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Effects of Age, Maturation, and Sex on Trunk Muscle Performance in Elementary and Secondary School Students: ISQUIOS Program

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Abstract: Physical education students participated in this study to explore maturity status (MAT), chronological age (CA), and sex-specific trunk muscle endurance differences. Method: Static and dynamic trunk endurance were assessed using five field-based tests. The main results show differences in all trunk endurance tests according to CA and MAT, with greater performance being found at an at older CA or higher MAT. With respect to CA and sex, differences were only found in the DEE test and from the age of 14 onwards, where boys performed better than girls. In addition, interactions were also found between sex and MAT, where boys classified as having circa- and post-peak height velocity performed better than girls in all tests. Physical fitness appears to be particularly sensitive to MAT, so it is important to consider biological maturation when assessing physical fitness rather than the CA factor commonly used in international fitness batteries for children and adolescents.

Keywords: puberty; maturational stage; core muscle; assessment; training; physical education

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1. Introduction

The presence of back pain (BP) in children and adolescents is increasingly common [1]. Although most of them report having no pain, an increase in the prevalence of BP has been observed in children and adolescents with advancing age [2]. The prevalence of BP during the past 12 months in children and adolescents has been estimated around 62% in children aged 10 to 13 years and around 83% in adolescents aged 17 to 19 years [3]. The most common diagnoses associated with BP in adolescents include strain/spasm, scoliosis, degenerative disk disease, and disk herniation [4]. While the etiology of BP in children and adolescents is multifactorial, involving both medical (e.g., infectious, oncological, and congenital diseases) and environmental (e.g., short or inadequate sleep quality and smoking) factors [5–7], the increasingly sedentary lifestyle of children and adolescents, where children and adolescents engage in sedentary activities, such as watching television and playing video games or using smartphones, and spend less time carrying out physical activities, becoming increasingly weaker, may also be viewed as a key driver of its rising prevalence [8,9]. The main consequences of the presence of BP during childhood and adolescence include school absenteeism, the need for medical care and medication [10], and difficulties with various activities of daily life (e.g., standing in a queue, carrying a backpack, or performing physical activities) [1].

A large-scale study conducted in Denmark and involving more than a thousand adolescents concluded that pubertal development and linear growth are associated with spinal pain [11]. Boys and girls with advanced pubertal development and a greater growth rate may have an increased frequency and duration of spinal pain [11]. Puberty might then be the time for a rapid increase in the prevalence values of BP. During this period, rapid changes at different growth rates occur in the legs and trunk, with the long bones of the legs growing earlier than the shorter bones of the trunk [12]. These changes might not follow a similar level, timing, and rate of development for the muscles involved in spinal stability (e.g., multifidus, transversus abdominis, external and internal abdominal obliques, erector spinae, quadratus lumborum, and rectus abdominis). Therefore, the phase of peak height velocity (PHV) could be considered a particularly vulnerable period compared to the episodes before or after this stage due to the rapid change in the mechanical load on the spine [11,13,14]. This momentary situation may contribute to asymmetric muscle growth, muscular imbalance [15,16], the misalignment of the sagittal spinal curvatures [17], and, consequently, a higher risk of BP [18]. In fact, low trunk muscle endurance has been proposed as a risk factor for BP in some previous studies [19]. Several researchers have concluded that the reduced endurance of trunk extensor muscles, as well as trunk flexor muscles, may be associated with low back pain (LBP) in adolescents [20,21]. This association between poor trunk muscle performance and BP justifies the need for its assessment during childhood and adolescence [22].

Previous studies that have described not only trunk muscle endurance but also trunk muscle strength in children and adolescents have been focused on the changes that occur according to chronological age (CA) [15,16,23–26]. However, the above-mentioned inter-individual variations in the level (magnitude of change), timing (onset of change), and tempo (rate of change) of physical and physiological changes support conducting an analysis based on participants' maturational stage rather than on the CA when assessing physical fitness in the youth population. Likewise, the effects of maturation on boys and girls are significantly different at anatomical, hormonal, and musculoskeletal levels [12,27,28]. For example, at the onset of puberty, girls are temporarily taller and heavier due to their earlier growth spurt [12,27], but they soon lose the size advantage as the growth spurt of boys occurs in which they achieve greater stature and muscle mass [12,27,28]. Due to these physical changes associated with puberty, girls during the PHV tend to perform worse in tasks that involve weight-bearing or strength. In contrast, boys generally tend to have a superior physical performance during PHV, particularly in activities that require strength, speed, or power [27,29,30].

Understanding how trunk endurance evolves through the developmental stages in boys and girls can assist in the design of individualized exercise-based interventions to prevent BP and optimize trunk motor performance during growth and development. To the authors' knowledge, only one study has been conducted where the influence of CA, MAT, and sex on trunk muscle endurance (i.e., ventral Bourban test) has been analyzed in young elite athletes (8–18 years) [31]. Therefore, the aim of this study was to explore MAT-, CA-, and sex-specific trunk muscle endurance differences in the general population of children and adolescents. Based on other studies where the MAT has been analyzed together with other variables (i.e., anatomical and postural characteristics and exercise behavior), we hypothesize that the values of trunk muscle endurance are similar in boys and girls before the pubertal growth spurt and that differences in performance according to sex can increase as pubertal development progresses [12,28,29].

2. Materials and Methods

2.1. Design

A cross-sectional study was conducted to investigate the trunk muscle endurance measure in Spanish children and adolescents. The study design, protocol, and methodology were fully approved by the Review Committee for Research Involving Human Subjects at the University of Murcia (Spain) (ID: 1920/2018) and in accordance with the Declaration of Helsinki (1961), revised in Fortaleza (2013). Students, parents/guardians, and PE teachers were fully informed verbally and in writing about the nature and purpose of this study. All parents/guardians signed an informed consent form prior to participation.

