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RESEARCH

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Knee muscle strength, body composition, and balance performance of youth soccer players

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Abstract

Background Muscle strength and balance abilities have been related to game performance injury prevention. This study aimed to (1) assess knee muscle strength performance based on intra- and inter-limb asymmetries, (2) investigate the relationships between knee muscle strength, body composition, and balance, and (3) analyze the variance in the overall stability index (OSI) explained by knee muscle strength indicators after controlling for age and body composition.

Methods The sample included 104 young male soccer players (16.0 ± 1.6 years). Body composition, knee muscle strength, and balance ability were assessed. A paired samples t-test was used to examine differences between the preferred leg (PL) and the non-preferred leg (NPL). Pearson correlations and hierarchical multiple regression were conducted to explore the relationships between strength, body composition, and balance.

Results No significant inter-limb asymmetries were detected for the knee flexors (KF) and knee extensors (KE) performance. The hamstrings-to-quadriceps ratio does not suggest the existence of intra-limb asymmetries ($p=0.06$). Significant and negative correlations were found between KF ($r=-0.38$, $p\leq 0.01$) and KE ($r=-0.58$, $p\leq 0.01$) for the PL. Concerning the NPL, KE also revealed a significant and negative relationship with balance ($r=-0.30$, $p\leq 0.01$). Significant and positive relationships were found between bodyweight, fat-free mass, and balance. After controlling for age and body composition, knee muscle strength could explain between 13% and 30% of the variance observed in the OSI (NPL and PL, respectively).

Conclusions The results underline knee muscle strength as an important predictor of balance. Thus, training programs targeting knee muscle strength development should be considered during the season periodization by coaches and their staff throughout the players' developmental stages.

Keywords Stability, Knee flexors, Knee extensors, Bodyweight, Fat-free mass, Football

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Introduction

In soccer, muscle strength and balance abilities have been related to injury prevention and game-action performance [1, 2]. During the match, players are often required to perform high-intensity actions (i.e., jumping, sprinting, and changes of direction), which are associated with force-time characteristics [3, 4]. Consistently, the literature has advocated that greater muscle strength is associated with decreased injury rates [2].

Muscle strength is the capacity to produce force on an external resistance [2]. Between several testing procedures, isokinetic strength assessments have emerged as safe and reliable in the sports literature. In soccer, knee muscle strength evaluation has become an important part of players' monitoring process, particularly in examining intra- and inter-limb asymmetries, which might provide valuable data concerning injury occurrence [5, 6]. The literature has described the hamstrings to quadriceps ratio (H/Q) as an indicator of intra-limb asymmetry, and lower values than 60% were previously related to injury, such as hamstring strain and anterior ligament injuries [7]. On the other hand, the bilateral strength deficit represents inter-limb asymmetry, with scores over 15% being concerning for injury occurrence [7]. In soccer, several investigations have been conducted on intra- and inter-limb asymmetries, particularly targeting elite players [6, 8], and data is still scarce in youth soccer.

On the other hand, soccer involves executing several movements while maintaining balance on one foot (i.e., kicking, dribbling, passing), demanding players' postural control [9]. In youth sports, previous research has described the positive effects of balance training programs on other physical fitness measures, such as sprinting and jumping, as well as on sport-specific skills [10, 11]. Indeed, in a previous investigation on physical fitness parameters in soccer players from different competitive levels, elite players had better balance ability than their non-elite counterparts [12].

Besides its influence on sports performance, muscle strength and balance are crucial injuries-related attributes. In fact, most of the injury prevention and rehabilitation programs are supported by strength and balance exercises [13, 14]. When examining relationships between strength and balance performance, the literature has suggested transfer effects from balance to strength training and vice-versa [15]. Research on adult male soccer players indicated that muscle strength levels may benefit postural control [16, 17]. The same trend has been reported in youth soccer. In a sample of 88 male youth soccer players aged 15.9 ± 1.6 years, knee muscle strength (expressed by the PT of KE and KF) was able to explain between 18% and 22% of the variance observed in balance measures [18]. In another study, muscle strength and power measures, assessed using jumping tasks, showed medium to large correlations with balance measures [15]. The authors have emphasized that youth players with improved balance should perform better on strength and power tests [15].

