Title: Effects of age and maturation on lower extremity range of motion in male youth soccer players.

Running head: Effects of age and maturation on ROM.

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Abstract:

Restricted joint range of motion (ROM) has been considered as a primary risk factor for some sport-related injuries. Consequently, pre-participation assessment of lower extremity joints ROM could help identify youth soccer players at high risk of injury and to aid in the design of tailored age and maturational specific training interventions. The purpose of this study was to analyze and compare the influence of chronological age and maturational stage on several lower extremity ROM measures, as well as to describe the lower extremity ROM profile using a comprehensive approach in youth soccer players. A total of 286 male youth soccer players ROM was assessed including: passive hip (extension [PHE], adduction with hip flexed 90º [$PHAD_{HF90º}$], flexion with knee flexed [PHF_{KF}] and extended [PHF_{KE}], abduction with hip neutral [PHABD] and flexed 90º [$PHABD_{HF90º}$], external [PHER] and internal [PHIR] rotation), knee (flexion [PKF]) and ankle (dorsiflexion with knee flexed [ADF_{KF}] and extended [ADF_{KE}]) ROMs. Between-group differences were analyzed using a one-way ANOVA and magnitude-based decisions. The results only report statistically significant ($p < 0.05$; $d > 0.5$) and clinically relevant differences (> 8º) for the PKF ROM between U12 vs. U19, and Pre-PHV vs. Post-PHV groups. Furthermore, approximately 40%, 35% and 20% of players displayed restrictions in their PHF_{KE}, PKF, and ADF_{KF} ROM values, respectively. These findings emphasize the necessity of prescribing (across all age groups and periods of growth and maturation) compensatory measures in daily soccer training and these exercises should be equally applied to both limbs with the aim of improving PHF_{KE}, PKF and ADF_{KF} ROM values.

Key Words: peak height velocity, injury risk, flexibility, adolescence, athletic development, associated football.

INTRODUCTION

Despite the numerous evidence-based health benefits, participation in a physically demanding sport such as soccer can lead to greater exposure to causal factors of injury (e.g., high mechanical loads repetitively imposed on bones and soft tissues during trainings and matches, fatigue-induced alterations in movement patterns during the execution of high intensity dynamic actions, collisions with other players) (30). The increased risk of injury (mainly in the lower extremities) produced by playing soccer is especially relevant in cases in which growth and maturation are not yet completely developed, especially during adolescence (23). Indeed, injury incidence in adolescent soccer players has recently been aligned to peak height velocity (PHV) (48), which is defined as the age at which the maximum rate of growth occurs during the adolescent stage (34).

Several mechanisms have been suggested to explain this increase in injury incidence during the years of maximal rate of growth. For example, the rapid increase in the length of arms and legs relative to the trunk that occurs during PHV is not always followed by a similar onset and rate of muscle-tendon flexibility development (46). Therefore, during this growth spurt, adolescents often experience a situation in which the length of the extremities has already achieved its full development but the muscles still have to reach their full size (38). This temporary situation (commonly known as “adolescent motor awkwardness”) might generate a growth-related decrease in muscle-tendon flexibility (mainly in postural and biarticular muscles) that may result in significant restrictions on joint range of motion (ROM). Furthermore, soccer players are required to perform a number of repeated high-intensity and multidirectional actions (e.g., sprinting, jumping, kicking, changes of direction) during training and matches that frequently involve high levels of unilateral force production (3). Consequently, soccer players develop and selectively use preferred limbs for most game-based actions (35) that generate asymmetric lower extremity loading patterns. As a result, the yet immature musculoskeletal system of the adolescent soccer players is expose to compressive, torsional, transverse and tensile loads whose magnitude, rate, frequency and unique distribution to each leg may also foster asymmetrical adaptations in muscle-tendon flexibility that are likely to contribute to significant bilateral differences in lower extremities joint ROMs. These potentially restricted and bilaterally asymmetric joint ROMs (especially in the lower extremity [hip, knee and ankle joints]) may lead (alongside with other sensorimotor and structural changes) adolescent soccer players to adopt altered movements and motor-control strategies during the execution of high intensity dynamic tasks, such as jumping, cutting and landing (38,40). This decline in essential motor performance that occur during the pubertal years may be one of the main factors behind the increased susceptibility to lower extremity injuries (mainly ligamentous injuries in the knee and ankle joints) demonstrated by youth soccer players during the stage of PHV (41). This theory suggests that from an injury prevention perspective that joint ROM assessment should be employed in screening protocols, during all phases of the athlete development framework, but especially around PHV. This in turn may help identify youth soccer players at high risk of injury and to aid in the design of tailored maturational specific training interventions.

Some studies have investigated the influence of maturation on several parameters of physical performance (running speed and acceleration (33), jumping distance (42)), neuromuscular control (static and dynamic balance (22), landing kinematics (43)) and muscle strength (knee flexion and extension isokinetic strength (14)) in youth soccer players, reporting some adaptations or deficits that may contribute to the increased injury risk during the adolescent growth spurt. However, no studies have been published (to the authors' knowledge) that have examined the effects of biological maturity on lower extremity joint ROMs in youth soccer players. Some studies have explored changes in chronological age on some lower extremity ROM measures including the hip (7,10,32,45), knee (7) and ankle (7) in youth soccer players reporting a decreasing trend in hip rotation (mainly internal rotation) and knee flexion ROMs with advancing age. In addition, two of these studies (32,45) have also shown that young soccer players had significantly lower (>8º) hip internal rotation ROM than their age-matched controls. Likewise, one study did not find statistically significant bilateral asymmetries between the average hip, knee and ankle joints ROM of both legs in a large cohort of youth soccer players (7). This restricted hip rotation ROM profile generated over time, as a consequence of soccer training and match play, might play a meaningful role in the increased risk of non-contact anterior cruciate ligament (ACL) injuries shown in adolescent (16-18 years) players (5). Previous studies have clearly demonstrated that individuals of the same chronological age can differ markedly with respect to biological maturity (13). Thus, significant interindividual differences regarding level (magnitude of change), tempo (rate of change) and timing (onset of change) of biological maturation have been observed between children and adolescents of the same chronological age (up to 15 cm and 21 kg in the stature and body mass, respectively) (13). Depending on these three variables, children and adolescents will be viewed as either biologically ahead of their chronological age (early-maturing individual), “on-time” with their chronological age (average maturer) or behind their chronological age (late-maturing individual) (27). Therefore, this relative mismatch and wide variation in biological maturation between children and adolescents of the same chronological age emphasizes the limitations in using chronological age as the sole determinant to explore decreases in lower extremity joint ROMs and highlights the importance of also considering biological maturation to aid the identification and understanding of the possible changes in joint ROMs and injury risk in youth soccer players. This knowledge may help coaches and sports science specialists to design tailored age and/or maturational stage-based training programs to both optimize motor performance and reduce potential injury risk in young soccer players.

In an attempt to minimize the effects of inter-player variability and achieve a more realistic diagnosis regarding the presence (or absence) of changes in ROM measures attributed to a certain phenomenon (e.g. growth-related effects), recently López-Valenciano et al. (29) suggested using a new comprehensive profile of joint ROMs. In this profile not only average ROM scores are reported but also the number of players showing bilateral asymmetries (between limb differences >6-10º) (12,15) and normal (compared to their age-matched controls) and non-pathologic (based on the previously published cut-off scores to classify athletes at high risk of injury) ROM values.

Therefore, the main purpose of the present study was to analyze and compare the influence of chronological age and PHV (as an indicator of biological maturity) on lower extremity joints (hip, knee and ankle) ROM as well as to describe the lower extremity ROM profile using a comprehensive approach in youth soccer players. Based on both the documented negative and temporary influence of maturation on essential motor performance (22,33,42,43), and the reported decrease in hip (mainly internal rotation) and knee (flexion) ROMs with advancing age in young athletes (7,32,45), the hypothesis of the present study was that the soccer players belonging to the younger age groups (under 12 and under 14 y) and whose predicted maturation status was categorized as "before-PHV" would show higher hip and knee ROM values than their counterparts of the older age groups and that were immersed in the maturation years of "around" and "after-PHV".

METHODS

Experimental Approach to the Problem

A cross-sectional design was used to analyze and compare the potential influence of chronological age and stage of maturation on lower extremity ROM measures in young soccer players. The study was conducted during the preseason phase (September) of the years 2017-18.

