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Associations Between Anthropometric Variables, Maturation, Physical Activity and Jumping Performance in Adolescents: A Sex-Specific Analysis

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Abstract

Lower-limb strength is a health and performance indicator in adolescents, although its assessment often fails to account for the influence of sex and biological development. This study aimed to analyze the associations between anthropometric parameters, maturational status, and physical activity levels with jumping performance in adolescents. A cross-sectional study was conducted with male and female adolescents (mean age: 13.60 ± 1.50 years). Anthropometric variables, maturational status, and physical activity levels were assessed. Performance was measured using the Countermovement Jump (CMJ) and Standing Broad Jump (SBJ). In males, jumping performance was significantly associated with height ($p = 0.002$), lower-limb length ($p < 0.001$), and muscle mass ($p < 0.001$). However, fat mass emerged as a substantial factor, exhibiting a large effect size on performance ($p < 0.001$). Maturational status in males showed significant differences, with late maturers performing lower than on-time and early maturers ($p < 0.023$). In females, structural anthropometry and maturation showed limited-to-no significant associations with performance, except for a negative association with fat mass ($p < 0.035$) and a positive association between muscle mass and CMJ ($p < 0.020$). Active adolescents of both sexes performed significantly better than inactive ones in both CMJ and SBJ ($p < 0.011$). In conclusion, jumping performance in adolescents is characterized by marked sexual dimorphism. In males, greater height, lower-limb length, lower fat mass, and early maturation are positively associated with superior performance. Conversely, in females, these factors exhibit limited influence on jump outcomes.

Keywords: adolescents; stage of maturation; lower-limb length; performance; horizontal jump; vertical jump; sex

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1. Introduction

Lower-limb strength is an essential component of physical fitness during childhood and adolescence [1,2]. It is closely linked to adolescents' health and athletic performance, particularly in sports involving jumping [2]. In the field of health, muscular power has become one of the most widely used parameters for diagnosis and assessment [3,4], as a significant increase in power is associated with a lower prevalence of cardiometabolic risk factors [5], improved body composition [6], and enhanced physical function [6]. From an athletic performance perspective, the ability to generate force rapidly is directly linked to success in multiple sports disciplines [7,8]. This is especially true for those involving explosive movements such as jumps, sprints, or changes in direction, were lower-limb power serves as a key predictor of performance [9,10].

For years, lower-limb strength has been assessed using various jump tests [6,11]. Among these, the countermovement jump (CMJ) has become the most widely used method, both in the fields of health and athletic performance [11,12]. Its prevalence is due to its high validity, test–retest reliability, and ease of administration, making it an ideal test for use in school and sports settings [12]. Concurrently, the standing broad jump (SBJ) is also widely used to assess explosive strength in growing populations [11,13]. The SBJ is included in standardized physical fitness batteries, such as the ALPHA-Fitness Battery [14] or EUROFIT [15], which underscores its applicability due to its low cost and high reproducibility [16].

Despite their widespread use, the applicability of these tests is limited by certain anthropometric parameters that significantly influence jumping performance [17,18]. This relationship has been extensively documented in adult populations [17,19], where greater height and lower-limb length confer mechanical advantages, specifically longer lever arms and extended force application times, that favor propulsion during the concentric phase of the jump [19]. In addition, body composition is recognized as a critical determinant of physical fitness and neuromuscular performance during adolescence [6]. Previous research has suggested that increased levels of muscle mass are directly related to superior performance in tests of strength an explosive power [9,20]. Conversely, excessive fat mass accumulation acts as a mechanical constraint by compromising the efficient mobilization of the skeletal structure, altering the strength-to-weight ratio, and shifting the center of gravity [21,22]. Despite its importance, the scientific literature regarding adolescent populations remains limited and heterogeneous, making it difficult to draw definitive conclusions [17,19]. Previous studies have often attempted to address this issue without accounting for critical methodological limitations, such as the lack of control for sex or maturational stage [4,20].

Understanding the influence of biological maturation is essential because, during puberty, muscle tissue growth is mediated by increased concentrations of sex steroid hormones, growth hormone (GH), and insulin-like growth factor 1 (IGF-1) [23,24]. These factors are pivotal for success in motor actions requiring rapid force generation. This interaction is particularly relevant due to the sexual dimorphism that emerges during puberty, where males experience more pronounced musculoskeletal development, while in females, adipose tissue deposition predominates [25–27], differentially conditioning their mechanical jumping capacity.

These sexual discrepancies are deeply rooted in the distinct growth and development trajectories of each sex [25], which differ not only in nature but also in timing [28]. Specifically, key hormonal shifts during this period lead to accelerated increases in height and lower-limb length, particularly around the age at peak height velocity (APHV) [29,30]. Such changes in body proportions can alter movement mechanics by modifying body segments and lever arms [31], thereby influencing performance in jumping tests [19]. Crucially, biological maturation is a heterochronic process that varies significantly between sexes and individuals [32]. Females typically reach APHV between 11.4 and 12.2 years of age, while males reach it between 13.8 and 14.4 years [33]. Furthermore, intra-individual variability exists within each sex; consequently, individuals of the same chronological age may be at entirely different maturational stages [34,35], exhibiting significant differences in musculoskeletal development and force-generating capacity [23]. The importance of these parameters has been confirmed in previous studies analyzing other components of physical fitness, such as upper-limb muscle power, running speed, cardiorespiratory capacity, and agility [23,36,37].

