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Prediction of physical performance in young soccer players through anthropometric characteristics, body composition, and somatic maturation states

Predicción del rendimiento físico en futbolistas jóvenes a través de características antropométricas, composición corporal y estados de maduración somática

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Abstract. Introduction: Physical performance in young soccer players may be influenced by body composition, anthropometric measures, and maturation status. This study examines how these variables affect isometric strength, vertical jump, and change of direction. Objective: To analyze the impact of fat mass, lean mass, anthropometric measures, and maturation status on physical performance in young soccer players. Methodology: A correlational study was conducted with players from a Chilean soccer team ((N=34; 16.06 ± 0.78 y; 1.69 ± 0.06 m; 62.39 ± 8.26 kg), using a DEXA scanner to assess body composition and physical tests (Change of direction; Isometric Midthigh Pull and Countermovement Jump) to measure performance. A LASSO regression model was employed to identify significant predictors. Results: The anthropometric variables, body composition, and PHV explain the percentage of variance in the model to varying degrees (R^2 0.05 to 0.78) with medium and large effect sizes (Cohen's f^2 0.6 to 3.0). Conclusion: Body composition and maturation status are crucial for optimizing performance in young soccer players.
Keywords: Body Composition, Young Soccer Players, Maturation, Physical Performance

Resumen. Introducción: El rendimiento físico en jóvenes futbolistas puede estar influenciado por la composición corporal, las medidas antropométricas y el estado de maduración. Este estudio examina cómo estas variables afectan la fuerza isométrica, el salto vertical y el cambio de dirección. Objetivo: Analizar el impacto de la masa grasa, la masa magra, las medidas antropométricas y el estado de maduración en el rendimiento físico de jóvenes futbolistas. Metodología: Se realizó un estudio correlacional con jugadores de un equipo de fútbol chileno (N=34; 16.06 ± 0.78 años; 1.69 ± 0.06 m; 62.39 ± 8.26 kg), utilizando un escáner DEXA para evaluar la composición corporal y pruebas físicas (cambio de dirección; tirón isométrico de muslo medio y salto con contramovimiento) para medir el rendimiento. Se empleó un modelo de regresión LASSO para identificar predictores significativos. Resultados: Las variables antropométricas, la composición corporal y el APHV explican el porcentaje de varianza en el modelo en diferentes magnitudes (R^2 0.05 a 0.78) con tamaños del efecto medios y grandes (f^2 de Cohen 0.6 a 3.0). Conclusión: La composición corporal y el estado de maduración son cruciales para optimizar el rendimiento en jóvenes futbolistas.
Palabras clave: Composición Corporal, Jóvenes Futbolistas, Maduración, Rendimiento Físico.

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Introduction

Soccer is, an intermittent and acyclic sport that involves actions performed at varying intensities (Dolci et al., 2020). Moreover, soccer performance is influenced by a combination of technical, tactical, physiological, biomechanical, and psychological factors (Stølen et al., 2005), highlighting the relevance of maintaining all these variables at reasonable levels. According to global positioning system (GPS) technology analyses, most activities occur at moderate to low intensities (Andrzejewski et al., 2019). However, the actions that determine the game´s outcome are those performed at high intensity. Accordingly, Faude et al. (2012) describes that the sequences leading up to a goal involve linear sprints, accelerations, and changes of direction (COD). Thus, the ability to generate high muscle tension quickly becomes fundamental, as an optimal level of physical fitness is crucial for achieving high performance. This is way researchers often look for factors that can be manipulated to improve physical performance (Pérez et al., 2021)

Maintaining an appropriate body composition and weight is essential for high performance in soccer. Research shows that players with lower body fat percentages cover longer distances and at higher intensities (Radziminski et al., 2020). Additionally, Figueiredo et al. (2020) found negative correlations between fat mass and vertical jump height, and positive correlations between lean mass and power. Negative associations were also observed between fat mass and performance in repeated sprints. Campa et al. (2019) emphasize the importance of reducing fat and maintaining or increasing lean mass. These findings highlight the need for a comprehensive approach to training and nutrition to improve endurance, power, and the ability to perform repeated explosive efforts.

