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RELATIONSHIP BETWEEN BODY COMPOSITION AND VERTICAL JUMP PERFORMANCE IN YOUNG SPANISH SOCCER PLAYERS

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ABSTRACT

The aim of this study was to examine the relative contribution of body composition to vertical jump performance in young Spanish soccer players. Seven hundred and twenty-three soccer players aged 7 to 19 years (156 ± 17 cm; 47.8 ± 15.1 kg) who had prior soccer experience (≥ 3 yrs) and had trained for ~2 h·day^{-1}, 4 days·week^{-1} were selected. Anthropometric measurements were taken and three vertical jumps were performed: squat jump (SJ); counter-movement jump (CMJ); counter-movement jump with arm swing (CMJa). Multiple regression equations revealed that age (SJ, β = 0.635; CMJ, β = 0.687, CMJa, β = 0.674) and fat mass (SJ, β = -0.203; CMJ, β = -0.215, CMJa, β = -0.196) in children and age (SJ, β = 0.431; CMJ, β = 0.496; CMJa, β = 0.536), appendicular lean body mass (SJ, β = 0.214; CMJ, β = 0.160) and waist circumference (SJ, β = -0.187; CMJ, β = -0.119) in adolescents were the body composition variables that better explained vertical jump height. Thus, in addition to age and fat mass for children, we observed for the first time that appendicular lean body mass and waist circumference in adolescents could be taken into consideration as body composition predictors to assess and improve vertical jump performance in young soccer players.

Keywords: jump ability, body size, children and adolescents

INTRODUCTION

The development of motor skills in pre-adolescence and adolescence is affected by a wide variety of factors, one of which is training (26). Jump ability is a motor skill that depends on muscle contractile capacity, stretch-shortening cycle (SCC), and high power production (6, 15).

In childhood and adolescence, lower levels of vertical jump performance have been found to be a predictor of inactivity (14). Thus, jump ability (both vertical and long jumps) is a common test in schools (7), but jump tests have also been used in sport performance. In soccer, the vertical jump has been used to monitor performance (30), to compare training loads (3, 17), and to prevent injuries (23), though for young players, it has been mainly utilized to identify talented athletes (35, 39). Moreover, squat jump (SJ) and counter-movement jump (CMJ) height have been associated with performance success in this sport (5, 12).

Nonetheless, the interpretation of jump ability performance during childhood and adolescence in educational or sport performance environments is often based simply on a chronological age assessment. However, maturation status should be taken into consideration (25) by taking into account other biological or body composition parameters (8).

Body size has been described as a confounding variable in vertical jump performance (22), and several studies have attempted to categorize those body composition variables which better explain jump ability during childhood and adolescence. Markovic and Jaric (20, 21) identified six variables as jump predictors: maturation, age, gender, race, physical activity level, and motor skills. Further, several studies have attempted to identify novel body composition variables from a variety of young populations: Serbians, aged 12 to 17 years (25); Norwegians, aged 7 to 11 years (13); French youth, aged 11 to 16 years (38); and English youth, aged 10 to 15 years (37). Finally, Aouichaoui et al. (4) found a positive correlation between total fat free mass (FFM) and vertical jump performance in a Tunisian population between the ages of 7 and 13 years, supporting the body size paradigm (22).

Therefore, the aims of this study were first to quantify the relationship between body composition variables and vertical jump performance. Secondly, to establish reference values for vertical jump in young Spanish soccer players between the ages of 7 and 19 years. We hypothesized that the anthropometric measurement of skeletal muscle and/or appendicular lean body mass could be predictors of vertical jump performance in childhood and/or adolescence. Furthermore, these variables would serve as non-invasive measurements to take into consideration when assessing vertical jump performance of young soccer players.

METHODS

Seven hundred and twenty-three Spanish males between 7 and 19 years of age took part in the present study. The participants had at least 3 years of prior soccer experience and had trained for ~2 $h \cdot day^{-1}$, 4 $days \cdot week^{-1}$ (including a weekly competition) in Madrid, Spain. Further, they were familiarized with vertical jump tests, and those without previous experience or who were unable to properly perform any of the required tests were excluded. No participants had any previous history of metabolic disease, and no participants were taking any type of medication.