The testing sessions conducted in each soccer academy were divided into two different parts within a single testing session. The first part of each testing session was used to record the anthropometric measures needed to calculate the stage of maturation of the participants. The second part was designed to assess the lower extremity ROMs.

Subjects

A total of 286 male youth soccer players from the academies of five Spanish soccer clubs completed this study. Descriptive statistics for each chronological age and maturation group are displayed in Table 1 and Table 2, respectively. Participants met the following inclusion/exclusion criteria: 1) engaged regularly in soccer training and competitions (at least 2-3 training sessions and 1 match per week), 2) no history of orthopedic problems to the ankle, knee, thigh, hip or lower back in the 3 months before the data collection phase, and 3) were free of delayed onset muscle soreness (DOMS) at the time of testing (self-reported). In addition, none of the participants were involved in systematic and specific strength training programs and stretching regimes within the last six months, apart from the 1-2 sets of 15-

30 seconds of static stretches designated for the major muscles of the lower extremities that were performed daily during their pre-exercise warm-up and/or post-exercise cool down phases.

Before any participation, experimental procedures and potential risks were fully explained to both parents and children in verbal and written forms, and written informed consent was obtained from parents and children. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethics and Scientific Committee of the University of Murcia (Spain) (ID: 1551/2017).

Table 1. Participants´ descriptive anthropometric scores (mean ± standard deviation) for each chronological age group. The maturity offset per chronological age group is also presented.

Age group	N	Age (years)	Body mass (kg)	Stature (cm)	Leg length (cm)	Maturity offset
U12	76	11.1 ± 0.5	39.6 ± 6.8	148.0 ± 6.8	72.6 ± 4.1	-2.4 ± 0.6
U14	79	13.2 ± 0.5	51.8 ± 8.7	162.0 ± 7.9	80.7 ± 5.2	-0.7 ± 0.6
U16	68	14.9 ± 0.5	61.7 ± 8.0	172.3 ± 6.2	84.5 ± 3.8	0.9 ± 0.6
U19	63	17.3 ± 0.8	68.6 ± 8.2	176.9 ± 6.7	86.8 ± 5.4	2.5 ± 0.7

Table 2. Descriptive anthropometric values (mean ± standard deviation) for participants per maturation sub-group.

Maturation sub-group	N	Age (years)	Body mass (kg)	Stature (cm)	Leg length (cm)	Maturity offset
Pre-PHV	101	11.6 ± 0.9	40.9 ± 7.1	149.6 ± 7.1	73.8 ± 4.8	-2.2 ± 0.7
Circa-PHV	43	13.9 ± 0.7	57.2 ± 7.0	167.3 ± 4.8	82.8 ± 4.5	-0.0 ± 0.3
Post-PHV	93	16.6 ± 1.3	67.8 ± 7.9	176.9 ± 5.9	86.5 ± 4.8	2.2 ± 0.8

Procedures

Anthropometry

Body mass in kilograms was measured on a calibrated physician scale (SECA 799, Hamburg, Germany). Standing and sitting heights in centimeters were recorded on a measurement platform (SECA 799, Hamburg, Germany). A measuring tape was used to assess the leg length to all the soccer players. Leg length was defined as the length measured in centimeters from the anterior superior iliac spine to the most distal portion of the medial tibial malleolus (44).

Maturity status

Stage of maturation was calculated in a noninvasive manner using a regression equation comprising measures of age, body mass, standing height and sitting height taken during the first part of the testing sessions (34). Using this method, maturity offset (calculation of years from PHV) was completed (Equation 1). The equation has been used to predict maturation status with a standard error of approximately 6 months in pediatric population (34). Therefore, the following equation to calculate maturity offset was used:

- *9.236 + [0.0002708*leg length and sitting-height interaction] – [0.001663*age and leg-length interaction] + [0.007216*age and sitting-height interaction] + [0.02292*weight by height ratio]*

Range of motion

The passive hip extension [PHE], hip adduction with hip flexed 90º [$PHAD_{HF90º}$], hip flexion with knee flexed [PHF_{KF}] and extended [PHF_{KE}], hip abduction with hip neutral [PHABD] and hip flexed 90º [$PHABD_{HF90º}$], hip external [PHER] and internal [PHIR] rotation, knee flexion [PKF], ankle dorsiflexion with knee flexed [ADF_{KF}] and extended [ADF_{KE}] ROM measures of the dominant (defined as the participant´s preferred kicking leg) and non-dominant legs were assessed following the methodology described by Cejudo et al. (6,7).

These ROM tests were selected because they have been considered operationally valid by some American Medical Organizations (17) and included in prominent manuals of Sports Medicine (31) based on anatomical knowledge and extensive clinical and sport experience. In addition, previous studies from our laboratory (6,7) have reported moderate to high intra-tester reliability scores for all the ROM procedures employed by the testers who were in charge of carrying out all the testing sessions, with coefficients of variation (CV) ranging from 0.2 to 9.1% (CVs = 0.4, 1.7, 9.1, 3.5, 3.7, 3.5, 3.4, 1, 0.2 and 1.2% for PHF_{KF}, PHF_{KE}, PHE, $PHABD_{HF90º}$, PHABD, $PHAD_{HF90º}$, PHIR, PHER, PKF, ADF_{KF} and ADF_{KE}, respectively).

For the ROM measurement, an ISOMED Unilevel inclinometer (Portland, Oregon) was used with an extendable telescopic arm as the key measure for the PHE, $PHAD_{HF90º}$, PHF_{KF}, PHF_{KE}, $PHABD_{HF90º}$, PHER, PHIR, PKF, ADF_{KF} and ADF_{KE} tests, while a metallic long arm goniometer (Baseline® Stainless) was employed for the PHABD test. A low-back protection support (Lumbosant, Murcia, Spain) was used to maintain the normal lordotic curve during most of the assessment tests (6).

Prior to the ROM assessment (second part of the testing sessions), players performed the standardized dynamic warm-up designed by Taylor et al. (47). The overall duration of the entire warm-up was approximately 20 min. A 3-5 min rest interval between the end of the warm-up and beginning of the ROM assessment was given to the soccer players for rehydrating and drying their sweat prior to the ROM assessment. It has been shown that the effects elicited by the dynamic warm-up on muscle properties might last more than 5 min (2) and hence, decreases in ROM values within the 3-5 min rest interval were not expected. Standardization procedures, (including the warm-up, test setup and participant instructions) were replicated at each test session conducted in the different academies. After the warm-up, soccer players were instructed to perform, in a randomized order, two maximal trials of each ROM test for each leg, and the mean score for each test was used in the statistical analyses. One of the following criteria determined the endpoint for each test: a) palpable onset of pelvic rotation, and/or b) the soccer player feeling a strong but tolerable stretch, slightly before the occurrence of pain (6). When a variation >5% was found in the ROM values between the two trials of any test, an extra trial was performed, and the two most closely related trials were used for the subsequent statistical analyses (6).

Soccer players were examined wearing sports clothes and without shoes. A 30 s rest was given between trials, legs and tests. All tests were carried out by the same two experimented sport scientists under stable environmental conditions.

Data analyses

To account for the reported error (approximately 6 months) in the equation (34), players were grouped into discrete bands based on their maturational offset (pre-PHV [<-1], circa-PHV [-0.5 to 0.5], post-PHV [>1]). Players who recorded a maturational offset from -1 to -0.5 and 0.5 to 1 were subsequently removed from the dataset when players were analyzed by stage of maturation.

Likewise, in each participant the hip, knee and ankle ROM scores were categorized as normal or restricted according to the reference values previously reported to consider an athlete as being more prone to suffer an injury (18,25,39,48). When no cut-off scores for detecting athletes at high risk of injury were found for a ROM score, it was compared with data derived from the age-matched controls. Otherwise, when several cut-off scores were found for the same ROM, the most conservative criteria were selected. Thus, ROM values were reported as restricted according to the following cut-off scores: < 114º PHF_{KF} (18), < 70º PHF_{KE} (26), < 0º PHE (50), < 50º $PHABD_{HF90º}$ (17), < 28º PHABD (11), < 25º $PHAD_{HF90º}$ (25), < 30º PHIR (48), < 30º PHER (48), < 120º PKF (37), < 34º ADF_{KF} (39), < 17º ADF_{KE} (11). Using the mean value of the cut-off scores suggested by Fousekis et al. (15) and Ellenbecker et al. (12), the number of players with side-to-side differences (>8º) in each ROM measure were also calculated.

