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Research article

Reliability of single-leg maximal dynamic strength performance and inter-limb asymmetries in pre-pubertal soccer players. The influence of maturity in asymmetries

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ABSTRACT

The aims of this repeated measures study were (I) to determine the reliability of single-leg squat 1RM and inter-limb asymmetries in pre-pubertal athletes, and (II) to assess associations between bilateral and/or unilateral squat 1RM performance, inter-limb asymmetries, and participants' chronological and biological age. Thirty-one soccer players (age [mean ± standard deviation] = 8.48 ± 0.47 years; body mass = 28.32 ± 3.47 kg; body height = 121.70 ± 4.11 cm) practiced two familiarization and two experimental sessions. Bilateral and unilateral squat 1RM and asymmetries between both legs were assessed. Biological age was obtained through the age at peak height velocity (12.87 ± 0.38 years) and maturity offset (3.92 ± 0.44 years). Absolute and relative reliability and Pearson's correlations were calculated. Right and left leg 1RM and asymmetries presented good relative reliability (ICCrange = 0.84–0.85) levels, but non-acceptable absolute reliability (CV ~ 12 %). Asymmetries presented trivial to small correlations with strength (Range = 0.01–0.11). Similarly, chronological, and biological age presented small correlations with strength and asymmetries (Range = 0.01–0.22). Considering the good reliability, the bilateral and unilateral 1RM back half squat test can be considered in youth soccer players. Finally, lower-body mechanical performance and asymmetry between legs show trivial to small correlations, with maturation not affecting asymmetry in male youth soccer players. In conclusion, strength and

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power activities and training should be placed on younger soccer players with high asymmetry scores regardless of their stage of maturation.

List of abbreviations

APHV	Age at peak height velocity
CV	Coefficient of variation
ICC	Intraclass coefficient
PHV	Peak height velocity
RM	Maximum repetition
SD	Standard deviation
SEM	Standard error of the mean

1. Introduction

Testing is of paramount importance for training prescription in youth athletes [1,2]. Different factors should be considered when selecting the most appropriate tests to evaluate physical performance in athletes such as age, equipment, environment, time, training, and the reliability of the given test [3]. A basic requirement of any fitness test is that the variables can be collected with high reliability; otherwise, practitioners will not be able to confidently monitor individual changes in performance [4]. Furthermore, testing performance conform part of the daily work that athletes and practitioners exert to determine the effectiveness of a training period or to establish its initial guidelines. To this end, the validity, feasibility, reliability, and sensitivity components of any performance test are required to be well-known prior to pushing athletes to their maximum effort [5]. In the case of youth football athletes, previous research has demonstrated the relationship between extensor muscles (i.e., calves and quadriceps) strength and rapid stretch-shortening cycle actions such as 5–20m sprints and jumping [6–8].

To ensure a quick and reliable assessment of the explosive abilities of athletes, strength tests are commonly used as an easier mean tool in the physical conditioning field [1,2]. For instance, sports such as soccer, have used bilateral strength tests to evaluate lower limb power [1,9]. However, soccer performance is also characterized by unpredictable actions, which include sprinting, jumping, tackling, kicking, and changing direction [10,11]. In this regard, these multiplanar and unilateral efforts require force production in single-leg conditions [12,13]. As players are repeatedly involved in these movement patterns, previous research has suggested a plausible development of strength imbalances in these sports [14,15]. Furthermore, since the global threat pandemia of coronavirus disease and the plausible development of functional impairments in performance (e.g., joint and muscle pain, respiratory and cardiovascular stress) even in young practitioners [16,17], testing is a key factor in the overall evaluation of the athletes.