Participants were divided into the following age groups, accordingly to age categories of the Spanish young soccer leagues: (A) under the age of 10 (n = 130), (B) between the ages of 10 and 12 (n = 147), (C) between the ages of 13 and 14 (n = 205), (D) between the ages of 15 and 16 (n = 130), (E) between the ages of 17 and 19 (n = 111). Before agreeing to participate in the study, prospective participants' guardians were fully informed of the procedure and any possible discomforts associated with the study. They then gave their written informed consent. The study was in accordance with the University of Alcala´s Ethics Committee and the latest version of the Declaration of Helsinki.

Participants were tested during their regular training schedules (between 6 and 9 PM) in the preparation period of the season. Environmental conditions were maintained (20 ± 1 ºC; 56 ± 5 %), and participants were encouraged not to eat or drink for 2 hours before the study.

Body composition assessments

Anthropometry was the method used to measure body composition. Standing height was measured by a stadiometer to the nearest 0.1 cm, and body mass was measured on a digital scale with an accuracy of 0.1 kg (Harpenden Portable Stadiometer, Holtain Ltd, Crosswell, Crymych, Pembs, United Kingdom). Skinfold thicknesses on the right side of the body were measured to the nearest 0.2 mm using a Holtain Ltd skinfold caliper (Crosswell, UK). All materials were calibrated, and the same ISAK accredited specialist took all measurements. In order to assess the reliability of each measure, technical error of measurement (TEM%) was calculated for all skinfolds, triceps (1.1%), subscapular (1.6%), biceps (2.0%), iliac crest (1.9%), supraspinale (2.2%), abdominal (2.1%), front thigh (2.3%), medial calf (1.2%); and circumferences taken, relaxed arm (0.3%), waist (0.3%), hips (0.4%), gluteal (0.3%), and calf (0.6%).

Fat mass (FM) (R^2 = 0.77) (31, 32, 34), appendicular lean body mass (corrected muscle girth model) (ALBM) (R^2 = 0.93) (28), and skeletal muscle mass (SMM) (R^2 = 0.97) (27) were obtained from previously reported formulas.

Vertical Jump Tests

After anthropometric measurements, a warm-up routine consisted of low-intensity aerobic exercises (3 minutes), dynamic stretching (5 minutes), and single and rebound jumps (2 minutes) was completed. Then, participants performed three protocols of vertical jump tests with proven reliability and validity (19): squat jump (SJ), counter-movement jump (CMJ), and Abalakov test or counter-movement jump with arm swing (CMJa). Based on a pilot study performed previously, two attempts were carried out for each type of test, allowing 1 minute of rest between attempts of the same test and 2 minutes between different vertical jump tests to ensure total recovery.

The SJ is composed of a concentric phase preceded by an isometric phase with 90º knee flexion. To prevent the use of elastic energy, participants stayed in the isometric phase for 3 seconds. Also, they kept their hands on their hips to avoid arm swing impulse when they were required to perform a maximal jump (15). No sinking or countermovement was allowed.

The CMJ is composed of an initial negative or eccentric phase that finishes with the subject in the squat position with 90º knee flexion and is followed by an immediate concentric or positive phase to perform a maximal jump. Participants kept their hands on their hips.

Finally, the CMJa consists of a CMJ in which arm swing is permitted. All participants performed the swing by beginning with their arms extended in the anatomical position. Any other arm swing was not permitted.

All trials were video recorded to ensure proper technique. Vertical jump performances were collected by an infrared photocell system called Optojump (Microgate SRL, Bolzano, Italy) which was connected to a portable computer with the adequate software (Optojump software, version 3.01.0001) (11).

Statistical Analysis

The SPSS statistical software package (version 17.0) was used, and all results obtained were presented as mean ± SD. The Kolmogorov-Smirnov test was used to assess the normality of the anthropometric and vertical jump variables ($p > 0.05$). One-way ANOVA was used to analyze the comparisons between age groups and Bonferroni was used as post hoc test. Intraclass correlation coefficients (ICCs) were also calculated to confirm the concordance of the measurements.