Additionally, França et al. (2024) found that greater lean mass and lower fat mass are associated with better performance in direction changes among young soccer players. Concentric strength, dependent on muscle mass, is crucial for re-acceleration, but excessive lean mass can negatively affect performance (Stanković et al., 2023). Therefore, while increased muscle mass improves explosive strength and acceleration, it can also limit agility if not optimized for soccer-specific movements. Balancing body composition to maximize performance in direction changes without compromising movement efficiency is essential.

Among the methods for analyzing body composition, dual-energy X-ray absorptiometry (DEXA) is considered the gold standard due to its high precision in measuring lean and fat mass (Shepherd et al., 2017). Although anthropometry and bioelectrical impedance are also used (Moreira et al., 2015), DEXA offers detailed and accurate measurements, which are crucial for adjusting training and improving performance in soccer players (Figueiredo et al., 2020; Radziminski et al., 2020). Additionally, DEXA allows monitoring body mass changes over time, as evidenced by studies showing significant variations in lean mass during different training stages (Staśkiewicz-Bartecka et al., 2023).

Biological maturation, which can be assessed through four indicators—sexual, skeletal, dental, and somatic—significantly affects athletic performance (Albaladejo-Saura et al., 2021; Gómez-Campos et al., 2013; Malina et al., 2004). Somatic maturation states can be assessed by calculating the Age at Peak Height Velocity (APHV), which estimates the point at which an individual reaches their highest growth rate. This indicator, along with the assessment of bone and sexual maturation, provides valuable information on how physical development influences athletic capacities such as strength and agility (Mirwald et al., 2002; Peña-González et al., 2022).

In young soccer players, APHV is crucial for adjusting training programs and optimizing performance. Players at advanced stages of maturation may have an advantage in muscle strength (Eskandarifard et al., 2022). In contrast, those at earlier stages of maturation may have greater future development potential (de la Rubia et al., 2024).

To date, there is a limited number of studies exploring the influence of body composition assessed by DEXA on physical performance in young soccer players. Moreover, this study is notable for its focus on the relationship between age at peak growth and physical performance, which has received scant attention in existing literature. In this context, the research aims to analyze how body composition and maturation states affect the physical performance of young soccer players.

Methods

Design and participants

Quantitative study with a descriptive scope, non-experimental type, and a crossectional temporal dimension. The study was conducted with young soccer players (N=34; 16.06 ± 0.78 y; 1.69 ± 0.06 m; 62.39 ± 8.26 kg) from a Chilean professional soccer team, all of whom had at least 2 years of experience in the sport. These players trained five times a week and participated in one official competition match per week.

Procedures

Data collection occurred over two weeks during the competitive period. Body composition measurement were taken in the first week, while physical performance tests were conducted in the second week. Body composition measurements were performed at the Universidad Autónoma de Chile using a DEXA scanner (Lunar Prodigy, GE Medical Systems, Madison, Wisconsin, USA). Relative and absolute values of fat, lean, and bone mass were analyzed.

The study followed ethical standards for research involving human subjects, following the Helsinki Declaration. Approval was obtained from the relevant ethics committee before the study began (Adventist University of Chile, resolution 2023-07, Acta No. 2023-04, and vote No. 2023-08). Informed consent and assent from their parents or guardians were obtained from the participants. Participation was entirely voluntary, and confidentiality of the data was ensured. Participants were provided detailed information about the study's objectives, procedures, and potential risks.

Anthropometry

Anthropometric measurements were conducted to complement the assessment of body composition. Skinfolds evaluated included the thigh and calf, using a Rosscraft SLIGUI Body Fat Caliper® (Beta Technology, Richmond, Canada). Body circumferences (thigh and calf) were measured with a metal anthropometric tape from Rosscraft to ensure precision and consistency in each measurement. Body mass was recorded using a calibrated digital scale (SECA 803), while height was measured with a portable stadiometer (SECA 213).

