Jornal de Pediatria 2023;**99(1):** 38−44

Jornal de
Pediatria
www.jped.com.br

ORIGINAL ARTICLE

Fat-free mass and maturity status are determinants of physical fitness performance in schoolchildren and adolescents

Paz Pezoa-Fuentes [a], Marco Cossio-Bolaños [a], Camilo Urra-Albornoz [a], Fernando Alvear-Vasquez [b], Evandro Lazari [c], Luis Urzua-Alul [d], Luis Felipe Castelli Correia de Campos [e], Rossana Gomez-Campos [f,*]

[a] *Programa de Doctorado en Ciencias de la Actividad Física, Universidad Católica del Maule, Talca, Chile*
[b] *Universidad de Valencia, Valencia, Spain*
[c] *Facultade de Ciencias Aplicadas, Universidad Estadual de Campinas, São Paulo, SP, Brazil*
[d] *Escuela de Kinesiología, Facultad de Ciencias de la Salud, Universidad Santo Tomás, Chile*
[e] *Universidad del Bio Bio, Chillán, Chile*
[f] *Departamento de Diversidad e Inclusividad Educativa, Universidad Católica del Maule, Talca, Chile*

Received 24 January 2022; accepted 29 April 2022
Available online 5 June 2022

KEYWORDS
Fat-free mass;
Maturity status;
Physical fitness;
Schoolchildren

Abstract
Objectives: The objective of the study was to verify whether (FFM), maturity status (MS) and chronological age (CA) are determinants of physical fitness performance, and to analyze FFM and physical performance aligned by CA and MS in children and adolescents.
Methods: A descriptive correlational study was carried out in 863 schoolchildren. Weight, height, and waist circumference (WC) were evaluated. Body mass index (BMI), FFM, fat mass (FM), MS (Age at peak height velocity, APHV) were calculated. The physical tests of velocity 20 m, agility 5 m x 10rep, and horizontal jump (HJ) were evaluated.
Results: The APHV was estimated in boys at 14.0 ± 0.36APHV and in girls at 11.96 ± 0.49APHV. The relationships between CA and APHV with FFM was r = 0.80 in boys and r = 0.44 to 0.45 in girls. The relationships between FFM and physical tests in boys were [HJ (r = 0.70), agility 5m x 10rep (r = -0.68), velocity (r = -0.61)] and in girls [HJ (r = 0.42), agility 5m x 10rep (r = -0.52), velocity (r = -0.20)]. The differences in FFM and physical fitness tests were more pronounced when aligned by APHV than by CA.
Conclusion: It was verified that both FFM, CA, and APHV are determinants of physical fitness performance. In addition, the APHV should be introduced in physical education as a means of ranking physical performance among schoolchildren.

* Corresponding author.
E-mail: rossaunicamp@gmail.com (R. Gomez-Campos).

https://doi.org/10.1016/j.jped.2022.03.007

Introduction

Body composition (BC) is indispensable for understanding the effects of diet, physical exercise, disease, and physical growth, among other environmental factors on the human organism.[1] In fact, the absolute and relative components of body mass are a major focus in BC studies, as they change during growth and biological maturation, so care is required when selecting assessment methods for children and adolescents.[2]

In general, BC body compartments are determined by laboratory and field methods. They are considered useful tools to assess both children and adolescents at different stages of growth and maturation.[3]

From an anthropometric perspective, the fractionation of fat mass (FM) and fat-free mass (FFM) is often used. For example, fat mass provides important information on body fat gain and is associated with increased risk for diseases such as obesity, cardiovascular disease, type 2 diabetes, and hypertension, among others,[4,5] while FFM plays an important role in physical performance,[6] posture maintenance and body movement in adults, children and adolescents.[7]

Consequently, it is widely known that the proportions of the body compartments (FM and FFM) change during growth and development. Consequently, these components can be determinant when analyzing the physical fitness of children and adolescents.