Pearson correlation and partial correlation controlling for age were used to assess association between anthropometric and vertical jump parameters ($p < 0.01$; $p < 0.05$). Subsequently, a linear regression between vertical jump performance variables and body composition (SMM, ALBM, and FFM) was performed. Finally, three multiple regressions were calculated to obtain the body composition variables ($p < 0.05$) that predict vertical jump height performances for children, adolescents, and both.

RESULTS

Effects of categories on Anthropometric and Vertical Jump variables

Mean and standard deviation data from the anthropometric and vertical jump variables were calculated and are presented in Table 1. Children and adolescents showed statistically significant differences for demographic variables (age, height, and weight) ($p < 0.05$) between all categories, as well as for SMM, ALBM, and FFM ($p < 0.01$). Nevertheless, the FM variable was not statistically different between groups A, B, and C, but significant relationships were found between these groups and the remaining ones (D and E; $p < 0.05$). Also, waist circumference (WC) showed a progressive and significant increase between categories A, B, C, and D, whereas no significant differences were found between categories D and E.

Finally, vertical jump repeatability (ICC; 95% CI) was calculated for all protocols: SJ (0.995, 0.994-0.996), CMJ (0.994; 0.993-0.995), and CMJa (0.996; 0.995-0.997), and significant differences were also found in all vertical jump tests among all age groups ($p < 0.001$) (Table 1).

Associations between Anthropometric and Vertical Jump variables

Relationship between the anthropometric and vertical jump variables was calculated through a Pearson correlation coefficient (data not presented). Given that Pearson correlation showed strong correlations between anthropometric and vertical variable measurements ($p < 0.01$), a partial correlation was performed controlling for age (Table 2). In partial correlation, a reduction in all coefficients was detected compared to Pearson's correlation. Also, a significant association between heights of the three vertical jump tests and body composition variables of height, weight, FM, and FFM ($p < 0.01$) was observed. SMM, ALBM, and waist circumference were also significantly related, though this relationship was less pronounced ($p < 0.05$).

Linear Regression model for Vertical Jump Height

Figure 1 showed linear contribution of the independent body composition variables (SMM, ALBM, and FFM) to the vertical jump tests (SJ height, CMJ height, and CMJa height) of the whole cohort of participants. A moderate to strong relationship ($R^2 = 0.44$ to 0.61) between the SMM, ALBM, and FFM and the vertical jump tests was observed, though the FFM has the strongest relationship with the tests when compared to the SMM and ALBM.

Table 1. Mean ± SD of anthropometric and vertical jump variables compared by category.