Participants were tested during PE classes. Since PE teachers have only 2 sessions lasting 60 min per age-based grade per week, a time-efficient assessment procedure was developed that was divided into 2 distinct parts within a single testing session. The first part of each testing session was used to collect the anthropometric measurements needed to calculate the maturation stages of the students. In the second part, trunk muscle endurance was assessed through five field-based tests (endurance of trunk extensors, flexors, and lateral flexors). Participants were asked not to perform any strenuous exercise for 24 h before the testing sessions.

This study was conducted under a larger project entitled "ISQUIOS Program", a postural education program implemented in the Region of Murcia (Spain). Nevertheless, the sample involved in this research did not receive any type of intervention at the time of data collection.

2.2. Participants

A total of 994 students (primary education, n = 548; secondary education, n = 446) from 10 and 4 different primary and secondary schools, respectively, were initially invited to participate in this study. Participants who (a) had a diagnosed spine pathology or serious physical injury that limited the correct performance of the tests, (b) did not provide signed informed consent (from both parents/guardians and students) prior to the start of the study, (c) did not attend the testing sessions, and/or (d) were involved in structured physical fitness programs during the time of data collection were excluded. Based on these exclusion criteria, 132 of the initially invited students were removed, and a total of 862 (age: 12.19 $\pm$ 2.05 years; range: 9–17 years; 49.07% female) students were finally included for the analyses.

2.3. Procedures

Before the testing sessions, the PE teachers participated in a practical session where they were introduced to the tests and trained in their proper execution. Following this, the PE teachers were asked to practice all the field-based tests with their students at least four times before the assessment session, which took place within a month after the teachers' practical training. This decision was based by previous studies on high school students and trunk muscle endurance field-based tests [32], which showed acceptable inter-session reliability values (ICC > 0.75) but poor precision of measurement for each field-based test (CV_{TE} > 10%), along with learning effects observed when fewer than four practice trials were conducted. As a result, by the day of the assessments, each participant was already familiar with the execution of the five trunk endurance tests.

At the beginning of the testing session, all participants received comprehensive instructions for the tests, and their potential questions about the protocols were answered. After the collection of anthropometric measures, all participants completed their usual warm-up training, which was led by their PE teachers and consisted of 6–10 min of low- to moderate-intensity (self-perceived) running (including forward/backward movements and side-stepping) and general mobilization (i.e., arm circles and leg kicks), followed by 4–6 min of dynamic stretching. Due to time constraints, all tests were performed randomly in a circuit. Five different stations were set up (one for each trunk endurance test). Groups of 4–6 participants were randomly assigned to one of the 5 stations and performed the 5 field-based trunk endurance tests with a 5 min break between each test. All the tests were conducted by five trained testers (i.e., 2 master's and 3 PhD students in sports science) coordinated by the principal investigator (M.T.M.-R).

During the performance of all the field-based tests, participants were verbally encouraged to hold the position for as long as possible or to perform the maximum number of repetitions.

2.3.1. Anthropometry and Maturity Status

Body mass in kilograms was measured on a calibrated physician scale (SECA 799, Hamburg, Germany). Body height was recorded in centimeters on a measuring platform (SECA 799). Sitting height was measured in centimeters. Leg length was calculated as the difference between body height and sitting height. The maturity status (MAT) was then calculated in a non-invasive way using two regression equations (equation 1 for boys and equation 2 for girls), including measurements of age, body mass, body height, sitting height, and leg length taken during the first part of the testing sessions [33]. To take into account the error of approximately 6 months described for the prediction equation in a pediatric population [33], participants with a maturity offset of −0.99 to −0.51 years and +0.51 to +0.99 years were removed from this analysis [34]. Also, participants whose maturity offset was outside of −3 or +3 years were removed to maximize accuracy [34]. This approach allowed for the identification of 3 distinct maturity groups: pre-PHV (maturity offset < -1), circa-PHV (maturity offset between −0.5 and +0.5), and post-PHV (maturity offset $> +1$).

$$\text{Boys} = -9.236 + 0.0002708 \times (\text{Leg Length} \times \text{Sitting Height}) - 0.001663 \times (\text{Age} \times \text{Leg Length}) + 0.007216 \times (\text{Age} \times \text{Sitting Height}) + 0.02292 \times (\text{Weight}/(\text{Height} \times 100)) \quad (1)$$

$$\text{Girls} = -9.376 + 0.0001882 \times (\text{Leg Length} \times \text{Sitting Height}) + 0.0022 \times (\text{Age} \times \text{Leg Length}) + 0.005841 \times (\text{Age} \times \text{Sitting Height}) - 0.002658 \times (\text{Age} \times \text{Weight}) + 0.07693 \times (\text{Weight}/(\text{Height} \times 100)) \quad (2)$$

2.3.2. Trunk Extensor Endurance Field-Based Tests

Biering-Sorensen (BS) test. Isometric endurance of the trunk extensors was assessed using the BS test (Figure 1A) [35]. During the test, the upper body was maintained in a horizontal position with the arms crossed on the chest, while the head was held in a neutral position. The test consisted of holding the trunk in the described position for as long as possible until exhaustion or until participants lost the correct position more than 3 times. The test duration was given in seconds.

Dynamic Extensor Endurance (DEE) test. Dynamic endurance of the trunk extensors was assessed using the DEE test (Figure 1B) [36]. Participants were in the same position as in the BS test. During the test, participants had to extend the trunk horizontally and then return to the starting position with arms crossed on the chest. Participants were asked to perform the maximum possible repetitions in 60 s.

An extendable goniometer (Lafayette Instrument Co, Lafayette, IN, USA) was used to control the position during these tests [32].