Statistical analyses

Prior to the statistical analysis, the distribution of raw data sets was checked using the Kolmogorov-Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$). Descriptive statistics including means and standard deviations were calculated for each ROM measure and group separately.

A one-way analysis of variance (ANOVA) was performed to determine the existence of between-groups differences for all normal data distribution. Homogeneity of variance was tested by Levene's statistic, and where violated Brown-Forsythe adjustment was used to calculate the F-ratio. Post-hoc comparisons were made using the Bonferroni or Dunnett's T3 test to determine significant between-group differences when equal variance was or was not assumed, respectively. In particular, separate analyses were performed to examine between-group differences for a range of chronological age groups that represented those in a soccer academy (U12, U14, U16 and U19). A secondary analysis was also employed, grouping players by their stages of maturation (pre-PHV, circa-PHV or post-PHV). The significance level was set to $p < 0.05$ for all tests.

Batterham & Hopkins (4) suggested that for intra and inter-groups comparisons, the traditional null hypothesis tests (i.e. analysis of variance) whose qualitative decisions or interpretations are based on the basic of a specific p value (when a p value is lower than 0.05 the magnitude of the difference is considered statistically significant) should be complemented (as this approach may be misleading, depending on the magnitude of the statistic, error of measurement, and sample size) with a more intuitive and practical approach based directly on uncertainty in the true value of the statistic. Consequently, magnitude-based decisions on differences between chronological age groups (U12 vs. U14 vs. U16 vs. U18), maturity offset groups (pre-PHV vs. circa-PHV vs. post-PHV) and legs (dominant vs non-dominant) were also determined by expressing the probabilities that the true effect was trivial or substantial in relation to predetermined threshold values (i.e. smallest worthwhile clinical changes). Probabilities were then used to make a qualitative probabilistic inference about the effects (20). Based on the cut off scores proposed by Fousekis et al. (15) and Ellenbecker et al. (12) (>6º and >10º, respectively), the cut off value of >8º (mean from both previous studies) was used to determine the smallest substantial/worthwhile change for all paired-comparisons and for each of the ROM variables. The qualitative descriptors proposed by Hopkins (19) were used to interpret the probabilities that the true affects are harmful, trivial or beneficial: <1%, almost certainly not; 1–4%, very unlikely; 5– 24%, unlikely or probably not; 25–74%, possibly or may be; 75–94%, likely or probably; 95–99%, very likely; >99%, almost certainly.

Effect sizes were also calculated to determine the magnitude of differences between groups and legs for each of the ROM measures using the method and descriptors previously described by Cohen (8) assigning descriptors to the effect sizes (d) such that an effect size < 0.2 was considered as being trivial, between 0.2 and 0.5 represented a small magnitude of change, while 0.5–0.8 and greater than 0.8 represented moderate and large magnitudes of change, respectively.

The current study considered a "clinically relevant" main effect when a change was noted between paired-comparisons in ROM measures that reported a p values < 0.05, a probability of the worthwhile differences of "possible" or higher (> 50% positive or negative) and at least a moderate effect size (d > 0.5).

Pearson's chi-squared (χ^2) test was used to examine the existence of a relationship between the ROM classification (normal and restricted) and the chronological age and maturational stage groups.

Finally, Pearson (*r*) correlation analysis was performed to examine the correlation between players' leg length and each ROM score. Magnitudes of correlations were assessed using the following scale of thresholds: < 0.80 low, 0.80–0.90 moderate and > 0.90 high (21).

All the analysis was completed using SPSS version 20 (SPSS Inc, Chicago, IL, USA) and an online spreadsheet (www.sportsci.org).

RESULTS

Tables 3 and 4 show the descriptive ROM values for hip (PHF_{KF}, PHF_{KE}, PHE, $PHABD_{HF90º}$, PHABD, $PHAD_{HF90º}$, PHIR and PHER), knee (PKF) and ankle (ADF_{KF} and ADF_{KE}) joints and for all chronological age and maturational groups, respectively.

Table 3. Mean range of motion scores and percentage of players with bilateral differences per age group.

	U12 (n = 76)		**U14 (n = 79)**		**U16 (n = 68)**		**U19 (n = 63)**	
Ranges of motion (º)	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8º**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8º**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8º**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8º**
PHF_{KF}	136.3 ± 4.8 (Normal [0])	4	132.7 ± 5.2 (Normal [0])	9	132.7 ± 6.4 (Normal [0])	6	135.4 ± 6.7 (Normal [0])	8
PHF_{KE}	71.5 ± 7.2 (Normal [38])	8	69.3 ± 6.6 (Restricted [57])	0	70.2 ± 9.0 (Normal [49])	1	74.8 ± 9.3 (Normal [32])	2
PHE	15.7 ± 4.4 (Normal [0])	3	12.8 ± 5.8 (Normal [1])	1	10.4 ± 4.5 (Normal [0])	0	10.5 ± 5.3 (Normal [6])	0
$PHABD_{HF90º}$	73.0 ± 4.9 (Normal [0])	5	71.0 ± 5.4 (Normal [0])	6	69.4 ± 7.0 (Normal [0])	3	70.5 ± 6.5 (Normal [0])	0
PHABD	38.6 ± 3.1 (Normal [0])	0	37.2 ± 2.2 (Normal [0])	0	36.9 ± 3.4 (Normal [0])	0	37.3 ± 2.3 (Normal [0])	0
$PHAD_{HF90º}$	28.8 ± 3.5 (Normal [8])	3	27.7 ± 3.0 (Normal [10])	3	28.1 ± 3.1 (Normal [10])	1	31.5 ± 3.8 (Normal [3])	2

PHIR	47.0 ± 6.1 (Normal [0])	4	43.9 ± 6.2 (Normal [1])	3	42.8 ± 6.6 (Normal [1])	1	42.6 ± 7.0 (Normal [1])	0
PHER	58.6 ± 6.8 (Normal [0])	5	56.8 ± 7.2 (Normal [0])	5	58.9 ± 9.4 (Normal [0])	4	57.2 ± 5.4 (Normal [0])	5
PKF	129.6 ± 8.8 (Normal [14])	9	126.7 ± 9.0 (Normal [19])	4	123.1 ± 11.3 (Normal [41])	4	121.4 ± 11.4 (Normal [49])	6
ADF_{KF}	36.7 ± 4.6 (Normal [20])	1	37.2 ± 4.1 (Normal [16])	0	36.6 ± 5.3 (Normal [18])	1	36.6 ± 5.2 (Normal [25])	0
ADF_{KE}	30.0 ± 4.6 (Normal [0])	1	29.4 ± 3.9 (Normal [0])	1	30.2 ± 4.7 (Normal [0])	1	32.0 ± 4.9 (Normal [0])	0

º: degrees.

[a]: Qualitative score of the mean range of motion, in brackets the percentage of players with a restricted range of motion scores according to previously published cut-off scores (see Statistical analysis section). PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $PHABD_{HF90º}$: passive hip abduction at 90º of hip flexion; PHABD: passive hip abduction; $PHAD_{HF90º}$: passive hip adduction at 90º of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsi-flexion with the knee flexed; ADF_{KE}: ankle dorsi-flexion with the knee extended.

Table 4. Mean range of motion scores and percentage of players with bilateral differences per maturation group.