Meantime, body composition variables, such as bodyweight and body fat percentage (BF%), have been associated with strength testing scores. In a sample of 161 male youth soccer players, bodyweight presented small to large positive correlations with vertical jumps and handgrip strength, respectively, while the opposite relationship was seen regarding BF% [19]. Concerning knee muscle strength, body mass, and BF% were significantly and positively correlated to knee flexors and knee extensors performance (peak torque values) in male adult hockey players [20] and male youth weightlifters [21]. In youth soccer, only one study was found on the relationship between knee muscle strength, assessed through the isokinetic dynamometer and balance measures [18]. The results indicate that knee muscle strength has a positive contribution to balance outputs, with knee flexors and knee extensors explaining between 18 and 22% of the variance observed in the balance scores for the preferred leg and the non-preferred leg, respectively [18]. However, data on the influence of body composition variables is still scarce among youth soccer population. In a previous study among adolescent male soccer players, BF% was negatively associated to balance performance [22], while lower balance ability was related to increased bodyweight and lower FFM in non-athlete populations [23, 24].

Although evidence is available on the positive correlation between knee muscle strength and balance in soccer, the literature has mostly focused on elite players [16, 17]. Moreover, the possible effects of body composition variables on this relationship have been disregarded, which might bring crucial insights for the training process. Enhancing knowledge during the stages of players' development is of great interest to support future success. Thus, the aims of the present study were: (1) to assess knee muscle strength performance based on intra- and inter-limb asymmetries, (2) to investigate the relationships between knee muscle strength, body composition, and balance, and (3) to analyze the variance in the overall stability index explained by knee muscle strength indicators after controlling for age and body composition among youth soccer players. It is first hypothesized that intra- and inter-limb asymmetries would be within the recommended values in the literature (H/Q ratio below 0.60 and bilateral strength deficit below 15%). For the second and third objectives, it is hypothesized that knee muscle strength contributes positively to balance measures, while bodyweight and FFM would also present significant relationships with balance scores.

Methods

Study design

This cross-sectional study is based on several assessments performed at the beginning of the season. All the evaluations were conducted in a physical fitness laboratory during the morning period over ten consecutive days (Fig. 1). Following the Declaration of Helsinki, the procedures were implemented and supervised by an experienced, trained staff and approved by the Faculty of Human Kinetics Ethics Committee, CEIFMH N°34/2021. The participation was voluntary, and informed consent was obtained from the players' legal guardians.

Participants

The sample comprised 104 young male soccer players aged 16.0 ± 1.6 years. All players were competing at a regional level with a training frequency varying between four and five sessions per week plus one match during the weekend. Among the participants, 28 players identified the left leg as preferred to kick the ball, while 76 presented the right leg as favored. All players belonged to the same club and had, at least, three years of soccer training experience. To participate in this study, a minimum of two years of soccer training experience was demanded and players had to attend to at least 85% of the training sessions in the last three months. Players who presented some injury in the last six months were excluded. All players were assessed for body composiyion, knee muscle strength, and balance performance (Fig. 2).

The optimal sample size was calculated using G*Power [25]. A priori paired sample t-test indicated a minimum sample size of 34 participants to achieve 80% power with an effect size of 0.50 at the 0.05 significance level. A priori analysis determines a sample of 84 participants for hierarchical multiple regression (eight predictors) with an effect size of 0.20 at the 0.05 significance level.