	A		**B**		**C**		**D**		**E**	**Total**
	(N = 130)		*(N = 147)*		*(N = 205)*		*(N = 130)*		*(N = 111)*	*(N = 723)*
	Mean±SD	Sig.	Mean±SD	Sig.	Mean±SD	Sig.	Mean±SD	Sig.	Mean±SD	Mean±SD
Age (yr)	9.1 ±0.7	BCDE**	11.1 ±0.6	CDE**	12.9 ±0.6	DE**	15.1 ±0.7	E**	17.3 ±0.9	13.3 ±3.1
Height (cm)	130 ±7	BCDE**	144 ±7	CDE**	156 ±9	DE**	169 ±7	E**	174 ±7	156 ±17
Weight (kg)	31.2 ±6.1	BCDE**	37.1 ±6.4	CDE**	45.7 ±9.2	DE**	57 ±10	E**	66.0 ±7.6	47.7 ±15
BMI	17.3 ±2.3	CDE**	17.8 ±2.2	CDE**	18.5 ±2.5	DE**	19.9 ±2.3	E**	21.7 ±2.1	19 ±2.5
WC (cm)	64.3 ±8.5	CDE**B*	68.0 ±9	CDE***	72.6 ±11	DE**	78.1 ±11		80.8 ±10	72.8 ±11
%FM	17.3 ±6.4	E**D*	18.5 ±5.9	DE**	18.4 ±6.7	DE**	15.0 ±4.5		13.9 ±4.7	16.7 ±6.1
FM (kg)	5.7 ±3.2	CDE**B*	7.1 ±3.3	E**CD*	8.7 ±4.4		8.8 ±4.3		9.3 ±4.0	8.0 ±3.9
FFM (kg)	13.9 ±4.7	BCDE**	18.6 ±5.1	CDE**	27.2 ±8.6	DE**	42.0 ±8.7	E**	52.1 ±7.0	31 ±16
SMM (kg)	15.8 ±3.1	BCDE**	19.0 ±3.4	CDE**	22.9 ±6.6	DE**	28.3 ±4.9	E**	32.9 ±3.7	24 ±7.7
ALBM (kg)	14.4 ±2.8	BCDE**	17.1 ±3.0	CDE**	20.6 ±6.7	DE**	25.2 ±4.4	E**	29.2 ±3.4	21.5 ±7
SJ Height (cm)	17.0 ±2.6	BCDE**	19.5 ±3.1	CDE**	21.6 ±3.4	DE**	25.6 ±5.1	E**	31.0 ±3.7	22.9 ±6.0
CMJ Height (cm)	19.3 ±3.0	BCDE**	22.7 ±3.8	CDE**	25.0 ±3.8	DE**	29.8 ±4.9	E**	36.2 ±4.2	26.6 ±7.0
CMJa Height (cm)	22.5 ±3.7	BCDE**	27.0 ±4.6	CDE**	29.6 ±4.9	DE**	35.9 ±5.6	E**	42.9 ±4.9	31.6 ±8.4

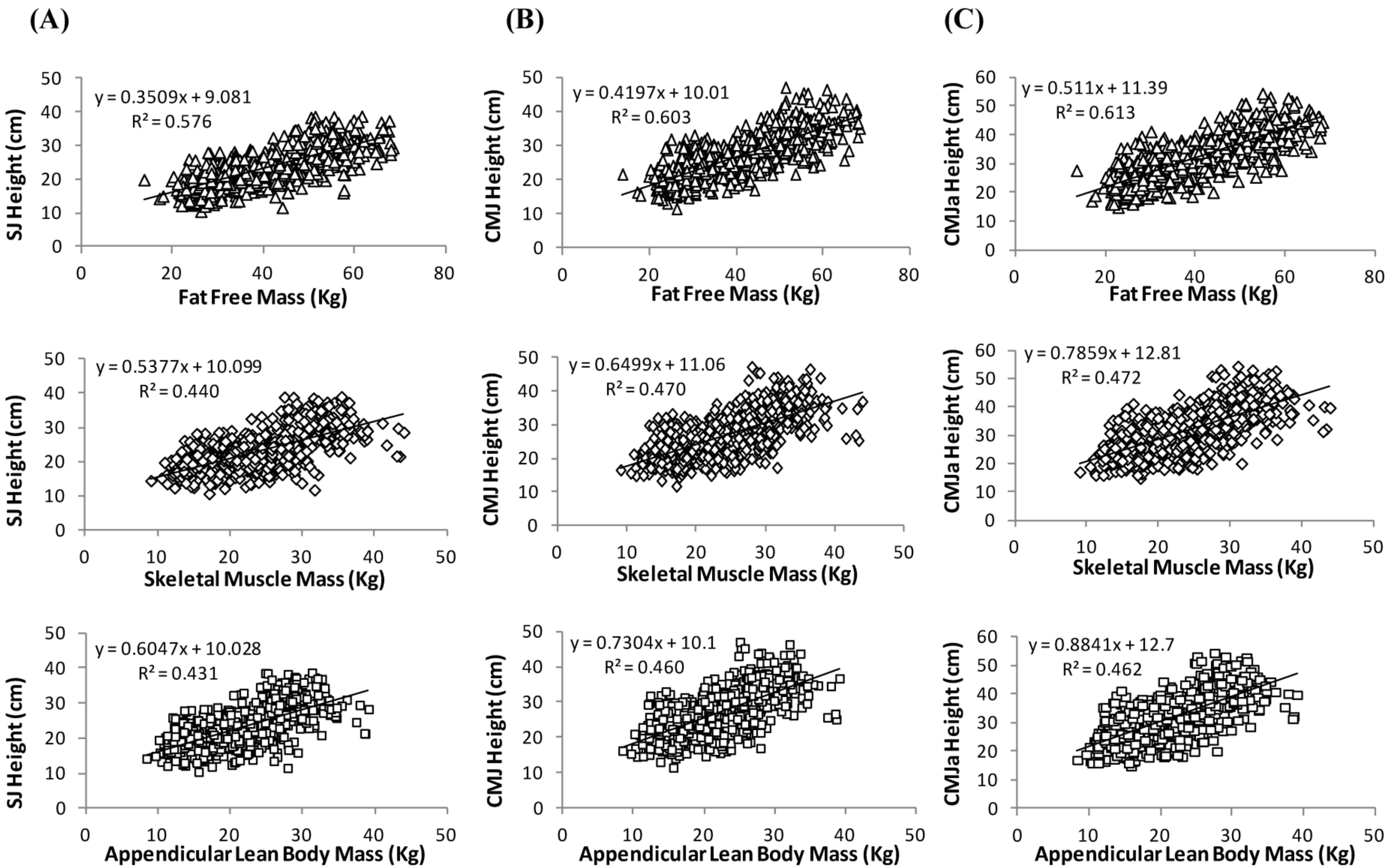
A, under 10 yrs; B, under 13 yrs; C, under 15 yrs; D, under 17 yrs; E, under 19 yrs.
*SD, standard deviation; Sig. statistical significance ** $p < 0.001$; * $p < 0.05$.*
BMI, Body Mass Index; WC, waist circumference; FM, fat mass; FFM, fat free mass; SMM, skeletal muscle mass; ALBM, appendicular lean body mass; SJ, squat jump; CMJ, counter-movement jump; CMJa, counter-movement jump with arm swing.