Monitoring inter-limb asymmetry is key for sports performance and rehabilitation [18]. In this sense, while the magnitude of inter-limb asymmetries remains important, recent research shows that mean asymmetry value may be a poor indicator of the true variability of inter-limb differences [19]. Additionally, the direction of inter-limb asymmetries has also been reported to determine which is the dominant limb [18,20]. For instance, observed how the levels of agreement on the same side were low between different isometric and ballistic strength assessments in recreational athletes. Thus, asymmetries may be approached with individualized tests according to athletes' context [19,20]. In this sense, McCubbine et al. [21] reported that unilateral jump tests (i.e., single-leg countermovement jump height, single-leg hop for distance, triple hop for distance, and crossover hops for distance) can be considered a reliable protocol (ICC range = 0.81–0.99; SEM range = 0.11–0.49 %; and CV range = 2.6–6.0 %) for this purpose in elite youth female soccer players. In addition, a wide variety of unilateral strength tests including isokinetic assessment [22] and split-squat-test [23] have also been used to evaluate lower limb asymmetries. However, due to the high degree of movement variability associated with strength tests [21] and the lower confidence in testing unilaterally, assessing the reliability of these tests becomes even more important.

Previous cross-sectional studies [24–26] investigated the relationship between lower limb asymmetry and unilateral mechanical performance. Thomas et al. [24] showed no significant relationships between dominant–non-dominant ratios and strength tests. In this study, it was also reported that the percentage of agreement of lower limb strength asymmetry ranged from 64.7 to 88.2 % between muscle strength qualities. These results provide support for the use of field tests to detect lower-limb strength imbalances. In contrast, Blagrove et al. [27] recently explored the relationships between inter-limb strength asymmetry, strength performance, and running economy. The relationships between strength asymmetry, performance, and running economy were low or negligible ($r < 0.47$, $p > 0.05$), except for hip abduction strength asymmetry and running economy in the female participants ($r = 0.85$, $p < 0.001$).

Furthermore, prepubertal youths present fewer movement adaptation mechanisms in comparison to more mature individuals [28], which mainly involves neural mechanisms, such as an enhanced excitation-contraction coupling [29]. However, Read et al. [30] showed that the stage of maturation did not have a deep effect on muscular asymmetry. In this study, authors speculated that inter-limbs differences in functional performance seem to be established in early childhood. Thus, interventions to reduce this injury risk factor should start in athletes before they reach their peak height velocity (PHV) during growth and should be maintained throughout childhood and adolescence. Accordingly, further studies need to clarify the impact of chronological age and maturation on lower limb asymmetry.

Thus, the aims of this study were (I) to determine the reliability of single-leg maximal dynamic strength performance (unilateral squat one-repetition maximum; 1RM) and inter-limb asymmetries in pre-pubertal soccer players, and (II) to elucidate whether bilateral and/or unilateral squat 1RM performance is associated with inter-limb asymmetries and participants' chronological and biological age, as well as maturity. In accordance with previous studies [18,22,23], it was hypothesized that the relative and absolute reliability of single-leg squat 1RM and inter-limb asymmetries would be high. Our second hypothesis was that bilateral squat 1RM performance would not be significantly associated with the inter-limb asymmetries detected during the unilateral squat 1 RMs.

2. Materials and methods

2.1. Study design

A repeated-measures design was used to investigate the reliability of right and left lower limb unilateral performance and asymmetry between legs on maximal strength tests, to explore the relationship between unilateral mechanical performance and asymmetry between legs on maximal strength tests in prepubertal youth soccer players. In the present study, participants were allocated to one experimental group that performed the bilateral and unilateral 1RM back half squat twice (test-retest) after performing previously two familiarization sessions (see procedures section). The order of each trial was randomized among participants, in order to avoid learning effects and fatigue. Every participant was identified by an ID number which was entered into an online randomizer (https://www.randomizer.org/). The dependent variables were: (a) unilateral (right and left leg 1RM) and (b) bilateral muscle strength (1RM), (c) lower limb asymmetry (%), (d) age, and (e) age at peak height velocity (APHV), which is the age at which adolescents experience their fastest growth [31].

2.2. Participants

An a priori sample size analysis G*Power version 3.1.9.6 (13) indicated that 30 participants would be enough to obtain a power (1-β) of 0.80, an alpha of 0.05, and a moderate effect size of 0.49. Therefore, thirty-one young and healthy soccer players (age = 8.48 ± 0.47 years; body mass = 28.32 ± 3.47 kg; body height = 121.70 ± 4.11 cm) voluntarily participated in this study (Table 1). Participants were experienced in soccer training for at least 2.4 years. In this regard, participants performed strengthening/plyometric and soccer-specific exercise programs (i.e., small-sided games, ball throwing) during competitions and trained for a minimum of one year before the start of the study. The study duration was of six weeks involving all the familiarization and experimental sessions of the participants.