Body composition

Bodyweight, body fat percentage (BF%), and fat-free mass (FFM) were assessed using hand-to-foot bioelectrical impedance analysis (InBody 770, Cerritos, CA, USA). The literature has reported excellent test-retest reliability for these measures (intra-class correlation coefficient [ICC]=0.98 to 0.99 for BF% and 0.99 to 1.00 for FFM) [26]. Technical error of measurement of 4.2% for BF% and 2.4 kg for FFM was previously reported [27]. The evaluations took place early in the morning, with participants fasting. During the assessment, participants were barefoot and wearing only their underwear. Height measurements were recorded to the nearest 0.01 cm using a stadiometer (SECA 213, Hamburg, Germany),

Knee muscle strength

Knee muscle strength was evaluated using the Biodex System 4 Pro Dynamometer (Biodex, Shirley, NY, USA). The literature has reported good to excellent reliability for this testing procedures (ICC=0.87 to 0.98) [28, 29]. Technical error of measurement was reported to range between 6.6 and 10.1% [29]. The knee extensors (KE) and knee flexors (KF) of both the preferred leg (PL) and the non-preferred leg (NPL) were assessed at 60°/s. Before data collection, participants engaged in a 5-minute warm-up on a reclining bicycle (Technogym Xt Pro 600 Recline, Cesena, Italy) followed by basic stretching exercises targeting the lower-body. Following the manufacturer's guidelines, participants were seated on the dynamometer, adopting a standardized position of 85° hip flexion from the anatomical position. The