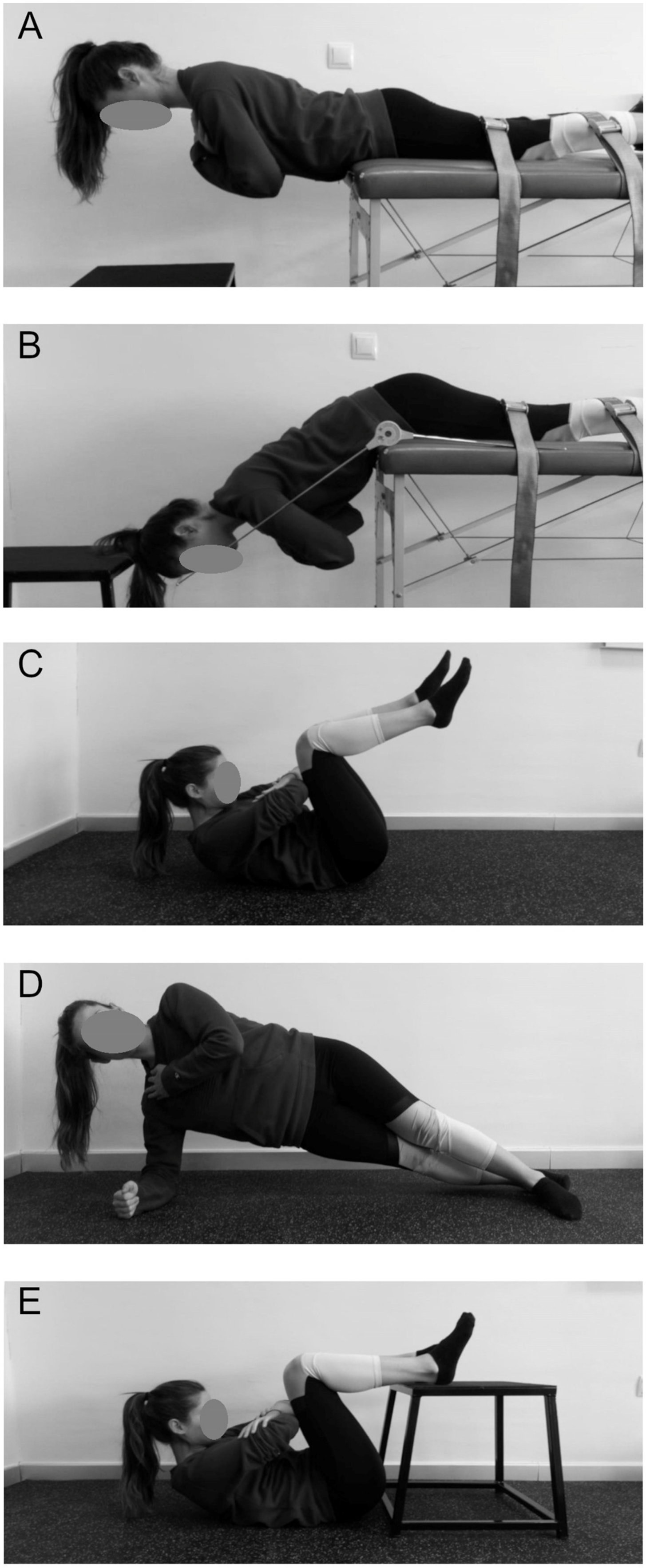

Figure 1. Trunk endurance field-based tests. (**A**) Biering-Sorensen test; (**B**) Dynamic Extensor Endurance test; (**C**) Ito test; (**D**) Side Bridge test; (**E**) Bench Trunk Curl-Up test.

2.3.3. Trunk Flexor Endurance Field-Based Tests

Ito test. Isometric endurance of the trunk flexors was assessed using the Ito test (Figure 1C) [37]. Participants were in the supine position with hips and knees flexed at 90° and arms crossed with hands grasping the opposite elbow. From this position, participants performed a trunk flexion ("curl-up") until their elbows touched their thighs. The test consisted of maintaining this position for as long as possible until exhaustion. The test duration was given in seconds.

Bench Trunk Curl-Up (BTC) test. Dynamic endurance of the trunk flexors was assessed with the BTC test (Figure 1E) [38]. Participants were in the same position as in the Ito test. From this position, participants performed a trunk flexion ("curl-up") until their elbows touched their thighs and then returned to the starting position. The test consisted of performing the maximum number of repetitions possible in 2 min.

As before, an extendable goniometer (Lafayette Instrument Co., Lafayette, IN, USA) was used to control the position during these tests [32].

2.3.4. Trunk Lateral Flexor Endurance Field-Based Test

Side Bridge (SB) test. Isometric endurance of the lateral trunk flexors was assessed with the Side Bridge right (SB-R) and left (SB-L) tests (Figure 1D) [39]. Participants were placed in a lateral position with legs extended. The test consisted of keeping the body supported on the elbows and feet for as long as possible until exhaustion. The test duration was recorded in seconds.

