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Relationship between ankle dorsiflexion range of motion and sprinting and jumping ability in young athletes

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A R T I C L E I N F O

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A B S T R A C T

Objectives: To investigate the relationship between predicted risk of injury based on the dichotomous classification of the weight-bearing lunge (WBL) test scores and variables related to jumping and sprinting ability in young athletes. Furthermore, to compare the impact of the classical dichotomous classification versus a more specific quartile subdivision of the WBL test scores on the explored variables.
Design: Cross-sectional study.
Participants: 125 healthy athletes (mean age 10.38 (SD = 2.28) years) were recruited.
Main outcome measures: Ankle dorsiflexion was evaluated with the WBL test, jumping distance with the standing long jump (SLJ) test, and maximal running speed with the 14-m and 28-m sprint test.
Results: Athletes with WBL test scores lower than 10 cm exhibited significantly poorer results for the SLJ test as well as lower 14-m and 28-m sprint times than those with WBL test scores higher than 10 cm ($p < 0.05$). Likewise, when WBL test scores were subdivided by quartiles, a positive trend between range of motion and improved performance was shown.
Conclusions: Reduced ankle dorsiflexion mobility may affect sprinting and jumping ability in young athletes. In addition, a more detailed classification of ankle restriction by quartiles is proposed in this study in order to prevent injury and enhance athletic performance.

1. Introduction

Elite sports are associated with a very high injury rate (Arnason et al., 2004; Medina McKeon et al., 2021). A player suffers at least one injury per session (even a minor one) and 16% of these injuries are serious, and in the case of 12%, they reoccur (reinjury) (Ekstrand et al., 2011). Sustaining an injury hampers the player's availability and performance by reducing strength (Sole et al., 2012), flexibility (Cejudo, 2021), aerobic fitness (Pinto et al., 2023) and sprint performance (Røksund et al., 2017), among others. This is especially important in young athletes, when injury incidence may hinder development and future career opportunities (Maffulli et al., 2010). In this scenario, injury prevention screening strategies aimed at identifying risk factors in young elite players is of paramount importance to allow the implementation of prevention programmes and optimise player development (Verhagen et al., 2018). Indeed, 87% of professional teams in Europe perform injury prevention screening (McCall et al., 2016).

Particularly, the incidence of ankle joint injuries among basketball players has been established in 3.85 per 1000 (McKay et al., 2001). In the case of rugby, ankle injuries account for up to 13.1% of all injuries. An epidemiological study identified three factors that influence the risk of injury. One of these factors is the lack of specific stretching before practicing basketball estimating that those who do not perform this preconditioning have up to 2.6 times higher risk of injury than those who do (McKay et al., 2001). In this sense, ankle hypomobility is a common denominator and risk factor in rugby (Machado et al., 2023) and basketball (McKay et al., 2001) A reduction in ankle dorsiflexion is not only due to a shortening of the ankle's antagonist muscles and a

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reduction in joint play to a shortening of the antagonist muscles and a reduction of the joint play but also to the involvement of the axis displacement which could explain the increased risk of injury (Daikuya and Okayama, 2021).

A common procedure to identify risk of injury in sports is the assessment of ankle range of motion (ROM). In particular, limitations in ankle dorsiflexion (DF) ROM have been associated not only with ankle, knee (Backman and Danielson, 2011) or calf (Volpi and Taioli, 2012) injury incidence, but recently even with shoulder and elbow injuries (Shitara et al., 2021) in elite sports players. Furthermore, it has been shown that ankle dorsiflexion ROM also influences sports performance. In this regard, diminished ankle dorsiflexion ROM has been related to changes in the gait pattern during running (Sasaki and Neptune, 2006), modifications in muscle activation (Macrum et al., 2012), altered biomechanics of the lower limbs when performing sport-functional movements (Wyndow et al., 2016) and diminished balance capacities (Hoch et al., 2020).