Body Composition

The participants′ body composition was assessed using dual-energy X-ray absorptiometry (DEXA) (Lunar Prodigy, GE Medical Systems, Madison, Wisconsin, USA). The analysis′s measurements included total body mass, total fat mass, lower limb lean mass, total lean mass, lower limb bone mineral content, and total bone mineral content. A specialized technician performed all scans and standardized them to ensure data accuracy.

Somatic Maturation

Somatic maturation was assessed following the methodology proposed by Mirwald et al. (2002). The following variables were used: total height, sitting height, body mass, and decimal age of the participants.

Height: The participant′s total height was measured with a stadiometer (SECA 213, Basel, Switzerland) in a bipedal position, ensuring they were barefoot and had their head aligned in the Frankfurt plane. The measurement was recorded in centimeters.

Sitting Height: This was recorded with the same stadiometer but with the participant sitting on a flat surface of known height (40 cm). It ensured the trunk was upright and the legs flexed at a 90-degree angle.

Body Mass: Evaluated using a digital scale (SECA 803, Basel, Switzerland), with the weight recorded in kilograms, while the participant was barefoot and wearing light clothing.

Decimal Age: Calculated from the difference between birth and assessment date, expressed in years and fractions.

Once these data were collected, they were entered into the model proposed by Mirwald. This model estimates somatic maturation based on the participant's proximity to peak height velocity (PHV). Previous studies have extensively validated this model, demonstrating its accuracy in estimating biological maturation in young populations.

Performance Tests

Isometric Mid-Thigh Pull (IMTP)

The IMTP test was conducted on day 1 of week 1. The procedure followed the methodologies described by Comfort et al. (2019). Specific activation involved three IMTP attempts at 50%, 75%, and 90% of perceived effort, with one minute of rest between them. Subsequently, three maximum attempts were performed, starting with the instruction: "Push with your feet against the ground as fast and hard as you can." Each attempt lasted of 8 seconds, with 3 seconds dedicated to preparation and 5 seconds to effort. The rest between attempts was 2 minutes. Data were recorded using force plates (PASPORT force plate, PS-2141, PASCO Scientific, California) with SPARKvue software (version 4.6.1, USA), exported to an Excel spreadsheet (version 16, Microsoft, USA), and processed in Matlab (version 9.6, USA). Absolute peak force (PFI), as well as impulse at 100 ms (I100), were analyzed. The start of the tests was estimated based on a change of 5 standard deviations in the force-time curve (McMahon et al., 2018).

Countermovement Jump (CMJ)

The CMJ test was conducted on day 1 of week 1. Following a specific activation of 5 submaximal jumps, players performed 3 maximum CMJ attempts, with a 2-minute pause between attempts. The depth of the descent was self-determined according to the player's comfort. Players were instructed to jump "as fast and high as possible" (Lockie, 2018). Data were recorded with force plates (PASPORT force plate, PS-2141, PASCO Scientific, California) using SPARKvue software (version 4.6.1, USA), exported to an Excel spreadsheet (version 16, Microsoft, USA), and processed in Matlab (version 9.6, USA). The following variables were analyzed: jump height (JH), obtained through impulse-momentum (Xu et al., 2023), peak force (PFC), peak power (PP), braking impulse (BI), and concentric impulse (CI).

Change of Direction

The modified 505 test (m505) (Taylor et al., 2019) was applied during the second shift of the second session of week 1. A practice attempt was conducted to familiarize players with the exercise dynamics. Two photoelectric barriers (Chronojump software, version 2.3.0-79, Barcelona, Spain) and a marker on the ground 0.5 m from them were set up. Players were instructed to run as fast as possible for 5 m, turn 180°, and return to the starting point. Three attempts were made, changing direction with the right leg (Dos'Santos et al., 2020). The best recorded time was used for analysis.