In addition to physiological and biological factors related to the maturation process and puberty, contextual and environmental factors, such as physical activity levels, can be decisive for performance in these types of tests [38]. Thus, physical activity level has been identified as an essential modulating factor for lower-limb explosive power [6,11]. However, puberty is a critical stage for physical activity engagement; a large proportion of adolescents abandon regular practice, with nearly 80% of this population being physically inactive [39]. This decline is detrimental to performance in tests and sporting disciplines that require coordination and motor skills, as performance levels are diminished. Furthermore, it should be noted that the decrease in physical activity does not occur uniformly across sexes, with females withdrawing from physical activity to a greater extent than males [40], which could further affect their performance.

Despite the relevance of these factors, scientific evidence remains scarce regarding the combined influence of maturational status, anthropometric variables, physical activity levels and sex on jumping performance during adolescence. For this reason, the objectives of this study were (a) to analyze the influence of adolescents' anthropometric parameters on jump performance in both males and females; (b) to establish the influence of maturational status on jump performance in male and female adolescents; and (c) to determine the differences in jumping performance between active and inactive adolescents in both males and females.

Based on previous studies conducted on adults and on other physical fitness variables in adolescents [6,17,19,20], the following research hypotheses are established: males and females with greater lower-limb length, higher muscle mass and lower fat mass will demonstrate higher performance in jump tests (H1); males and females who mature early will demonstrate higher performance in jump tests (H2); active adolescents will perform higher in jump test than the inactive ones, regardless of sex (H3).

2. Materials and Methods

2.1. Design

A cross-sectional study was conducted to analyze the impact of biological maturation, physical activity level and anthropometric variables on jump performance (CMJ and SBJ) in adolescents.

Adolescents from eight schools participated in the study. Prior to the start of the study, the institutional ethics committee of the Catholic University of Murcia (code: CE022102) approved the study design in accordance with the World Medical Association and the Declaration of Helsinki. Furthermore, the study design and the preparation of the manuscript followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [41].

2.2. Participants

A non-probabilistic convenience sampling was used to recruit participants from eight compulsory secondary schools located in different geographic areas of the Region of Murcia (Spain). Schools were selected based on having a large student body (more than 200 enrolled in each school). After obtaining institutional consent, meetings were held with the administrative teams and the physical education department to explain the nature of the study. Once institutional authorization was obtained, the families and students involved were informed. Participation in the study was voluntary and was formalized through the signing of an informed consent form by the adolescents and their legal guardians. This ensured anonymity and confidentiality in the handling of the data.

The minimum sample size was calculated using the statistical software Rstudio (v3.15.0; Rstudio Inc., Boston, MA, USA). The calculation was based on the formula for estimating a mean in an infinite population: $n = (Z_{\alpha}^2 \times \sigma^2)/d^2$, where Z_{α} is the Z-score for a 95% confidence interval (1.96). To do so, the standard deviation (σ) from previous studies analyzing performance in the CMJ ($\sigma = 3.8$) and SBJ ($\sigma = 2.5$) in adolescents was used [21,42]. The margin of error (d) was set at 0.17 for the CMJ and 0.11 for the SBJ. This methodology for calculating sample size has been employed in previous studies [43]. Thus, the minimum sample size required was 2037 adolescents. Finally, a total of 2599 adolescents (males: n = 1286; females: n = 1313) aged 12 to 16 years (mean age: 13.60 ± 1.50) participated in the study, ensuring sufficient statistical power.

The inclusion criteria were defined as: (a) being between 12 and 16 years of age; (b) having no injuries or having undergone no surgical procedures that would prevent participation in the jump tests; and (c) being enrolled in compulsory secondary education. The exclusion criterion was defined as: failing to complete the questionnaires, jump tests or anthropometric measurements in their entirety.

2.3. Instruments

The instruments selected for this study are highly valid and reliable for measuring adolescents [37,44].

2.3.1. Physical Activity Questionnaire

The "Physical Activity Questionnaire for Adolescents" questionnaire (PAQ-A) [45] was used to establish the level of physical activity of the adolescents. This questionnaire was previously validated in Spanish for the adolescent population, and an intraclass correlation coefficient of 0.71 was calculated for the final score of the questionnaire [46]. It is composed of 9 items, the first 8 of which are answered with a Likert scale of 1 to 5 points (1: a low level of physical activity; 5: a high level of physical activity), while the last item is answered with a dichotomous question (yes or no). This questionnaire provides information on the physical activity status of adolescents by means of the arithmetic mean of the first eight items. This score allows a cut-off point to be established to classify adolescents as either active (≥2.75) or inactive (<2.75) [47].

2.3.2. Anthropometric Variables

The assessment of the adolescents' anthropometric characteristics was conducted by Level 3 and 4 anthropometrists accredited by the International Society for the Advancement of Kinanthropometry (ISAK). The measurement protocol included three basic measurements (body mass, height and sitting height), three skinfolds (triceps, thigh and calf) and four girths (relaxed arm, waist, thigh and calf) [48].

All data collection procedures adhered to the guidelines standardized by ISAK [48]. To ensure the reliability of the measurements, each variable was measured twice, with a third measurement taken if the discrepancy between the first two exceeded 1% in basic measurements and girths, and 5% in skinfolds. In cases where two readings were obtained, the average value was used for the analysis. When a third measurement was necessary, the median of the three measurements was used for the final calculation [48].