In this context, physical fitness has been recognized as a key determinant of healthy lifestyles.[8] For example, muscular strength and more global muscular fitness have important implications in daily life and are essential for performing activities of daily living.[9] So too, agility and velocity are fitness qualities that are related to a range of diverse sports[10,11] and are necessary for an individual to successfully demonstrate a variety of basic motor skills and movement patterns.[12]

Consequently, within the scope of school physical education, physical qualities such as horizontal jumping, agility, and velocity are generally developed in the learning contents according to age and sex. The development of these contents includes common activities such as running, jumping, and throwing, which are performed daily through play.[13] Furthermore, physical performance is conditioned not only by the levels of physical activity,[14] but also by the level of maturation of children and adolescents, since the intensity and duration of puberty are specific to each individual and can vary considerably between individuals.[15]

From this perspective, based on the fact that changes in somatic growth and maturation occur during childhood and adolescence, it is possible that FFM levels and maturity status (MS) could be determinants when analyzing physical performance in schoolchildren.

Therefore, the aim of the study was to verify whether FFM, MS (APHV), and CA are determinants of physical fitness performance (horizontal jump, velocity, and agility) and additionally FFM and physical performance aligned by CA and maturity status in Chilean children and adolescents will be analyzed

Materials and methods

Type of study and sample

A descriptive (cross-sectional) study was carried out on schoolchildren aged 6 to 17.9 years attending public schools in the city of Talca (Chile). The commune of Talca has 31 schools in the urban area, with a population of 16,202 students, 8,035 boys and 8,167 girls. The selection of the study sample was probabilistic (random). The sample size corresponds to 10.7% of the population, being [500 men (6.2%) and 363 women (4.5%)]. The sample by strata (age ranges) presents a balanced size in both sexes, e.g., boys [6-7 years (*n* = 38), 8-9 years (*n* = 61), 10-11 years (*n* = 63), 12-13 years (*n* = 30), 14-15 years (*n* = 62) and 16-17 years (*n* = 91)] and girls [6-7 years (*n* = 55), 8-9 years (*n* = 57), 10-11 years (*n* = 62), 12-13 years (*n* = 40), 14-15 years (*n* = 31) and 16-17 years (*n* = 48)].

All parents and guardians were informed to participate in the study by letter. The schoolchildren and parents received information about the project objectives at a meeting (statement of objectives).

The parents who agreed to participate in the study signed the consent form and the children signed the informed consent form.

The protocols used for measuring anthropometry and physical tests were performed according to the suggestions described by the ethics committee of the Universidad Católica del Maule and the Declaration of Helsinki (World Medical Association) for human beings. The study was approved by the ethics committee (opinion no. 100-2019).

Techniques and procedures

The ages and dates of birth were requested from each school's administration. They were extracted from the enrollment forms. With this information, the decimal age of each student was calculated.

The anthropometric and physical fitness evaluations were collected at the facilities of each school during school hours from 8:30 am to 12:30 pm and from 2:30 pm to 6:00 pm from Monday to Friday during the months of August to October 2019.

Anthropometric measurements were evaluated according to the protocol described by Ross and Marfell-Jones.[16] Bodyweight (kg) was assessed without shoes, wearing a T-shirt and shorts, using an electronic scale (Tanita, United Kingdom, Ltd.) with a range of 0−150 kg and an accuracy of 100 g. Standing height was measured without shoes, according to the Frankfurt plan using a portable stadiometer (Seca Gmbh & Co. KG, Hamburg, Germany) with an accuracy of 0.1 mm. Waist circumference (WC) (cm) was measured using a metal tape measure, Seca brand, graduated in millimeters with an accuracy of 0.1 cm. To ensure the reliability of the anthropometric measurements, they were measured twice (retested). The technical measurement error (TEM) ranged from 1.0 to 1.4%.

Maturity status was calculated by means of a non-invasive anthropometric technique proposed by Moore et al.[17] For prediction, an equation was used for each sex, where CA and height are required. The equations deliver information related to peak years of growth velocity (APHV), according to levels, for example: -6, -5, -4, -3, -2, -2, -1, 0, 0, +1, +1, +2, +3, +4, +5APHV. Zero (0) means the time of the PHV, negative values mean the years remaining to reach the PHV and positive values, are the years passed from the PHV. The equations used are:

$$\text{Girls: Maturity status: APHV (years)} = -7.709133 + [(0.0042232 \times (\text{CA} \times \text{height})].$$

$$\text{Boys: Maturity status: APHV (years)} = -7.999994 + [(0.0036124 \times (\text{CA} \times \text{height})].$$

Body composition was estimated by anthropometric equations. Two body components were calculated (fat mass and fat-free mass).