2.4. Statistical Analyses

Descriptive statistics, including means and standard deviations (SDs) with 95% confidence intervals, were calculated for anthropometrics and trunk endurance measures. Comparisons were made through the Bayesian ANOVA with the factors CA, MAT, and sex used as between-subject comparators. Post hoc tests were computed for multiple comparisons to determine outcomes according to MAT and CA. The BF_{10} was interpreted using the following evidence categories suggested by Lee and Wagenmakers [40]: <1/100 = extreme evidence for H_0; from 1/100 to 1/30 = very strong evidence for H_0; from 1/30 to 1/10 = strong evidence for H_0; from 1/10 to 1/3 = moderate evidence for H_0; from 1/3 to 1 anecdotal evidence for H_0; from 1 to 3 = anecdotal evidence for H_1; from 3 to 10 = moderate evidence for H_1; from 10 to 30 = strong evidence for H_1; from 30 to 100 = very strong evidence for H_1; >100 extreme evidence for H_1. The median and the 95% central credible interval (CI) of the posterior distribution of the standardized effect size (δ) (i.e., the population version of Cohen's d) were also calculated for each of the comparisons carried out. Magnitudes of the posterior distribution of the standardized effect size were classified as follows: trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), and very large (2.0–4.0) [41]. Only those comparisons that showed at least strong evidence for supporting the alternative hypothesis ($BF_{10} > 10$), an error percentage < 10 (which indicates great stability of the numerical algorithm that was used to obtain the result), and $\delta > 0.6$ (at least moderate) were considered robust to describe significant differences. Statistical analysis was performed using the JASP computer software Version 0.11.1 (JASP Team, Amsterdam, the Netherlands).

3. Results

Descriptive statistics for each CA group and MAT are shown in Table 1.

3.1. Effects of Chronological Age

The existence of at least strong evidence in favor of the alternative hypothesis (H_1) with at least a moderate effect size was found between CA groups and all trunk muscle endurance values ($BF_{10} > 10$, an error percentage < 1, δ = 0.6–1.2) (Table 2). Post hoc analyses indicated better performances in all trunk endurance values with an increasing CA. Notably, trunk endurance performance increased with at least a moderate effect size for all tests for participants between <10 and 15 years old (δ = 0.6–0.91). Similarly, endurance values in dynamic and static tests for trunk flexors (BTC and Ito tests) and extensors (DEE and BS tests) also increased between the 10 and 14 groups (δ = 0.6–1.2) and between the 11 and 14 groups (δ = 0.7–0.83). However, trunk endurance performance did not increase considerably in any tests in the groups of 10–11 years old, 11–12 years old, 12–13 years old, 13–14 years old, 13–15 years old, and 14–15 years old ($BF_{10} < 10$, an error percentage > 1, δ < 0.6).

3.2. Effects of Maturity Status

The existence of at least strong evidence in favor of the alternative hypothesis (H_1) with at least a moderate effect size was found between MAT and all trunk muscle endurance values ($BF_{10} > 10$, an error percentage < 1, δ = 0.6–0.79), except for the SB-L test, where the evidence was moderate, and the effect size was small (Table 3). Post hoc analyses indicated that trunk muscle performances increased with at least a moderate effect size from pre- to post-PHV in the Ito ($BF_{10} = 9.177 \times 10^{+10}$; δ = 0.79), BS ($BF_{10} = 5.339 \times 10^{+5}$; δ = 0.6), and BTC ($BF_{10} = 7.961 \times 10^{+6}$; δ = 0.77) tests, with strong evidence and a small effect size in the SB-R ($BF_{10} = 173.2$; δ = 0.38), SB-L ($BF_{10} = 11.51$; δ = 0.22), and DEE ($BF_{10} = 14.47$; δ = 0.3) tests. Similarly, an increase was also shown from pre- to circa-PHV in the Ito ($BF_{10} = 36{,}456.22$; δ = 0.51), BS ($BF_{10} = 60.58$; δ = 0.36), and DEE ($BF_{10} = 128.7$; δ = 0.44) tests, but the effect size was small. Finally, from circa- to post-PHV, greater performance was also shown in the SB-R ($BF_{10} = 14.11$; δ = 0.3), SB-L ($BF_{10} = 11.56$; δ = 0.25), and BTC ($BF_{10} = 12.88$; δ = 0.43) tests, but evidence was moderate, and the effect size was small.

Table 1. Descriptive anthropometric values (mean and SD scores) for subjects per chronological age group and maturity status.

		N	Age (y)	Maturity Offset	Body Mass (kg)	Body Height (cm)	Leg Length (cm)
CA groups							
<10	M	150	10.1 ± 0.5	−2.6 ± 0.3	40.1 ± 9.1	141.7 ± 6.7	69.2 ± 5
	F	153	10 ± 0.5	−1.6 ± 0.6	39.7 ± 10.4	140.1 ± 7.3	67.9 ± 5.2
11	M	70	11.5 ± 0.2	−2.1 ± 0.4	45 ± 10.3	148.5 ± 6.8	72.6 ± 4.8
	F	77	11.5 ± 0.2	−0.1 ± 0.4	48.4 ± 10.4	150.9 ± 6.8	72.5 ± 4.3
12	M	61	12.4 ± 0.2	−1.4 ± 0.7	51.1 ± 12.3	154.9 ± 8.3	75.9 ± 5.5
	F	57	12.4 ± 0.2	0.3 ± 0.5	50.6 ± 13.1	153.5 ± 5.9	74.3 ± 3.4
13	M	51	13.4 ± 0.2	−0.4 ± 0.8	57.3 ± 13.5	162.2 ± 8.8	80 ± 5.1
	F	34	13.4 ± 0.3	1.3 ± 0.4	57.4 ± 11.7	158.1 ± 6.5	75.6 ± 4.2
14	M	62	14.5 ± 0.2	0.4 ± 0.8	63.8 ± 13.1	167.5 ± 6.7	82.4 ± 4.4
	F	47	14.5 ± 0.2	1.9 ± 0.4	58.9 ± 11.9	161.3 ± 5.5	77.8 ± 5.1
>15	M	45	15.8 ± 0.6	1.5 ± 0.7	67.2 ± 15.8	172.9 ± 8	84.9 ± 5.2
	F	55	15.8 ± 0.5	2.4 ± 0.3	60.3 ± 10.7	160 ± 5.7	76.8 ± 4.5
MAT groups							
Pre-PHV	M	167	11.4 ± 1.1	−2.1 ± 0.6	45.2 ± 8.9	148.8 ± 6.2	72.6 ± 5.1
	F	115	9.9 ± 0.5	−1.8 ± 0.5	37 ± 7.8	138.5 ± 5.7	67.2 ± 5.2
Circa-PHV	M	73	13.9 ± 0.9	0.01 ± 0.4	60.1 ± 10.7	165.2 ± 5.6	81.1 ± 4.8
	F	105	11.8 ± 0.7	0.01 ± 0.3	50 ± 8.9	152.2 ± 5	73.3 ± 3.7
Post-PHV	M	46	15.4 ± 0.8	1.6 ± 0.5	73.2 ± 14.7	175.4 ± 5.9	85.5 ± 4.7
	F	130	14.7 ± 1	1.9 ± 0.5	60.3 ± 11.6	160.2 ± 5.2	76.9 ± 4.5