Different systems for ankle dorsiflexion analysis have been developed due to the functional importance of this movement. The most sophisticated include motion analysis systems that can be combined with pressure analysis using force platforms and electromyographic activity of the muscles involved in a given movement (Ugbolue et al., 2013). However, these systems are specialized and expensive which makes them difficult to apply in clinical practice. For this reason, simpler tests are still often used, such as the weight-bearing lunge (WBL) test, by measuring the distance reached from a lunge position. This test has proven to be a valid and reliable procedure (Jones et al., 2005; Bennell et al., 1998) and is widely implemented among elite athletes (Clark and Campbell, 2021). A score of less than 10 cm distance has been proposed as a cut-off point for poor performance (Lagas et al., 2021; Pope et al., 1998), and has been related to increased risk of injury (Hoch et al., 2012).

This dichotomisation of scores is intended to be a quick and easy tool to identify those subjects at risk of ankle injury. However, the effect of this dichotomy on gesture and performance-related movements in sports has not been investigated. Sprinting and jumping are two gestures that are very present in the practice of many sports, such as basketball (Vázquez-Guerrero et al., 2020) and rugby (Williams et al., 2013), whose correct execution involves a high mechanical stress on the ankle, requiring adequate functioning at the level of proprioception and mobility (Dudley et al., 2017; Theisen and Day, 2019). Thus, it is not known whether a cut-off in two groups (i.e. 10 cm cut-off) is useful to discriminate correct performance in these movements; or whether, on the contrary, adding more cut-off points to subdivide the groups improves the detection and identification process. Furthermore, considering that physical abilities can be particularly improved during stages of physical development (adolescence (Maffulli et al., 2010)), it is relevant to study in detail the impact of the different DF test scores on the sprint jump in young athletes. More specifically, in basketball and rugby players, due to the high repetition of these gestures.

A better understanding of how to interpret ankle DF test results and their implications for sport performance would help to identify those athletes who may benefit most from injury prevention and a targeted conditioning programme. A new and useful subclassification of ankle DF test results, beyond dichotomisation, would help to achieve this goal.

Therefore, the aim of the current study was to investigate the relationship between predicted risk of injury based on the dichotomous classification of the WBL test scores and variables related to jumping and sprinting ability in young athletes. Furthermore, we aimed to compare the impact of the classical dichotomous classification versus a more specific quartile subdivision of the WBL test scores on the explored variables.

2. Methods

2.1. Study design

A cross-sectional study was carried out during December 2021.

2.2. Participants, ethical approval and informed consent

125 young players were recruited from two different elite teams (i.e., Abelles and L'Alqueria Basket) from December 1st to December 17th (year 2021). Inclusion criteria were: being $<$13 years age, a minimum of one year of sport expertise, the ability to perform the assessment procedures and the ability to understand instructions (Mini-Mental State Examination $>$23 points). Exclusion criteria were: current ankle injury receiving treatment or other concomitant diseases (i.e., neurological, traumatic or psychological), acute injuries in the last six months.

From the 205 potential participants. After applying the exclusion criteria, 125 were included. The study was approved by the Human Research Ethics Committee of the University of Valencia (approval number: UV-INV- ETICA-1523453). All participants' parents gave written informed consent prior to entering the study. All the procedures were performed in accordance with the principles of the World Medical Association's Declaration of Helsinki.

2.3. Procedures

The tests were performed and supervised by the same researchers who were specialists in conditioning and strength training and with experience in physical assessment. All tests were performed at the same facilities and in the same schedule. Participants refrained from strenuous physical effort for 24 h prior the testing and from the intake of any kind of stimulant (e.g., caffeine) in the 2 h before the test (Coburn and Malek, 2017; Doherty and Smith, 2005; Lowery et al., 2023). They were asked to maintain their resting and eating habits. They were also asked if there was any important change, for example, an illness, or any pharmacological treatment, and, in the case of being affirmative, the tests were not performed.

No familiarisation period was needed since the entire sample was experienced in the performance of all the tests included, these being frequently conducted throughout the competitive season.