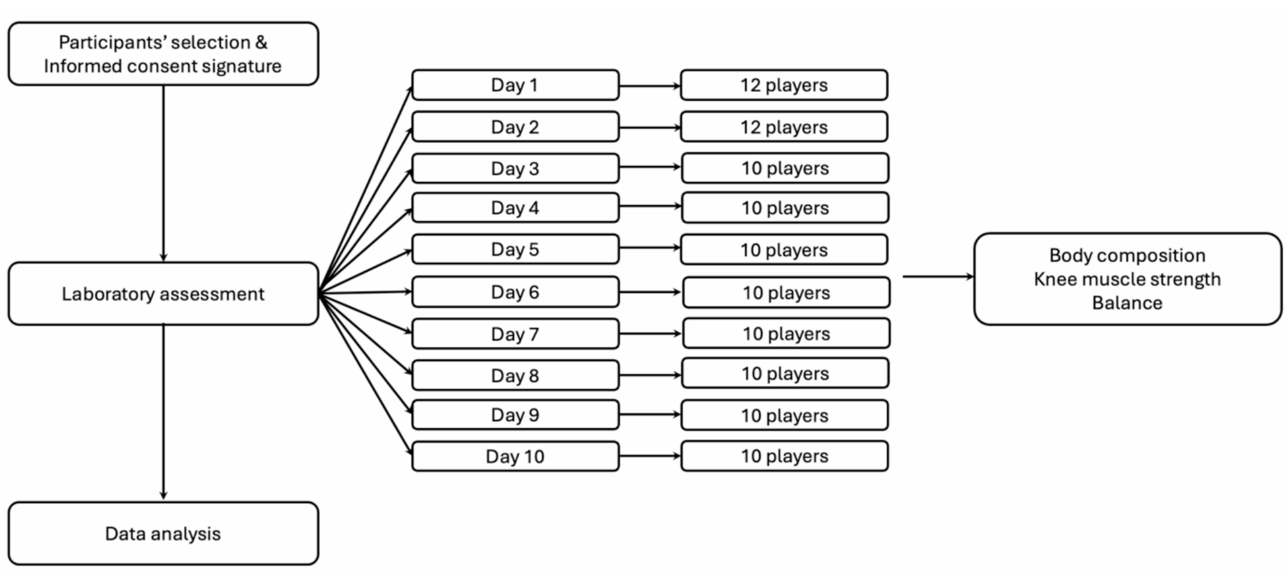

Fig. 1 Flowchart illustrating the experimental procedure

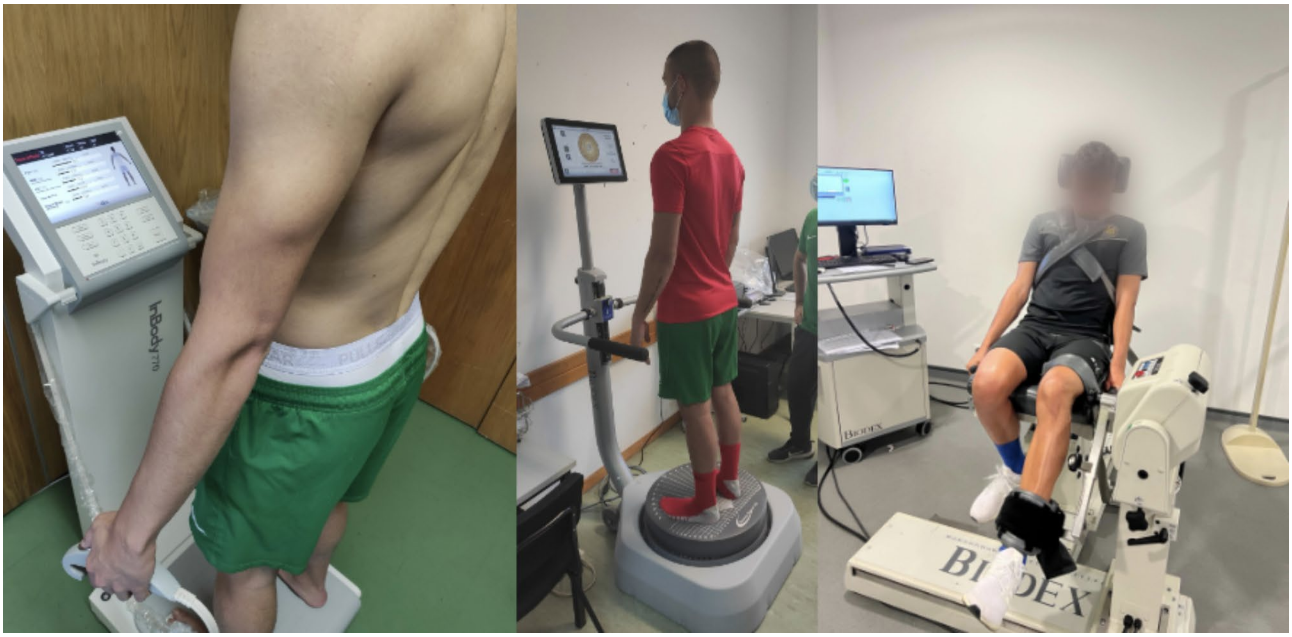

Fig. 2 Body composition, balance and knee muscle strength assessments

dynamometer's lever arm was aligned with the lateral epicondyle of the knee, and belts were used to stabilize the trunk, the evaluated thigh, and the leg. The range of motion was defined based on the individual's maximum knee extension. Then, participants were asked to bend the knee until 90° of flexion. Calibration for gravity correction was individually performed based on previous recommendations [30]. Throughout testing, one research team member provided verbal encouragement, and three trials were allowed for the protocol's familiarization [31]. For testing, participants executed five repetitions of concentric contraction efforts of knee flexion and knee extension at 60°/s with a 60-second interval after the sequence. The first round of assessments was performed with the PL, followed by the NPL with a rest interval of 3 min. For the analysis, peak torque (PT) and peak torque normalized by bodyweight (PT/BW) for KE and KF were used. Additionally, the H/Q conventional ratio was calculated by dividing the mean concentric KF PT by the mean KE concentric PT over the five repetitions [32]. Bilateral strength differences for KF and KE muscles were calculated based on the following equation [33, 34]:

$$Bilateral\ strength\ deficit = \frac{PL\ peak\ torque - NPL\ peak\ torque}{PL\ peak\ torque} \text{x } 100\ (\%)$$

Balance

Balance assessment was conducted using the Biodex Balance System (Biodex, Shirley, NY, USA). Before each testing session, the equipment was adjusted according to the participant's height. Participants underwent a training session to ensure protocol comprehension and mitigate learning effects during subsequent testing phases. A 60-second rest interval separated testing sessions. Participants performed the protocol in a unilateral stance while barefoot for bilateral comparison. The assessment included measurements of the overall index (OSI), the anteroposterior stability index (APSI), and the lateromedial stability index (LMSI). Previous research described good reliability and validity for these measures (ICC = 0.78 to 0.84, technical error of measurement = 0.08 to 0.10) [35]. Each index was evaluated at four levels of platform stability, ranging from level 4 (most stable) to level 1 (most unstable). Lower scores on these indexes indicate better balance, reflecting less deviation from the horizontal position [36].