A SECA 213 stadiometer (SECA, Hamburg, Germany) with an accuracy of 0.1 cm was used to measure height and sitting height; a TANITA BC 418-MA Segmental scale (TANITA, Tokyo, Japan), with an accuracy of 100 g for body mass; an inextensible tape, Lufkin W606PM (Lufkin, Missouri City, Texas, USA), with a 0.1 cm accuracy for girths; a

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skinfold caliper (Harpenden, Burgess Hill, UK), with an accuracy of 0.2 mm for skinfolds. The instruments were calibrated prior to the measurements.

Intra- and inter-rater technical measurement error (TEM) was calculated in a subsample. Intra-rater error was 0.03% for basic measurements, 1.21% for skinfolds, and 0.04% for girths; inter-rater error was 0.05% for basic measurements, 1.98% for skinfolds, and 0.06% for girths.

Based on the measured variables, lower-limb length (height − sitting height) [49], fat mass [50], muscle mass [51], three skinfolds sum, corrected girth of the arm [arm relaxed girth − (π × triceps skinfold)], thigh [middle thigh girth − (π × thigh skinfold)], and calf [calf girth − (π × calf skinfold)] and corrected girths sum were calculated. Following this, tertiles were established for each variable, allowing the adolescents to be classified into three groups based on the value of each variable: low, medium and high.

In addition, the participants' maturational status was determined using peak height velocity (PHV) as an indicator of somatic maturation [52]. Following sex-specific criteria, the predictive equations proposed by Mirwald et al. [53] were applied. These formulas have demonstrated high reliability and accuracy in adolescent populations, with a high intraclass correlation coefficient (ICC = 0.96), a low coefficient of variation (CV% = 0.8), and a low standard error (SE = 0.1) [54]. The value obtained using these equations reflected the maturity offset, allowing the estimation of the APHV using the formula: APHV = chronological age–maturity offset. Based on the APHV, the sample was divided into three maturation stages: the early maturation group (n = 787), consisting of adolescents whose APHV was below 0.5 years; the on-time maturation group (n = 1116), with an APHV within the range of ±0.5 years; and the late maturation group (n = 696), whose APHV was greater than >0.5 years [55].

2.3.3. Physical Fitness Test

Two researchers with prior experience in this field were responsible for familiarizing participants with the physical fitness tests and supervising their administration. Lower-limb strength and power were assessed using protocols validated in previous studies [36,56]. To minimize inter-rater variability, a single expert researcher was assigned to each testing station. Before the final data collection, all adolescents were familiarized with the tests to ensure proper technical execution.

For the CMJ, participants performed the jump on a force platform (MuscleLab, Stathelle, Norway) at a sampling frequency of 200 Hz, aiming to achieve maximal flight height. Starting from an upright position with hands on hips, the subjects performed a knee flexion of approximately 90°, immediately followed by a concentric extension at the maximum possible speed. Following the guidelines of Baker et al. [57], participants were required to keep their hands on their hips throughout the aerial phase, their knees and ankles fully extended from takeoff to ground contact, and their trunk in a vertical position.

For the SBJ, the adolescents positioned themselves behind a starting line with their feet parallel and shoulder-width apart. The test consisted of performing a forward jump to achieve maximum horizontal distance using a preparatory movement that involved swinging the arms and bending the knees. Free use of the arms was permitted to optimize propulsion. The measurement was taken from the starting line to the rear heel upon landing. For the attempt to be valid, the participant had to maintain balance while landing, without using their hands for support or stepping backward [58].

2.4. Procedure

Initially, participants completed the PAQ-A in accordance with previous research [23,59]. Subsequently, anthropometric variables were measured for each adolescent. Following this, a standardized warm-up protocol was initiated, focusing on joint mobility specific to the muscle groups involved in the CMJ and SBJ. The warm-up concluded with a more specific segment dedicated to technical familiarization with both jumps. For each jump, two attempts were made, with the best result selected as the final value. To ensure complete recovery and minimize the effects of fatigue, a rest period of two minutes was established between repetitions of the same type of jump and five minutes between the two jumps. The order of test execution was randomized for each participant to avoid learning biases or accumulated fatigue. The design of this evaluation protocol was based on the guidelines of the National Strength and Conditioning Association (NSCA) [60], considering metabolic demands, neuromuscular impact, and the necessary physiological recovery times.

As for environmental conditions, the questionnaire was administered in quiet, noise-free classrooms at each school. Anthropometric assessments were conducted inside the changing rooms of the indoor pavilion, ensuring a controlled and stable temperature. All measurement sessions were scheduled between 8:30 a.m. and 2:30 p.m., coinciding with the Physical Education class schedule. The indoor sports pavilion was used for the physical fitness tests to avoid any interference from external weather variables on the participants' performance.