Prior to performing the tests, a standardised warm-up was conducted consisting of 5 min of light aerobic running followed by 5 min of mobility and dynamic flexibility exercises mainly oriented to the lower extremities. The warm-up was standardised and designed following the guidelines established by the National Strength and Conditioning Association (NSCA) in which the initial part is a general warm-up based on gentle cardiovascular exercise with the objective of increasing body temperature and the second part is a specific warm-up that includes mobility and dynamic flexibility exercises aimed at preparing the joints involved (Gregory and Travis, 2016; Domínguez-Díez et al., 2021).

2.3.1. Ankle dorsiflexion ROM test

Both ankles (left and right) dorsiflexion ROM were evaluated for each of the subjects with the WBL test, using LegMotion ® equipment (LegMotion ®, Check your Motion, Albacete, Spain) and following the methodology described by Cejudo et al. (2014). The LegMotion ® device comprises a horizontal platform with a measurement scale in centimetres and a vertical metal rod than can be moved across the platform. This system has demonstrated very high levels of test-retest reliability (ICC values ranged from 0.96 to 0.98) (Cejudo et al., 2014; Calatayud et al., 2015), as well as an excellent degree of correlation with the original WBL test ($r = 0.99$) (Calatayud et al., 2015).

Participants, being barefoot, were asked to put the assigned foot on the horizontal platform, specifically in the middle of the longitudinal line just behind the transversal line. The other foot was positioned outside of the platform with toes at the edge of the platform. Hands were placed on their hips. Participants were then asked to bring the front knee as far forward as they could, without the tested foot losing contact with the platform (Fig. 1). When subjects were able to maintain heel and knee contact, the test foot was taken forward placing the vertical metal rod 1 cm away from the knee. The procedure was repeated until failure to maintain heel and knee contact for at least 3 s. The distance achieved was recorded in centimetres. Three trials were allowed for each side, with a 10-s rest between trials. The attempt with the best score was recorded. Then, the contralateral foot was evaluated using the same procedure after resting for 1 min.

2.3.2. Physical fitness tests

The tests were performed in a randomised way and a 3-min active rest period was allowed between tests. During the tests, the research team encouraged the participants to give the best of their abilities/performance.

The standing long jump (SLJ) and sprint test were carried out following standardised procedures described previously (Gregory and Travis, 2016). In the SLJ test, the participants stood with both feet just behind the standing line that was marked on the floor previously. The distance between the standing line and the participant's heel was measured, using a non-extensible tape measure fixed to the floor, after each trial. Participants were allowed to perform both a swinging arm inertia movement and a countermovement (e.g., squatting to a self-selected depth) prior to jumping in order to jump as far forward as possible. Each participant performed three attempts with 1-min passive recovery intervals.

For the sprint test, all participants began in the standardised position using a 3-point stand behind a marked starting line. Participants stayed in this stationary position and were not allowed to move forward until a signal sounded, whereby participants sprinted the 28 m distance at maximal speed; being basketball players, these are the distances used according to the dimensions of the field (14 m for half court and 28 m at the end of the court) (McInnes et al., 1995; Padulo et al., 2016). In order to record the time in 14 m and 28 m, photocells (Microgate® Polifemo Radio Light, Italia) were placed at the starting line, at 14 m and at 28 m. Each participant was allowed two attempts with 3-min intervals of passive recovery, the best mark being the one recorded for further analysis.

2.4. Statistics

Statistical data analysis was conducted using SPSS v26 (Inc., Chicago, IL, USA). Mean was used as a central measure of trend while standard deviation (SD) was used as a measure of dispersion. The normality of the data distribution was analysed with the Kolmogorov-Smirnov test, and homoscedasticity was analysed with Levene's test.

Fig. 1. Protocol set-up.

For the inferential analysis, a between-subjects T test was used to analyse differences between athletes with and without risk of injury on the dependent variables (i.e., 14-m and 28-m sprint test and SLJ test). Moreover, a between-subjects analysis of variance (one-way ANOVA) was performed to establish ankle dorsiflexion ROM quartile differences based on the WBL test distance (i.e., Q1, Q2, Q3 and Q4) on the dependent variables (i.e., 14-m and 28-m sprint test and SLT). Post-hoc comparisons were adjusted by Bonferroni or Games-Howell corrections. The type I error was set at 5% ($p \leq 0.05$).