Statistics

Descriptive statistics for body composition, knee muscle strength and balance performance are resumed as means ± standard deviation. The Kolmogorov-Smirnov test was used to check the data normality. Paired-sample t-tests were conducted to evaluate differences between PL and NPL performance. Effect size was interpreted using d-Cohen as follows [37]: $d < 0.2$ (small), $0.2 \le d < 0.6$ (moderate), $0.6 \le d < 1.2$ (large), $1.2 \le d < 2.0$ (very large). The relationships between lower-body explosive strength, knee muscle strength, and body composition were explored using the Pearson product-moment correlation coefficient. The strength of correlation was interpreted as follows: $0.1 < r < 0.3$ (small), $0.3 < r < 0.5$ (medium), and $0.5 < r < 1.0$ (large). Hierarchical multiple regression analyses were performed to investigate the amount

Table 1 Descriptive statistics for age, body composition, and bilateral strength deficit

Variables	Mean (95% CI)	SD
CA (years)	16.0 (15.7 to 16.4)	1.6
Stature (cm)	173.5 (171.5 to 175.1)	8.1
Bodyweight (kg)	64.4 (62.5 to 66.3)	9.4
Body fat (%)	11.8 (10.8 to 12.9)	5.2
Fat-free mass (kg)	56.7 (55.0 to 58.4)	8.4
KF bilateral strength deficit (%)	1.17 ± 13.90	
KE bilateral strength deficit (%)	2.13 ± 11.30	

CI (confidence interval), SD (standard deviation), CA (chronological age), KF (knee flexors), KE (knee extensors)

Table 2 Descriptive statistics for balance indicators, knee muscle strength performance, and comparison results between the PL and NPL

Variables	PL	NPL	t	*p*	d
	M ± SD	M ± SD			
Balance					
OSI	2.01 ± 1.78	2.26 ± 1.86	-2.050	0.04	-0.14
APSI	1.48 ± 1.74	1.59 ± 1.72	-0.987	0.33	-0.06
LMSI	1.04 ± 0.76	1.30 ± 0.96	-2.749	0.01	-0.30
Isokinetic strength					
KF PT (N·m)	95.3 ± 23.5	93.3 ± 23.5	1.665	0.10	0.09
KF PT/BW (N·m)	1.48 ± 0.30	1.45 ± 0.28	1.288	0.20	0.10
KE PT (N·m)	160.9 ± 45.5	162.7 ± 44.2	-1.081	0.28	-0.04
KE PT/BW (N·m)	2.52 ± 0.62	2.55 ± 0.62	-1.166	0.25	-0.05
H/Q ratio	0.61 ± 0.14	0.59 ± 0.14	1.934	0.06	0.14

M ± SD (mean ± standard deviation), PL (preferred leg), NPL (non-preferred leg), OSI (overall stability index), APSI (anteroposterior stability index), LMSI (lateromedial stability index), KF (knee flexors), KE (knee extensors), PT (peak torque), PT/BW (peak torque normalized by bodyweight), H/Q (hamstrings-to-quadriceps ratio)

of variance in balance performance (using the OSI) explained by knee muscle strength indicators (entered in step 3) after controlling for CA (entered in step 1) and body composition (entered in step 2). All analyses were performed using the IBM SPSS Statistics software 29.0 (SPSS Inc., Chicago, IL, USA). The significance level was set at 5%.

Results

Table 1 resumes descriptive statistics for age, body composition, and bilateral strength deficits for KF and KE. The bilateral strength deficit ranged from 1.17 to 2.13% for KF and KE, respectively.

Table 2 summarizes the descriptive statistics and comparison results between the PL and NPL in balance and knee muscle strength performance. Significant inter-limb differences were seen in the OSI ($p=0.04$, small effect size) and LMSI ($p=0.01$, moderate effect size), with mean scores obtained with the PL being better than the NPL performance. Regarding knee muscle strength, no significant differences were seen between the PL and NPL performance both in KF and KE, as well as in H/Q ratio values ($p=0.06$).