The FFM mass was determined by means of an anthropometric equation proposed by Cossio-Bolaños et al. [18] using variables such as age, weight and height. The equations used are:

$$\text{Boys: FFM} = -28.669 + 0.887 * \text{Age} + 0.298 * \text{Weight} + 0.255 * \text{Height}.$$

$$\text{Girls: FFM} = -16.264 + 0.182 * \text{Age} + 0.302 * \text{Weight} + 0.198 * \text{Height}.$$

$$\text{Fat mass (FM) was deduced from: FM} = \text{Body weight} - \text{FFM}, \text{ and the \%FM from: \%FM} = (\text{FM} * 100) / \text{Body weight}.$$

The physical fitness tests were evaluated in the facilities of each school (gymnasium). The evaluation procedures for each physical test were explained to the students. Everyone performed a warm-up of 10 to 15 min to warm up. Then the physical tests were evaluated in the following order: Horizontal jump (HJ), Velocity 20 m (V20 m), and agility (10 × 5 m).

The horizontal jump test (cm) evaluates the explosive strength of the lower extremities.[19] It was performed three times and the longest distance was recorded. The 20 m velocity test was evaluated with a high start. A Casio ® digital stopwatch (1/100S) was used, following the procedures of Grosser and Starischka.[20] For the 5m x10rep agility test, two lines (5 m apart) were marked as described by Verschuren et al. [21] The subject should run at maximum velocity from one side to the other, repeating 10 times without stopping (covering 50 m in total). The time taken to perform the 10 repetitions (sec) was controlled. The best time of the two repetitions was recorded.

To control the quality of the measurements, the TEM was calculated, the results of which yielded values between 1.5 and 2.2%. In all cases highly acceptable.

Statistics

The normality of the data was verified by means of the Kolmogorov-Smirnov test. Descriptive statistics (mean, standard deviation, and range) were calculated. Comparisons between both sexes were performed by means of a t-test for independent samples. Relationships between variables were performed using Pearson's test. Comparisons between ages and APHV were performed by means of Ancova and Tukey's test of specificity. The coefficient of determination r^2 and standard error of estimation (SEE) were calculated. In all calculations, $p < 0.05$ was considered. Statistical analysis was performed in SPSS 18.0.

Results

The anthropometric characteristics, physical performance, and body composition of the sample studied are shown in Table 1. There were no differences in FM between both

Table 1. Anthropometric profile, body composition and physical performance of the sample studied.

Variables	Boys (*n* = 500)		Girls (*n* = 363)		t	p
	Mean	SD	Mean	SD		
Age (years)	12.96	3.91	11.55	3.67	5.37	0.000
MS (APHV)	14.00	0.36	11.96	0.49	17.13	0.000
Anthropometry						
Weight (kg)	54.03	20.48	44.9	16.84	6.95	0.000
Height (cm)	153.72	18.7	143.88	15.68	8.16	0.000
WC (cm)	73.4	12.88	69.54	11.29	4.57	0.000
BMI (kg/m^2)	22.03	4.77	20.92	4.71	3.38	0.001
Body composition						
Fat mass (kg)	15.9	8.96	17.01	8.82	−1.81	0.071
FFM (kg)	38.12	13.55	27.88	8.46	12.71	0.000
Physical fitness						
Agility (sec)	20.12	3.9	23.02	4.09	−10.58	0.000
Velocity 10m (sec)	4.28	0.78	4.59	0.79	−5.69	0.000
Horizontal jump (cm)	146.26	40.87	109.97	23.11	15.21	0.000

t, Student's t-value, MS, maturity stage, APHV, peak growth velocity years, WC, waist circumference, BMI, body mass index, FFM, fat-free mass, FFM, fat-free mass.

sexes (p = 0.071), while boys showed higher CA, APHV, weight, height BMI, FFM, and HJ in relation to girls ($p < 0.001$). In addition, boys were more agile and faster than their counterparts ($p < 0.001$).