CA = chronological age; cm = centimeters; F = female; kg = kilograms; M = male; MAT = maturity status; PHV = peak heigh velocity; SD = standard deviation; y = years.

Table 2. Mean and SD scores obtained from trunk endurance field-based tests per chronological age group and sex.

Test	CA												Between-Group Effects		
	<10		11		12		13		14		>15		Age	Sex	Age * Sex
	M	F	M	F	M	F	M	F	M	F	M	F	BF_{10}	BF_{10}	BF_{10}
Trunk flexor endurance tests															
BTC (reps)	50.1 ± 21.6	50.7 ± 17.8	56 ± 20.5	44.8 ± 16.9	58.1 ± 15.7	54.6 ± 20.9	57.9 ± 24	71.1 ± 29.5	63.9 ± 23.3	72.1 ± 19.4	70.1 ± 14.8	64.4 ± 17.8	**$4.440 \times 10^{+7}$ (extreme for H_1)**	0.12 (moderate for H_0)	0.26 (moderate for H_0)
Ito (s)	79.5 ± 62.3	78.8 ± 66.8	94.7 ± 79.1	101.4 ± 92.2	118.9 ± 110.3	136.1 ± 118.6	179.4 ± 169.8	120.4 ± 115.4	192.8 ± 163.4	184.9 ± 162.3	232 ± 173.3	188.2 ± 144.3	**$1.89 \times 10^{+21}$ (extreme for H_1)**	0.08 (strong for H_0)	0.02 (very strong for H_0)
Trunk extensor endurance tests															
DEE (reps)	32.7 ± 12.4	30.7 ± 10.5	36.6 ± 12.3	35.6 ± 9.9	41.2 ± 11.2	37.3 ± 9.1	44.1 ± 11.9	36.1 ± 10	50.7 ± 13.3	37.9 ± 7.7	51.4 ± 11.7	36.6 ± 10.3	**$2.654 \times 10^{+15}$ (extreme for H_1)**	**$7.324 \times 10^{+5}$ (extreme for H_1)**	**478.71 (extreme for H_1)**
BS (s)	100.9 ± 65.3	118.8 ± 68.5	112.2 ± 80	139.8 ± 86.8	125.6 ± 67.4	150.6 ± 59.5	143.3 ± 69.2	150.6 ± 59.5	141.7 ± 61.2	156.9 ± 71.6	156.1 ± 57.2	151.1 ± 61.1	**$8.751 \times 10^{+5}$ (extreme for H_1)**	8.95 (moderate for H_1)	0.06 (strong for H_0)
Trunk lateral flexor endurance tests															
SB-R (s)	44.3 ± 31.7	40.1 ± 23.9	46.3 ± 22	38.7 ± 24.5	42.9 ± 26.5	46.6 ± 24.2	48.2 ± 27.2	47.4 ± 23	54.1 ± 25.5	44.1 ± 23.7	72 ± 25.2	55 ± 25	**$2.086 \times 10^{+6}$ (extreme for H_1)**	6.69 (moderate for H_1)	0.4 (anecdotal for H_0)
SB-L (s)	46.9 ± 33.9	39.2 ± 24.9	50.5 ± 26.1	40.5 ± 24.3	46.5 ± 28.4	46.7 ± 21.6	52.8 ± 27.9	51.9 ± 29.5	54.2 ± 27.9	42.6 ± 20.3	69.3 ± 25.1	50.8 ± 24.9	**199.84 (extreme for H_1)**	**482.81 (extreme for H_1)**	0.23 (moderate for H_0)

BF = Bayesian factor; CA = chronological age; F = female; H_1 = alternative hypothesis; H_0 = null hypothesis; M = male; reps = repetitions; s = seconds; SD = standard deviation.

Table 3. Mean and SD scores obtained from trunk endurance field-based tests per maturity status and sex.