Statistical Analysis

The normality of the variables was assessed using the Shapiro-Wilk test, and the normality assumption was met ($p > 0.05$). All descriptive statistics for anthropometric variables and physical performance will be expressed as means and standard deviations. A LASSO (Least Absolute Shrinkage and Selection Operator) regression was performed due to its robustness against multicollinearity and its ability to select and eliminate redundant variables, which enhances the precision and interpretability of the models (Kipp & Warmenhoven, 2022). All variables were scaled before entering the model (centered [mean zero] and standardized [standard deviation 1]). The data were split into 70% for the training set and 30% for the test set. A 5-fold cross-validation was used with 100 values of "lambda" ranging from 0.001 to 100. The root mean square error (RMSE) metric was employed to select the lambda that minimized this metric. The model was then evaluated on the test set, and the results will describe the RMSE and the coefficient of determination (R^2). Cohen's f^2 is appropriate for calculating the effect size (ES) within a multiple regression model in which the independent variable of interest and the dependent variable are both continuous. Cohen's f^2 was calculated as previously described (Selya et al ., 2012) . The following threshold values for ES reported as f^2 were employed: ≥0.02 as small, ≥0.15 as medium, and ≥0.35 as large. All statistical analyses were conducted using RStudio, with the following libraries: *rsample* for partitioning the training and test sets; *glmnet* and *caret* for performing the LASSO regression.

Results

Regarding anthropometric variables, the average age of the players was 16.06 ± 0.78 years, with an average height of 1.69 ± 0.06 meters. The Age Peak Height Velocity (APHV) averaged 1.05 ± 0.65, suggesting that participants have already passed through the pubertal growth spurt. Skinfolds measured at the thigh and calf (SkT and SkC) had means of 8.41 ± 2.86 mm and 5.31 ± 2.63 mm, respectively. The thigh circumference (CcT) averaged 47.7 ± 3.38 cm, while the calf circumference (CcC) averaged 35.3 ± 2.07 cm. Body mass averaged 58.3 ± 8.04 kg, with an average fat mass of 8.99 ± 3.05 kg and a fat-free mass (FFM) of 47.07 ± 5.70 kg. Average values for bone mineral content in the lower limbs (BMCLL) and total bone mineral content (BMC) were 1091 ± 141 g and 2239 ± 323 g, respectively (table 1).

For physical performance variables, results showed an average time of 2.58 ± 0.11 seconds for the change of direction (COD) and 1640 ± 258 N for peak isometric force (PFI). The impulse at 100 ms (I100) was 91.2 ± 15.22 N·s, while jump height (JH) averaged 0.33 ± 0.04 meters. The concentric peak force (PFC) averaged 1469 ± 201 N, and peak power (PP) reached 3248 ± 531 W. For braking impulse (BI), the average was 68.0 ± 22.19 N, and the average concentric impulse (CI) was 155 ± 30.7 N·s (table 2).

Table 1.
Descriptive Statistics of Anthropometric and Physical Performance Variables

Anthropometric variables			PP variables		
	M	±SD		M	±SD
Age (y)	16.06	0.78	COD	2.58	0.11
Height (m)	1.69	0.06	PFI (N)	1640	258
APHV	1.05	0.65	I100 (N*s)	91.2	15.22
SkT (mm)	8.41	2.86	JH (m)	0.33	0.04
SkC (mm)	5.31	2.63	PFC (N)	1469	201
CcT (cm)	47.7	3.38	PP (W)	3248	531
CcC (cm)	35.3	2.07	BI (N*s)	68.0	22.19
BM (kg)	58.3	8.04	CI (N*s)	155	30.7
FM (kg)	8.99	3.05			
FFMLL (kg)	17.36	2.29			
FFM (kg)	47.07	5.70			
BMCLL (gr)	1091	141			
BMC (gr)	2239	323			

Abbreviations: PP: physical performance; APHV: age peak height velocity; SkT: thigh skinfold; SkC: calf skinfold; CcT: thigh circumference; CcC: calf circumference; BM: body mass; FM: fat mass; FFMLL: lower limb free fat mass; FFM: total body free fat mass; BMCLL: lower limb bone mineral content; BMC: total bone mineral content; COD: change of direction; PFI: peak force IMTP; I100: impulse 100ms; JH: jump height CMJ; PFC: peak force CMJ; PP: peak power CMJ; BI: braking impulse CMJ; CI: concentric impulse CMJ.