The relationships between the physical fitness tests with FFM, APHV, and CA are observed in Table 2. The three physical tests were related to CA, APHV, and FFM. In boys, the coefficients of determination (r^2) ranged for HJ from 48 to 63%, agility from 47 to 56% and velocity from 37 to 49%. In girls, the coefficients of determination were relatively lower. In HJ they ranged from 18 to 21%, in agility from 27 to 39%, and in velocity from 0.03 to 0.04%.

Fig. 1 shows the comparisons of FFM according to CA and APHV in both sexes. In the comparisons by CA, differences are observed from 9 to 17 years ($p < 0.05$), however, when compared by MS, the differences are significant in all APHV (from -5APHV to +4APHV) ($p < 0.05$).

Comparisons of physical performance by CA and APHV are seen in Fig. 2. In HJ when compared to CA, differences were observed from 11 to 17 years and by APHV, differences are significant at all APHV levels. In velocity, when compared by CA there were no differences from 6 to 14 years ($p > 0.05$), however, from 15 to 17 years, the differences were significant ($p < 0.05$). For MS, differences started to appear from +2APHV to +4APHV. In agility, there were no differences at 6 and 7 years of age when compared to CA, while from 8 to 17 years of age there were significant differences ($p < 0.05$). On the other hand, when compared according to APHV, there were differences from -5APVC to +4APHV ($p < 0.05$). In general, the use of the APHV allows a better categorization of the performance of the children and adolescents studied.

Discussion

The first objective of the study was to verify whether FFM, MS, and CA are determinants of physical fitness performance (horizontal jump, velocity, and agility) in Chilean children and adolescents. The results have evidenced moderate relationships between FFM, MS, and CA with HJ, agility, and velocity tests in both sexes, except in girls in the velocity test.

In fact, the results obtained are consistent with what has been described in the literature, where it is emphasized that the physical fitness of children and adolescents is affected by various factors, such as age and sex, body

Table 2 Relationship between physical fitness tests with fat-free mass and maturity status in schoolchildren of both sexes.

Physical fitness	Independent variable	Boys				Girls			
		R	r^2	SEE	P	r	r^2	SEE	p
HJ	Age (years)	0.80	0.63	24.29	0.001	0.44	0.19	21.00	0.001
	MS (APHV)	0.80	0.63	24.38	0.001	0.45	0.21	20.81	0.001
	FFM (kg)	0.70	0.48	28.77	0.001	0.42	0.18	21.18	0.001
Agility (sec)	Age (years)	−0.74	0.55	2.63	0.001	−0.63	0.39	3.16	0.001
	MS (APHV)	−0.75	0.56	2.61	0.001	−0.63	0.39	3.15	0.001
	FFM (kg)	−0.68	0.47	2.85	0.001	−0.52	0.27	3.47	0.001
Velocity (sec)	Age (years)	−0.70	0.49	0.56	0.001	−0.16	0.03	0.79	0.001
	MS (APHV)	−0.69	0.48	0.56	0.001	−0.16	0.03	0.78	0.001
	FFM (kg)	−0.61	0.37	0.62	0.001	−0.20	0.04	0.78	0.001

MS, maturity stage, APHV, peak years of growth velocity, SEE, standard error of estimation, HJ, horizontal jump; r, correlation, r^2, coefficient of determination.