Table 2. Partial correlation coefficient controlling for age.

	Height *(cm)*	Weight *(kg)*	WC *(cm)*	FM *(%)*	FM *(kg)*	FFM *(kg)*	SMM *(kg)*	ALBM *(kg)*
SJ Height (cm)	0.173**	0.091*	-0.073*	-0.347**	-0.232**	0.372**	0.076*	0.083*
CMJ Height (cm)	0.169**	0.098*	-0.081*	-0.334**	-0.214**	0.368**	0.093*	0.101*
CMJa Height (cm)	0.203**	0.099*	-0.082*	-0.359**	-0.236**	0.389**	0.092*	0.104*

*Significance: ** $p < 0.01$; * $p < 0.05$.*
WC, waist circumference; FM, fat mass; FFM, fat free mass; SMM, skeletal muscle mass; ALBM, appendicular lean body mass; SJ, squat jump; CMJ, counter-movement jump; CMJa, counter-movement jump with arm swing.

Figure 1. Single linear regression between SMM, ALBM, and FFM and (A) SJ height, (B) CMJ height, and (C) CMJa.



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Multiple Regression model for Vertical Jump Height

Finally, the relative contribution of each independent body composition variable in the groups of children, adolescents, and the two combined to vertical jump height in the SJ, CMJ, and CMJa tests was examined (Table 3). Multiple prediction models for children indicated that age and fat mass were the best variables for explaining height changes in the three vertical jump tests, while the models for adolescents showed that age, ALBM, and waist circumference were the best predictors of the SJ and CMJ height. But, WC and ALBM was excluded from the CMJa height model. Finally, the prediction model from the whole cohort of players (7 to 19) years showed that age, FM, ALBM, and waist circumference were the variables which best predicted SJ and CMJ height. However, ALBM and waist circumference were excluded from the CMJa height model.

