Assessing the impact of body composition and physical fitness parameters on performance prediction in youth soccer players

Evaluación del impacto de la composición corporal e indicadores de condición física en la predicción del rendimiento en jóvenes futbolistas

Authors

Santiago Castro-Infantes [1]
Ana Filipa Silva [2]
Víctor M. Soto Hermoso [1]
Jesús Olivares-Jabalera [1,3]
Filipe Manuel Clemente [4]
Francisco Tomás González-Fernández [1]

[1] University of Granada, Spain
[2] Sport Physical Activity and Health Research & Innovation Center, Rio Maior, Portugal
[3] FSI Sport Research Lab, Spain
[4] Gdansk University of Physical Education and Sport, Gdansk, Poland

Autor de correspondencia:
Francisco Tomás González-Fernández
ftgonzalez@ugr.es

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Abstract

Introduction: In youth soccer, athletic performance depends on biological maturation, body composition, and physical fitness. Although age and maturation influence performance, it is necessary to further explore how these factors interact.
Objective: To examine the evolution of body composition and fitness indicators in athletes enrolled in a professional soccer academy and to study the relation between these variables and performance outcomes.
Methodology: 131 male players aged 10 to 15 years were stratified into three age groups (U11, U13, U15) and further classified by team level (A, B, C). Anthropometric assessments, along with tests measuring countermovement jump (CMJ), 10-m sprint, change of direction (505 test), and aerobic capacity (Yo-Yo Intermittent Recovery Test Level 1), were conducted. Data analysis involved ANOVA, post-hoc comparisons, adjusted ANCOVA controlling for age, and correlation and regression analyses to identify relationships and predictors of performance.
Results: U15 athletes exhibited significantly lower body fat percentages and superior performance in explosive and aerobic tests compared to younger cohorts, with large effect sizes. U11 players demonstrated faster sprint times and higher levels of body fat. Post-hoc analyses confirmed these performance disparities, and ANCOVA results showed that these differences remained significant after adjusting for chronological age. Moderate correlations between CMJ and sprint times suggested that greater jumping ability was associated with faster sprints. In the U13 group, CMJ negatively correlated with VO_2 max, indicating a potential trade-off. Regression analyses identified CMJ as a key predictor, accounting for approximately 44-47% of the variance in sprint performance.
Discussion: These findings underscore the intricate relationship between maturation, body composition, and fitness in youth soccer players. The development of power, agility, and aerobic capacity appears to progress with age, although individual variability linked to maturation status persists.
Conclusion: Recognizing such differences is critical for refining talent identification processes and tailoring training interventions. Future longitudinal studies are needed to further elucidate developmental trajectories and optimize athlete development pathways.

Keywords

Body composition; performance; 10m sprint; youth soccer players; VO_2 max.

Resumen

Introducción: En el fútbol juvenil, el rendimiento depende de la maduración biológica, la composición corporal y la condición física. Aunque la edad y la maduración influyen en el rendimiento, es necesario profundizar cómo interactúan estos factores.
Objetivo: Examinar la evolución de los indicadores de composición corporal y condición física en deportistas inscritos en una academia de fútbol profesional y explorar las relaciones entre estas variables y los resultados en los test de campo en distintas categorías de edad.
Metodología: Se evaluaron 131 jugadores masculinos de entre 10 y 15 años, distribuidos en tres grupos de edad (U11, U13, U15) y clasificados por nivel del equipo (A, B, C). Se midieron variables antropométricas, salto en contramovimiento (CMJ), un sprint de 10 m, cambio de dirección (prueba 505) y la capacidad aeróbica (Test Yo-Yo de recuperación intermitente nivel 1). El análisis estadístico incluyó un análisis de varianza (ANOVA), comparaciones post-hoc, ANCOVA ajustada por edad y análisis de correlación y regresión. Resultados: Los atletas U15 presentaron porcentajes de grasa corporal significativamente menores y un rendimiento superior en pruebas de potencia explosiva y capacidad aeróbica que los grupos más jóvenes, con tamaños de efecto grandes. Atletas U11 presentaron más grasa corporal y mejores tiempos de sprint. Los análisis post-hoc confirmaron estas diferencias y la ANCOVA mostró que se mantenían tras ajustar por edad. Las correlaciones moderadas entre el salto CMJ y los tiempos de sprint sugieren que una mayor capacidad de salto está relacionada con velocidades de sprint más altas. En U13, el salto CMJ se correlacionó negativamente con VO_2 max, lo que puede indicar una especie de compensación o relación de intercambio. El análisis de regresión identificó el salto CMJ como predictor clave, explicando entre el 44% y 47% de la variabilidad en el rendimiento de sprint. Discusión: Los hallazgos reflejan la compleja relación entre maduración biológica, composición corporal y condición física en futbolistas jóvenes. La potencia, agilidad y capacidad aeróbica mejoran con la edad, aunque persiste variabilidad individual ligada a la maduración. Conclusión: Reconocer estas diferencias es clave para mejorar la detección de talentos y adaptar el entrenamiento. Se requieren estudios longitudinales que profundicen en las trayectorias de desarrollo y optimicen la formación de los atletas.

Palabras clave

Composición corporal; esprint de 10m; futbolistas jóvenes; rendimiento; VO_2 máx.