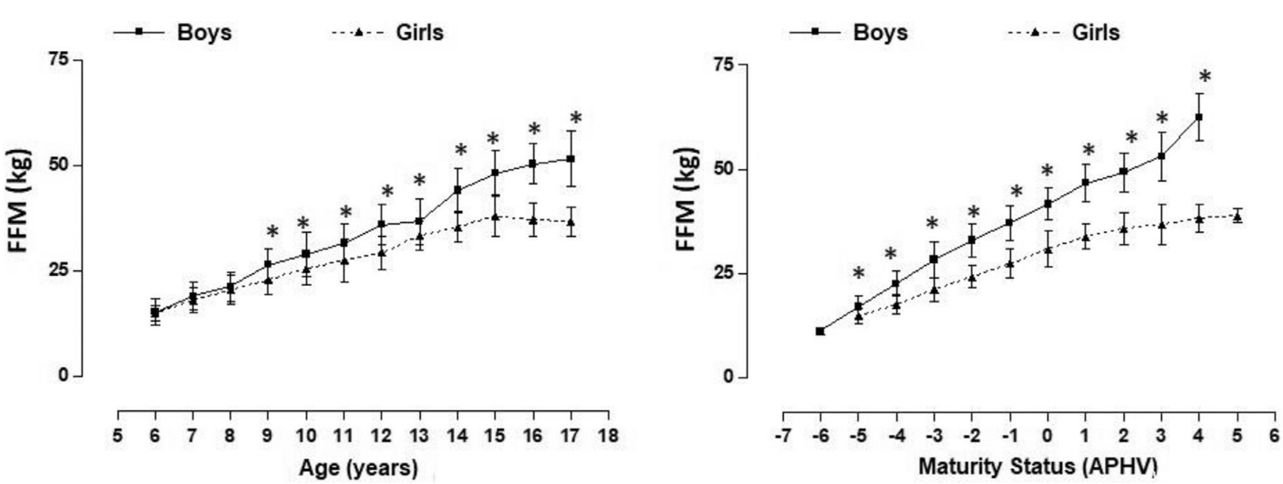

Fig. 1. Mean FFM values of children and adolescents by chronological age and maturity status.*, significant difference in relation to girls.