3. Results

The study included 125 healthy athletes between 6 and 13 years old (29 females and 96 males; mean (SD) age of 10.38 (2.28) years; weight of 46.58 (16.43) kg and height of 1.57 (0.92) m.

Table 1 shows the results of the comparison between athletes with WBL test scores lower and higher than 10 cm on sprint and SLJ tests. Athletes with a score lower than 10 cm spent more time to cover 14 and 28 m than those with higher scores ($t(123) = 4.11$, $p < 0.05$, $r = 0.35$ and $t(123) = 3.86$, $p < 0.05$, $r = 0.33$, respectively). In the same way, athletes with a score lower than 10 cm were able to jump a shorter distance than those without risk of injury ($t(123) = -2.88$, $p < 0.05$, $r = 0.25$).

As explained in the Methods section, ankle dorsiflexion ROM based on the WBL test was divided into quartiles, thus representing four groups from the minimum (Q1) to the maximum dorsiflexion ROM of the sample (Q4). Table 2 shows ankle dorsiflexion range based on the distance achieved in the WBL test for each quartile.

Therefore, when the risk of injury was divided into quartiles based on left ankle dorsiflexion ROM, results showed significant differences in time to complete both sprint 14 or sprint 28 ($F(3, 28.48) = 14.96$, $p < 0.05$, $\eta^2 = 0.22$ and $F(3, 28.10) = 15.39$, $p < 0.05$, $\eta^2 = 0.23$, respectively). Furthermore, when quartiles were divided based on the right ankle dorsiflexion ROM, significant differences were found ($F(3, 27.91) = 11.24$, $p < 0.05$, $\eta^2 = 0.26$ and $F(3, 28.03) = 9.62$, $p < 0.05$, $\eta^2 = 0.23$, respectively). Accordingly, results showed significant differences in the distance achieved in the SLJ test between quartiles ($F(3, 28.41)$, $p < 0.05$, $\eta^2 = 0.22$ for left ankle and $F(3, 121) = 2.43$, $p < 0.05$, $\eta^2 = 0.15$ for right ankle).

Fig. 2 (A) and Table 3 show post-hoc comparisons between quartiles of the left ankle dorsiflexion ROM in sprint variables. Results showed that those athletes with the lower dorsiflexion ROM required more time to complete both sprint tests. Indeed, significant differences were found between Q2 and Q3, and between Q2 and Q4 both in 14-m sprint test ($t(28.48) = 4.37$, $p < 0.05$, $r = 0.66$ and $t(28.48) = 6.58$, $p < 0.05$, $r = 0.78$, respectively) and in 28-m sprint test ($t(28.10) = 4.87$, $p < 0.05$, $r = 0.68$ and $t(28.10) = 4.16$, $p < 0.05$, $r = 0.62$, respectively).

Fig. 2 (B) and Table 3 show post-hoc comparisons between quartiles of the right ankle dorsiflexion ROM in sprint outcomes. As before, results show an increased time required to complete distances for athletes with lower dorsiflexion, with significant differences between Q1 and Q3, between Q1 and Q4 and between Q2 and Q3 for the distance of 14 m ($t(27.10) = 5.89$, $p < 0.05$, $r = 0.75$; $t(27.10) = 3.86$, $p < 0.05$, $r = 0.60$ and $t(27.10) = 4.28$, $p < 0.05$, $r = 0.64$, respectively) and for the distance of 28 m ($t(28.03) = 3.81$, $p < 0.05$, $r = 0.58$; $t(28.03) = 3.50$, $p < 0.05$, $r = 0.55$; $t(28.03) = 4.29$, $p < 0.05$, $r = 0.63$, respectively).