	MAT						Between-Group Effects		
Test	**Pre-PHV**		**Circa-PHV**		**Post-PHV**		**MAT**	**Sex**	**MAT * Sex**
	M	**F**	**M**	**F**	**M**	**F**	BF_{10}	BF_{10}	BF_{10}
Trunk flexor endurance tests									
BTC (reps)	52.1 ± 20.7	50.9 ± 17.8	69.1 ± 24.6	49.1 ± 16.8	68.7 ± 16.34	67 ± 22.3	**$2.507 \times 10^{+7}$ (extreme for H_1)**	**43.14 (very strong for H_1)**	**58.48 (very strong for H_1)**
Ito (s)	90.1 ± 78.5	82.3 ± 72.2	210.9 ± 171.9	99.4 ± 80.9	215.6 ± 179.7	163 ± 149.8	**$2.116 \times 10^{+9}$ (extreme for H_1)**	**188,549.13 (extreme for H_1)**	**693.9 (extreme for H_1)**
Trunk extensor endurance tests									
DEE (reps)	38.1 ± 12.6	31.7 ± 10.5	52.9 ± 11.5	36.1 ± 10.3	47.9 ± 12.7	36.8 ± 9.5	**$4.865 \times 10^{+11}$ (extreme for H_1)**	**$6.527 \times 10^{+13}$ (extreme for H_1)**	**79.48 (very strong for H_1)**
BS (s)	107.2 ± 71.6	115.7 ± 68.3	144.1 ± 67.7	133 ± 85.5	159.6 ± 61.3	149.1 ± 63.8	**12,501.91 (extreme for H_1)**	0.07 (strong for H_0)	0.03 (0 strong for H_0)
Trunk lateral flexor endurance tests									
SB-R (s)	44.1±26.3	42.1 ± 25.1	51.8 ± 26.9	39.2 ± 23.1	66.9 ± 22.3	48.9 ± 25.1	**5292.63 (extreme for H_1)**	**510.62 (extreme for H_1)**	**10.73 (strong for H_1)**
SB-L (s)	47.9 ± 28.1	42.3 ± 26.6	53 ± 27.2	39.7 ± 24.3	65.8 ± 27.2	47.1 ± 22.5	7.48 (moderate for H_1)	**2240.57 (extreme for H_1)**	1.74 (anecdotal for H_1)

BF = Bayesian factor; F = female; H_1 = alternative hypothesis; H_0 = null hypothesis; M = male; MAT = maturity status; PHV = peak heigh velocity; reps = repetitions; s = seconds; SD = standard deviation.

3.3. Effects of Sex

Regarding the participants' sex, males showed a higher endurance compared to females in the SB-R (BF_{10} = 14.36, δ = 0.2), SB-L (BF_{10} = 400.85, δ = 0.29), and the DEE (BF_{10} = 8582.87, δ = 0.41) tests, but the effect size was small. However, females outperformed males in the BS test (BF_{10} = 5.55, δ = 0.21), though the evidence was moderate, and the effect size was small.

3.4. Interaction Effects of the Factors Maturity, Age, and Sex

Our analyses showed sex by CA interactions with at least strong evidence in favor of the alternative hypothesis (H_1) for the DEE test (BF_{10} > 10, an error percentage < 1, δ = 0.95–1.26) (Table 2). Post hoc analyses indicated that 14- (BF_{10} = 41.14, δ = 0.95) and 15-year-old (BF_{10} = 16,971.08, δ = 1.26) males showed better performance on the DEE test compared to females.

Furthermore, significant sex-by-MAT interactions were observed, with at least strong evidence supporting the alternative hypothesis (H_1) for all trunk endurance tests (BF_{10} > 10, an error percentage < 1, δ = 0.69–1.52), except for the BS and SB-L tests (Table 3). Post hoc analyses revealed more pronounced sex-specific differences in circa-PHV for the Ito (BF_{10} = 15,252.67, δ = 0.78), BTC (BF_{10} = 699.11, δ = 0.9), and DEE ($BF_{10} = 9.290 \times 10^{+8}$, δ = 1.52) tests, with boys outperforming girls. For the SB tests, a significant interaction was found with strong evidence but a small effect size (SB-R: BF_{10} = 19.16, δ = 0.48; SB-L: BF_{10} = 23.07, δ = 0.49). Similarly, in post-PHV, boys demonstrated better performance than girls in the SB-R (BF_{10} = 292.23, δ = 0.69), SB-L (BF_{10} = 1246.92, δ = 0.76), and DEE (BF_{10} = 1208.42, δ = 0.99) tests. However, no sex-specific differences were found before PHV in any test, except for the DEE test, where boys showed better performance than girls (BF_{10} = 49.17, δ = 0.51).

4. Discussion

The aim of the present study was to describe and compare the trunk muscle endurance in children and adolescents in relation to the CA, MAT, and sex. The main results showed differences in all trunk endurance tests according to the CA and MAT, with greater performance being found in the tests at an older CA or higher MAT. Differences were also found by sex; boys presented higher performance in the SB and DEE tests, while girls performed better in the BS test. Regarding interactions, boys performed better than girls in the DEE test (14 and 15 years old). In addition, interactions were also found between sex and MAT, where boys performed better than girls in all tests (with the only exception being the BS test) in the circa-PHV group, as well as in the post-PHV group for the SB-R, SB-L, and DEE tests. However, no interaction with sex was found for the pre-PHV group (except for the DEE test, where boys performed better than girls).

The current findings are consistent with the results of previous studies evaluating trunk muscle endurance [15,16,30,42] and other physical demands related to performance (strength, power, speed, etc.) [24,25,30,43,44] in youths, where an increase with advances in CA was observed. These findings are also in line with our MAT results, as well as those provided by Lesinski et al. [31] in their study assessing trunk muscle endurance through the ventral Bourban test in youth athletes, in which an increase with MAT was found. The changes in individual structures at the whole-body level (e.g., size, weight, proportion, and architecture of muscles and specific patterns of muscle activation) as well as at a system level (e.g., skeletal, muscular, and endocrine systems) that occur during puberty may improve the ability to generate strength with age and maturation, explaining the better scores obtained by older and more mature youths in physical tests that require this capacity [34,45]. By contrast, and unlike to what we found in this study, some researchers did not report age-related differences in trunk muscle performance for the BS [16], BTC [23], and SB [16,26] tests. In these studies, Dejanovic et al. [16] involved a sample of male and female adolescents between 15 and 18 years old, Moya-Ramón et al. [23] evaluated a sample of male and female adolescents with a mean age of 16.26 ± 1.13 (14–18 years), and Papadopoulou et al. [26] evaluated a sample of female volleyball players with a mean age of 13.9 ± 1.9. Considering that the early onset of puberty occurs at age 12 in females and around age 14 in males [27] and that the largest differences in performance tend to appear at circa-PHV (as shown in our MAT analyses), it is plausible that these authors did not find age-related differences in performance, in part because most of their participants were at the post-pubertal stage.