Table 2.
LASSO Regression Model for Predicting Physical Performance Variables Based on Anthropometric and Body Composition Variables

	COD	PFI	I100	JH	PFC	PP	BI	CI
R^2	0.68	0.78	0.50	0.39	0.64	0.64	0.05	0.75
f^2	2.1**	3.5**	1.0**	0.6**	1.8**	1.8**	0.1*	3.0**
RMSE	0.055	173	14.8	0.036	99	399	21	21
Variables	β	β	β	β	β	β	β	β
Intercept	2.58	1612	90.1	0.34	1471	3357	66.1	160
Age (y)	-0.01		1.97	-0.0002		-89.8		
Height (m)		20.2	1.09					
APHV		0.19				36.8		
SkT (mm)			-1.21	0.003		-19.2		
SkC (mm)		-14.7	-0.66	-0.01				
CcT (cm)		59.0	3.23	0.01		23.8	6.28	8.83
CcC (cm)			-0.72		6.28	186	6.16	
BM (kg)					89.6			
FM (kg)	0.03			-0.02		-204		
FFMLL (kg)				0.01		265		0.01
FFM (kg)		80.0			43.5	118	1.42	
BMCLL (gr)			1.57					13.1
BMC (gr)		0.77	2.99					

Abbreviations: R^2 coefficient of determination; RMSE root mean square error; β beta coefficient; f^2 Cohen's effect size; APHV age peak height velocity; SkT thigh skinfold; SkC calf skinfold; CcT thigh circumference; CcC calf circumference; BM body mass; FM fat mass; FFMLL lower limb free fat mass; FFM total body free fat mass; BMCLL lower limb bone mineral content; BMC total bone mineral content; COD change of direction; PFI peak force IMTP; I100 impulse 100 ms IMTP; JH jump height CMJ; PFC peak force CMJ; PP peak power CMJ; BI braking impulse CMJ; CI concentric impulse CMJ. ES *medium; **ES large.

The results of the LASSO regression model show the significant predictor variables for various physical performance tests of young soccer players, evaluated through different measurements of strength, power, and change of direction ability.

For COD capacity, the model explains 68% of the variability in performance (R^2 = 0.68), with a root mean square error (RMSE) of 0.055. Among the predictor variables, the CcC stands out with a beta coefficient (β) of 59.0, indicating that larger calf circumferences are associated with improved change of direction ability. Conversely, the SkT has a negative coefficient (β = -1.21), suggesting that a greater skinfold thickness is related to poorer performance in this test.

Regarding the PFI, the model has an R^2 of 0.78 and an RMSE of 173. Height is a significant variable with a β of 20.2, indicating that greater height is associated with a higher peak force. Additionally, FFM showed a strong positive influence (β = 80.0), confirming the importance of muscle mass in developing maximum strength.

For I100, the model explains 50% of the variability (R^2 = 0.50). The SkT and SkC stand out with negative beta coefficients (β -1.21 and β=-0.66, respectively). This result indicates the negative effect of skinfold thickness on maximum force production. On the other hand, the beta coefficients for CcT (β=3.23), BMCLL (β=1.57), and BMC (β=2.99) indicate a positive influence on the performance of this variable. This finding underscores the importance of muscular and bone structure in the early phases of force production.

Regarding JH, the model explains 39% of the variability (R^2 = 0.39), with an RMSE of 0.036. The SkC and FM have a negative effect on jump height (β = -0.01; β = -0.02, respectively), while CcC and FFMLL show a positive effect (β = 0.01). These results highlight the significant influence of muscular dimensions and fat mass on jump performance, suggesting the need to consider them in training and assessment programs.