Fig. 3 (A) and Table 3 show post-hoc comparisons between quartiles of the left ankle dorsiflexion in SLJ test. Athletes with more limited dorsiflexion jump a shorter distance than athletes with greater dorsiflexion, with significant differences between Q1 and Q3 ($t(28.41) = -2.89$, $p < 0.05$, $r = 0.48$), between Q1 and Q4 ($t(28.41) = -3.51$, $p < 0.05$, $r = 0.55$), between Q2 and Q3 ($t(28.41) = -3.45$, $p < 0.05$, $r =$

Table 1
Comparison between athletes with and without risk of injury in sprint and SLJ tests.

	Left ankle							
	WBL test score <10 cm (N = 55)			WBL test score >10 cm (N = 70)				
	Mean	SD	95%CI	Mean	SD	95%CI	P value	Cohen d
14-m sprint test (seconds)	3.14 *	0.49	3.01–3.27	2.78	0.30	2.71–2.85	<0.001	0.88
28-m sprint test (seconds)	5.78 *	0.99	5.52–6.04	5.07	0.64	4.92–5.22	<0.001	0.85
SLJ test (meters)	4.15 *	0.68	3.97–4.33	4.60	0.68	4.44–4.76	<0.001	−0.66
	Right ankle							
	WBL test score <10 cm (N = 55)			WBL test score >10 cm (N = 70)				
	Mean	SD	95%CI	Mean	SD	95%CI		Cohen d
14-m sprint m test (seconds)	3.13 *	0.51	3.00–3.26	2.82	0.31	2.75–2.89	<0.001	0.73
28-m sprint test (seconds)	5.75 *	1.04	5.48–6.02	5.16	0.67	5.00–5.32	<0.001	0.67
SLJ test (meters)	4.15 *	0.70	3.96–4.34	4.55	0.67	4.39–4.71	0.005	−0.58

WBL test: Weight-Bearing Lunge test; SLJ: Standing Long Jump test; SD: Standard Deviation; 95%CI: 95% Confidence Interval. *: significant differences between groups ($p < 0.05$).

Table 2
Ankle dorsiflexion range of movement for each quartile.

	Q1	Q2	Q3	Q4
Left ankle	2.67–6.45~~6~~	6.46–10.24~~5~~	10.25–14.03~~4~~	14.04–17.83
Right ankle	2.83–6.61~~2~~	6.62–10.40~~1~~	10.41–14.19~~20~~	14.20–18

Q1: Quartile 1; Q2: Quartile 2; Q3: Quartile 3; Q4: Quartile 4.

0.54), and between Q2 and Q4 (t (28.41) = -4.11, $p < 0.05$, r = 0.61).

Fig. 3 (B) and Table 3 show post-hoc comparisons between quartiles of the right ankle dorsiflexion for the SLJ test. Athletes with more limited dorsiflexion jumped a shorter distance than those with greater dorsiflexion, with significant differences between Q1 and Q2 (t (121) = −3.05, $p < 0.05$, r = 0.27) and between Q1 and Q3 (t (121) = -4.00, $p < 0.05$, r = 0.34).

4. Discussion

The purpose of this study was to investigate the relationship between predicted risk of injury based on the dichotomous classification of the WBL test scores and parameters related to sports performance, such as sprinting or the jumping; as well as to compare the impact of the classical dichotomous classification versus a more specific quartile subdivision of the WBL test scores on the explored variables. The results derived from this investigation revealed that athletes with risk of injury based on the classical dichotomous classification of the WBL test scores (i.e., WBL test score <10 cm) exhibited significantly poorer results for the 14-m and 28-m sprint test as well as lower SLJ test scores than those without risk of injury (i.e. WBL test score >10 cm). Likewise, when WBL test scores were subdivided by quartiles, significant differences in terms of sprint and jump performance were found too. These findings suggest that risk of injury, as measured by the WBL test, is related to physical-performance parameters, such as sprinting and jumping, not only when the already proposed 10 cm cut-off point is used, but also when a quartile division is applied, finding that those athletes with better ankle dorsiflexion also exhibit better sprinting and jumping values.