Table 3 Correlation coefficients between balance and knee muscle strength performance according to the PL and NPL

Variable	Preferred leg			
	1.	2.	3.	4.
1. OSI	-	-0.38**	-0.58**	0.43**
2. KF PT/BW		-	0.71**	0.06
3. KE PT/ BW			-	-0.63**
4. H/Q ratio				-
	Non-preferred leg			
	1.	2.	3.	4.
1. OSI	-	-0.07	-0.30**	0.36**
2. KF PT/BW		-	0.70**	0.28**
3. KE PT/ BW			-	-0.46**
4. H/Q ratio				-

OSI (overall stability index), KF (knee flexors), KE (knee extensors), PT/BW (peak torque normalized by bodyweight), H/Q ratio (hamstrings-to-quadriceps ratio)

* $p \leq 0.05$, ** $p \leq 0.01$

Table 3 presents the correlation coefficients between balance (using OSI) and knee muscle strength indicators for each leg performance. Significant and negative correlations were observed between the OSI and KF ($r = -0.38$, $p \leq 0.01$) and KE ($r = -0.58$, $p \leq 0.01$) for the PL. Concerning the NPL performance, KE also revealed a significant and negative relationship with the OSI ($r = -0.30$, $p \leq 0.01$). Both legs analysis showed a significant and positive correlation between the OSI and the H/Q ratio ($p \leq 0.01$).

Table 4 resumes the correlation coefficients between balance, age, and body composition variables. CA presented a strong and positive relationship with OSI performance both for the PL ($r=0.42$, $p \leq 0.01$) and NPL ($r=0.35$, $p \leq 0.01$), with higher age being associated with lower balance performance. In body composition analyses, FFM revealed the strongest relationships with OSI scores both for the PL ($r=0.25$, $p \leq 0.05$) and NPL ($r=0.26$, $p \leq 0.05$), with higher FFM being related to lower balance performance.

Finally, Table 5 presents the results of the hierarchical multiple regression conducted to investigate the amount of variance in the OSI performance explained by knee muscle strength indicators, after controlling for CA and body composition. The model explained nearly 51% and 17% of the variance in the OSI scores for the PL and NPL, respectively. After controlling for CA and body composition, knee muscle strength indicators could explain almost 13% and 30% of the variance observed in the OSI performance, respectively, for the NPL and PL. However, only KF PT/BW remained a significant predictor of the model in the PL analysis.

Table 4 Correlation coefficients between balance and knee muscle strength performance according to the PL and NPL

Variable	1.	2.	3.	4.	5.	6.	7.
1. OSI (PL)	-	0.76**	0.42**	0.17	0.21*	-0.07	0.25*
2. OSI (NPL)		-	0.35**	0.12	0.29**	0.06	0.26*
3. CA			-	0.48**	0.57**	-0.21*	0.65**
4. Stature				-	0.71**	-0.30**	0.84**
5. Bodyweight					-	0.17	0.89**
6. BF%						-	-0.29**
7. FFM							-

OSI (overall stability index), PL (preferred leg), NPL (non-preferred leg), CA (chronological age), BF% (body fat percentage), FFM (fat-free mass)

* $p \leq 0.05$, ** $p \leq 0.01$

Table 5 Summary of hierarchical regression analysis with knee muscle strength predicting balance after controlling for CA and body composition

Variables	OSI (PL)			OSI (NPL)		
	Model I	Model II	Model III	Model I	Model II	Model III
	β	β	β	β	β	β
CA	0.48**	0.54**	0.48**	0.02	0.08	0.10*
Stature		-0.01	-0.01		0.01	0.01
Bodyweight		-0.26	-0.23		-0.05	-0.06
BF%		0.27	0.17		0.05	0.06
FFM		0.29	0.24		0.03	0.05
KF PT/BW			-3.66*			-0.27
KE PT/ BW			0.76			0.33
H/Q ratio			0.08			-0.01
R^2	0.19	0.21	0.52	0.00	0.04	0.17
F for change in R^2	22.775**	0.536	17.700**	0.342	0.869	4.471**