Ranges of motion (º)	Pre-PHV (n = 101)		Circa-PHV (n = 43)		Post-PHV (n = 93)	
	Mean ± SD (Qualitative outcome[a])	**Percentage of players with bilateral difference >8º**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8º**	**Mean ± SD (Qualitative outcome[a])**	**Percentage of players with bilateral difference >8º**
PHF_{KF}	136.1 ± 4.4 (Normal [0])	5	130.9 ± 5.8 (Normal [0])	5	134.4 ± 6.5 (Normal [0])	8
PHF_{KE}	71.9 ± 7.0 (Normal [37])	6	69.5 ± 6.1 (Restricted [51])	0	73.6 ± 9.8 (Normal [38])	2
PHE	15.2 ± 5.0 (Normal [1])	2	11.6 ± 5.7 (Normal [0])	0	10.5 ± 5.0 (Normal [4])	0
$PHABD_{HF90º}$	72.6 ± 5.4 (Normal [0])	7	69.3 ± 6.8 (Normal [0])	7	70.4 ± 6.4 (Normal [0])	1
PHABD	38.4 ± 2.7 (Normal [0])	0	37.0 ± 2.2 (Normal [0])	0	37.1 ± 2.7 (Normal [0])	0
$PHAD_{HF90º}$	28.5 ± 3.3 (Normal [6])	4	28.0 ± 3.4 (Normal [14])	1	30.2 ± 3.9 (Normal [8])	1
PHIR	46.7 ± 5.8 (Normal [0])	3	42.9 ± 6.5 (Normal [1])	5	42.5 ± 6.9 (Normal [2])	1
PHER	58.3 ± 7.0 (Normal [0])	4	56.4 ± 8.0 (Normal [0])	9	57.4 ± 7.2 (Normal [0])	4
PKF	129.5 ± 8.7 (Normal [14])	8	124.4 ± 10.5 (Normal [30])	0	121.0 ± 11.2 (Normal [51])	4
ADF_{KF}	37.2 ± 4.4 (Normal [16])	1	36.4 ± 5.3 (Normal [28])	0	36.3 ± 5.1 (Normal [24])	0
ADF_{KE}	30.0 ± 4.4 (Normal [0])	2	30.3 ± 5.0 (Normal [0])	0	31.3 ± 4.5 (Normal [0])	1

º: degrees.

[a]: Qualitative score of the mean range of motion, in brackets the percentage of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section). PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $PHABD_{HF90º}$: passive hip abduction at 90º of hip flexion; PHABD: passive hip abduction; $PHAD_{HF90º}$: passive hip adduction at 90º of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsi-flexion with the knee flexed; ADF_{KE}: ankle dorsi-flexion with the knee extended.

With all players combined, ANOVA and magnitude-based decisions analyses reported no clinically relevant differences between dominant and non-dominant legs for each ROM measure (most likely trivial effect with a probability of 100% [Appendix 1 and Appendix 2]) and hence, the mean ROM score for both limbs was used for between groups comparisons.

Although the one-way ANOVA analysis showed statistically significant differences ($p < 0.05$; $d = 0.5\text{-}1.25$) between chronological age groups in almost all (PHF_{KF}, PHF_{KE}, PHE, $PHABD_{HF90º}$, PHABD, $PHAD_{HF90º}$, PHIR, PKF, ADF_{KE}) ROM measures (Figure 1), the magnitude-based decisions analysis reported non-substantial differences (<8º) for all the ROM values (likely trivial effect with a probability of 81-100%) and between pairwise chronological age groups comparisons, except for the PKF ROM measure where a possibly negative effect (with a probability of 54%; $d = 0.92$; $p < 0.05$) was found between U12 and U19 players' groups.

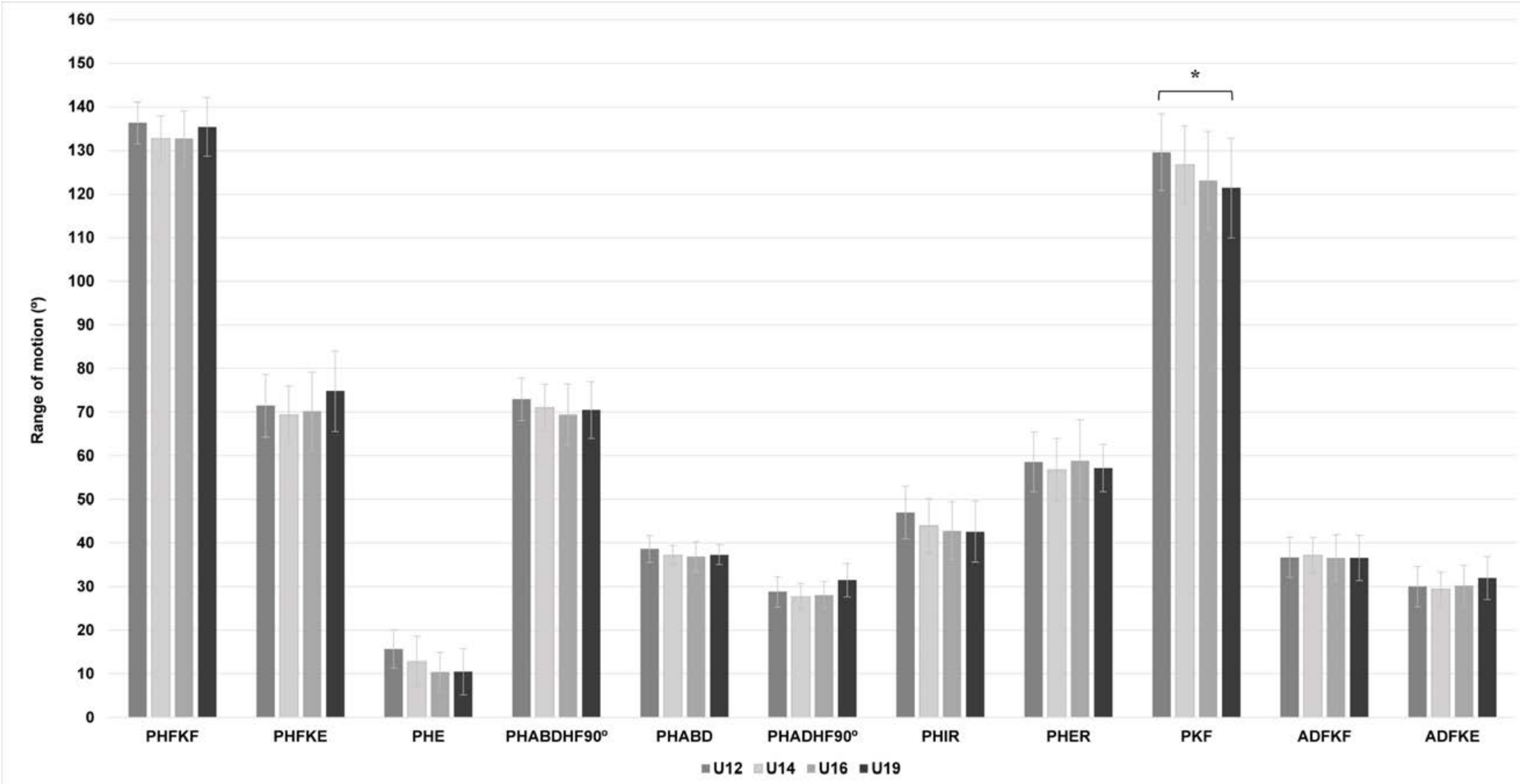

Figure 1 Age-related inter-group differences for lower extremity joint ranges of motion values.

*: Clinically relevant (probability of the worthwhile differences > 50%; d > 0.4; p < 0.05).

PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $PHABD_{HF90º}$: passive hip abduction at 90º of hip flexion; PHABD: passive hip abduction; $PHAD_{HF90º}$: passive hip adduction at 90º of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsi-flexion with the knee flexed; ADF_{KE}: ankle dorsi-flexion with the knee extended.

U12: under-12; U14: under-14; U16: under-16; U19: under-19.

Likewise, the ANOVA analysis also showed statistically significant differences ($p < 0.05$; $d = 0.5$-1.17) between paired maturational groups comparisons in all the ROM measures with the exception of PHER, ADF_{KF} and ADF_{KE} (Figure 2). However, magnitude-based decisions did not find any substantial difference in ROM measures between maturation groups (likely trivial effect with a probability of 94-100%), with the exception of PKF where a possibly negative effect (with a probability of 65%; $d = 0.98$; $p < 0.05$) was shown between the pre-PHV and post-PHV groups.