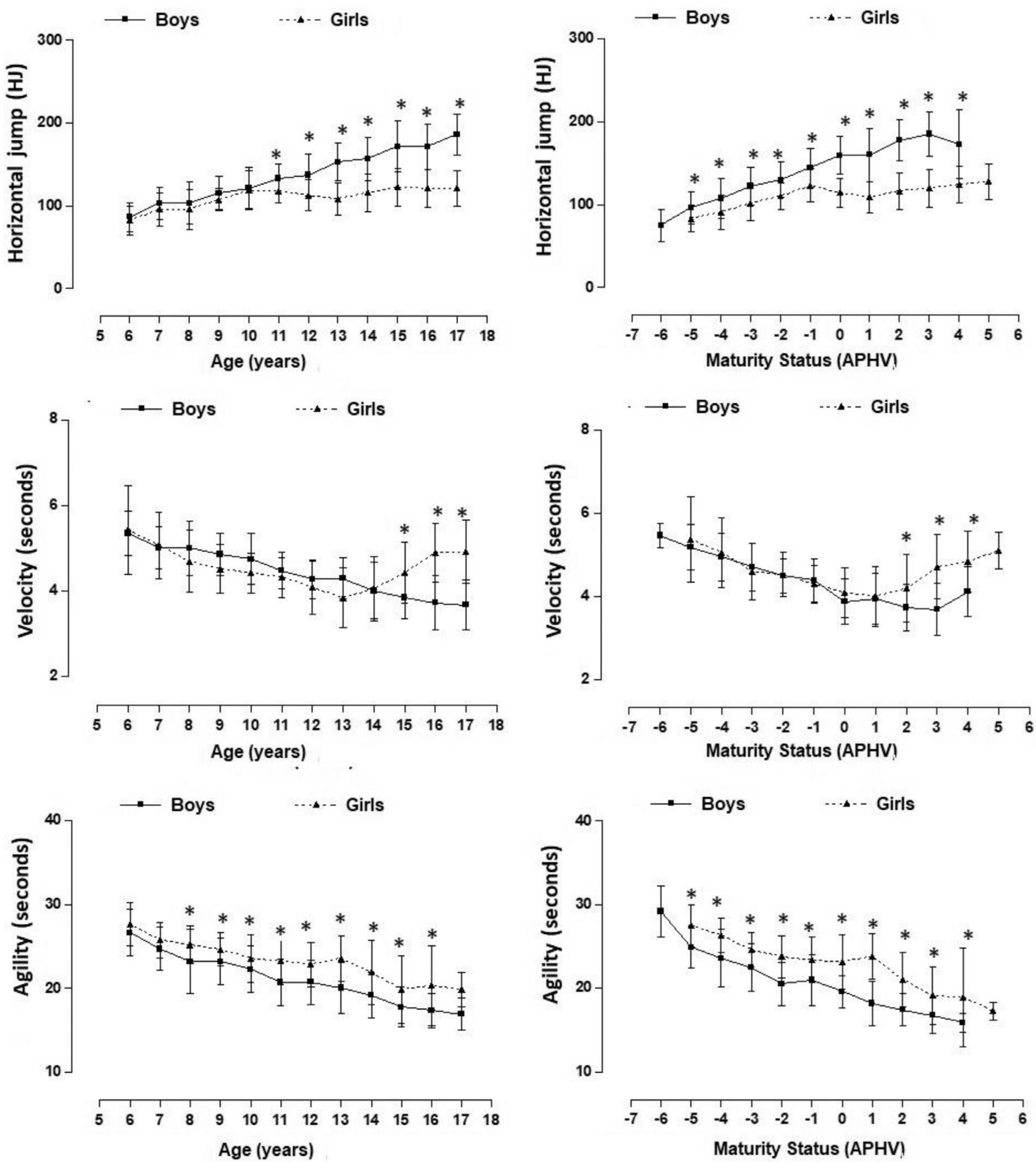

Fig. 2. Mean physical performance values of children and adolescents by chronological age and maturity status.*, significant difference in relation to girls.

size and composition, state of biological maturity, level of habitual physical activity, [15,22] among other factors. However, the fact of observing low correlations between FFM and the velocity test in girls could be associated with a lower FFM in relation to boys, in addition to reaching its maximum values at approximately 13 years of age, and then remaining stable until 17 years of age, although, on the other hand, other factors such as motivation could be involved in the results.[15]

In general, these relationships are explained by the fact that in the HJ, agility, and velocity are presented in a series of motor actions that must be developed efficiently. Therefore, the result of the execution of these tests is reflected in the performance and depends on the acquired muscle strength levels.

Consequently, muscle strength is defined as the ability to exert maximum force in the shortest possible time, such as when accelerating, jumping, and throwing implements, [23] whereby, both HJ, agility, and velocity are dependent on FFM.

These findings suggest that CA, APHV, and FFM during childhood and adolescence have a positive effect on physical performance. These studies highlight that, maintaining adequate muscle mass has important implications in daily life and is essential for performing activities of daily living[9] and brings a number of health-related benefits.[24]

On the other hand, a wide variety of studies have shown that a high level of FFM can increase insulin sensitivity [25,26] and low muscle mass is associated with multiple metabolic risk factors and insulin resistance.[27,28]

In that sense, the preservation and acquisition of adequate levels of skeletal muscle mass during childhood and adolescence should be a constant concern for parents and the physical education curriculum. This is because maintaining optimal skeletal muscle mass in childhood and adolescence can improve peak muscle mass and bone strength.[29] Consequently exerting beneficial effects on physical performance.

A second aim of the study was to analyze FFM and physical performance aligned by CA and MS. The results have shown discrepancies between both indicators since the analysis by means of MS (through the APHV) evidenced significant differences between both sexes, which was not observed by means of CA.

These results suggest that the assessment and monitoring of FFM and physical performance of children and adolescents should be performed by controlling for MS since this indicator of somatic maturation is often determined by age- and sex-specific regression equations,[17] which aim to classify the state of maturation by APHV.

In general, it is considered that children may have advantages/disadvantages in fitness testing by being more or less mature than their chronologically age-matched counterparts. Thus, controlling the timing and rate of growth is of utmost importance, given that maturation is highly individual and asynchronous with decimal age throughout adolescence.[15] Therefore, it is essential to classify children and adolescents according to their MS, especially if the authors are to analyze in terms of FFM and physical performance.

In that sense, young people of the same CA vary considerably in their MS, so there are differences in height, weight, fat mass, and FFM between adolescents who mature faster relative to those who mature on average and late. In fact, late-maturing adolescents generally possess diminished physical and functional characteristics (i.e., more linear physique, less absolute and relative fat mass) than their average and accelerated maturing counterparts.

In essence, as observed in Figs. 1 and 2, the greatest changes are observed after the 0APHV level forward, especially in FFM, agility, and HJ, whereas in velocity up to 1 year after the PHV. Subsequently, girls show poor performance in velocity, while boys continue to improve their performance as they mature further.