2.5. Data Analysis

Statistical analysis was performed using SPSS software (v. 25, IBM Corp., Armonk, NY, USA). Data distribution and homogeneity of variances were assessed using the Kolmogorov–Smirnov and Levene's tests, respectively. Student's *t*-test for independent samples was used to compare CMJ and SBJ performance between sexes. Cohen's d was used to calculate the effect size in these cases, defined as small when $d < 0.2$; moderate when $d < 0.8$; and large when $d > 0.8$ [61]. Subsequently, a series of two-way analyses of variance (ANOVA) were conducted to examine the influence of sex in combination with (a) anthropometric categories (low, medium, and high groups for body mass, height, lower-limb length, and body composition variables); (b) maturation stage (early, on-time, and late); and (c) physical activity level (active and inactive). The main effects of each factor and their interaction (sex x group) were analyzed for each model. Post hoc comparisons with Bonferroni correction were applied to determine specific differences between groups. Effect size was determined using partial eta-squared, with small ($\eta^2 \geq 0.01$), medium ($\eta^2 \geq 0.06$), and large ($\eta^2 \geq 0.14$). The level of statistical significance was set at $p < 0.05$.

3. Results

Table 1 shows sex differences in performance on the CMJ and SBJ tests. Significant differences were found in both tests, with males performing better than females ($p < 0.001$). The effect size was large for the changes observed in the CMJ and moderate for the SBJ. In addition, Table 1 shows the interaction of sex with maturational status and physical activity level. The interaction was significant, showing significant differences in performance when considering maturational status ($p < 0.001$) and physical activity level ($p < 0.001$) in conjunction with sex.

Table 1. Differences by sex and interaction effects between sex and maturity status on countermovement jump (CMJ) and standing broad jump (SBJ) performance.

				Sex				Sex × Maturity		Sex × PA Level	
Jump	Total (n = 2599)	Males (n = 1286)	Females (n = 1313)	Mean Diff.	t, *p*	95% CI	Effect Size	*p*	Effect Size	*p*	Effect Size
CMJ (cm)	23.19 ± 8.07	26.39 ± 8.35	20.05 ± 6.38	6.34 ± 0.29	21.66; *p* < 0.001	5.77; 6.91	0.85	<0.001	0.17	<0.001	0.08
SBJ (m)	1.39 ± 0.43	1.54 ± 0.44	1.26 ± 0.37	0.28 ± 0.03	11.12; *p* < 0.001	0.23; 0.33	0.69	<0.001	0.12	<0.001	0.09

CMJ: countermovement jump; SBJ: standing broad jump; CI: confidence interval; PA: physical activity.

Differences in CMJ performance for both males and females, categorized by anthropometric variable groups, are presented in Table 2. Significant differences were found across all variables, with the exception of the waist-to-height ratio. Post hoc analysis revealed that in males, performance was significantly influenced by body dimensions and composition. Specifically, those in the low body mass and low height groups showed lower performance compared to their medium (p = 0.007; CI: −4.69; −0.57; p = 0.002; CI: −5.32; −0.93, respectively) and high counterparts (p = 0.043; CI: −3.90; −0.04; p < 0.001; CI: −9.75; −6.04, respectively). Regarding lower-limb length, males in the high lower-limb group outperformed those in the low (p < 0.001; CI: 4.27; 8.63) and medium groups (p < 0.001; CI: 1.88; 5.36), while the medium group also performed better than the low group (p = 0.014; CI: 0.43; 5.23). The effect sizes were small for body mass (0.01) and lower-limb length (0.05), and medium for height (0.10).

In terms of body composition, males in the low fat mass and low three-skinfold sum groups outperformed those in the medium (p < 0.001; CI: 2.36; 5.91; p < 0.001; CI: 3.25; 6.70, respectively) and high groups (p < 0.001; CI: 5.91; 7.77; p < 0.001; CI: 8.12; 11.69, respectively). The high muscle mass and high corrected girths sum groups showed superior performance compared to both low (p < 0.001; CI: 3.92; 9.14; p < 0.001; CI: 3.82; 7.82, respectively) and medium levels (p < 0.001; CI: 2.64; 6.12; p < 0.001; CI: 1.76; 5.50, respectively). The effect sizes were small for muscle mass (0.05) and corrected girths sum (0.05), and large for fat mass (0.15) and three skinfolds sum (0.16)

Among females, the low fat mass group exhibited higher performance than the medium (p < 0.001; CI: 1.95; 6.70) and high groups (p < 0.001; CI: 1.85; 4.68), and those with a low three-skinfold sum outperformed the high group (p < 0.001; CI: 2.46; 6.69). In addition, females with high muscle mass development achieved significantly better results than those in the low (p = 0.010; CI: 0.61; 6.03) and medium groups (p = 0.020; CI: 0.36; 5.88). The effect sizes were small for fat mass (0.04), three skinfolds sum (0.03) and muscle mass (0.01).

Table 2. Differences in CMJ performance among male and female adolescents across different anthropometric variable groups.