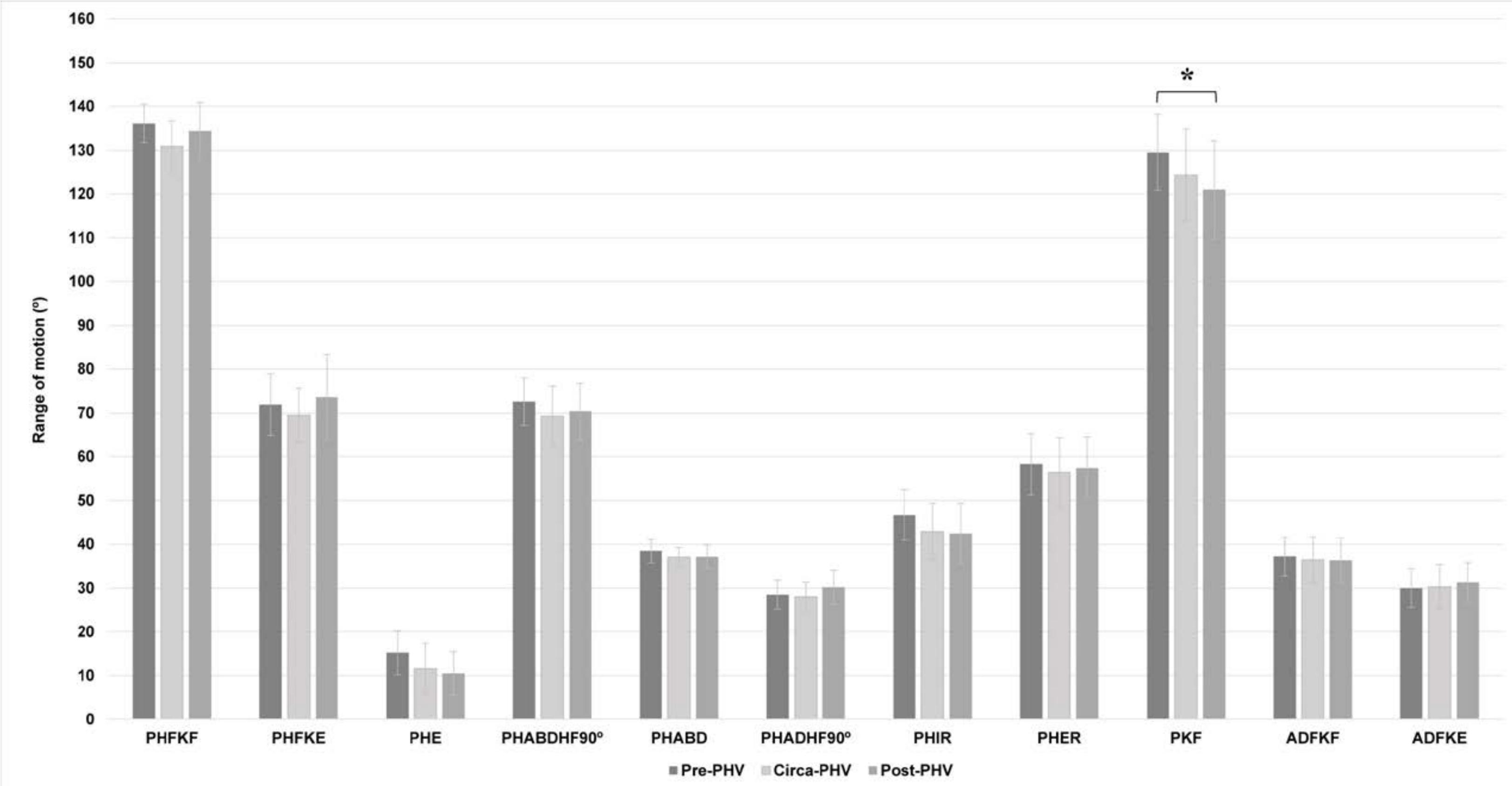

Figure 2 Maturation-related inter-group differences for lower extremity joint ranges of motion values.

*: Clinically relevant (probability of the worthwhile differences > 50%; $d > 0.4$; $p < 0.05$).

PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $PHABD_{HF90º}$: passive hip abduction at 90º of hip flexion; PHABD: passive hip abduction; $PHAD_{HF90º}$: passive hip adduction at 90º of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsi-flexion with the knee flexed; ADF_{KE}: ankle dorsi-flexion with the knee extended.

PHV: peak height velocity.

The comprehensive analysis conducted in this study found that approximately 40%, 35% and 20% of the total players displayed restrictions in their PHF_{KE}, PKF, and ADF_{KF} ROM values, respectively. This analysis also displayed an incremental number of soccer players with restricted PKF ROM values throughout chronological age and maturational stage (from 14% in the U12 and pre-PHV groups to 50% in the U19 and post-PHV groups; $\chi^2 = 28.541–30.352$; $p < 0.05$), whereas the proportion of players with restricted PHF_{KE} reached its peak in the U14 and U16 age groups ($PHF_{KE} \approx 50\%$; $\chi^2 = 10.805$; $p < 0.05$) and also in the circa-PHV group ($PHF_{KE} = 51\%$; $\chi^2 = 2.923$; $p > 0.05$).

Pearson correlation analysis did not report any significant correlation between leg length and ROM measures (all *r* values < 0.37) for both chronological age and maturational groups.

DISCUSSION

The main findings of the present study indicated that only PKF ROM was clearly and equally influenced by the course of chronological age and maturational stage in this cohort of male young soccer players. A gradual and continuous decrease in the PKF ROM score was found across the chronological ages (Figure 1) and maturational stages (Figure 2). However, only the magnitude of the observed changes in the PKF ROM between the groups situated in the opposite extremes of both grouping categories may be considered as clinically relevant. Soccer players in the U12 (129.6º) and pre-PHV (129.5º) groups reported clinically relevant (p < 0.05 [statistically significant], d > 0.8 [large effect size] and very likely substantial [>8º]) higher PKF ROM values than their peers in the U19 (121.4º) and post-PHV (121º) groups, respectively. These findings are in agreement with the previous results reported by Cejudo et al. (7), who also found that U12 soccer players showed substantially higher PKF ROM values than U19 soccer players (133.8º [U12] vs. 120.4º [U19]).

This progressive decrease in the PKF ROM values of players with advancing age and stage of maturation may be partially explained by the impact that the systematic practice of soccer might have on the development of body posture. For example, rapid changes in spinal curvature and the sudden increase in the length of extremities experienced by adolescents during the growth spurt are not always followed by a similar onset and rate of strength development of the muscles involved in postural control adjustment (e.g., abdominal external and internal obliques, erector spinae, quadratus lumborum, rectus abdominis). This temporary circumstance may place adolescents in a vulnerable situation to develop body posture disorders caused, among other, by misalignments of the spinal curvatures in the sagittal plane (9). In order to generate maximal power during the repeated high intensity movements required in soccer, players often adopt postures (mainly in flexion) that require strong and coordinated contractions of the trunk extensor and flexor muscles to keep balance and energy transfer to the distal segments (24). Therefore, as a measure to improve soccer-related motor skills (among others), in their daily soccer trainings, players often perform exercises designed to improve the strength and endurance of the major trunk muscles (e.g., planks, prone “Supermans”, traditional abdominal crunches). However, these strength and endurance training programs are not usually well-balanced (from the authors’ extensive applied experience in youth soccer settings), whereby the number and repetitions of the exercises included to improve the strength and resistance of the trunk flexor muscles are higher than their antagonist trunk extensors. It is plausible that these training programs may generate muscle imbalances between trunk flexors and extensors that might altered the postures adopted by the players during the execution of the movements inherent to soccer play and this repeated over time may lead to the development of soccer-specific adaptations in players spinal morphotypes. In support of this assumption, Wodecky et al. (49) found significant increases in the anterior pelvic tilt angle of young adult soccer players, in contrast with their age-matched sedentary counterparts. Therefore, it is possible that the young soccer players of the present study had also started to develop an increased angle of anterior pelvic tilt. This circumstance may generate a hyper lordotic morphotype that places the quadriceps musculature in a relative shortened position that may result in gradual and continuous restrictions on PKF ROM, which may become clinically relevant in older and more mature players (9).

It should be highlighted that, although less evident, there seems to be a slow and gradual decrease in PHE and PHIR ROMs as the chronological age (Figure 1) and maturational stage (Figure 2) increase. However, and unlike that found for PKF ROM, the magnitude of the observed changes between the groups that demonstrated the highest and lowest PHE and PHIR average ROM values were not large enough (approximately 5º) to be considered clinically relevant (but they were close to the previously established cut-off scores of 8º). A similar decrease (but higher in magnitude and slope) over the adolescent years in PHIR ROM was also found in previous studies conducted in young soccer players and in contrast with their age-matched non-athlete counterparts (10,32,45).