Model I: CA; Model II: CA, stature, bodyweight, BF%, FFM; Model III: CA, stature, bodyweight, BF%, FFM, KF PT/BW, KE PT/ BW, H/Q ratio

OSI (overall stability index), PL (preferred leg), NPL (non-preferred leg), CA (chronological age), BF% (body fat percentage), FFM (fat-free mass), KF (knee flexors), KE (knee extensors), PT/BW (peak torque normalized by bodyweight), H/Q ratio (hamstrings-to-quadriceps ratio)

Discussion

The present study explored knee muscle strength performance based on intra- and inter-limb asymmetries among youth male soccer players. Moreover, the relationships between body composition and balance ability were investigated to complement past research on this topic [22]. The results indicate the absence of significant inter-limb asymmetries or bilateral strength deficits in knee muscle strength. Simultaneously, the values of the H/Q ratio do not suggest the existence of intra-limb asymmetries. Regarding balance, the OSI and LMSI values were significantly better in the PL performance. The analysis of the relationships between knee muscle strength, body composition, and balance suggests a significant and positive influence of KE and FFM on balance scores, both in the PL and NPL performance. On the other hand, bodyweight and FFM showed a significant and positive correlation with balance ability.

In soccer, players may exhibit uneven development between their PL and NPL, resulting from specific technical actions that could cause functional asymmetries. According to the literature in soccer, the quadriceps and the hamstrings are the most affected by injury [38, 39]. Therefore, coaches and their staff have widely adopted the assessment and monitoring of knee muscle strength to identify players at injury risk. The current study observed no significant inter-limb asymmetries or bilateral strength deficits in the KF and KE performances. The literature has reported inter-limb asymmetries differences of at least 15% [7] and bilateral strength deficits of at least 10% [40] as problematic for non-contact injuries. The analysis of PT values indicated similar scores between the PL and NPL performance both for KF and KE, which is consistent with previous investigations in young soccer players [18], while the bilateral strength deficit ranged from 1.17 to 2.13% for KF and KE, respectively. These results underline the conclusions of a recent literature review on the asymmetries topic in youth soccer, which reported that soccer does not generate significant strength asymmetries during players' development stages [41].

It is worth noting that a statistically significant difference was seen in the H/Q ratio, favoring the PL performance. A higher H/Q ratio of the PL compared to the NPL has been observed in past studies among youth male soccer players in similar testing conditions to the ones used in the present study [42, 43]. Among youngsters aged 15.7 ± 0.8 years, the H/Q ratio ranged from

0.61 to 0.63 for the NPL and NPL, respectively [43]. In another study conducted with 41 U16 national team soccer players, values of the H/Q ratio varied between 0.56 and 0.59 for the NPL and NPL, respectively [42]. This trend might be justified by the dominance of the PL in the performance of more varied actions and based on the fact that several movements performed by the PL exhibited greater strength demands, particularly in the hamstrings. Moreover, in the current study, the H/Q score in the NPL analysis was slightly below the recommended value of 0.60 at an angular velocity of 60º/s, which has been associated with anterior cruciate ligament injuries and hamstring strains [7]. Therefore, monitoring asymmetries and/or imbalances might provide valuable data to identify players at injury risk and design tailored training programs according to their needs.

Meantime, the analysis of balance measures indicated statistically significant differences in the OSI and LMSI, with better scores attained in the PL performance. However, multiple factors could influence inter-limb differences in balance, and the influence of leg dominance on unilateral balance tasks should probably be context-dependent [44].