Introduction

Considering youth soccer, players´ athletic performance is influenced by multiple factors, including anthropometric characteristics (body composition variables) and physical fitness (Bongiovanni et al., 2021). Elite soccer players exhibit superior anthropometric characteristics and higher levels of physical performance compared to their non-elite counterparts (Hazir, 2010) and demonstrate greater change of direction (COD) ability, superior high-intensity performance, enhanced sprint speed and improved jumping capacity (Toselli et al., 2022). For that reason, factors like body size, sprinting ability, COD skills or muscular power play a prominent role in identifying talent (Sarmento et al., 2018).

Optimal body composition is crucial for young soccer players, as lower fat levels and greater muscle mass enhance performance. Campa et al. (2019) found that reduced fat in the upper arm, thigh, and calf, along with greater calf muscle area, correlated with better repeated sprint performance. Evidence suggests efficient body composition supports both muscle power and movement efficiency (Lloyd et al., 2015). While physical outcomes remain the primary distinguishing factor between elite and non-elite teams, body composition merits further investigation in youth soccer research (Toselli et al., 2022).

From a physiological point of view, soccer is an acyclic sport with complex demands, requiring elite players to sustain high levels of aerobic endurance. A key determinant of this capacity is maximal oxygen uptake (VO_2 max), which is considered essential for endurance performance (Mcmillan et al., 2005). Chamari et al. (2005) and Helgerud et al. (2001) indicate that increasing cardiorespiratory fitness-VO_2 max directly enhances key aspects of soccer performance, including total distance covered, work intensity, sprint frequency and ball involvement during matches, being aerobic and anaerobic metabolic pathways key determinants of performance (Redvka et al., 2018) and play a crucial role in the development of elite-level players (Chamari et al., 2005). Faude et al. (2012) identified sprinting as the most common action preceding goal situations, highlighting the relevance of speed and power in decisive moments. Repeated high-intensity efforts and sprinting ability are key performance determinants in soccer, with CoD and maximal sprint ability being essential physical qualities across all ages and levels (Buchheit et al., 2010; Buchheit et al., 2014; Malina et al., 2004). A comprehensive analysis of these physiological variables and pathways can elucidate their evolution across age groups and competitive levels, informing training prescription and long-term athlete development models.

Considering body composition and physical capabilities development, age plays a crucial role in young soccer players performance. In studies involving participants of the same age group, Under-15 players were taller, heavier, and more physically mature than their Under-13 and Under-11 counterparts, while no significant differences were observed in body fat percentage (Abarghoueinejad et al., 2021). Specifically, higher age groups exhibited superior performance in jumping, sprinting, change of direction (COD), and overall locomotor profile. Silva et al. (2022) in a youth soccer population from 14-18 years indicated that age was the primary determinant of changes in physical fitness, whereas playing position had no significant impact on parameters as jump height, sprinting time, COD ability or velocity. Irurtia et al. (2022) examined performance differences across U10, U12, and U14 soccer players in relation to talent identification, and found that age was not a discriminating factor for talent status in any age group. Only U12 talented players exhibit significantly superior performance in countermovement jump (CMJ) compared with not talented players. Thus, exploring the timing and magnitude of age-related adaptations in body composition and physical abilities is key to optimizing talent identification in youth soccer.

Beyond age, biological maturation appears to be significantly associated with anthropometric characteristics and physical fitness (Towlson et al., 2018). Early maturing players exhibit greater body mass, height, BMI, and fat mass percentage, along with superior performance in physical fitness tests, particularly in countermovement jump (CMJ) and squat jump (SJ) assessments, probably for the hormonal effect in muscle gain. However, maturational status does not appear to be associated with performance in the Yo-Yo test (Albaladejo-Saura et al., 2021). Silva et al. (2022) indicate that sprinting and jumping abilities in young soccer players can be effectively monitored based on either chronological age or maturity offset, thereby highlighting the importance of considering maturity status as an additional factor when evaluating performance outcomes in youth soccer. Although endurance capacity is required to sustain repeated efforts as jumps or long distances, the ability to perform quicker sprints and higher jumps than an opponent is decisive in match situations (Campa et al., 2019; Helgerud et al., 2001; Lloyd et al., 2015). Sprint performance and aerobic capacity have been associated with anthropometric variables, suggesting their predictive value in these physical capacities (Bongiovanni et al., 2021). However, other studies failed to accurately predict COD deficit and CMJ performance, indicating that additional factors may contribute to explaining variance in sprint performance and aerobic capacity (Bongiovanni et al., 2021), highlighting the need to further explore these relationships in youth soccer players across different age categories and competitive levels.

Within this context, the objectives of the present study are i) to investigate the evolution of physical fitness parameters and body composition in a professional football academy and ii) to examine the relationship between these variables to determine the predictive value on 10-m sprint performance and VO_2 max across three categories (i.e. U11, U13 and U15).

Method

Participants

This observational, cross-sectional study include a sample of 131 young soccer players of elite level participated in this study. They all play in a top professional Spanish academy team (1st division, La Liga), with ages from 10 to 15 years. Players belong to three different team categories depending on their chronological age including two or three levels teams in each category (A, B and C team in Under 11 and A and B in under 13 and 15): Under 11 category (44 players), Under 13 category (41 players) and under 15 category (46 players).