The qualitative interpretation (normal vs. restricted) of the average PHE, PHIR and PKF ROM values demonstrated in this cohort of young soccer players reports that these three ROM measures may be classified as normal or non-restricted (independently of the chronological age and maturational stage) according to the cut-off scores previously established by the scientific literature (PHE > 0º, PHIR > 30º, and PKF > 120º) (37,48,50). Similar results were found by Cejudo et al. (7) and López-Valenciano et al. (29), who after having carried out the same ROM maneuvers and testing procedures (ROM-Sport protocol) found average PHE, PHIR and PKF ROM values that may be categorized as normal in a cohort of young (independent of the chronological age of the participants assessed) and professional male soccer players, respectively. However, these findings were different to those reported by Scaramussa et al. (45) in also young soccer players and for the average PHIR ROM. Scaramussa et al. (45) found average PHIR ROM values that may be categorized as restricted (<30º) in all chronological ages they assessed (from 9 to 18 years). Perhaps, this discrepancy may be attributed to the different testing position chosen by Scaramussa et al. (45) to assess the PHIR ROM (lying supine with hip and knee actively flexed to 90º) which could require a more restrictive cut-off score to identify soccer players with limited PHIR ROM than the <30º cut-off score used in the current study and that was previously defined for a testing position in which participants were laying prone with hip neutral and knee flexed to 90º (48). Thus, the previously reported decrease between maturational stage in the PHE, PHIR and PKF ROMs of our youth soccer players might be considered as musculoskeletal adaptations generated as a consequence of the increase in single sport specialized soccer training play experience and the enhance of the soccer-specific physical and technical skills (e.g., kicking the ball and cutting) without any apparent negative repercussion on the likelihood of sustaining an injury. Similarly, the rest of the ROM measures also reported average scores that could be classified as normal or non-restricted according to their respective cut-off scores previously defined. Therefore, this traditional profiling approach could lead to the conclusion that there is no need to deliver measures aimed at improving lower extremity joints ROMs in young soccer players.

However, when a novel and more comprehensive analysis is carried out (in which the inter-players variability in the lower extremity ROM profile is considered) the current data indicates that an incremental number of the soccer players demonstrated restricted PKF ROM values (cut-off score <120º) throughout chronological age and maturational stage. Our data indicate that in the early adolescent years (12 years) and before the period of maximal rate of growth (pre-PHV) the percentage of soccer players with restricted PKF ROM values was approximately 14%. However, there is a marked increase with both chronological age and maturational status with 50% in the players in the U19 and post-PHV groups demonstrating restricted PKF ROM. As it has been stated before, the possible effects of soccer play on players' posture may partially justify this increased in the number of players that displayed restricted PKF ROM values with advancing age and maturational stage. Contrarily, the proportion rates of players showing restricted PHE (cut-off score < 0º) and PHIR (cut-off score < 30º) ROM values were minimal (not exceeding the 6% and 2%, respectively) for each chronological age and maturational stage group.

This comprehensive approach used for describing lower extremity ROM profile also reported a reasonably large proportion of young soccer players with restricted PHF_{KE} (cut-off score < 70º) (26) and ADF_{KF} (cut-off score < 34º) (39) ROM values in all chronological age and maturational stage groups. The proportion of players with restricted PHF_{KE} and ADF_{KF} ROMs reached its peak in the circa-PHV group (PHF_{KE} = 51%; ADF_{KF} = 28%). This latter circumstance might be explained by the demands of soccer training and match play, which are abruptly increased in the 14-16U categories, which corresponds with PHV in most soccer academies (sport specialization). The majority of the movements inherent to soccer play impose strong concentric but mainly eccentric loads on the hip and ankle dorsi-flexion muscles at shortened contracted positions (36). When these actions are repeated several times during training sessions and games, they have the potential to generate muscle damage and micro-trauma. The increase in the weekly training frequency (from 2-3 days to 3-4 days per week) and match congestion that often are experienced by the U14 and U16 players along with the absence of proper recovery and protective measures might induce impairments in the mechanical and neural properties of the posterior kinetic chain muscle-tendon units, including a reduction in the normal PHF_{KE}, and ADF_{KF} ROMs (16).

It would appear that the growth spurt that is experienced by adolescents around PHV manifests itself in restricted ROM in the hip, knee and ankle flexion in the sagittal plane, and this restriction may be exaggerated by the course of chronological age and/or single sport specialization of soccer (38). This restrictive profile of lower extremity flexion movements in the sagittal plane may be an age- and maturity-related injury risk factor and may partly explain the high incidence of low back pain, and knee and ankle ligament injuries observed during the stage of PHV (41). Due to the adverse consequences that the back, knee (mainly) and ankle ligament injuries usually have in the physical and emotional well-being of the adolescent athletes, those soccer players around or just after PHV should be targeted for screening and prevention strategies. Thus, the trauma associated with an ACL injury contributes to significant pain, depression, decreased athletic identity and lower academic performance (1), in addition to the potential ending of an athletic career, greatly amplified risk of a subsequent ACL injury, likelihood for long term disability and risk of early osteoarthritis and chronic pain (28). Consequently, the findings reported by this more realistic profiling approach suggest that the application of specific preventive measures aimed at improving hip, knee and ankle flexion ROMs (i.e., stretching programs, well-balance muscle strength and endurance training programs) in the year before, but mainly during PHV, seems to be essential in young soccer players.

Despite having been considered as an asymmetrical sport (35), the results of the current study also found non-clinically relevant bilateral differences (>8°) between the dominant and non-dominant lower extremity joints ROM average values in this cohort of soccer players (independent of chronological age and maturational stage). In addition, by calculating the number of players with bilateral differences greater than 8° in any hip, knee and ankle ROM measure, a very low percentage (≤ 9%) of players were identified as having bilateral asymmetries. These results are in conflict with the findings reported by López-Valenciano et al. (29) in professional male soccer players, who found that approximately 30% of the players could be identified as having bilateral asymmetries (>6º) for $PHABD_{HF90}$, PHIR and PHER. An explanation for this discrepancy may be associated with the differences that exist between both cohorts of soccer players (young vs. professional players) regarding, among others, weekly training load (3 sessions [young players] vs. 6-8 sessions [professional players]), number of matches per week and year (28-32 matches per year at the weekends [young players] vs. 40-60 matches per year with periods of two matches per week [professional players]), training age and the physical demands associated with soccer. Potentially congested training and competitive calendars, alongside the very high physical demands inherent in current professional soccer may result in a suboptimal recovery and an overexposure of the players to perform a substantive number of asymmetrical and repeated technical movements inherent to soccer that may lead them to develop bilateral ROM asymmetries in favor of the dominant leg. Other hypotheses for this discrepancy may be based on fact that player's roles vary more greatly in youth soccer which may in part help to preserve symmetrical between-joints ROM distribution. Finally, the slightly less restrictive cut-off score (>6º) used by López-Valenciano et al. (29) to identify professional soccer players with bilateral asymmetries in comparison with our cut-off score (>8º) may also play a role (but probably to a less extent than other hypotheses) in explaining this discrepancy.

Finally, some limitations to this study should be acknowledged. The age at PHV has been calculated using an equation based on the participants' leg length, sitting height, age, height and weight, which may not be as accurate as using skeletal imaging; however, to minimize the group allocation error derived from the equation, players with a maturational offset between -1 to -0.5 and 0.5 to 1 were removed from the data set. This decision subsequently led to a smaller sample size in the circa-PHV group in comparison with the other groups. Nonetheless, the large total sample size attempted to mitigate differences in group sample size distribution.

PRACTICAL APPLICATIONS

Given the large percentage of total number of players with restricted $PHF_{KE,}$ (≈40%) PKF (≈35%) and ADF_{KF} (≈20%) ROM scores, the findings of the present study emphasize the necessity of prescribing compensatory measures (e.g., stretching exercises, well-balanced muscle strength and resistance training programs) with the aim of improving ROM values in the daily soccer training practices of youth players. As we found no age- and maturation-related differences (> 8º) in almost all ROM assessed we would recommend that stretching is included across all periods of growth and maturation, as early single sport specialization appears to contribute to restricted ROM. Likewise, as no bilateral differences between dominant and non-dominant legs were found, it is recommended that these routines should be equally applied to both limbs.