Participants were not eligible to participate in the present study if they suffered from any physical, neurological, metabolic o cardiovascular pathology that could compromise the aims of the project. Participants and their representatives were asked not to consume any stimulating substance (e.g., caffeine) and not to perform any intense physical exercise 24 and 48 h before each session, respectively.

Data were recorded during training sessions. Participants and their legal representatives provided written informed consent after an explanation of the objectives and scope of the research project, including the procedures, risks, and benefits of the study. The study was conducted according to the tenets of the Declaration of Helsinki, and the protocol was fully approved by the Local Clinical Research Ethics Committee "Personal Protection Committee" under the following code (CPP SUD N° O221/2022) before the start of the assessments.

2.3. Procedures

Two weeks before the first session of the study, all participants completed two familiarization sessions. During the first session, height and body mass were collected using a wall-mounted stadiometer (OHAUS, Florham Park, NJ, United States) and an electronic scale (Baty International, West Sussex, England). Body fat measurements were conducted according to Deurenberg et al. [32] and the maturity offset was estimated according to Moore et al. [33]. Skinfold thickness was measured to the nearest mm, except for low values (usually 5 mm or less) in which the nearest 0.5 mm was used [32]. These measures were collected with a Harpenden skinfold caliper

Table 1
Descriptive data of the study subjects (n = 31).

Variable	Mean ± standard deviation
Body height (cm)	121.7 ± 4.1
Body mass (kg)	28.3 ± 3.5
Fat mass (%)	7.15 ± 2.84
Chronological age (years)	8.48 ± 0.47
Maturity offset (years)	3.92 ± 0.44
APHV (years)	12.87 ± 0.38

APHV: age at peak height velocity.

(Baty International, West Sussex, England) from the following anatomical areas: (i) biceps, (ii) triceps, (iii) subscapular, and (iv) supra-iliac areas. After the anthropometric measurements were completed, participants performed a 10-min standardized warm-up consisting of jogging and stretching followed by dynamic lower limb exercises (e.g., lunges and skipping). In each session, participants performed the same strength tests (bilateral and unilateral 1RM back half squat) as in the experimental sessions of the study.

After two weeks, on two non-consecutive test days, participants performed two attempts of the 1RM in the back half squat exercise (Fig. 1). All tests were repeated and intra-class correlation coefficients (ICC), together with standard error measurement (SEM) and coefficient of variation (CV) were calculated (see Section Statistical Analysis).

All strength tests were randomized and conducted with 2 min of rest between attempts and tests. In each session, a strength and conditioning specialist instructed participants on how to perform the tests and supervised the procedures. None of the participants practiced exercise for a minimum of 48 h before testing. None of the participants reported any injury at the time of testing. Anthropometric and performance measurements were collected by the same researchers under similar environmental conditions (22–24 °C and 55 % humidity). Participants were instructed to wear the same clothing and footwear during all the sessions.

2.4. Dynamic strength

Muscle strength was directly assessed with a 1RM squat as reported by Keiner et al. [2]. Before attempting the 1RM, participants completed three sub-maximal sets of 1–6 repetitions with a light-to-moderate load (40–50 % 1RM). Participants then performed the incremental load test. The increase in the absolute load (i.e., between 1 and 2.5 kg) was dependent on the effort required for the lift and became progressively smaller as the participants were nearer their 1RM [2]. Each participant was given four to six attempts. For the unilateral and bilateral strength tests, participants were required to perform a controlled eccentric velocity and make maximal efforts during the concentric phase and with a range of motion of 90°. The same squat technique was used throughout the study (including warm-up and test).

Failure was defined as an attempt not completed in the full range of motion for at least two attempts spaced at least 2 min apart. Therefore, 1RM was determined within 5–6 attempts. The procedure used to measure maximal dynamic strength was similar for both legs and for each single leg.