The eligibility criteria for participation included: (i) possessing an official license issued by the Royal Spanish Football Federation (RFEF), ensuring official recognition and adherence to regulatory standards; (ii) demonstrating the absence of any physical conditions or injuries that could impair performance or pose health risks during testing, as confirmed through medical screening; and (iii) obtaining written informed consent from legal guardians, in accordance with ethical research protocols and to ensure understanding of the study procedures and potential risks involved. All players actively participated throughout the entire season, and no data loss occurred, as evaluations were conducted at the beginning of the season when all team members were healthy and fully available for both coaching and research assessments, ensuring a complete and representative dataset.

A priori sample size determination was carried out using the free online software G*Power (www.gpower.hhu.de; accessed May 18, 2025). Based on data from prior studies and similar research, with a desired statistical power of 95% and an alpha level of 0.05, the analysis suggested that a minimum of 62 participants would be adequate to achieve the study objectives. The research adhered to the principles outlined in the Declaration of Helsinki and received ethical clearance from the University of xxxxxxxx Research Ethics Committee (Approval code: xxxx/xxxx/xxxx, issued on December 16, 2024).

Procedures

The evaluation process took place over two consecutive training sessions (Monday and Thursday between 05:09 and 06:00 pm). Anthropometry was evaluated at the beginning of the season on the first day, with subjects dressed only in their training pants to ensure accuracy and consistency (weight, height and body fat percentage information was obtained). Subsequently, athletes performed a pre-match warm-up to prepare them for the following test: (i) the countermovement jump (CMJ) test and (ii) the 10-meter sprint test. Once the tests were completed, players continued with their regular coach-led activities. Similar structure was followed on the second day, with a pre-match warm up and then players completed two additional assessments: (i) the 505 change of direction (COD) test and (ii) the Yo-Yo Intermittent Recovery Test Level 1, from which VO_2 max was determined. Before testing, players were given verbal information and examples from the research team about the protocol. A five-minute familiarisation attempt was established for each test with participants. Fully recovery was needed before testing. Accordingly, a three-minute recovery interval was established between attempts.

Measures

Body Composition Assessment

The evaluation of body composition was conducted during the initial assessment day. To obtain these measurements, the Bioelectrical Impedance Analysis (BIA) technique was utilized, employing a TANITA® device (model MC980MA PLUS, located in Arlington Heights, Illinois). Additionally, participants' height was recorded using a stadiometer (Seca® 206, manufactured in Hamburg, Germany) to ensure precise anthropometric data collection.

Countermovement Jump Test (CMJ)

CMJ performance was evaluated using the Chronojump-Boscosystem® system (Barcelona, Spain), with data captured through the Chronojump software version 2.0.2. During testing, each athlete performed three maximal effort jumps on a contact platform, with a rest interval of 20 seconds between trials to minimize fatigue. The highest jump height attained, recorded in centimeters (cm), was used for analysis. Participants were instructed to perform the jump explosively immediately after flexing their knees to approximately 90°. They were also directed to keep their hands on their hips throughout the movement and to land with fully extended legs and maximal plantar flexion. If any of these movement criteria were not fulfilled, the attempt was repeated to ensure consistency and accuracy in measurement.

10-m sprint test

The 10-meter sprint test involved two separate sprints, with a 2-minute rest period between attempts. The fastest time recorded in seconds was used for analysis. The timing determination was conducted using a dual-beam photoelectric gate system (Microgate, Bolzano, Italy). Participants began in a standing split stance, with their lead foot positioned 0.3 meters behind the starting line. The infrared gate was mounted at a height of 0.75 meters to accurately detect trunk movement and reduce the likelihood of false signals generated by limb motion during the sprint.

505 Change of direction (COD) test

The 505 COD test was performed following established protocols (Buchheit, 2008). The test timing was recorded with a dual-beam timing gate system (Microgate, Bolzano, Italy), with times measured to the nearest 0.01 seconds. Participants started from a standing position 10 meters upstream from the start/finish line. They sprinted at maximum effort through the line, then performed a 180° pivot turn at the 15-meter mark designated by a cone and immediately sprinted back as quickly as possible through the start/finish line. To ensure proper execution, a researcher was positioned at the turning point to monitor correct performance. Trials where participants changed direction before reaching the designated marker were invalidated and repeated after a recovery period. Each player completed two trials, separated by a three-minute rest, and the best time of the two attempts was recorded for analysis.

The Yo-Yo Intermittent Recovery Test (YYIRT) level 1

The YYIRT level 1 was conducted following the original protocol. (Krustrup et al., 2003). Participants completed two consecutive 20-meter runs, separated by a 10-second recovery period, totaling 40 meters per shuttle. The entire test consisted of 91 shuttles. The test began with four running bouts at speeds of 10–13 km/h, followed by seven runs at 13.5–14 km/h. Afterward, the running speed increased by 0.5 km/h every eight shuttles, with the pace regulated by an audio beep signal. The test continued until participants could no longer maintain the required pace or failed to reach the designated line twice consecutively in synchrony with the signal. During the test, the total distance covered, and the final running velocity were recorded for each player.