Table 3. Multiple regression equations predicting vertical jump height variables

		SJ Height			CMJ Height			CMJa Height		
		β	SEE	R^2	β	SEE	R^2	β	SEE	R^2
Children (7-13 yrs)	Constant	5.490*	2.922	0.360	4.495*	3.272	0.436	4.610*	4.097	0.410
	Age	0.635			0.687			0.674		
	FM	-0.203			-0.215			-0.196		
Adolescents (13-19 yrs)	Constant	2.461*	3.495	0.266	0.223*	4.662	0.306	-0.584*	5.369	0.288
	Age	0.431			0.496			0.536		
	ALBM	0.214			0.160					
	WC	-0.187			-0.119					
All (7-19 yrs)	Constant	3.761*	3.587	0.619	2.941*	3.853	0.671	0.455*	4.635	0.672
	Age	0.801			0.824			0.840		
	FM	-0.091			-0.098			-0.094		
	ALBM	0.097			0.085					
	WC	-0.131			-0.081					

SJ, squat jump; CMJ, counter-movement jump; CMJa, counter-movement jump with arm swing; SEE, Standard error of estimate; FM, fat mass; ALBM, appendicular lean body mass; WC, waist circumference.
Function 1 (children): Vertical jump (SJ, CMJ or CMJa) = constant + (age coefficient x age) + (FM coefficient x FM).
Function 2a (adolescents): Vertical jump (SJ or CMJ) = constant + (age coefficient x age) + (ALBM coefficient x ALBM) + (WC coefficient x WC).
Function 2b (adolescents): Vertical jump (CMJa) = constant + (age coefficient x age).
Function 3a (7-19 yrs): Vertical jump (SJ or CMJ) = constant + (age coefficient x age) + (FM coefficient x FM) + (ALBM coefficient x ALBM) + (WC coefficient x WC).
Function 3b (7-19 yrs): Vertical jump (CMJa) = constant + (age coefficient x age) + (FM coefficient x FM).
** $p<0.001$*

DISCUSSION

Vertical jump is a relevant skill for assessing motor development during preadolescence and adolescence (14) as well as for examining soccer performance (5, 39). Body size has been proposed as a confounding factor in vertical jump performance during childhood and adolescence (22, 25), and several variables related to body composition have been found to be predictors of vertical jump performance (4, 20, 21): age, height, weight, and fat free mass. Therefore, we hypothesized that skeletal muscle mass and/or appendicular lean body mass may influence and improve the existing model for predicting vertical jump height in young Spanish soccer players.

Puberty involves important bodily and physiological changes in humans and could explain the significant increase in all anthropometric parameters that we found in this study (29). As expected, the association between fat mass and male pubertal onset was nonlinear (Table 1), and the progressive increase of the fat mass began after group C (under 15 yrs), in accordance with the beginning of puberty in boys (~13 years) (36); thus, a high fat mass in this age range could be explained as "hormonal preparation" for puberty (1, 2). Accordingly, skeletal muscle mass showed the largest increase (5.4 kg) between groups B (under 13 yrs) and C (under 15 yrs), whereas appendicular lean body mass reported a more progressive and significant increase.

It has been suggested that between the ages of 13 and 15 years, young soccer players obtain their best performance in vertical jump tests (18, 25). Thus, we expected to find greater differences between groups C and D (under 15 and under 17, respectively). However, in Table 1, it can be observed that within the progressive and statistically significant increase in vertical jump heights of the three tests, the greatest improvement in performance was detected between groups D and E (under 17 and under 19, respectively) for all tests, even though the increase between group C and D (under 15 and under 17, respectively) was also considerable (5.4 *vs.* 4.0 cm, SJ; 6.4 *vs.* 4.8 cm, CMJ; 7.0 *vs.* 6.3 cm, CMJa; respectively).

Malina et al. (18) showed that vertical jump performance increased concurrently with sexual maturity. Moreover, testosterone and androgen hormones have been marked as the main factors responsible for the higher performance in young male soccer players during puberty (8), based on their anabolic effects, including bone and muscle development, loss of fat mass, and increased lean body mass (9). Concretely, testosterone levels increase significantly after Tanner stage 2 and until stage 5, but not before (10). Thus, those young soccer players in later stages of puberty with higher androgen levels had higher vertical jump performance in all tests compared to those in early or mid-puberty with lower androgen levels. Nevertheless, motor unit synchronization and recruitment must be also taken into consideration (16).