2.5. Bilateral asymmetry

Bilateral asymmetry was calculated from the strength test performance measure during the 1RM back half squat. A negative sign (−) was arbitrarily assigned when the left leg was the stronger one, and a positive sign (+) was used when the right leg was the stronger one. In the literature [34], relative inter-limb asymmetry for the lower limbs was determined with the following equation: (Right leg − Left leg)/(Right leg + Left leg) × 100.

2.6. Statistical analysis

Absolute (CV [%] = standard error of measurement/participants' mean score × 100) and relative reliability (ICC, model 3.1) were calculated with their corresponding 95 % confidence intervals for right and left leg mechanical performance and asymmetry between

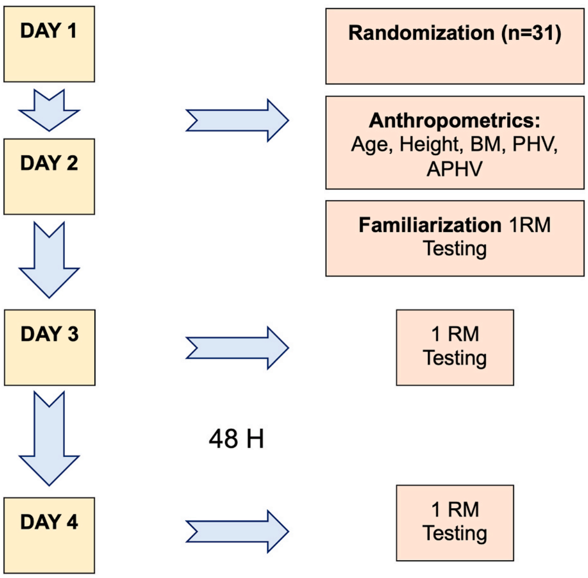

Fig. 1. Overview of the study protocol.

legs. Acceptable and high-reliability thresholds for the CV were set at ≤ 10 % and ≤5 %, respectively [35–39]. In addition, ICC values were interpreted according to the following guideline: poor [ICC <0.50], moderate [ICC = 050–75], good [0.75–0.90], and excellent [ICC >0.90] reliability [40].

Besides, the Pearson correlation coefficient was used to explore the influence of maximal strength (bilateral 1RM), chronological age, and biological age on single-leg mechanical performance and inter-leg asymmetries. Data from the first session was used for correlation analyses. Qualitative interpretations of the r coefficients as defined by Hopkins et al. [41] (0.00–0.09 trivial; 0.10–0.29 small; 0.30–0.49 moderate; 0.50–0.69 large; 0.70–0.89 very large; 0.90–0.99 nearly perfect; 1.00 perfect) were provided for all correlations.

All reliability assessments were performed by means of a custom Excel spreadsheet [42], while other statistical analyses were performed using the software package SPSS (IBM SPSS version 22.0, Armonk, NY, United States). Descriptive data are presented as means and standard deviations (SD). Statistical significance was set at $p < 0.05$.

3. Results

Descriptive data of single-leg mechanical performance and inter-limb asymmetry outcomes, CV, and ICC are reported in Table 2. All outcomes (right leg 1RM, left leg 1RM, and inter-limb asymmetry) reported good reliability (ICC range = 0.84 to 0.85). However, the CV of right and left leg mechanical performance was 12.24 % and 12.68 % respectively, which show non-acceptable reliability based on CV.

Pearson correlation coefficient between right and left leg mechanical performance and asymmetry between legs on maximal strength tests are reported on the left side of Fig. 2. Right and left leg mechanical performance showed very large correlations ($r = 0.897$; $p < 0.001$). However, asymmetry showed small non-significant correlations to the right ($r = 0.102$; $p = 0.583$) leg mechanical performance. Non-significant moderate correlations were found between asymmetry and left-leg mechanical performance ($r = -0.336$; $p = 0.065$).

The influence of maximal strength (bilateral 1RM) on single-leg mechanical performance and inter-leg asymmetries is reported on the right side of Fig. 2. Trivial to small correlations were found for all outcomes (r range = −0.007 to 0.266).