The PFC also showed a high predictive capability with an R^2 of 0.64, with BM being the most influential variable (β = 89.6), followed by FFM (β = 43.5). This reinforces the idea that greater body mass and muscular dimensions contribute to higher force production.

Regarding PP, the model explains 64% of the variability, highlighting the positive influence of the PHV (β = 36.8), CcT (β = 23.8), CcC (β = 186), FFMLL (β = 265), and FFM (β = 118). Meanwhile, FM and SkT present a significant negative effect (β = -19.2; β = -204), indicating that body fat accumulation negatively impacts the ability to generate power. Finally, both BI and CI are positively influenced to varying degrees by variables related to total and regional fat-free mass. Thus, together, the findings demonstrate the influence of muscular and bone structure as well as fat accumulation on static and dynamic strength production.

Discussion

The aim of the study was to analyze the impact of body composition, anthropometric variables, and maturation states on physical performance in young football players. Our findings highlight the varied influence of independent variables as predictors of physical performance in young footballers.

In football, high-intensity horizontal movements play a crucial role in the success of actions (Faude et al., 2012). It has been described that these movements are influenced by the anthropometric and body composition characteristics of the players (Atakan et al., 2017). Furthermore, the use of this information has been proposed as part of the talent selection process (Toselli et al., 2024). In this context, the COD (change of direction) ability may be influenced by lean mass and fat mass indices. An interesting consideration is the proportion of lean mass that enhances performance. In this regard, Stanković et al. (2023) hypothesize that high levels of muscle mass could affect actions involving changes in direction. However, most of the studies consulted conclude that higher lean mass indices favor these types of actions. Our findings are contradictory in this respect. While it is true that performance in COD is explained by anthropometric and body composition variables to 68% with a large effect size (f^2 2.1), lean mass seems to have no implication in this result, with fat mass showing a greater effect (β = 0.03). Lean mass total, and particularly lean mass of the lower limb, does not influence this association.

In the present study, a significant relationship was observed between body composition and anthropometric variables with force production in isometric tests. The analyses revealed a coefficient of determination (R^2) of 0.78 for peak force with a large effect size (f^2 2.1), indicating that a high percentage of the variability in maximum strength can be explained by these variables. In contrast, the R^2 of 0.50 for the 100 ms impulse suggests a moderate influence. However, a large effect size (f^2 1.0), suggests that the predictor variables have a considerable relationship with performance on this measure. This discrepancy highlights the need to interpret both indices together to obtain a more complete picture of the impact of the variables on physical performance The beta coefficients (β) of individual variables highlight their differential impact on isometric strength: the calf skinfold had a β of -14.7, suggesting a negative relationship, indicating that higher skinfolds are associated with lower levels of strength. On the other hand, the thigh perimeter showed a β of 59.0, and lean mass a β of 80.0, both indicating a positive and significant relationship, where greater measurements in these variables are associated with a higher peak force. Bone mineral content, with a β of 0.77, also showed a positive association, although less pronounced. These findings underscore the importance of lean mass and thigh perimeter in optimizing isometric strength, while reducing subcutaneous fat may be crucial for improving performance.

Recent studies underscore the significant influence of body composition on power tests, especially in dynamic efforts requiring explosive strength production. In this context, lower limb muscle mass has proven to be a key factor, facilitating a higher generation of power relative to total body mass (Toselli et al., 2022). This finding suggests that soccer players with a higher proportion of lean mass have a competitive advantage in terms of strength production. However, scientific literature still presents discrepancies. For instance, Ishida et al. (2021) reported significant correlations between lean mass percentage and strength generation ability ($r=0.50$, $p<0.05$), while fat mass showed an inverse correlation ($r=-0.37$). These results reinforce the notion that fat mass acts as an additional load that does not contribute to power production, which has been confirmed in studies demonstrating its negative impact on vertical jump height, in contrast to the positive influence of lean mass (Esco et al., 2018).