Therefore, the assessment of some variables related to the androgenic or anabolic changes produced during the maturation process would be useful in interpreting vertical jump performance (8, 18). Thus, a partial correlation controlling for age (Table 2) was carried out and revealed that FM and FFM were more strongly correlated with height variables of the SJ, CMJ, and CMJa tests ($p < 0.01$), while SMM and ALBM were less significantly correlated ($p < 0.05$). Subsequently, linear regressions among vertical jump test variables and FFM, SMM, and ALBM were performed, and they showed that FFM was a more accurate body composition variable for explaining vertical jump height compared to ALBM and SMM.

Finally, three multiple regression equations were calculated for children, adolescents, and the whole cohort. Previous data from a population of active Tunisian children between the ages of 7 and 13 years revealed that age, height, weight, and fat-free mass were the body composition variables that most accurately predicted vertical jump performance (4). Though our previous analysis seemed to support that idea, we did not find this relationship. In contrast, in table 3 it can be observed that for children between the ages of 7 and 13 years, age and FM were the best predictors of vertical jump height. The discrepancy in the two regression models might reside in the population differences. In this study, a population of seven hundred and twenty-three children who trained ~2 $h \cdot day^{-1}$, 4 $days \cdot week^{-1}$ and had 3 years of soccer experience was recruited. Likely, the degree of training and soccer expertise could explain why in this study height, weight, and FFM did not predict vertical jump height in the regression models performed (20, 21). On the other hand, for the adolescent group (table 3), age, ALBM, and waist circumference were the most accurate variables for predicting SJ and CMJ height, while for the CMJa, only age was included in the function. The inclusion of waist circumference, which has been related to abdominal fat among children and adolescent populations (33), suggests that trunk fat mass may play an important role in vertical jump prediction in pubertal soccer players. Likewise, lean body mass has been associated with maximal anaerobic power during growth (24), and fat free mass has been related to vertical jump performance in children as well (4). Thus, the identification of appendicular body mass as a body composition variable that predicts vertical jump height was not a surprise, even though it had not been observed previously. Lastly, we observed that age, FM, ALBM, and waist circumference were the body composition variables that predicted SJ and CMJ height for a population of young soccer players aged 7 to 19 years. It is also observed that age coefficient increased substantially ($\beta = 0.801$ *vs.* $\beta = 0.635$ *vs.* $\beta = 0.431$) compared to children and adolescents models in accordance with the influence of age in vertical jump performance (37).

PRACTICAL APPLICATIONS

Vertical jump is simple and recurrent skill measured by physical educators and strength and conditioning coaches during childhood and adolescent for several purposes. However, chronological age is the only variable used to categorize the result obtained in this population. According to the present study, it should take into consideration body composition variables such as fat mass, appendicular lean body mass and waist circumference in order to consider biological individuality of each children and/or adolescent and thus to perform a more adequate assessment of vertical jump skill and also improve it performance throughout the reduction of fat mass and waist circumference as well as the augment of appendicular lean body mass.

CONCLUSIONS

We conclude that for a Spanish population of children and adolescents between the ages of 7 and 19 who had prior soccer experience (≥ 3 yrs) and had trained for ~2 $h \cdot day^{-1}$, 4 $days \cdot week^{-1}$, age, fat mass, appendicular lean body mass, and waist circumference were identified as predictors of vertical jump height. Although. total skeletal muscle mass measured anthropometrically has not been identified as a predictor of vertical jump neither in childhood or adolescence, we found for the first time a relationship between appendicular lean body mass and waist circumference in the adolescent group (13 to 19 yrs) of young soccer players.

Thus, in addition to age, the anthropometric measure of fat mass in children and appendicular lean body mass and waist circumference in adolescents could be taken into consideration to perform a fairly assessment of vertical jump performance in an educational or performance perspective of young soccer players.

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