Regarding the effect of sex on trunk endurance performance, boys demonstrated, in general, a higher performance than girls for all field-based tests (with the exception of the BS test). Likewise, when the endurance of the trunk muscles is assessed in the adolescent population, boys tend to obtain higher scores than girls (i.e., the SB test, BTC test, ventral Bourban test, and FLEX-EXT dynamometer test) [16,23–25,30,31], except in the BS test [15]. This difference can be partially attributed to sex-based morphological and neuromuscular characteristics. On average, males have larger and higher-density trunk muscles than females, which likely contributes to their superior performance [46,47]. However, sex differences in performance may not depend solely on anthropometric measures, as intrinsic differences in muscle contractile properties, adaptations to training, and responses to clinical treatments may also play a role. Additionally, physiological mechanisms related to fatigue resistance, such as the activation of the motor neuron pool, synaptic inputs from metabolically sensitive afferent fibers, muscle perfusion, skeletal muscle metabolism, and fiber type properties, could further explain the observed differences in endurance between males and females [48]. These mechanisms highlight the complex interplay of anatomical, physiological, and neuromuscular factors contributing to sex differences in muscle endurance and fatigue resistance. In contrast, the BS test presents a notable exception to this general pattern. Several reasons have been proposed to explain this sex-related difference observed in the BS test: First, girls usually have greater lumbar lordosis than boys. Previous studies have shown that the lever arm length for the erector spinae muscles is higher with an increased lumbar lordosis [49], and the functional consequence of longer lever arm lengths is that less force is needed to create a certain external torque, such as lifting [50]. Second, females' erector spinae muscles have been shown to contain a greater proportion of slow-twitch muscle fibers than those of males [8]. The metabolic and physiological characteristics of slow-twitch (type I) muscle fibers provide them with superior oxidative capacity and the ability to maintain isometric contractions with more efficient tension maintenance compared to type II fibers [51]. Consequently, contractions predominantly supported by type I fibers are associated with a reduced rate of accumulation of metabolic by-products which have been linked to the onset of fatigue [52], thereby facilitating the endurance of this musculature in girls compared to boys.

On the other hand, when test scores were compared between peers of the same CA or MAT group, these sex differences in performance were maintained. However, with respect to the CA and sex, differences were only found between boys and girls in the DEE test and from the age of 14 onwards, where boys performed better than girls. In addition, as hypothesized, interactions were also found between sex and MAT, where boys classified as circa- and post-PHV performed better than girls in all tests. Although these significant sex-specific differences have been observed in studies involving participants at all ages [15,16,23–25,42], the marked acceleration of strength development during the growth spurt of male adolescents sets and magnifies these differences by males and females [27,53]. As shown in previous research, during the onset of puberty, the responses in estradiol and testosterone levels are different in males and females [54], so this divergence could contribute to differences in physical fitness between sexes that are becoming increasingly evident during puberty, as seen in this study. For example, increases in insulin-like growth factor 1 hormone (IGF−1) and growth hormone foment protein synthesis in both males and females, but the additional anabolic effect of increased testosterone, means that boys experience greater formation and development of fast-twitch muscle fibers and much greater gains in muscle mass during puberty than girls [31,54]. In addition, increased testosterone in males promotes a significant rise in the growth of bone, height, and muscle mass [12,27,28,53], while increased estradiol in females promotes an increase in body fat and stimulates ovulation and breast development [16,30,53]. Therefore, the sex-related differences found in trunk endurance measures could be due to these physical changes associated with puberty, leading to greater performance in boys compared to girls during circa- and post-PHV [23,27,29]. The results of our study coincide with previous research, where it has been shown that females tend to perform worse during PHV on tasks that require weight-bearing or strength [29], as is the case of the tests used in the present study. In contrast, males generally perform better during PHV, especially in activities that require strength, speed, or power [27,29–31,53]. Perhaps for the reasons mentioned above, sex differences according to CA appear in this study, only in a dynamic test (DEE test) where the application of strength endurance plays a key role during the execution of these tasks rather than endurance per se, since it coincides with the onset of the pubertal growth spurt in boys and the development of strength discussed previously. Considering the MAT, sex differences were more pronounced in all tests for participants in circa-PHV, whether in static or dynamic tests, providing better insights into the results than when using only the CA for analysis.

Finally, no significant interaction was found between sex and pre-PHV. These results of performance in pre-PHV students are unsurprising and in agreement with previous studies analyzing not only trunk muscle endurance but also upper and lower extremity strength or power [30,43]. Maturational sex differences before the adolescent spurt do not differ significantly in body height, body mass, girth, bone width or skinfold thickness, and physical fitness [27,28,30]. The results of maturation should be interpreted with caution, considering the methods used to estimate PHV. Skeletal age via a hand–wrist radiograph is considered the "gold standard", but it has clear disadvantages. These include significant radiation exposure for participants, invasiveness, high costs, and time requirements, as well as the need for a high level of expertise to administer [55]. Although Mirwald et al.'s [33] predictive equation is widely used in the literature because it is non-invasive, time efficient, and practical for child–youth contexts, other equations may be more appropriate for estimating maturity offset, such as that of Moore et al. [56] or that of Fransen et al. [57] (only for boys), as well as the Khamis and Roche equation [58] used to estimate the percentage of the final estimated adult stature attainment (%EASA). Regardless of the method employed, from a practical standpoint, it is recommended that anthropometric measurements and subsequent maturation estimates be performed at least three times per year on a routine and consistent basis. This will enable sports professionals and PE teachers to identify the onset and cessation of PHV and therefore prescribe training loads based on maturation status [55].