The influence of chronological age and maturity offset on single-leg mechanical performance and inter-leg asymmetries is depicted in Fig. 3. Right leg mechanical performance was significantly correlated to chronological age ($r = 0.437$; $p = 0.014$) and maturity offset ($r = -0.425$; $p = 0.017$). Left leg mechanical performance was also significantly correlated to chronological age ($r = 0.465$; $p = 0.008$) and maturity offset ($r = -0.442$; $p = 0.013$). Non-significant correlations between asymmetries and chronological age ($r = -0.132$; $p = 0.481$) or maturity offset ($r = 0.123$, $p = 0.511$) were found.

4. Discussion

The aims of this study were: a) to assess the reliability of lower limb asymmetry and lower limb dynamic strength (half squat), and b) to examine the relationships among back squat unilateral and bilateral 1RM, and lower limb asymmetry in pre-pubertal soccer players. Finally, (c) the influence of maximal strength (bilateral 1RM), chronological age, and biological age on single-leg mechanical performance and inter-leg asymmetries were also investigated.

According to the CV results, absolute and relative reliability was confirmed for the asymmetry strength when the back squat test was used. This finding aligns with previous research [20,23]. Bishop et al. [18] reported acceptable variability (CV = 5.44–5.70) and perfect relative reliability (ICC = 0.93–0.94) for peak force during the dominant and non-dominant unilateral isometric squat. Furthermore, Spiteri et al. [43] showed acceptable absolute (CV = 5.5–7.0 %) and near-perfect relative (ICC = 0.97) reliability for peak force. Their results suggest that unilateral isometric squat is a reliable variable, but asymmetry strength is more prominent in younger athletes and decreases as they grow and mature [44,45]. Therefore, strength and jumping training would be required to achieve jumping-specific motor control adaptations.

Considering that asymmetry strength was calculated with both unilateral 1RM results, it is relevant to highlight that unilateral 1RM was reliable. In addition, previous research [18] has shown trivial absolute reliability (i.e., <5.8 %), when participants performed single-leg countermovement jump tests, but good relative reliability as it is also shown in the present study (i.e., ICC >0.85). For this reason, if coaches and physical trainers aim to evaluate an athlete's side-to-side imbalances, the single-leg hop test might be valuable, mainly when considering unilateral jump tests as it is an easier assessment in comparison to other strength and conditioning exercises

Table 2
Reliability of single-leg maximal dynamic strength performance and inter-limb asymmetry.

	Right leg 1RM (kg)			Left leg 1RM (kg)			Asymmetry (%)	
	Mean ± SD	CV (%) (95 % CI)	ICC (95 % CI)	Mean ± SD	CV (%) (95 % CI)	ICC (95 % CI)	Mean ± SD	ICC (95 % CI)
Trial 1	9.66 ± 2.95	12.20 (9.80, 16.4)	0.85 (0.71, 0.92)	9.19 ± 2.84	12.70 (10.10, 17.00)	0.85 (0.70, 0.92)	2.80 ± 8.96	0.84 (0.70, 0.92)
Trial 2	9.22 ± 2.83			8.62 ± 2.74			3.74 ± 8.46	

1RM: 1-repetition maximum; SD: standard deviation; CV: coefficient of variation; ICC: intraclass correlation coefficient; CI: confidence interval.