Variable	Sex	Low	Medium	High	F	*p*	Effect Size
Body mass (kg)	Male	24.91 ± 6.14	27.54 ± 8.03	26.88 ± 9.72	8.74	<0.001	0.02
	Female	22.02 ± 5.25	20.69 ± 5.23	19.81 ± 5.62			
Height (cm)	Male	21.51 ± 6.44	24.64 ± 7.97	29.41 ± 8.14	29.23	<0.001	0.06
	Female	21.05 ± 4.99	20.82 ± 5.79	20.13 ± 6.29			
Lower-limb length (cm)	Male	22.16 ± 6.83	24.99 ± 7.98	28.61 ± 8.43	14.64	<0.001	0.03
	Female	20.75 ± 5.34	21.04 ± 5.52	20.52 ± 6.20			
Waist/height ratio	Male	29.48 ± 7.21	27.68 ± 8.02	23.78 ± 8.85	1.02	0.360	0.00
	Female	22.71 ± 5.08	21.87 ± 4.45	18.55 ± 5.90			
Fat mass	Male	29.94 ± 7.70	25.81 ± 7.52	20.46 ± 7.25	9.00	<0.001	0.02
	Female	23.37 ± 5.55	22.31 ± 4.85	21.05 ± 5.53			

Muscle mass	Male	21.85 ± 6.40	24.00 ± 6.88	28.38 ± 8.90	22.21	<0.001	0.04
	Female	21.29 ± 5.23	21.09 ± 5.46	17.97 ± 6.50			
Three skinfolds sum (mm)	Male	30.06 ± 7.69	25.09 ± 7.15	20.16 ± 7.43	10.66	<0.001	0.02
	Female	23.74 ± 4.95	21.89 ± 5.13	19.17 ± 5.62			
Corrected girths sum (cm)	Male	22.73 ± 7.30	24.92 ± 7.37	28.55 ± 8.78	18.38	<0.001	0.04
	Female	20.89 ± 5.09	21.33 ± 5.62	19.91 ± 6.30			

Differences in SBJ performance for both males and females, categorized by anthropometric variable groups, are presented in Table 3. Significant differences were found across all variables, with the exception of the body mass and waist-to-height ratio. Post hoc analysis revealed that for males, height and limb length were key performance factors; those in the high height group outperformed their medium ($p < 0.001$; CI: 0.15; 0.34) and low counterparts ($p < 0.001$; CI: 0.22; 0.41). Similarly, males in the high lower-limb group showed significantly higher performance than those in the low ($p < 0.001$; CI: 0.16; 0.39) and medium ($p < 0.001$; CI: 0.08; 0.27) groups. The effect sizes were medium for height (0.07) and small for lower-limb length (0.04).

Regarding body composition, the low fat mass group outperformed the medium ($p < 0.001$; CI: 0.07; 0.26) and high groups ($p < 0.001$; CI: 0.28; 0.47), a trend also observed for the low three-skinfold sum group compared to medium ($p < 0.001$; CI: 0.11; 0.30) and high groups ($p < 0.001$; CI: 0.28; 0.48). In addition, the high muscle mass group performing better than the low ($p < 0.001$; CI: 0.14; 0.42) and medium groups ($p < 0.001$; CI: 0.06; 0.24). Likewise, those with a high corrected girths sum outperformed the low ($p < 0.001$; CI: 0.14; 0.35) and medium groups ($p = 0.009$; CI: 0.02; 0.22). The effect sizes were medium for three skinfolds sum (0.09) and fat mass (0.09), and small for corrected girths sum (0.03) and muscle mass (0.03).

Among females, high body fat was detrimental to performance, as the high fat mass group scored lower than the low ($p = 0.035$; CI: −0.23; −0.03) and medium groups ($p < 0.001$; CI: −0.21; −0.05). Consistently, females with a low three-skinfold sum exhibited higher performance than those in the high group ($p = 0.005$; CI: 0.04; 0.27). The effect sizes were small for both variables (three skinfolds sum: 0.02; fat mass: 0.02).

Table 3. Differences in SBJ performance among male and female adolescents across different anthropometric variable groups.

Variable	Sex	Low	Medium	High	F	*p*	Effect Size
Body mass (kg)	Male	1.50 ± 0.32	1.58 ± 0.35	1.57 ± 0.49	2.27	0.104	0.01
	Female	1.31 ± 0.23	1.29 ± 0.31	1.27 ± 0.38			
Height (cm)	Male	1.37 ± 0.36	1.44 ± 0.34	1.68 ± 0.41	11.90	<0.001	0.02
	Female	1.27 ± 0.26	1.30 ± 0.31	1.31 ± 0.43			
Lower-limb length (cm)	Male	1.38 ± 0.36	1.48 ± 0.36	1.65 ± 0.42	6.98	<0.001	0.01
	Female	1.27 ± 0.28	1.31 ± 0.31	1.31 ± 0.42			
Waist/height ratio	Male	1.70 ± 0.31	1.61 ± 0.41	1.43 ± 0.44	2.11	0.122	0.00
	Female	1.35 ± 0.25	1.36 ± 0.28	1.19 ± 0.36			
Fat mass	Male	1.69 ± 0.39	1.52 ± 0.40	1.32 ± 0.36	8.52	<0.001	0.02
	Female	1.33 ± 0.25	1.36 ± 0.27	1.23 ± 0.35			
Muscle mass	Male	1.34 ± 0.30	1.48 ± 0.32	1.62 ± 0.45	10.11	<0.001	0.02
	Female	1.29 ± 0.25	1.33 ± 0.36	1.22 ± 0.40			
Three skinfolds sum (mm)	Male	1.70 ± 0.39	1.49 ± 0.37	1.32 ± 0.39	6.81	0.001	0.01
	Female	1.38 ± 0.27	1.33 ± 0.28	1.23 ± 0.35			
Corrected girths sum (cm)	Male	1.39 ± 0.37	1.51 ± 0.32	1.63 ± 0.45	10.51	<0.001	0.02
	Female	1.29 ± 0.26	1.32 ± 0.33	1.25 ± 0.38			