Our study's results align with this description. Significant relationships are observed between body composition and anthropometric variables with different measures of strength and power. For peak concentric strength, the coefficient of determination R^2 of 0.64 and there is a large effect size (f^2 1.8), suggests that the analyzed variables explain a considerable proportion of the variability in this measure. Beta coefficients indicate that leg circumference (β = 6.28), total body mass (β = 89.6), and lean mass (β = 43.5) have a significant positive influence on peak concentric strength, highlighting the importance of lean mass and muscle size in strength generation.

Regarding peak power, also with an R^2 of 0.64 and there is a large effect size (*f^2 1.8)*, the results show varied influences of the variables. Negative coefficients for thigh skinfold (β = -19.2) and fat mass (β = -204) suggest that greater subcutaneous fat thickness and higher fat mass are associated with lower power. In contrast, thigh circumference (β = 23.8), leg circumference (β = 186), and measures of lean mass both in the lower limb (β = 265) and total body (β = 118) have a positive association, indicating that larger muscle dimensions and lean mass may enhance explosive capacity.

Finally, concentric impulse showed an R^2 of 0.75 and there is a large effect size (f^2 3.0), indicating a high predictive capacity of the considered variables. Thigh circumference (β = 8.83), lean mass in the lower limb (β = 0.01), and bone mineral content in the lower limb (β = 13.1) have a positive influence on concentric impulse, suggesting that greater muscle mass and adequate bone mineralization significantly contribute to impulse generation.

In summary, these findings highlight the importance of lean mass and muscle size in strength and power production, while reducing subcutaneous fat and ensuring adequate bone mineralization can enhance performance in measures of isometric strength and power.

Our findings show that the APHV has a notable influence on physical performance, evidenced by a beta coefficient (β) of 0.19 for the isometric peak force (IMTP) and 36.8 for the peak power (CMJ). These relationships, with R^2 values of 0.78 and 0.64 respectively with a large effect size (and there is a large effect size (f^2 1.0 and 1.8, respectively), highlight how APHV contributes to performance in these tests.

Comparing these results with existing literature reveals an interesting contrast. The literature suggests that APHV can significantly impact strength and power development due to hormonal changes and body composition shifts occurring during the pubertal growth spurt. For example, studies such as those by Malina et al. (2004) and Till et al. (2017) have noted that peak height velocity is associated with improvements in strength and power, but often report a more pronounced effect during or immediately after APHV, which could be related to rapid neuromuscular adaptation and changes in muscle mass. In contrast, the beta coefficient of 0.19 for IMTP in our study suggests a relatively moderate influence of APHV on isometric strength, which might indicate that other factors, such as muscle maturation and training experience, play a more significant role in this measure. On the other hand, the β of 36.8 for CMJ suggests a more significant influence of APHV on explosive power, which is consistent with previous findings suggesting a greater sensitivity of power performance to hormonal and growth changes during adolescence (Albaladejo-Saura et al., 2021).

In summary, while our findings confirm that APHV impacts physical performance, the magnitude of this influence varies according to the performance measure and may be moderated by additional factors such as muscle maturation and training adaptation. This variability in the effects of APHV highlights the need to consider multiple aspects of physical development and maturation when evaluating performance in different physical tests.

Conclusion

The results of this study highlight the complexity of the interaction between body composition, anthropometric variables, and maturational states in the physical performance of young soccer players. While fat-free mass and anthropometric measures such as thigh and leg circumference proved to be key predictors of peak force and power, body fat was negatively associated with the ability to generate explosive force. Additionally, APHV showed a variable impact on performance, with a more pronounced influence on peak power than on isometric strength. These findings underscore the importance of considering both body composition and biological development to optimize physical performance in young soccer players, suggesting that personalized training and talent selection should account for these individual differences. However, the moderate influence of biological maturation on certain measures suggests that other factors, such as training experience, could play a critical role. Future research could focus on identifying how these variables interact throughout athletic development to maximize long-term performance.

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