Due to its ease of implementation and useful functional meaning, the WBL test is a widely used test to detect limited ankle dorsiflexion in the assessment of musculoskeletal disorders and in the sports (Clark and Campbell, 2021; Simondson et al., 2012), with the LegMotion ® equipment being a valid tool for this purpose (Cejudo et al., 2014). In addition to having emerged in several studies as a relevant factor related to risk of lower limb injury (Hoch et al., 2012; Malliaras et al., 2006), the present research suggests that reduced ankle dorsiflexion mobility may be related to a poorer capacity for sprinting or jumping. Therefore, these findings would support the belief that limited ankle mobility also affects other functional-physical outcomes, such as balance (Hoch et al., 2020) or biomechanics (Sasaki and Neptune, 2006), which may provide grounds to argue that such mobility limitation has an adverse impact on sports performance.

A score above or below 10 cm had been previously proposed by some authors to determine the degree of performance in this test (Lagas et al., 2021), affecting the risk of injury (Clark and Campbell, 2021; Hoch et al., 2012), hence this is how the test is usually interpreted in clinical practice. In this study, using this score as a cut-off point to stratify the risk of injury, significant differences were found between the two groups in terms of the physical outcomes of sprinting and jumping, and, therefore, it is suggested that this mobility score-based classification is relevant also for sprinting and jumping performance, as are the new cut-off points established by the proposed quartile classification.

Furthermore, the results derived from the present investigation revealed slight differences between right and left ankle mobility, which may be explained by the fact that the majority of athletes had substantial side-to-side absolute-asymmetries in ankle dorsiflexion (Clark and Campbell, 2021). In this regard, any side-to-side difference in WBL for dorsiflexion among a clinical population should be interpreted while

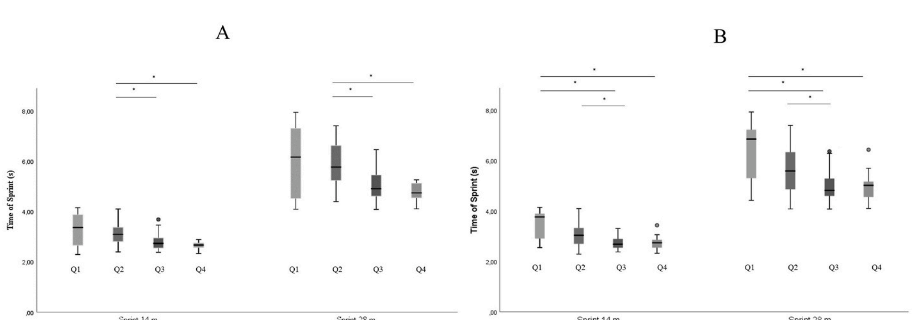

Fig. 2. Comparison between left (A) and right (B) ankle dorsiflexion ROM quartiles for sprint tests. * ($p < 0.05$).

Table 3
Quartiles comparison for ankle dorsiflexion range of movement.

	Q1 (N = 9)			Q2 (N = 52)			Q3 (N = 51)			Q4 (N = 13)			P value, Cohen d				
Left ankle	Mean	SD	95%CI	Mean	SD	95%CI	Mean	SD	95%CI	Mean	SD	95%CI	Q1-Q2	Q1-Q3	Q1- Q4	Q2- Q3	Q2-Q4
14-m sprint m test (seconds)	3.27	0.73	2.71–3.83	3.14 *#	0.43	3.02–3.26	2.79	0.31	2.70–2.88	2.64	0.17	2.54–2.74	0.96; -	0.29; -	0.13; -	<0.001; 0.93	<0.001; 1.53
28-m sprint test (seconds)	6.05	1.54	4.87–7.23	5.80 *#	0.85	5.57–6.03	5.07	0.64	4.89–5.25	4.77	0.37	4.55–4.99	0.96; -	0.31; -	0.14; -	<0.001; 0.97	<0.001; 1.57
SLJ test (meters)	3.62* #	0.84	2.97–4.27	4.13 *#	0.61	3.96–4.30	4.62	0.66	4.44–4.80	4.91	0.48	4.62–5.20	0.48; -	0.04; −1.32	0.03; −1.89	0.005; −0.77	0.003; −1.42
Right ankle	Q1 (N = 12)			Q2 (N = 58)			Q3 (N = 45)			Q4 (N = 11)			Cohen d				
	Mean	SD	95%CI	Mean	SD	95%CI	Mean	SD	95%CI	Mean	SD	95%CI	Q1- Q2	Q1- Q3	Q1- Q4	Q2- Q3	Q2- Q4
14-m sprint m test (seconds)	3.48*#	0.58	3.11–3.85	3.05 *	0.43	2.94–3.16	2.75	0.26	2.67–2.93	2.75	0.26	2.58–2.92	0.11; -	0.005; 1.62	0.006; 1.62	<0.001; 0.84	0.054; -
28-m sprint test (seconds)	6.38*#	1.19	5.62–7.14	5.61 *	0.87	5.39–5.83	5.01	0.58	4.84–5.18	4.98	0.67	4.53–5.43	0.20; -	0.01; 1.46	0.01; 1.45	<0.001; 0.81	0.06; -
SLJ test (meters)	3.67‡*	0.68	3.24–4.10	4.34	0.70	4.16–4.52	4.63	0.46	4.03–4.29	4.40	0.18	4.28–4.52	0.04; −0.97	0.004; −1.65	0.06; -	0.26; -	0.95; -