Figure 1 shows the interaction profile between sex and maturation status on CMJ and SBJ performance. Regarding the CMJ in males, late maturers performed worse than on-time maturers (mean diff: −3.88; $p < 0.001$; CI: −5.62; −2.15) and early maturers (mean diff: −5.73; $p < 0.001$; CI: −8.41; −3.05). No differences were found between early maturers and on-time maturers ($p = 0.293$). The effect size for these differences was small (0.04). In females, no significant differences in CMJ performance were found among the different maturation groups (late vs. on time: $p = 0.156$; late vs. early: $p = 0.452$; on time vs. early: $p = 1.000$). Regarding the SBJ, differences were found in the male group between late maturers and on-time maturers (mean diff: −0.10; $p = 0.023$; CI: −0.20; −0.01) and early maturers (mean diff: −0.24; $p < 0.001$; CI: −0.39; −0.10), with late maturers performing to a lesser extent. No differences were found between early maturers and on-time maturers ($p = 0.059$). The effect size for the differences was small (0.02). In the case of females, differences were found between late maturers and on-time maturers, with the on-time group showing higher performance (mean diff: −0.16; $p < 0.001$; CI: −0.25; −0.07). However, no significant differences were found in the remaining comparisons between groups (on time vs. early: $p = 0.118$; late vs. early: $p = 0.477$). The effect size for these differences was small (0.02).

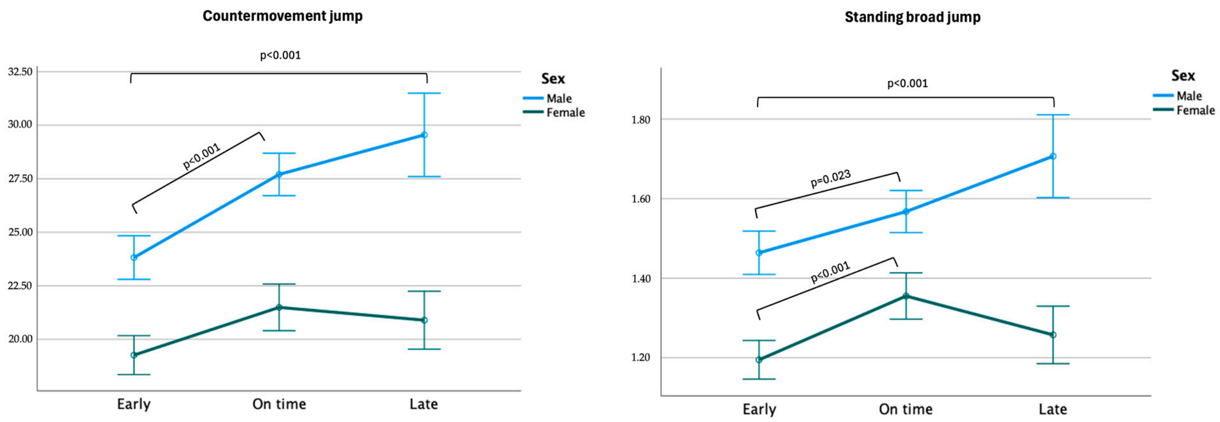

Figure 1. Interaction profile between sex and maturity status (early, on-time, late) on CMJ and SBJ performance.

Figure 2 shows the interaction profile between sex and physical activity level on CMJ and SBJ performance. Regarding the CMJ, active adolescents performed better than inactive ones both in males (mean diff: −2.26; $p = 0.001$; CI: −3.63; −0.90) and females (mean diff: −1.81; $p = 0.011$; CI: −3.20; −0.42). The effect size for these differences was small (males: 0.01; females: 0.00). Regarding the SBJ, differences were also found for males (mean diff: −0.16; $p < 0.001$; CI: −0.23; −0.09) and females (mean diff: −0.14; $p < 0.001$; CI: −0.21; −0.06), with active adolescents performing to a greater extent. The effect size for the differences was small (males: 0.02; females: 0.01).

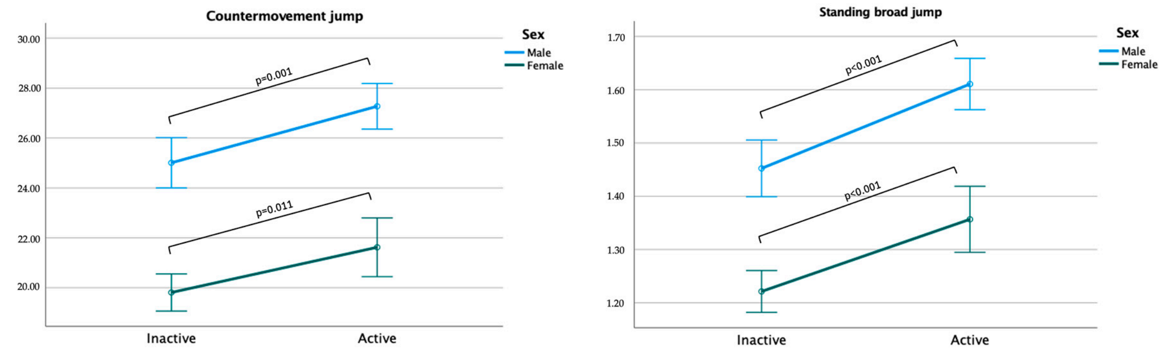

Figure 2. Interaction profile between sex and physical activity level (active, inactive) on CMJ and SBJ performance.