Based on the results obtained, youth fitness specialists (i.e., researchers, physical therapists, PE teachers, and strength and conditioning coaches) should be aware of the effects of the CA and MAT when assessing trunk muscle endurance, in particular, and physical fitness, in general, in children and adolescents. In turn, despite taking into account that previous studies have shown that the reduced endurance of trunk muscles and the endurance imbalance (asymmetry) between trunk muscle groups are related to the higher prevalence and intensity of BP in children and adolescents [18,19,22,59,60], and that the improvement in the endurance of the flexor and extensor muscles of the trunk is associated with the reduction in LBP in adolescents [61,62], most health-related physical condition test batteries for children and adolescents only include dynamic trunk flexor measures, that is, sit-up or curl-up tests (e.g., Eurofit, Connecticut Physical Fitness Assessment, FITNESSGRAM®/ACTIVITYGRAM®, ALPHA-Fitness test battery). That is why we decided to include five different field-based tests, both dynamic and static, as well as in the sagittal and frontal planes, covering the different muscle groups that participate in trunk movements, since there is no single test to measure trunk muscle endurance. Each test has its advantages and limitations, and the choice depends on many factors, such as the context in which the test will be applied, the characteristics and needs of the participants, and the capability of the trunk muscles to be measured [63]. More research is needed to better understand the relationship between these trunk endurance test scores, which will allow us to determine the extent to which a single trunk endurance test may be generalizable to other measures of trunk endurance. In this regard, static tests could be applied in environments or sports that require isometric trunk endurance demands, such as maintaining a more upright sitting posture in educational settings over long days or hockey, gymnastics, and cycling. Dynamic tests could be used in daily life situations or in sports requiring continuous trunk flexion or extension movements, such as kayaking, volleyball, handball, dressage, or soccer, for example.

This research also has some limitations that should be stated. First, the results are limited to Spanish children and adolescents, which may not be representative of students of the same age around the world. Second, the sample size of each sub-group varies according to the sub-group under investigation, and the large variability in test results (i.e., the Ito test) may have affected the comparison between sub-groups. In addition, special attention would be required when performing trunk endurance tests due to the high inter-individual variability, not only from differences in participants' muscle endurance but also from the challenges in maintaining a standardized posture. Even minor variations in the initial position or in balance maintenance can significantly affect the results [64]. It is then crucial to follow standardized protocols, provide clear instructions, involve expert evaluators, and conduct several familiarization sessions to ensure consistency and reliability [23,32]. In any case, the standardization of protocols will not entirely eliminate the inherent variability and validity concerns associated with certain trunk endurance tests. In fact, it has been shown that female SB test performance may be influenced by factors beyond trunk lateral flexor endurance, including contributions from the external oblique and deltoid muscles, body mass, and trunk height [65]. These factors, along with the activation of shoulder musculature and fatigue levels, may affect the validity of the SB test as a measure of lateral flexor endurance. Similar concerns, though potentially to a lesser extent, may also apply to other trunk endurance tests used in this study, highlighting the complexity of isolating trunk muscle performance in field-based assessments. Therefore, the results obtained in this study regarding muscle strength and endurance should be interpreted with caution as they are subject to variability and validity limitations inherent to the methods used.

Another limitation of this study that should be mentioned is that the maturity offset was calculated using an equation based on the leg length, sitting height, age, body height, and body weight of the subjects, which may not be as accurate as using the gold standard method (x-ray exams). The leg length was also obtained by the difference between the standing and sitting heights, and for future research, it would be advisable to directly measure the leg length to offer greater accuracy and reduce the likelihood of error due to postural variations, measurement inaccuracies, and individual differences in body proportions. However, to minimize the sub-group assignment error derived from the equation, participants with a maturational offset between −1 to −0.5 and +0.5 to +1 were removed from the dataset, as were students who fell outside of −3 or +3 years. As a result, this decision led to a smaller sample size in the post-PHV sub-group compared to the other sub-groups.

Finally, personal factors, such as motivation, may influence field test performance, even if participants received full information about the tests as well as encouragement during performance. Additionally, factors like physical activity levels could significantly impact trunk endurance, potentially affecting test results independently of the CA or MAT. Therefore, future research should consider including this variable and exploring its relationship with trunk endurance test outcomes.

5. Conclusions

This study describes the MAT, CA, and sex-specific differences found in trunk muscle endurance through five field-based tests in a large sample of children and adolescents. In conclusion, there is a clear trend that trunk muscle endurance increases as participants become older or more mature. In relation to sex, boys presented higher performance in the SB and DEE tests, while girls performed better in the BS test. Furthermore, these sex-differences in performance were maintained when test scores were compared between peers of the same CA or MAT group. However, with respect to the CA and sex, differences were only found in the DEE test from the age of 14 onwards, where boys performed better than girls. Additionally, interactions were also found between sex and MAT, where boys classified as circa- and post-PHV performed better than girls in all tests. On the other hand, pre-pubertal boys and girls showed similar performance in almost all tests.

Therefore, taking into account that physical fitness seems to be particularly sensitive to MAT, it is important to consider biological maturation when assessing physical fitness, rather than the CA, which is commonly used in international fitness batteries for children and adolescents.

Despite these findings, this study has several methodological limitations that should be acknowledged. First, the estimation of biological maturation was based on a predictive equation using anthropometric variables rather than the gold standard method (hand–wrist radiographs). Future research should consider more precise methodologies for assessing lower limb length and biological maturity to reduce potential errors in classification. Additionally, sample distribution was not completely balanced across all age and maturation groups, which may have influenced some results. Future studies should aim to recruit more homogeneous and representative samples to minimize disparities. Addressing these aspects will contribute to refining the understanding of how maturation influences trunk endurance performance in children and adolescents.

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