In general, it is widely known that during physical education classes and sports practice, often the motor actions of decelerating, re-accelerating, changing direction, jumping, and landing require the ability to absorb and produce force quickly, both unilaterally and bilaterally, as, during these activities, many boys and girls may show varied results in physical performance, due to the presence of diverse maturation rhythms.

Therefore, it is relevant, to introduce the control of MS in physical education classes and in sports practice, since this indicator can contribute to an adequate classification among adolescents. It is considered a powerful indicator for the classification of workgroups, especially when it comes to variables related to the physical capacities of strength, velocity, and endurance, respectively.[15]

This study presents several potentialities, given that it is one of the first studies carried out in Chile, in which large sample size is considered (6 to 17.9 years), in addition, the probabilistic type of sample selection (stratified) and the reliability of the anthropometric measurements and physical tests (retesting) allow generalizing the results to contexts with similar characteristics. On the other hand, the type of study adopted (cross-sectional) also stands out as one of the main limitations, since a longitudinal study allows causal relationships to be established and even to verify changes over time. The control of MS by means of a non-invasive technique (anthropometric) could lead to slight biases in the results obtained; however, in the absence of other techniques, the authors consider its use and application opportune. In addition, this technique was recently validated in a representative sample of young Chileans, so its use and application are valid and reliable.[30]

Conclusions

In conclusion, this study verified that both FFM, CA and MS are determinants of physical fitness performance (horizontal jump, velocity, and agility). Furthermore, MS should be introduced in physical education as a means to classify the physical performance of schoolchildren, since it ostensibly reduces anthropometric and physical differences in relation to CA.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

To the UCM doctoral fellowship, Talca, Chile.

References

1. Valtueña Martínez S, Arija Val V, Salas-Salvadó J. Estado actual de los métodos de evaluación de la composición corporal: descripción, reproducibilidad, precisión, ámbitos de aplicación, seguridad, coste y perspectivas de futuro. Med Clin. 1996; 106:624−35. (Barc).
2. Malina RM, Geithner CA. Body composition of young athletes. Am J Lifestyle Med. 2011;5:262−78.