DISCLOSURE STATEMENT

The authors report no conflict of interest.

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Appendix 1. Descriptive values and decision about side-to-side difference for the lower extremity joint ranges of motion by players' age-group (N = 286).

Ranges of motion (º)	Dominant leg		Non-dominant leg		Standardised difference[T]	Qualitative outcome[a]
	Mean ± SD	Qualitative outcome[a]	Mean ± SD	Qualitative outcome[a]		
U12 (n = 76)						
PHF_{KF}	136.3 ± 5.7	Normal (0)	136.3 ± 5.0	Normal (0)	-0.01 ± 0.25	Trivial (0/100/0)
PHF_{KE}	71.8 ± 7.9	Normal (32)	71.2 ± 7.3	Normal (36)	-0.09 ± 0.23	Trivial (0/100/0)
PHE	15.5 ± 5.1	Normal (0)	15.8 ± 4.5	Normal (0)	0.06 ± 0.23	Trivial (0/100/0)
$PHABD_{HF90º}$	72.9 ± 5.6	Normal (0)	73.1 ± 5.3	Normal (0)	0.03 ± 0.23	Trivial (0/100/0)
PHABD	38.7 ± 3.1	Normal (0)	38.5 ± 3.8	Normal (0)	-0.08 ± 0.25	Trivial (0/100/0)
$PHAD_{HF90º}$	28.6 ± 4.1	Normal (17)	29.0 ± 4.0	Normal (14)	0.11 ± 0.25	Trivial (0/100/0)
PHIR	46.8 ± 6.6	Normal (0)	47.2 ± 6.5	Normal (0)	0.06 ± 0.25	Trivial (0/100/0)
PHER	59.1 ± 7.4	Normal (0)	58.2 ± 6.9	Normal (0)	-0.12 ± 0.25	Trivial (0/100/0)
PKF	129.4 ± 9.2	Normal (13)	129.8 ± 9.1	Normal (13)	0.03 ± 0.23	Trivial (0/100/0)
ADF_{KF}	37.0 ± 5.4	Normal (17)	36.4 ± 4.6	Normal (20)	-0.12 ± 0.25	Trivial (0/100/0)
ADF_{KE}	29.9 ± 5.0	Normal (0)	30.0 ± 4.7	Normal (0)	0.01 ± 0.23	Trivial (0/100/0)
U14 (n = 79)						
PHF_{KF}	133.2 ± 5.6	Normal (0)	132.2 ± 6.0	Normal (0)	-0.18 ± 0.23	Trivial (0/100/0)
PHF_{KE}	69.5 ± 6.9	Restricted (57)	69.1 ± 6.6	Restricted (54)	-0.05 ± 0.22	Trivial (0/100/0)
PHE	12.5 ± 6.1	Normal (1)	13.2 ± 6.0	Normal (3)	0.12 ± 0.22	Trivial (0/100/0)
$PHABD_{HF90º}$	71.3 ± 6.1	Normal (0)	70.8 ± 5.8	Normal (0)	-0.09 ± 0.22	Trivial (0/100/0)
PHABD	37.5 ± 3.0	Normal (0)	37.0 ± 2.3	Normal (0)	-0.19 ± 0.23	Trivial (0/100/0)
$PHAD_{HF90º}$	27.5 ± 3.6	Normal (27)	27.9 ± 3.6	Normal (14)	0.11 ± 0.23	Trivial (0/100/0)
PHIR	44.1 ± 6.4	Normal (0)	43.8 ± 6.5	Normal (1)	-0.05 ± 0.23	Trivial (0/100/0)
PHER	56.6 ± 7.1	Normal (0)	57.0 ± 8.0	Normal (0)	0.06 ± 0.23	Trivial (0/100/0)

PKF	126.9 ± 9.4	Normal (16)	126.5 ± 9.1	Normal (22)	-0.04 ± 0.22	Trivial (0/100/0)
ADF_{KF}	37.2 ± 4.1	Normal (10)	37.2 ± 4.7	Normal (20)	0.01 ± 0.23	Trivial (0/100/0)
ADF_{KE}	29.5 ± 4.1	Normal (0)	29.4 ± 4.2	Normal (0)	-0.01 ± 0.22	Trivial (0/100/0)
			U16 (n = 68)			
PHF_{KF}	133.6 ± 6.7	Normal (0)	131.8 ± 6.9	Normal (0)	-0.26 ± 0.29	Trivial (0/100/0)
PHF_{KE}	70.2 ± 9.0	Normal (47)	70.3 ± 9.2	Normal (44)	0.01 ± 0.24	Trivial (0/100/0)
PHE	10.0 ± 5.0	Normal (1)	10.7 ± 4.6	Normal (0)	0.13 ± 0.24	Trivial (0/100/0)
$PHABD_{HF90^o}$	70.0 ± 7.7	Normal (0)	68.9 ± 6.8	Normal (0)	-0.14 ± 0.24	Trivial (0/100/0)
PHABD	37.0 ± 4.0	Normal (0)	36.9 ± 3.5	Normal (0)	-0.03 ± 0.29	Trivial (0/100/0)
$PHAD_{HF90^o}$	28.0 ± 3.8	Normal (18)	28.3 ± 3.1	Normal (13)	0.10 ± 0.29	Trivial (0/100/0)
PHIR	43.4 ± 6.6	Normal (3)	42.2 ± 7.1	Normal (1)	-0.17 ± 0.29	Trivial (0/100/0)
PHER	58.6 ± 9.7	Normal (0)	59.1 ± 9.5	Normal (0)	0.05 ± 0.29	Trivial (0/100/0)
PKF	123.1 ± 12.0	Normal (40)	123.0 ± 11.0	Normal (38)	-0.01 ± 0.24	Trivial (0/100/0)
ADF_{KF}	36.4 ± 5.4	Normal (19)	36.8 ± 5.6	Normal (18)	0.07 ± 0.29	Trivial (0/100/0)
ADF_{KE}	30.4 ± 5.1	Normal (0)	30.1 ± 4.7	Normal (0)	-0.06 ± 0.24	Trivial (0/100/0)
			U19 (n = 63)			
PHF_{KF}	135.9 ± 7.2	Normal (0)	134.9 ± 7.0	Normal (0)	-0.13 ± 0.28	Trivial (0/100/0)
PHF_{KE}	74.9 ± 9.5	Normal (30)	74.8 ± 9.7	Normal (30)	-0.01 ± 0.25	Trivial (0/100/0)
PHE	10.3 ± 5.3	Normal (2)	11.1 ± 5.7	Normal (5)	0.14 ± 0.25	Trivial (0/100/0)
$PHABD_{HF90^o}$	71.0 ± 6.7	Normal (0)	69.9 ± 6.9	Normal (2)	-0.16 ± 0.25	Trivial (0/100/0)
PHABD	37.6 ± 2.9	Normal (0)	37.0 ± 2.6	Normal (0)	-0.20 ± 0.28	Trivial (0/100/0)
$PHAD_{HF90^o}$	31.1 ± 4.2	Normal (11)	32.0 ± 4.2	Normal (5)	0.22 ± 0.28	Trivial (0/100/0)
PHIR	42.3 ± 7.2	Normal (2)	42.9 ± 7.2	Normal (0)	0.08 ± 0.28	Trivial (0/100/0)
PHER	57.8 ± 6.5	Normal (0)	56.5 ± 5.5	Normal (0)	-0.18 ± 0.28	Trivial (0/100/0)
PKF	121.3 ± 11.4	Normal (51)	121.6 ± 11.9	Normal (49)	0.03 ± 0.25	Trivial (0/100/0)
ADF_{KF}	36.7 ± 5.2	Normal (22)	36.4 ± 5.5	Normal (27)	-0.05 ± 0.28	Trivial (0/100/0)
ADF_{KE}	32.6 ± 5.0	Normal (0)	31.5 ± 5.3	Normal (0)	-0.22 ± 0.25	Trivial (0/100/0)

°: degrees.

[a]: Qualitative score of the mean range of motion, in parentheses the percentage of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section). T: mean ± 90% confidence limits; + or - indicates an increase or decrease from dominant limb to non-dominant limb.