Data analysis

The statistical analysis was performed using JASP (version 0.19.3) (JASP team, 2025). Descriptive statistics (means, standard deviations, medians, interquartile ranges, minimums and maximums) were calculated for all dependent variables (i.e. CMJ, 505, 10m Sprint, VO2max, body fat). For the first objective, a one-way analysis of variance (ANOVA) was conducted to determine evolution in each of the tests across categories. Equality of variance was checked with the Levene's test. For the comparison between categories (i.e. U11, U13, U15), Omega squared (ω^2) effect sizes (ES) were calculated from ANOVA and its values were considered as follows: small: 0.010–0.059, medium: 0.060–0.149, and large: ≥0.150 (Cohen, 1988). When a significant effect was found, post hoc comparisons were performed using Tukey's Honest Significant Difference test to identify specific group differences. The magnitude of differences in pairwise comparisons was evaluated using standardized mean differences (Cohen's d), and were interpreted as follows: trivial (≤ 0.2), small (> 0.2–0.6), moderate (> 0.6–1.2), large (> 1.2–2.0), and very large (> 2.0–4.0) (Hopkins, 2002). Additionally, to determinate whether other factors than the age influence the differences, an ANCOVA was conducted, with age as a covariate. For the second objective, Pearson's correlation coefficient (r) was calculated for all test variables to determine the relationships between all dependant variables within each age category. ES were interpreted as: trivial (≤ 0.1), small (> 0.1–0.3), moderate (> 0.3–0.5), large (> 0.5–0.7), very large (> 0.7–0.9), and almost perfect (> 0.9–1.0) (Hopkins, 2002). Additionally, multiple linear regression analysis was performed to identify which physical tests best predict 10-m Sprint performance and VO_2 max. Separate regression models were built for each dependent variable (10-m sprint time and VO_2 max), with independent variables including the other 4 dependent variables (e.g. CMJ, 505, VO2max and body fat for 10m Sprint), and this process was repeated for each category. The assumptions of linear regression (normality, homoscedasticity, and multicollinearity) were checked before analysis. Model significance was determined at $p < 0.05$, and standardized beta coefficients (β) were reported to assess the relative contribution of each predictor variable. Only regression models reaching a shared variance (i.e. R2) of at least 0.30 were reported to ensure that the predictors explained a meaningful proportion of the variance in both 10m Sprint and VO2max (Cohen 1988).

Results

Physical fitness and body composition evolution across categories

Descriptive statistics for each category are displayed in Table 1. The ANOVA revealed large differences for body fat (ω 2 = 0.21, p < 0.001), CMJ (ω2 = 0.58, p < 0.001), 505 (ω2 = 0.29, p < 0.001), 10m sprint (ω2 = 0.71, p < 0.001), VO2max (ω2 = 0.18, p < 0.001) between categories.

Table 1. Descriptive statistics for body composition and physical fitness

	Mean±SD	Median	IQR	Min	Max
Body composition					
Body fat (%)	18.30±3.80	18.00	4.30	8.60	31.00
Physical fitness					
CMJ (cm)	26.2±7.20	23.70	9.80	14.2	52.20
505 COD (s)	2.52±0.19	2.54	0.22	1.86	2.98
10m Sprint (s)	1.87±0.17	1.85	0.25	1.48	2.24
VO_2 max (ml/kg/min)	53.2±7.10	52.20	10.30	40.8	67.30

Note: SD: Standard Deviation; IQR: Interquartile Range; Min: Minimum; Max: Maximum; CMJ: Countermovement Jump; COD: Change of Direction.

Post-hoc comparisons showed U15 category exhibited moderate differences (lower values) than U13 for body fat (d = 0.93, p < 0.001) and large differences for 505 (d = 1.62, p < 0.001)and 10m sprint (d = 1.42, p < 0.001), while very large differences were shown (higher values) for CMJ (d = 2.24, p < 0.001) and moderate differences for VO_2 max (d = 0.75, p = 0.005). Additionally, U15 presented lower values than U11 for body fat (d = 1.28, p < 0.001), for 505 (d = 0.91, p < 0.001), and for 10m sprint (d = 3.76, p < 0.001) showing large, moderate and very large differences, respectively, and higher for CMJ (d = 2.76, p < 0.001) and VO_2 max (d = 1.21, p < 0.001), presenting very large and large differences. Very large differences were shown between U13 and U11 players, with the formers exhibiting lower values for 10m sprint (d = 2.34, p < 0.001), while small and moderate differences (higher values) for CMJ (d = 0.52, p = 0.04) and for 505 (d = 0.72, p = 0.004). No differences between U13 and U11 were found for body fat (p = 0.25) and VO_2 max (p = 0.09). Figures 1 and 2 show a depiction of the magnitudes of the ES of the post-hoc comparisons between all categories, for all the dependent variables.

Figure 1. Raincloud plot showing CMJ heights (cm), 505 times (s) and 10m Sprint times (s) for U15, U13 and U11 categories.

Figure 1.1. CMJ heights (cm) for U15, U13 and U11 categories.

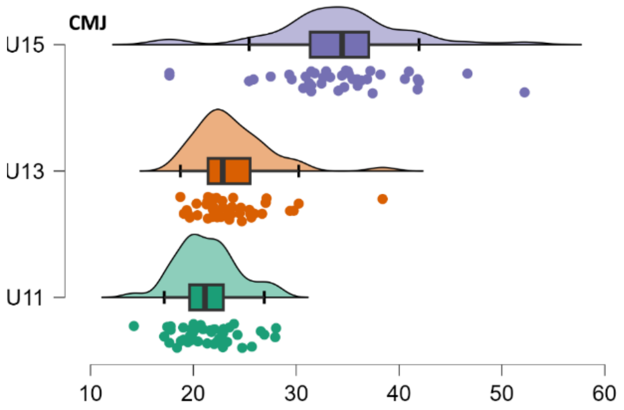


Figure 1.2. 505 COD times (s) for U15, U13 and U11 categories.