3. Sherar LB, Mirwald RL, Baxter-Jones AD, Thomis M. Prediction of adult height using maturity-based cumulative height velocity curves. J Pediatr. 2005;147:508—14.
4. Seidell JC, Hautvast JG, Deurenberg P. Overweight: fat distribution and health risks. Epidemiological observations. A review. Infusionstherapie. 1989;16:276—81.
5. Pulgaron ER, Delamater AM. Obesity and type 2 diabetes in children: epidemiology and treatment. Curr Diab Rep. 2014;14:508.
6. Poortmans JR, Boisseau N, Moraine JJ, Moreno-Reyes R, Goldman S. Estimation of total-body skeletal muscle mass in children and adolescents. Med Sci Sports Exerc. 2005;37:316—22.
7. Sayer AA, Syddall H, Martin H, Patel H, Baylis D, Cooper C. The developmental origins of sarcopenia. J Nutr Health Aging. 2008;12:427—32.
8. Ortega FB, Tresaco B, Ruiz JR, Moreno LA, Martin-Matillas M, Mesa JL, et al. Cardiorespiratory fitness and sedentary activities are associated with adiposity in adolescents. Obesity. 2007;15:1589—99. (Silver Spring).
9. Thivel D, Ring-Dimitriou S, Weghuber D, Frelut ML, O'Malley G. Muscle strength and fitness in pediatric obesity: a systematic review from the european childhood obesity group. Obes Facts. 2016;9:52—63.
10. Farrow D, Young W, Bruce L. The development of a test of reactive agility for netball: a new methodology. J Sci Med Sport. 2005;8:52—60.
11. Uzun A, Akbulut A, Erkek A, Pamuk Ö, Bozoğlu MS. Effect of age on speed and agility in early adolescence. IJAEP. 2020; 9:168—75.
12. SHAPE America. National Standards & Grade-Level Outcomes for K—12 Physical Education Society of Health and Physical Educators. Reston, VA: Society of Health and Physical Educators; 2014.
13. Milanese C, Sandri M, Cavedon V, Zancanaro C. The role of age, sex, anthropometry, and body composition as determinants of physical fitness in nonobese children aged 6-12. PeerJ. 2020;8:e8657.
14. Sola K, Brekke N, Brekke M. An activity-based intervention for obese and physically inactive children organized in primary care: feasibility and impact on fitness and BMI A one-year follow-up study. Scand J Prim Health Care. 2010;28:199—204.
15. Malina RM, Bouchard C, Bar-Or O. Growth, Maturation, and Physical Activity. 2nd ed. Champaign, IL: Human Kinetics; 2004.
16. Ross WD, Marfell-Jones MJ. Canadian Association of Sports Sciences. Kinanthropometry. In: MacDougall JD, Wenger HA, Green HJ, eds. Physiological Testing of the High-Performance Athlete, Champaign, Ill: Human Kinetics Books; 1991.
17. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones AD, Cameron N, et al. Enhancing a somatic maturity prediction model. Med Sci Sports Exerc. 2015;47:1755—64.
18. Cossio Bolaños MA, Andruske CL, de Arruda M, Sulla-Torres J, Urra-Albornoz C, Rivera-Portugal M, et al. Muscle mass in children and adolescents: proposed equations and reference values for assessment. Front Endocrinol. 2019;10:583. (Lausanne).
19. Castro-Piñero J, Ortega FB, Artero EG, Girela-Rejón MJ, Mora J, Sjöström M, et al. Assessing muscular strength in youth: usefulness of standing long jump as a general index of muscular fitness. J Strength Cond Res. 2010;24:1810—7.
20. Grosser M, Starischka S. Test de la Condición Física. Barcelona: Ediciones Martinez Roca; 1988.
21. Verschuren O, Takken T, Ketelaar M, Gorter JW, Helders PJ. Reliability for running tests for measuring agility and anaerobic muscle power in children and adolescents with cerebral palsy. Pediatr Phys Ther. 2007;19:108—15.
22. Malina RM. Anthropometry, strength and motor fitness eds.. In: Ulijaszek SJ, Mascie-Taylor CG, eds. Anthropometry: The Individual and the Population, Cambridge, UK: Cambridge University Press; 1994:160—77.
23. Beaudart C, Rolland Y, Cruz-Jentoft AJ, Bauer JM, Sieber C, Cooper C, et al. Assessment of muscle function and physical performance in daily clinical practice: a position paper endorsed by the European society for clinical and economic aspects of osteoporosis, osteoarthritis and musculoskeletal diseases (ESCEO). Calcif Tissue Int. 2019;105:1—14.
24. Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. Sports Med. 2014;44:1209—23.
25. Nam SY, Kim KR, Cha BS, Song YD, Lim SK, Lee HC, et al. Low-dose growth hormone treatment combined with diet restriction decreases insulin resistance by reducing visceral fat and increasing muscle mass in obese type 2 diabetic patients. Int J Obes Relat Metab Disord. 2001;25:1101—7.
26. Berman LJ, Weigensberg MJ, Spruijt-Metz D. Physical activity is related to insulin sensitivity in children and adolescents, independent of adiposity: a review of the literature. Diabetes Metab Res Rev. 2012;28:395—408.
27. Cohen DD, Gómez-Arbeláez D, Camacho PA, Pinzon S, Hormiga C, Trejos-Suarez J, et al. Low muscle strength is associated with metabolic risk factors in Colombian children: the ACFIES study. PLoS One. 2014;9:e93150.
28. McCarthy HD, Samani-Radia D, Jebb SA, Prentice AM. Skeletal muscle mass reference curves for children and adolescents. Pediatr Obes. 2014;9:249—59.
29. Liu J, Yan Y, Xi B, Huang G, Mi J. China child and adolescent cardiovascular health (CCACH) study group. Skeletal muscle reference for Chinese children and adolescents. J Cachexia Sarcopenia Muscle. 2019;10:155—64.
30. Cossio-Bolaños M, Vidal-Espinoza R, Castelli Correia de Campos LF, Sulla-Torres J, Cossio-Bolaños W, et al. Equations predicting maturity status: Validation in a cross-sectional sample to assess physical growth and body adiposity in Chilean children and adolescents. Endocrinol Diabetes Nutr. 2021;68:689—98. (Engl Ed).