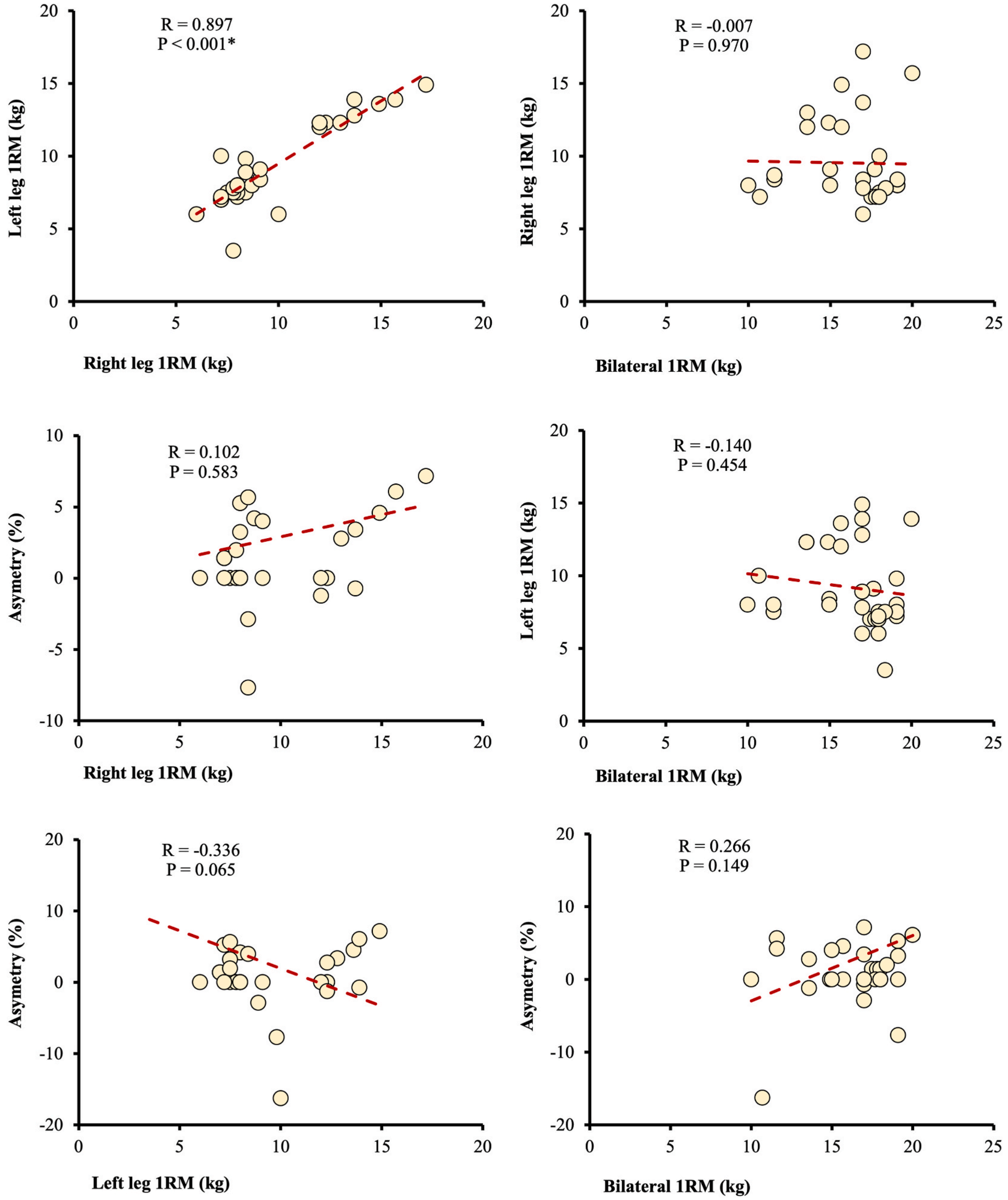

Fig. 2. Influence of maximal bilateral strength on single-leg mechanical performance and inter-leg asymmetries. r = Pearson correlation coefficient. * Represents significant results.

(e.g., 1RM squat test).

In addition, correlations were analyzed among unilateral and bilateral 1RM and lower limb asymmetry in youth soccer players. The present results showed a trivial positive correlation between asymmetry strength and bilateral 1RM (r range = 0.00 to 0.02). However, asymmetry exhibited a trivial correlation to right leg mechanical performance (r = 0.01) and a small correlation to left leg mechanical performance (r = 0.11). Within this context, the present results do not agree with previous similar studies [20,30]. The aforementioned studies showed a negative relationship between the dominant leg with a score of asymmetries (r = −0.43 to −0.47) and the non-dominant leg with a score of asymmetries (r = −0.42 to −0.71). However, previous findings are mainly based on cross-sectional data, which is not able to set a cause-and-effect relationship. Based on the correlations, it cannot be stated that elite youth athletes who exhibit improvements in muscle strength present a lower limb score of asymmetries. Based on prior reviews [46], training studies [47], and the trivial – to small correlations found in the current study, a greater emphasis on strength and jumping activities and training should be placed on younger athletes due to their less developed neuromuscular abilities.