4. Discussion

The first objective of this study was to analyze the influence of adolescents' anthropometric parameters on jump performance in both males and females. The results revealed that variables such as height and fat mass were significantly associated with jumping performance in males. Specifically, individuals with greater stature and lower body fat accumulation exhibited superior performance in both CMJ and SBJ. These findings are consistent with previous research indicating that greater height is related to increased lower-limb power during adolescence, while excessive fat mass accumulation is linked to lower performance levels [17,18]. This may be explained by the fact that adolescents with greater height tend to possess superior mechanical advantages, such as longer lever arms and extended force application times, which favor propulsion during the concentric phase of the jump [19]. Additionally, lower fat mass is associated with more efficient body mobilization, as the strength-to-weight ratio remains more favorable and the center of gravity is more effectively maintained [21,22].

Regarding females, it is noteworthy that no significant associations were found between height and performance in either CMJ or SBJ. Furthermore, while the relationship with fat mass reached statistical significance, the effect size was small. This is a relevant finding, as it suggests that although fat mass is related to performance, its role might not be as prominent in females as in other groups. A potential explanation for these results is that puberty is characterized by an inherent increase in fat mass accumulation in female adolescents, regardless of lifestyle habits or baseline characteristics [62,63]. Therefore, although a link exists between fat mass and performance, likely due to altered mechanical properties and the added resistance during jumping tasks, its relative importance appears to be lower than in males. This may be attributed to the fact that increased adiposity is a generalized physiological occurrence among females during this stage [62]. Nonetheless, these findings should be further explored in future research to clarify the specific weight of fat mass in female jumping performance.

Other body composition variables, such as lower-limb length and muscle mass, showed significant associations with CMJ and SBJ performance; however, the effect sizes were small, indicating limited practical relevance. Regarding lower-limb length, male adolescents with longer limbs exhibited higher performance in both CMJ and SBJ, while both males and females with higher muscle mass showed higher performance. These results are consistent with previous research where longer lower-limb lengths were related to a greater capacity for power production [17,18]. Biomechanically, greater segmental length is associated with longer lever arms [19] and, theoretically, with an extended duration of force application during the concentric push-off phase [19]. However, the lack of a significant association in females suggests that the advantage of longer levers may be offset by other limiting factors, such as lower relative muscle mass to mobilize that skeletal structure [27,64]. This suggests that, in females, jump mechanics may be more closely linked to body composition factors [64], such as fat and muscle mass [27], or neuromuscular adaptations [29], rather than anthropometric proportions during this stage of pubertal development. In fact, female adolescents with higher muscle mass exhibited superior CMJ performance compared to those with lower development, although this was not observed in the SBJ. This discrepancy could be attributed to the more complex coordinative component of the SBJ, where the horizontal displacement of the center of gravity demands a higher degree of motor control and technical efficiency than the vertical impulse of the CMJ [12,65]. Therefore, the absence of significant differences in CMJ performance among the different lower-limb length groups in females, contrasting with the significant findings related to muscle mass, suggests that other parameters may be more closely associated with jumping performance in this group than mechanical characteristics.

Based on the results obtained, the first research hypothesis (H1), which posited that both males and females with greater lower-limb length, higher muscle mass, and lower fat mass would exhibit superior jumping performance can be partially rejected, primarily due to the lack of significant associations between structural anthropometry and performance in females. However, a notable exception was observed regarding body composition in males. Unlike the small effect sizes recorded for most variables, fat mass emerged as a substantial factor, exhibiting a large effect size on jumping performance in the male group. This suggests that, for males, the negative association of adipose tissue is a far more decisive constraint on explosive power than segmental lengths or total height. Consequently, while H1 does not hold as a universal rule for both sexes, the pronounced impact of fat mass in males highlights a key physiological difference in how body composition relates to performance during this maturational stage.

The second objective of the study was to establish the influence of maturational status on jump performance in male and female adolescents. In this case, males with delayed maturation exhibited significantly lower performance in the CMJ and SBJ tests compared to their on-time and early-maturing counterparts. However, it is important to note that the effect sizes for these differences were small, suggesting that while maturational timing is associated with performance levels, its practical impact might be limited when compared to other physical or anthropometric factors. According to the scientific literature, biological maturation in males has been associated with accelerated musculoskeletal development and increased exposure to anabolic hormones, which could theoretically be linked to explosive power and jumping performance [34]. This phenomenon has been previously related to increases in circulating testosterone in longitudinal studies [66]. Such hormonal shifts are suggested to promote not only muscle hypertrophy through protein synthesis [67], but also the optimization of neuromuscular efficiency by improving the recruitment of fast-twitch motor units [68], which are essential for explosive tasks like the CMJ and SBJ. However, as hormonal levels were not directly measured in the present study, these mechanisms remain a potential theoretical explanation for the differences observed between maturational groups.

