2005.024356>