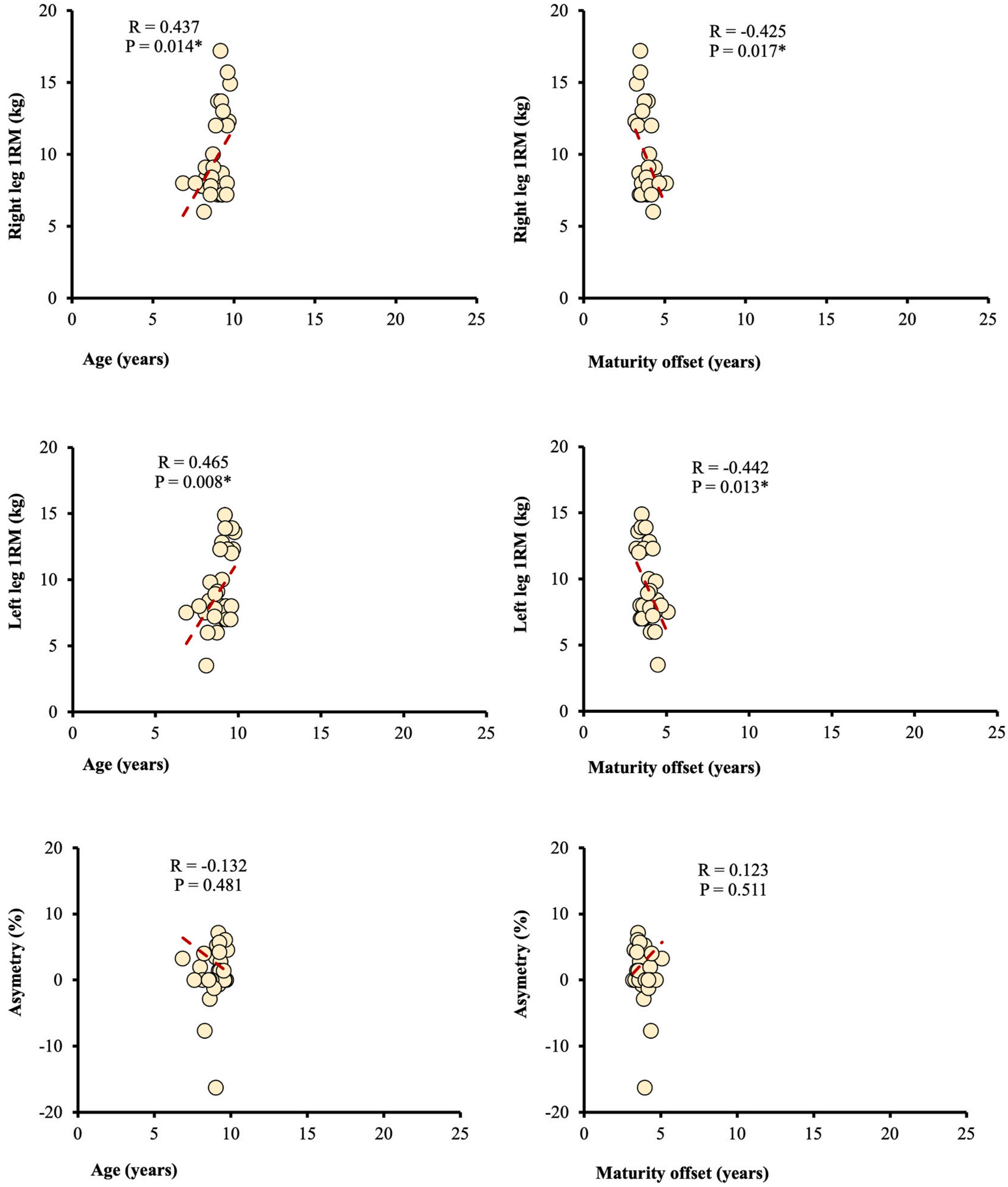

Fig. 3. Influence of chronological age and maturity offset on single-leg mechanical performance and inter-leg asymmetries. r = Pearson correlation coefficient; APHV, biological age. * Represents significant results.