WBL test: Weight-Bearing Lunge test; SLJ: Standing Long Jump test; SD: Standard Deviation; 95%CI: 95% Confidence Interval. ‡: significant differences with Q2; *: significant differences with Q3. #: significant differences with Q4.

considering several factors, such as ankle trauma (Clark and Campbell, 2021), or anatomical differences such as limb length discrepancy (Khamis and Carmeli, 2017).

Possible factors that enhance running capacities are better results in strength-power tests, and a higher contraction speed of the rectus femoris and biceps femoris (Loturco et al., 2019). Moreover, a restriction of ankle motion could alter the biomechanics of the lower limb, making it less efficient (Fong et al., 2011) and, consequently, slowing down the sprinting speed. In fact, when classifying by quartiles, athletes with an ankle dorsiflexion ≤6.62 cm in the WBL test needed more time to perform a 14 and 28 m sprint compared to those that had a greater mobility (≥10.41 cm) in the right ankle. Similarly, when the left ankle was measured, there were significant differences in velocity from the 10.25 cm cut-off point. Previously, Drewes et al. (2009) found that limited ankle dorsiflexion mobility due to chronic ankle instability was reflected in the time of maximal dorsiflexion during jogging and gait. However, it is also important to consider this issue in athletes without ankle instability in order to prevent injuries and enhance their performance. Furthermore, since there are differences in kinematic and kinetic characteristics between foot-strike patterns when running (Almeida et al., 2015), Nunns et al. (2013) reported statistically significantly greater values of ankle dorsiflexion for natural midfoot strikers compared to natural rearfoot strikers. Similarly, Valenzuela et al. (2015) observed that runners with forefoot strike had greater ankle dorsiflexion that those with rearfoot strike (22.10 ± 5.08° versus 17.63 ± 3.76°). Therefore, this new classification could help to refine the running technique, especially for those athletes who intend to achieve a higher sprinting performance.

With regard to jumping, the differences between quartiles were more evident. On the one hand, athletes with a right ankle dorsiflexion ≤6.62 cm had a significantly lower jumping power than those with a dorsiflexion between 6.62-10.41 cm and 10.41–14.20 cm. On the other hand, it was noted that athletes with a left ankle dorsiflexion of ≤6.46 cm performed a shorter long jump than those who were classified within the Q3 and Q4 quartiles (i.e., 10.41–14.20 cm and 14.20–18 cm, respectively). This can be explained because, generally, better jumpers have greater joint moments, power and effort at the ankle, knee and hip (Vanezis and Lees, 2005). Furthermore, an association between reduced ankle dorsiflexion-plantarflexion range and landing biomechanics has also been described (Tayfur et al., 2022). Thus, a restriction in ankle dorsiflexion ROM was found to be negatively correlated with frontal plane knee excursion during a drop land task (Sigward et al., 2008), greater knee-flexion displacement and smaller ground reaction forces during landing, which, in turn, could limit the forces to be absorbed by the lower extremity (Fong et al., 2011). All the above creates an unfavourable leg alignment during the jump-landing manoeuvre and favours the development of overuse injuries and acute injuries (Aerts et al., 2013). By contrast, since ankle kinematics are associated with vertical ground-reaction force loading rate, ankle flexor plantar moment and peak vertical ground-reaction force influencing knee loads, increasing ankle dorsiflexion excursion, may be an important strategy to reduce lower limb loads during landings (Martinez et al., 2021).