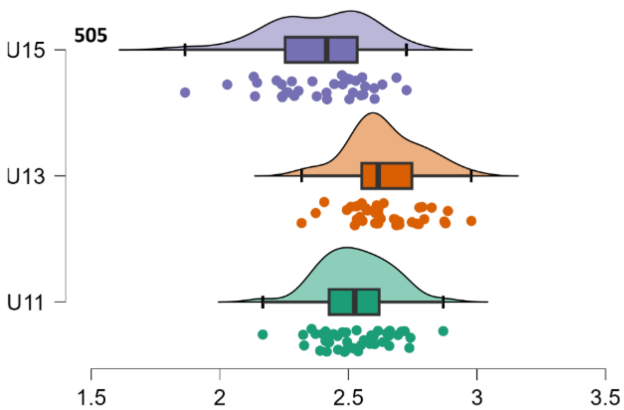
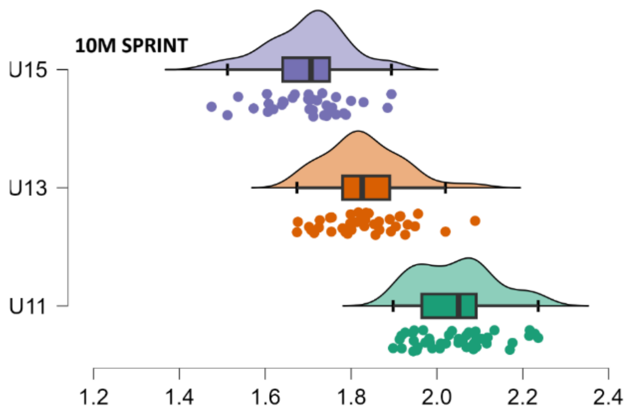


Figure 1.3. 10m Sprint times (s) for U15, U13 and U11 categories.



Note: Each group includes raw data points, a density curve, and a boxplot displaying the median and interquartile range.

Figure 2. Raincloud plot for body fat (%) and VO_2 max (ml/kg/min) for U15, U13 and U11 categories.

Figure 2.1. Body fat (%) for U15, U13 and U11 categories.

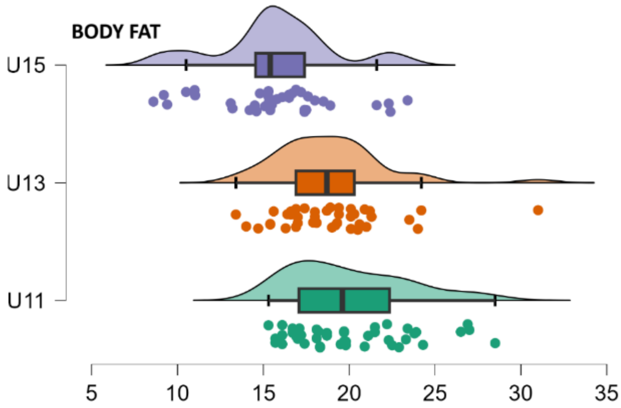
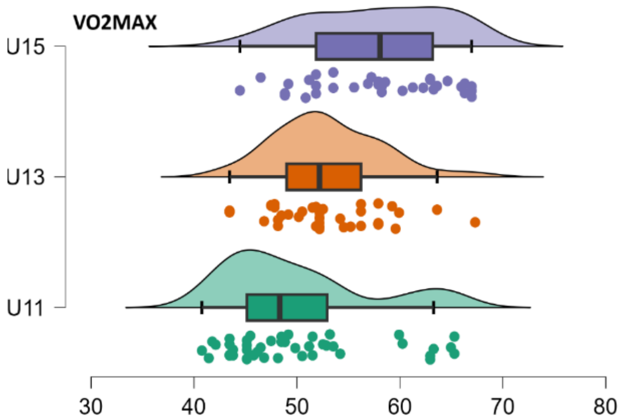


Figure 2.2. VO_2 max (ml/kg/min) for U15, U13 and U11 categories.



Note: Each group includes raw data points, a density curve, and a boxplot displaying the median and interquartile range.

When conducting ANCOVA adjusted by age, only large differences for CMJ ($\omega 2$ = 0.18, $p < 0.001$), 505 ($\omega 2$ = 0.25, $p < 0.001$), and medium diffences for 10m Sprint ($\omega 2$ = 0.06, $p = 0.006$) were found. U15 exhibited very large differences (higher values) than U13 ($d = 2.00$, $p < 0.001$) and U11 ($d = 2.30$, $p = 0.004$) for CMJ, while the comparison between U13 with U11 group exhibited very large differences (lower values) than U11 for 505 ($d = 2.05$, $p < 0.001$), and large for 10m Sprint ($d = 1.18$, $p = 0.01$).

Progression of the predictive relationships for 10m Sprint and VO_2 max outcomes across categories

The correlation matrix between the analysed variables across categories are shown in Table 2 (U11), table 3 (U13) and table 4 (U15).

Table 2. Correlation matrix between the analysed variables for the U11 category.