Furthermore, an unexpected finding of this study was that the biological and chronological age does not appear to display profound effects on the asymmetry of male youth soccer players. A period of adolescent awkwardness has been previously reported due to the rapid increase in limb length during this period [48]. As a consequence, young soccer players may experience temporary reductions in motor skill performance. This occurs approximately 12 months prior to PHV and potentially increases the risk of asymmetries [48]. Hence, as motor control improves with physical maturation [49], an enhancement in coordination would contribute to improving hopping, jumping, and throwing skills. Furthermore, Behringer et al. [50] emphasized that increasing strength also improves motor performance in children and adolescents. Overall, although the sample used in the present study is considered pre-PHV youth soccer players, the rationale for this finding might be attributed to the rapid growth during the PHV phase.

Previous research in school-aged boys has shown that chronological age or stage of maturation does not affect asymmetry in spatiotemporal variables during maximal velocity sprinting [51]. In the current study, our findings also indicate that chronological and biological age does not affect the magnitude of asymmetry across the different components of neuromuscular control measured. In this sense, players who presented higher asymmetry scores should be targeted for injury risk reduction programs regardless of their stage of maturation. While peak strength velocity is also reached after PHV [48], it could be suggested that lower limb asymmetry in functional strength (i.e., 1 RM) performance tasks are established early in a child's life. Therefore, interventions targeting this injury risk factor should start in pre-PHV athletes and should be maintained throughout childhood and adolescence.

Although this study provides new valuable information on the physical conditioning field, some limitations and future research directions may be discussed. First, there is a lack of enough similar studies to compare the current research results with others about the relationship between chronological and biological age (i.e., maturity offset) and physical factors. Second, based on the present study, it is suggested that future research could use linear sprint and agility tests to confirm our results in pre-pubertal soccer players. Finally, we were not able to examine the underlying neuromuscular mechanisms responsible for the observed correlation between mechanical performance and lower limb asymmetry due to the lack of neurophysiological tests in the design of this study. Therefore, future studies should include electrophysiological testing during the asymmetry tests (e.g., electromyography) to elucidate the underlying neural changes.

5. Conclusion

It is concluded that there was a good reliability of the selected inter-limb strength asymmetry in youth soccer players. Moreover, the calculation of the reliability of right and left lower limb unilateral performance and asymmetry between legs test was considered reliable as well due to reaching higher values than what was considered a reliable cut-off value (<10 %). This means that the 1RM back half squat test can be considered in youth soccer players.

Moreover, the calculation of the right leg single dynamic squat test was considered reliable as well due to reaching higher values that were considered above the absolute reliable cut-off value (10 %). In this sense, all the strength tests measured may be considered in youth players.

Furthermore, based on the second aim of this study, lower-body mechanical performance and asymmetry between legs show trivial to small correlations. Furthermore, maturation did not affect asymmetry in male youth soccer players. Therefore, a greater emphasis on how strength levels and asymmetries are related in more physical tests regardless of the stage of maturation is warranted in future research to fully understand the practical implications of this finding.

Data availability statement

All data associated with this manuscript will be made available upon reasonable request to the corresponding author.

CRediT authorship contribution statement

Nizar Bouafif: Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Raouf Hammami:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Abdelkader Mahmoudi:** Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Pablo Jiménez-Martínez:** Writing – review & editing, Writing – original draft, Formal analysis. **Carlos Alix-Fages:** Writing – review & editing, Writing – original draft, Formal analysis. **Amador Garcia-Ramos:** Writing – review & editing, Writing – original draft, Formal analysis. **Alvaro Juesas:** Writing – review & editing, Writing – original draft, Formal analysis. **Javier Gene-Morales:** Writing – review & editing, Writing – original draft, Formal analysis. **Sabri Gaied-Chortane:** Writing – review & editing, Validation, Methodology, Investigation, Data curation, Conceptualization. **Juan C. Colado:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis.

Declaration of competing interest

This study was approved by the Local Clinical Research Ethics Committee "Personal Protection Committee" under the following code (CPP SUD N° O221/2022). Amador Garcia-Ramos is an Academic Editor for Heliyon.

All data generated or analyzed during this study are included in this published article. The databases are available upon reasonable request to the corresponding author.

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