Among the strengths of the study is the large sample size of highly trained young athletes being evaluated, giving greater solidity to the results obtained, and may be considered a representative sample of such population. In addition, the study proposes a new and useful approach of classifying and interpreting the results of the DF ankle test in quartiles of results, as well as its implication in sports performance variables. It provides new evidence, since this manner of classifying athletes by quartiles according to WBL test results has not been previously used. Considering the clinical and sporting implication of ankle dorsiflexion, this quartile-based method allows a more detailed assessment of ankle dorsiflexion, and, thus, a more accurate identification of risk of injury. In this way, it would allow the design of specific injury prevention and sports performance strategies according to the specific needs of each athlete.

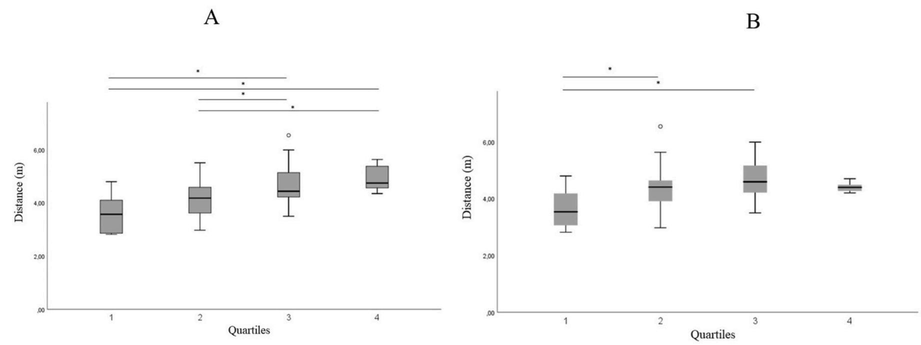

Fig. 3. Comparison between left (A) and right (B) ankle dorsiflexion ROM quartiles in SLJ test. * ($p < 0.05$).

This study has some limitations. Firstly, only young athletes between 6 and 13 years old were assessed, thus, the results cannot be entirely extrapolated to all athletes. Secondly~~,~~ having demonstrated the relationship between mobility and velocity and jumping, future research might investigate the direction of the cause-effect relationship between these parameters. Thirdly, only sprinting and jumping activities were assessed; therefore, future studies are needed to assess other types of physical performances. Finally, gender ratio (1 female: 3 males) also would have contributed to the varied results.

5. Conclusions

Limitation of ankle dorsiflexion is related to poorer athletic performance in terms of sprinting and jumping ability. In addition, this study proposes a more detailed classification of ankle restriction based on quartiles in order to prevent injury and enhance athletic performance.

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Ethics approval

The study was approved bythe Human Research Ethics Committee of the University of Valencia (approval number: UV-INV- ETICA-1523453), where it was performed and subjects gave informed consent to the work.

CRediT authorship contribution statement

Julia Cerrillo-Sanchis: Data curation, Conceptualization. **Borja Ricart-Luna:** Formal analysis, Conceptualization. **Darío Rodrigo-Mallorca:** Methodology, Investigation. **Elena Muñoz-Gómez:** Writing – review & editing, Formal analysis, Data curation. **Fernando Domínguez-Navarro:** Writing – review & editing, Data curation. **Sara Mollà-Casanova:** Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Conceptualization. **Iván Chulvi-Medrano:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Conceptualization.

Declaration of competing interest

No conflicts of interest, financial or otherwise, are declared by the authors.

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