When examining the relationships between knee muscle strength, body composition, and balance, significant and negative correlations were observed between PT values and the OSI. The analyses only included the OSI since it represents the overall score in balance testing. The performance in the OSI reflects the deviation from the horizontal position; and thus, lower scores indicate better balance ability [36]. Therefore, the negative correlation verified suggests a positive influence of KF and KE performance on balance measures, consistent with past studies on this topic [17, 18]. Additionally, chronological age (CA), bodyweight, and FFM also presented significant and positive relationships with the OSI scores. To our knowledge, no data on the relationships between age, body composition, and balance variables is available in the sports literature, particularly in soccer. However, a study on female non-athletes revealed BF% and FFM as predictors of poor performance on postural stability [24]. Besides, previous research has also described a substantial reduction in balance measures in participants with increased bodyweight [23]. Contrary to what was hypothesized in the present study, bodyweight showed a positive correlation with balance ability, which is probably related to the increased FFM values and decreased BF% observed (Table 1). In fact, in a previous literature review, the authors reported that the mean BF% of elite and amateur male youth soccer players ranged between 10% and 12%, respectively [45], which encompasses the mean values presented by the participants in this study.

The results of the hierarchical regression analyses underline knee muscle strength as a significant predictor of the OSI. After controlling for the effects of CA and body composition, knee muscle strength indicators could explain between 13 and 30% of the variance in OSI score. Importantly, CA remained a significant predictor of the whole model, emphasizing the influence of age on the overall score in balance in youth. Indeed, past investigations reported CA as an important predictor of balance [22], probably because physical fitness performance tends to increase with age during adolescence [46].

Some limitations of the present study must be recognized. First, the data presented is cross-sectional. Thus, no inferences about causal relationships can be drawn, nor can our findings be generalized to other populations. Including longitudinal data would allow a more detailed analysis of the variables studied. Second, biological maturation was not assessed, and it is well-known that maturity status can play an important role in physical fitness [46]. Finally, it is important to mention that no female or adult soccer players were included in this study.

Even so, the present study has strengths, as it highlighted the positive effect of muscle strength on balance performance and emphasizes the absence of significant inter- and intra-limb asymmetries in knee muscle strength among youth soccer players. The positive relationship between body weight and FFM on balance ability has also been presented. These data are relevant for coaches and their staff greatly, particularly by underlining the importance of including lower-body strength content in their training programs. Finally, continuous monitoring of knee muscle strength is recommended to prevent the detrimental effects of possible asymmetries or deficits, including longitudinal designs controlled by the maturity state. Even though, future research is still needed on this topic, especially performing a longitudinal assessment of knee muscle strength outputs controlling for the maturity status. Since little is still known about the relationships between body composition and balance ability among soccer players' developmental stages, there is still a need for future investigation to corroborate this data.

Conclusion

The results of the current study indicated that youth soccer does not elicit significant asymmetries in knee muscle strength. A substantial and positive contribution of knee muscle strength to balance ability was observed. Bodyweight and FFM also presented significant and positive correlations with balance indicators. Notably, after controlling for age and body composition effects, knee muscle strength indicators could explain between 13% and 30% of the variance observed in the balance performance for the NPL and PL, respectively. Although this study is based on cross-sectional data and players' maturity status was not assessed, the results underline knee muscle strength as an important predictor of balance. Thus, it is recommended that coaches consider integrating lower-body strength content into their training programs even during the early stages of soccer's development. Enhancing players' physical fitness profile, particularly regarding strength and balance, might be crucial to avoid injury occurrence and improve game performance.

Abbreviations

APSI	Anteroposterior stability index
BF%	Body fat percentage
CA	Chronological age
FFM	Fat–free mass
H/Q ratio	Hamstrings to quadriceps ratio
KE	Knee extensors
KF	Knee flexors
LMSI	Lateromedial stability index
NPL	Non–preferred leg
OSI	Overall stability index
PL	Preferred leg
PT/BW	Peak torque/bodyweight
PT	Peak torque

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Author contributions
C.F., F.M., and E.R.G. analyzed and interpreted the data and were involved in writing the first draft of the manuscript. H.L., A.M., and A.I. made substantial contributions to the conception and design of the work, as well as writing and editing the manuscript's final version. M.M.N, K.P., and P.C. contributed to data interpretation, writing, and editing of the manuscript's final version. All authors read and approved the final manuscript.

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Data availability
The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and ethical restrictions.

Declarations

Ethics approval and consent to participate
All the procedures implemented in this study were approved by the Faculty of Human Kinetics Ethics Committee, CEIFMH Nº34/2021.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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