		CMJ (cm)	505 COD (s)	10m Sprint (s)	VO_2 max (ml/kg/min)	Age (yrs)	Body fat (%)
CMJ (cm)	Pearson´s r	-					
	p-value	-					
505 COD (s)	Pearson´s r	-0.25	-				
	p-value	0.10	-				
10m Sprint (s)	Pearson´s r	-0.36*	0.30*	-			
	p-value	0.02	0.05	-			
VO_2 max (ml/kg/min)	Pearson´s r	0.06	-0.13	-0.26	-		
	p-value	0.72	0.42	0.09	-		
Age	Pearson´s r	0.11	-0.07	-0.30*	0.16	-	
	p-value	0.49	0.64	0.05	0.31	-	
Body fat (%)	Pearson´s r	-0.26	0.05	0.18	-0.12	-0.24	-

	p-value	0.08	0.74	0.24	0.44	0.12	-

Note: *p<.05, ** p<.01, *** p<.001.

Table 3. Correlation matrix between the analysed variables for the U13 category.

		CMJ (cm)	505 COD (s)	10m Sprint (s)	VO_2 max (ml/kg/min)	Age (yrs)	Body fat (%)
CMJ (cm)	Pearson´s r	-					
	p-value	-					
505 COD (s)	Pearson´s r	-0.12	-				
	p-value	0.44	-				
10m Sprint (s)	Pearson´s r	-0.09	0.23	-			
	p-value	0.56	0.15	-			
VO_2 max (ml/kg/min)	Pearson´s r	0.41**	-0.20	-0.20	-		
	p-value	<.001	0.21	0.22	-		
Age	Pearson´s r	-0.12	-0.27	-0.39*	0.02	-	
	p-value	0.47	0.09	0.01	0.88	-	
Body fat (%)	Pearson´s r	-0.21	0.10	0.11	-0.49**	-0.08	-
	p-value	0.20	0.52	0.47	<.001	0.64	-

Note: *p<.05, ** p<.01, *** p<.001.

Table 4. Correlation matrix between the analysed variables for the U15 category.

		CMJ (cm)	505 COD (s)	10m Sprint (s)	VO_2 max (ml/kg/min)	Age (yrs)	Body fat (%)
CMJ (cm)	Pearson´s r	-					
	p-value	-					
505 COD (s)	Pearson´s r	-0.07	-				
	p-value	0.70	-				
10m Sprint (s)	Pearson´s r	-0.40*	0.59***	-			
	p-value	0.02	<.001	-			
VO_2 max (ml/kg/min)	Pearson´s r	0.26	-0.35*	-0.20	-		
	p-value	0.13	0.05	0.26	-		
Age	Pearson´s r	0.16	-0.64***	-0.31	0.22	-	
	p-value	0.34	<.001	0.06	0.21	-	
Body fat (%)	Pearson´s r	-0.27	0.12	0.24	-0.30	-0.20	-
	p-value	0.10	0.47	0.15	0.09	0.23	-

Note: *p<.05, ** p<.01, *** p<.001.

The CMJ demonstrated a moderate inverse relationship with the 10m sprint performance in both U11 and U15 age groups, indicating that higher jump heights are associated with faster sprint times in these categories. Additionally, in the U13 group, CMJ was moderately negatively correlated with VO_2 max, suggesting that superior explosive power may be linked with higher aerobic capacity within this cohort. The 505 COD test showed a moderate positive correlation with the 10m sprint in U11, and a strong positive relationship in U15, implying that better agility and rapid change of direction are associated with faster sprinting abilities; however, no significant link was observed in U13. Furthermore, in U15, the 505 COD was moderately negatively related to VO_2 max, indicating that increased aerobic capacity might contribute to improved agility performance. In the U13 group, VO_2 max correlated moderately negatively with body fat percentage, underscoring the influence of body composition on aerobic fitness. Age was moderately negatively associated with 10m sprint times in U11 and U13, and strongly negatively related to the 505 COD in U15, reflecting gains in speed and agility with maturation.

Moreover, two multiple regression models were statistically significant across the dataset. The first model ($F = 94.18$, $p < 0.001$) revealed that CMJ alone accounted for 44% of the variance in 10-meter sprint performance ($R^2 = 0.44$), with a significant negative beta coefficient ($\beta = -0.67$). The second model ($F = 53.01$, $p < 0.001$) incorporated both CMJ and VO_2 max, explaining 47% of the variance ($R^2 = 0.47$), with each predictor showing significant contributions (CMJ: $\beta = -0.58$; VO_2 max: $\beta = -0.20$).

In the U13 age group, a separate model including body fat and CMJ accounted for 35% of the variance in VO_2 max ($R^2 = 0.35$), with body fat negatively influencing aerobic capacity ($\beta = -0.43$) and CMJ positively contributing ($\beta = 0.33$). In U15, a regression model ($F = 17.58$, $p < 0.001$) demonstrated that the 505 COD test predicted 35% of VO_2 max variance ($R^2 = 0.35$) with a strong positive beta coefficient ($\beta = 0.60$). An enhanced model, incorporating both the 505 test and CMJ, explained 48% of the variance in

VO_2 max ($F = 14.11$, $p < 0.001$), with the 505 COD test ($\beta = 0.57$) positively and CMJ ($\beta = -0.35$) negatively associated with aerobic capacity.