In the case of females, on-time maturers exhibited higher performance in the SBJ compared to late maturers; however, no significant advantages were observed for early maturers in this test, nor among any maturational groups in the CMJ. Furthermore, the effect sizes for these observations remained small. This performance pattern in females may be related to the fact that the SBJ involves horizontal displacement, requiring greater intersegmental coordination and stability, factors that could be theoretically compromised by the increase in body fat and shifts in the center of gravity typical of early maturation

[69,70]. In females, the maturation process is often associated with elevated estrogen levels [64] which, according to the literature, prioritize the deposition of essential fat mass [27,71]. This increase in non-contractile mass alters the strength-to-weight ratio, which could explain why early-maturing females do not always exhibit a clear advantage in jumping tests compared to their peers [22,72]. Regarding the SBJ, the advantage of on-time maturers over late maturers may be linked to achieving greater coordinative stability prior to the more drastic changes in the center of gravity associated with full maturation [69,70]. This disparity between sexes reinforces the heterochronic nature of maturation [32], where hormonal and physical shifts occur at different times and magnitudes [23,34], potentially resulting in a more pronounced association with physical power in males, as suggested by previous research [26,73].

Therefore, the second research hypothesis (H2), which posited that males and females who mature early will demonstrate higher performance in jump tests, can only be partially supported for the male group and must be rejected for females. While early-maturing males exhibited superior performance compared to their late-maturing peers, the small effect sizes indicate that maturation timing explains only a limited portion of the variance in jumping ability. In females, the lack of a clear advantage for early maturers, coupled with the non-significant differences observed in the CMJ, further contradicts the universal nature of this hypothesis. These findings suggest that the relationship between biological maturation and explosive power is sex-dependent and is likely modulated by the differing balance of lean and fat mass accumulation characteristic of each sex during pubertal development.

The third objective aimed to determine the associations between physical activity levels and jumping performance in both male and female adolescents. The results indicated that active subjects of both sexes exhibited significantly higher values in both the CMJ and the SBJ; however, the effect sizes for all comparisons were small. These findings are consistent with previous scientific literature, which has shown that active adolescents tend to present superior performance in physical fitness tests compared to their inactive peers [38]. The higher performance observed in active adolescents may be associated with neuromuscular adaptations [30], as well as with more favorable body composition profiles [6,68] and enhanced coordinative capacity [74], which are frequently observed in individuals engaging in regular physical activity. Nonetheless, the limited magnitude of the effect sizes suggests that while regular activity is linked to better performance, it is not the sole determinant of explosive power during this developmental stage.

The third research hypothesis (H3), which posited that active adolescents would perform higher in jump tests than the inactive ones, regardless of sex, is supported by the results. Active participants of both sexes exhibited significantly higher values in CMJ and SBJ compared to their inactive counterparts. However, this hypothesis should be interpreted with caution, as the small effect sizes observed across all comparisons suggest that the association between physical activity levels and jumping performance, while statistically significant, has limited practical relevance in this specific population. This indicates that other unmeasured factors, such as specific sports specialization or genetic predisposition, may also play a crucial role in explosive power during adolescence.

Based on the results obtained in this study, the significant interaction observed between sex and the other variables (anthropometry, maturation, and physical activity levels) reinforces the role of sex as a biological moderator. While in males, maturational and anthropometric development appears to show a more linear association with performance, in females, these changes involve a more complex interplay of mechanical and body composition factors [37,73]. However, it must be emphasized that although the interactions between these variables reached high statistical significance, the associated effect sizes were predominantly small. Consequently, while these parameters are identified as factors related to jumping performance, their practical relevance should be interpreted with caution, as they explain only a modest portion of the overall variance in this adolescent population.

Despite the significance of the results, this study has certain limitations that should be considered when interpreting the data. First, the cross-sectional design prevents the establishment of definitive causal relationships; thus, the associations described regarding maturational progression and performance should not be interpreted as longitudinal trends. Second, while the sample size is large, the non-random sampling method restricts the external validity and the ability to generalize these findings to other adolescent populations. Third, a key limitation is the absence of direct physiological measures, such as circulating hormone levels or skeletal age assessment. Consequently, the discussed hormonal mechanisms remain theoretical interpretations based on existing literature and cannot be directly confirmed by our data. Finally, although physical activity was categorized, other modulating factors such as nutritional intake, sleep patterns, or specific sports specialization were not considered, which could further explain the variance in explosive muscle power during this developmental stage.

5. Conclusions

In conclusion, this study demonstrates that performance in the CMJ and SBJ tests is significantly associated with the interplay between sex, maturational status, and anthropometric characteristics. The findings confirm a marked sexual dimorphism, with males exhibiting superior performance and a more pronounced relationship between jumping power and biological or structural changes. In the male population, height, lower-limb length, and early maturation were linked to superior performance; however, low fat mass emerged as the most substantial factor associated with jumping success, exhibiting a large effect size. In contrast, females showed a different pattern where structural anthropometry and maturation had a limited practical influence. Furthermore, habitual physical activity levels appear to be a consistent moderator of neuromuscular performance, as active adolescents of both sexes were associated with higher scores in both jump tests compared to their inactive peers. However, it is essential to emphasize that while these associations reached statistical significance, the predominantly small effect sizes indicate that these factors explain only a modest portion of the variance in performance. This highlights the multifactorial nature of physical development during adolescence. Finally, these results suggest that the choice of assessment should align with the specific evaluative objective. The CMJ appears to be more sensitive to morphological and maturational differences in males. In contrast, the SBJ may offer greater stability across different maturational stages in both sexes. These insights underscore the need for an individualized approach in physical education and sports training, moving beyond chronological age to consider the complex biological and lifestyle landscape of each adolescent.

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