PHF$_{KF}$: passive hip flexion with the knee flexed; PHF$_{KE}$: passive hip flexion with the knee extended; PHE: passive hip extension; PHABD$_{HF90°}$: passive hip abduction at 90° of hip flexion; PHABD: passive hip abduction; PHAD$_{HF90°}$: passive hip adduction at 90° of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF$_{KF}$: ankle dorsi-flexion with the knee flexed; ADF$_{KE}$: ankle dorsi-flexion with the knee extended.

Legend:

°: degrees.

[a]: Qualitative score of the mean range of motion, in parentheses the percentage of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section). T: mean ± 90% confidence limits; + or - indicates an increase or decrease from dominant limb to non-dominant limb.

PHF$_{KF}$: passive hip flexion with the knee flexed; PHF$_{KE}$: passive hip flexion with the knee extended; PHE: passive hip extension; PHABD$_{HF90°}$: passive hip abduction at 90° of hip flexion; PHABD: passive hip abduction; PHAD$_{HF90°}$: passive hip adduction at 90° of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF$_{KF}$: ankle dorsi-flexion with the knee flexed; ADF$_{KE}$: ankle dorsi-flexion with the knee extended.

Appendix 2. Descriptive values and decision about side-to-side difference for the lower extremity joint ranges of motion by players' maturation-group (N = 237).

Ranges of motion (º)	Dominant leg		Non-dominant leg		Standardised difference[T]	Qualitative outcome[a]
	Mean ± SD	Qualitative outcome[a]	Mean ± SD	Qualitative outcome[a]		
			Pre-PHV (n = 101)			
PHF_{KF}	136.1 ± 5.4	Normal (0)	136.0 ± 4.8	Normal (0)	-0.02 ± 0.21	Trivial (0/100/0)
PHF_{KE}	72.2 ± 7.7	Normal (33)	71.6 ± 7.1	Normal (34)	-0.07 ± 0.20	Trivial (0/100/0)
PHE	15.1 ± 5.6	Normal (1)	15.3 ± 5.1	Normal (2)	0.04 ± 0.20	Trivial (0/100/0)
$PHABD_{HF90º}$	72.7 ± 6.0	Normal (0)	72.6 ± 5.9	Normal (0)	-0.01 ± 0.20	Trivial (0/100/0)
PHABD	38.6 ± 3.0	Normal (0)	38.3 ± 3.5	Normal (0)	-0.10 ± 0.21	Trivial (0/100/0)
$PHAD_{HF90º}$	28.3 ± 4.0	Normal (21)	28.8 ± 3.8	Normal (12)	0.11 ± 0.21	Trivial (0/100/0)
PHIR	46.4 ± 6.1	Normal (0)	46.9 ± 6.2	Normal (0)	0.09 ± 0.21	Trivial (0/100/0)
PHER	58.7 ± 7.5	Normal (0)	57.9 ± 7.2	Normal (0)	-0.10 ± 0.21	Trivial (0/100/0)
PKF	129.5 ± 8.9	Normal (12)	129.5 ± 9.0	Normal (14)	0.00 ± 0.20	Trivial (0/100/0)
ADF_{KF}	37.4 ± 5.0	Normal (14)	36.9 ± 4.4	Normal (16)	-0.10 ± 0.21	Trivial (0/100/0)
ADF_{KE}	30.1 ± 4.9	Normal (0)	30.0 ± 4.6	Normal (0)	0.00 ± 0.20	Trivial (0/100/0)
			Circa-PHV (n = 43)			
PHF_{KF}	131.5 ± 5.9	Normal (0)	130.2 ± 6.6	Normal (0)	-0.22 ± 0.35	Trivial (0/100/0)
PHF_{KE}	69.8 ± 6.2	Restricted (49)	69.1 ± 6.4	Restricted (51)	-0.11 ± 0.31	Trivial (0/100/0)
PHE	11.2 ± 6.0	Normal (2)	12.0 ± 6.0	Normal (0)	0.12 ± 0.31	Trivial (0/100/0)
$PHABD_{HF90º}$	69.6 ± 7.8	Normal (0)	68.9 ± 6.5	Normal (0)	-0.09 ± 0.31	Trivial (0/100/0)
PHABD	37.5 ± 2.9	Normal (0)	36.6 ± 2.1	Normal (0)	-0.30 ± 0.35	Trivial (0/100/0)
$PHAD_{HF90º}$	27.9 ± 3.9	Normal (19)	28.1 ± 4.0	Normal (19)	0.04 ± 0.35	Trivial (0/100/0)
PHIR	43.2 ± 6.4	Normal (0)	42.5 ± 7.3	Normal (2)	-0.10 ± 0.35	Trivial (0/100/0)
PHER	56.6 ± 8.5	Normal (0)	56.2 ± 8.5	Normal (0)	-0.05 ± 0.35	Trivial (0/100/0)
PKF	124.4 ± 11.1	Normal (28)	124.4 ± 10.2	Normal (28)	0.00 ± 0.31	Trivial (0/100/0)
ADF_{KF}	36.5 ± 5.3	Normal (19)	36.2 ± 5.8	Normal (30)	-0.05 ± 0.35	Trivial (0/100/0)

ADF_{KE}	30.7 ± 5.2	Normal (0)	30.0 ± 5.0	Normal (0)	-0.12 ± 0.31	Trivial (0/100/0)
Post-PHV (n = 93)						
PHF_{KF}	134.7 ± 7.0	Normal (0)	134.0 ± 6.7	Normal (0)	-0.10 ± 0.22	Trivial (0/100/0)
PHF_{KE}	73.6 ± 9.8	Normal (37)	73.6 ± 10.2	Normal (35)	0.00 ± 0.21	Trivial (0/100/0)
PHE	10.2 ± 5.1	Normal (1)	11.1 ± 5.4	Normal (3)	0.16 ± 0.21	Trivial (0/100/0)
$PHABD_{HF90^o}$	71.0 ± 6.9	Normal (0)	69.8 ± 6.5	Normal (1)	-0.18 ± 0.21	Trivial (0/100/0)
PHABD	37.4 ± 3.4	Normal (0)	36.8 ± 2.8	Normal (0)	-0.15 ± 0.22	Trivial (0/100/0)
$PHAD_{HF90^o}$	29.8 ± 4.3	Normal (15)	30.7 ± 4.0	Normal (9)	0.21 ± 0.22	Trivial (0/100/0)
PHIR	42.5 ± 7.0	Normal (2)	42.4 ± 7.3	Normal (1)	-0.01 ± 0.22	Trivial (0/100/0)
PHER	57.6 ± 7.8	Normal (0)	57.3 ± 7.3	Normal (0)	-0.04 ± 0.22	Trivial (0/100/0)
PKF	120.9 ± 11.5	Normal (52)	121.1 ± 11.3	Normal (49)	0.02 ± 0.21	Trivial (0/100/0)
ADF_{KF}	36.4 ± 5.1	Normal (23)	36.3 ± 5.5	Normal (26)	-0.04 ± 0.22	Trivial (0/100/0)
ADF_{KE}	31.6 ± 4.8	Normal (0)	30.9 ± 4.8	Normal (0)	-0.14 ± 0.21	Trivial (0/100/0)

^{o}: degrees.

[a]: Qualitative score of the mean range of motion, in parentheses the percentage of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section). T: mean ± 90% confidence limits; + or - indicates an increase or decrease from dominant limb to non-dominant limb.

PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $PHABD_{HF90^o}$: passive hip abduction at 90º of hip flexion; PHABD: passive hip abduction; $PHAD_{HF90^o}$: passive hip adduction at 90º of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsi-flexion with the knee flexed; ADF_{KE}: ankle dorsi-flexion with the knee extended.

Legend:

^{o}: degrees.

[a]: Qualitative score of the mean range of motion, in parentheses the percentage of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section). T: mean ± 90% confidence limits; + or - indicates an increase or decrease from dominant limb to non-dominant limb.

PHF_{KF}: passive hip flexion with the knee flexed; PHF_{KE}: passive hip flexion with the knee extended; PHE: passive hip extension; $PHABD_{HF90º}$: passive hip abduction at 90º of hip flexion; PHABD: passive hip abduction; $PHAD_{HF90º}$: passive hip adduction at 90º of hip flexion; PHIR: passive hip internal rotation; PHER: passive hip external rotation; PKF: passive knee flexion; ADF_{KF}: ankle dorsi-flexion with the knee flexed; ADF_{KE}: ankle dorsi-flexion with the knee extended.