Discussion

The main objectives of the present study were to analyse the longitudinal development of body composition and physical fitness parameters within a professional football academy and to investigate the interrelationships among these variables. Specifically, the study aimed to assess their predictive capacity concerning 10-meter sprint performance and VO_2 max across different youth categories. The findings indicated that improvements in 10-meter sprint performance were more pronounced across categories compared to other physical and anthropometric variables, highlighting the sensitivity of short-distance sprinting to developmental changes during adolescence. Furthermore, the data underscore the significant influence of chronological age on sprint performance, corroborating findings from previous research (Abarghoueinejad et al., 2021; Silva et al., 2022). An analogous trend was observed regarding biological maturity, as more advanced maturational status was associated with higher match running performance metrics, consistent with prior studies (Buchheit & Mendez-Villanueva, 2014; Redkva et al., 2018). These results emphasize the critical role of both age and biological maturation in shaping physical development and competitive performance in youth football athletes.

On the one hand, adjusted analyses accounting for age reveal that most differences in physical performance between youth categories are primarily attributable to chronological age, with notable variations observed in body fat percentage and VO_2 max. These findings align with previous research emphasizing the pivotal role of age-related development in these parameters (Silva et al., 2022). However, despite age adjustment, differences in countermovement jump (CMJ) performance persisted, suggesting that factors beyond mere chronological age influence explosive power. A plausible explanation is that the significant muscular development observed during puberty is more closely tied to biological maturation than to chronological age alone, reflecting the complex interplay between hormonal changes, muscle hypertrophy, and neuromuscular improvements that occur during this critical growth phase. In line with this, Hernández Camacho et al. (2018) examined the relationship between biological maturity and anthropometric growth in young soccer players and found that increases in muscle cross-sectional area tend to accelerate after reaching peak height velocity (PHV), although individual growth patterns often follow a nonlinear trajectory. These findings support the notion that maturation-related changes in muscle structure and function, rather than age per se, predominantly drive performance enhancements during adolescence. Furthermore, studies by Hammani et al. (2016) showed that post-PHV athletes demonstrate significantly greater strength and power outputs, including back extensor strength, long jump, and CMJ performance. These findings suggest that maturity-related muscular development, rather than age itself, plays a crucial role in explosive capabilities. Therefore, future studies should include measures of biological maturity, like peak height velocity, and direct muscle strength assessments, such as hamstring or isokinetic tests, to better understand how growth influences performance and tailor training to individual developmental stages.

Regarding the primary aim of the study, it is particularly intriguing that U11 players outperformed their U13 counterparts in the 505 change-of-direction test, a result that appears counterintuitive given the expected progression in physical and neuromuscular capabilities with age. Several factors may help explain this unexpected finding. Firstly, the U11 group might have been part of a more competitive environment or training regimen that placed a stronger emphasis on agility and neuromuscular coordination, thereby resulting in superior performance in tasks demanding rapid directional shifts. Additionally, talent selection processes within this group may have favored lighter, more agile athletes, giving them an advantage in the test. The design of the 505 test itself may also influence results; its focus on sharp 180° turns could inherently favor lighter and more agile individuals, characteristics often more common in younger children with lower body mass. An important maturational factor to consider is puberty onset, which can temporarily impair motor coordination, a phenomenon commonly referred to as 'adolescent awkwardness', due to rapid changes in limb length and body proportions that can disrupt established movement patterns (Wachholz et al., 2020). These maturational fluctuations may negatively impact agility performance, especially in tasks requiring precise and swift directional changes. Therefore, both developmental stages and the specific demands of the test should be considered when interpreting these results, highlighting the complexity of assessing athletic ability during adolescence.

Interestingly, our findings did not demonstrate a consistent decline in the relationships between body composition variables and physical performance as players advanced through the various age categories. Generally, existing research indicates that with age and maturation, youth soccer players tend to show improvements in both physical capabilities and favourable body composition profiles, such as increased muscularity and reduced fat mass (Leao et al., 2022). However, these physiological advantages often plateau as athletes approach full physical maturity, leading to a reduction in observable disparities among age groups (Malina et al., 2000). One might expect greater heterogeneity in older groups, such as U15, due to differences in positional roles and individual development trajectories. Surprisingly, our data revealed consistent relationships across all age categories, suggesting that certain physical attributes, like speed, strength, and overall fitness, are maintained as stable performance indicators, regardless of age. This consistency likely reflects the influence of elite training environments, which tend to create uniform development pathways, emphasizing discipline and targeted physical conditioning. Supporting this, longitudinal studies, such as Wrigley et al. (2014), have shown that youth athletes in professional academies experience significant gains in agility, sprinting, aerobics, and jumping ability compared to less structured settings. This highlights the role of systematic training in promoting balanced and stable physical development across different age groups. Additionally, research by Gonaus and Muller (2012) emphasizes that soccer-specific traits like speed and upper-body power are critical discriminators in talent identification, reinforcing their importance as consistent performance markers throughout development. These insights underline the complex interplay between maturation, training environments, and performance, highlighting that while biological changes occur, structured training can help maintain favorable performance relationships beyond expected developmental fluctuations. These observations may reflect the early stages of positional specialization that typically become more pronounced around the U15 age group. As players mature, distinct physical and functional differences tend to emerge based on their specific roles on the field. For instance, goalkeepers and central defenders generally develop taller and heavier physiques, reinforcing strength and reach, whereas wide midfielders and forwards often excel in speed and agility, which are crucial for their offensive and transitional responsibilities. This progression supports the idea that, during mid-adolescence, physical differentiation related to playing positions becomes more evident, contributing to greater diversity in performance profiles among youth athletes (Deprez et al., 2015). However, our findings did not reveal significant disparities in body composition and performance relationships across age categories, possibly indicating that positional specialization is still in its nascent stages, especially in more structured training environments like elite academies. Interestingly, in the youngest groups (U11), the selection process might inherently favor early-maturing players, reducing variability, while older players (U15) display more individual differences due to advanced maturation and emerging role-specific development. These patterns align with existing literature, emphasizing that physical and technical differentiation tend to intensify around peak height velocity, shaping more specialized and role-dependent performance profiles as players progress through adolescence. This developmental trajectory underscores the need to account for maturity and individual growth patterns when designing training and selection strategies, ensuring fair opportunities for all players regardless of their maturation stage.

The secondary objective of the study aimed to explore the relationship between body composition and various physical fitness parameters in youth soccer players. Results indicate that players with higher countermovement jump (CMJ) scores tend to demonstrate faster performance in the 10-meter sprint, suggesting that explosive lower-body strength plays a significant role in short-distance acceleration. Interestingly, VO_2 max accounted for only a minimal proportion (~3%) of the variability in sprint performance, highlighting that muscular power, rather than aerobic capacity, is a more critical predictor of rapid sprinting ability in this population. This result is consistent with previous studies by Comfort et al. (2014) and McFarland et al. (2016), which consistently demonstrate strong correlations (ranging from 0.50 to 0.76) between explosive leg strength measures, such as CMJ or squat jump, and short sprint times in youth athletes.

In the U15 group, the association between explosive power and speed was further supported by the observed link between enhanced CMJ performance and improved results in the 505 change-of-direction test. These findings reinforce the importance of lower-body explosive strength and agility as key components for effective acceleration and quick directional changes, vital attributes for soccer performance, as shown in prior research (McFarland et al., 2016; Bakall'ár et al., 2020). The relationship between these variables underscores the multifaceted nature of physical fitness required for optimal performance. Further analysis within the U13 category revealed that lower body fat percentages and higher CMJ scores were associated with greater VO_2 max. This aligns with existing literature indicating a negative correlation between body fat and aerobic capacity, with body fat levels explaining significant variability in VO_2 max (Nalbant and Özer, 2018; Michailidis, 2024). While the direct causality between jumping ability and aerobic performance remains unclear, it is plausible that increased muscle power enhances muscular efficiency, thereby positively influencing endurance performance, especially when lean body mass is well-developed. Collectively, these findings suggest that optimizing muscle strength and managing body composition are crucial strategies for improving both anaerobic and aerobic capacities in young soccer athletes, ultimately contributing to more comprehensive athletic development.

The present study demonstrates several strengths that enhance its value and contribution to the field of youth soccer development. Firstly, the use of a broad range of physical tests and anthropometric measurements provides a comprehensive assessment of players' performance, covering strength, speed, agility, and aerobic capacity. This multidimensional approach allows for a more holistic understanding of the physical qualities relevant at different age categories. Additionally, analyzing the relationship between body composition and performance offers valuable insights for designing tailored training programs aimed at improving specific attributes. These strengths render this study a meaningful reference point for coaches and practitioners aiming to optimize youth athletic development. However, the study also has certain limitations that should be acknowledged when interpreting its findings. The primary limitation is the small sample size, which restricts statistical power and limits the generalizability of the results to larger populations. Variability in biological maturation and training experience among young athletes can significantly influence performance, so caution is needed when extrapolating these findings. Another notable limitation is the absence of biological maturity assessments, such as peak height velocity (PHV) or maturity offset, which are known to impact physical performance during adolescence. Including such markers in future research would allow for better accounting of intra-group differences and a more precise understanding of performance variations linked to maturation stages. For practical applications, the findings suggest that coaches should focus on developing explosive strength and incorporate sport-specific conditioning that addresses both anaerobic and aerobic capacities. Training programs should be tailored to individual maturation levels, accentuating strength development alongside endurance as players mature. Regular assessments of biological maturity markers could help in adjusting training loads and preventing overtraining or injury. Additionally, since repeated-sprint ability (RSA) is crucial in soccer match demands, future studies should include RSA testing to better understand neuromuscular and aerobic interactions during high-intensity, intermittent efforts. This would facilitate more sport-specific training strategies, ultimately supporting athletes' optimal development aligned with their maturational and physical profiles.

Conclusions

This study highlights the significant influence of age and biological maturation on sprint and aerobic performance in young soccer players, with explosive leg power consistently predicting sprint ability across age groups. Performance differences are largely explained by maturation, although variability in jump performance indicates the ongoing role of muscular development. Stability in fitness and body composition across categories may be attributed to elite training environments, whereas increased variability in older players may reflect early specialization. Future research should focus on longitudinal studies with larger, diverse samples across different levels, including assessments of neuromuscular features like rate of force development. Incorporating these factors can improve understanding of performance progression and contribute to tailoring training strategies, ultimately enhancing talent identification and long-term athlete development in youth soccer.

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Authors' and translators' details:

Santiago Castro Infantes	scastroinf8@gmail.com	Autor
Francisco Tomás González Fernández	ftgonzalez@ugr.es	Autor
Víctor Manuel Soto Hermoso	vsoto@ugr.es	Autor
Jesús Olivares Jabalera	jesusyolivares@gmail.com	Autor
Filipe Manuel Clemente Bautista	filipe.clemente5@gmail.com	Autor
Ana Filipa Silva	anafilsilva@gmail.com	Autora