Journal of Sports Sciences

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rjsp20

Physical fitness spurts in pre-adolescent boys and girls: Timing, intensity and sequencing

Sara Pereira, Carla Santos, Go Tani, Duarte Freitas, Fernando Garbeloto, Eduardo Guimarães, Leah E. Robinson, Adam Baxter-Jones, Peter T. Katzmarzyk & José Maia

To cite this article: Sara Pereira, Carla Santos, Go Tani, Duarte Freitas, Fernando Garbeloto, Eduardo Guimarães, Leah E. Robinson, Adam Baxter-Jones, Peter T. Katzmarzyk & José Maia (2022) Physical fitness spurts in pre-adolescent boys and girls: Timing, intensity and sequencing, Journal of Sports Sciences, 40:6, 630-637, DOI: 10.1080/02640414.2021.2009201

To link to this article: https://doi.org/10.1080/02640414.2021.2009201

Published online: 23 Dec 2021.

JOURNAL OF SPORTS SCIENCES
2022, VOL. 40, NO. 6, 630–637
https://doi.org/10.1080/02640414.2021.2009201

Routledge
Taylor & Francis Group

PHYSICAL ACTIVITY, HEALTH AND EXERCISE

Check for updates

Physical fitness spurts in pre-adolescent boys and girls: Timing, intensity and sequencing

Sara Pereira [a,b], Carla Santos [a], Go Tani [c], Duarte Freitas [a,d], Fernando Garbeloto [c], Eduardo Guimarães [a], Leah E. Robinson [e], Adam Baxter-Jones [f], Peter T. Katzmarzyk [g] and José Maia [a]

[a]CIFI2D, Faculty of Sport, University of Porto, Porto, Portugal; [b]CIDEFES, Faculty of Physical Education and Sports, Lusófona University, Lisboa, Portugal; [c]School of Physical Education and Sports, University of São Paulo, São Paulo, Brazil; [d]Department of Physical Education and Sports, University of Madeira, Funchal, Portugal; [e]School of Kinesiology, University of Michigan, Ann Arbor, MI, USA; [f]College of Kinesiology, University of Saskatchewan, Saskatoon, Canada; [g]Pennington Biomedical Research Center, Louisiana State University, Baton Rouge, LA, USA

ABSTRACT

We aim to (1) estimate age of attainment of the peak mid-growth spurt in stature (age-at-peak MGS) in pre-adolescent boys and girls; (2) identify the timing, intensity, and sequences of physical fitness (PF) spurts aligned by the age-at-peak MGS; and (3) identify any sex differences in PF spurts aligned by age-at-peak MGS. The sample included 180 Portuguese children (90 girls) aged 6 to 10 years at study entry who were followed annually for 4 years. Height, health-, and performance-related PF were assessed. Age-at-peak MGS and PF spurts were estimated using a non-smooth mathematical procedure. Boys' and girls' age-at-peak MGS occurred at 7.8 ± 0.47 years and 8.0 ± 0.72 years, respectively. PF spurts' timing aligned by age-at-peak MGS were as follows: (1) before age-at-peak MGS: *boys* – static strength, aerobic capacity, explosive leg strength, and flexibility; *girls* – speed, agility, aerobic capacity, and upper body strength; (2) coincident with age-at-peak MGS: *girls* – explosive leg strength and flexibility; (3) after age-at-peak MGS: *boys* – abdominal strength, upper body strength, agility, and speed; *girls* – abdominal strength and static strength. Boys and girls attained their MGS at relatively similar ages. However, the timing and sequences of PF spurts, aligned on age-at-MGS, were different between boys and girls.

ARTICLE HISTORY
Accepted 17 November 2021

KEYWORDS
MID-growth spurt; children; longitudinal; motor performance

Introduction

Growth involves measurable changes in body size and composition with advancing age, whereas biological maturation refers to progress towards the mature state. There are four distinct phases of growth during childhood and adolescence: rapid growth in infancy, steady growth in childhood, rapid growth in adolescence, and slow growth as emerging adulthood approaches. The acceleration during adolescence is known as the adolescent growth spurt and is assessed by identifying the age when peak height velocity (PHV) occurs. This maturational milestone occurs in all children, though it varies in intensity and duration between and within the sexes. The importance of aligning adolescent growth (Boas, 1892a; Boas, 1892b, 1892c; Shuttleworth, 1937) and physiological (Geithner et al., 2004; Mirwald et al., 1981) data on age-at-peak height velocity (age-at-PHV) to control for maturational timing has long been recognized. The timing, intensity, and sequence of these growth spurts are important for auxologists and paediatricians (Cole, 2020; Tanner, 1962) and paediatric exercise physiologists (Rowland, 2005; Rutenfranz, 1986). Furthermore, aligning physical fitness (PF) data on age-at-PHV is also critical for physical education teachers and sport coaches to understand the dynamics of adolescent growth spurts' performance outcomes.

In addition to the well-known adolescent growth spurt, a mid-childhood growth spurt in stature (MGS), or juvenile growth spurt, has also been described. The intensity of the MGS is a relatively small transient increase in growth velocity, compared to the adolescent growth spurt (Malina et al., 2004). The MGS is observed in most children, but not necessarily in all, and usually occurs between 6 and 10 years of age (Robertson, 1915). The MGS has a long history, first being described in 1915 (Robertson, 1915). Since then, the MGS has been described in children from various countries (Berkey et al., 1983; Bock & Thissen, 1980; Butler et al., 1990; Gasser et al., 1991, 1985; Stützle et al., 1980). The MGS is regulated by the orchestration of several hormones (Lejarraga, 2012; Muhl et al., 1992), and its genetic architecture has been described previously (Towne et al., 2008). We documented the emergence of the MGS in Portuguese boys and girls aged 6 to 9 years and explored the relationship of the MGS with gross motor coordination spurts (GMCS), finding sex differences in timing, intensity, and sequence of GMCS (Dos Santos et al., 2019).

In boys, it has been found that developmental spurts in explosive strength and flexibility occur before or coincident with the age-at-peak MGS. In contrast, boys' spurts in running speed, agility, and abdominal muscular strength occurred after or coincident with age-at-peak MGS (Pereira et al., in press). What is less well known is if the MGS in girls is also related to PF spurts (e.g., muscular strength, flexibility, agility, running speed, and endurance)? This is important for teachers and coaches when dealing with children in physical education classes, in their learning processes of sport-specific skills, and in training

CONTACT Sara Pereira sara.s.p@hotmail.com CIFI2D, Faculty of Sport, University of Porto, Plácido da Costa 91, Porto 4200-450, Portugal

their motor abilities. Hence, this study aims to: (Shuttleworth, 1937) identify the age of attainment of the MGS; (Boas, 1892a) ascertain the timing, intensity, and sequences of PF spurts in relation to age-at-peak MGS; and (F. Boas, 1892b) test for sex-differences in PF spurts aligned by age-at-peak MGS.

Material and methods

Participants

Data for this study came from children participating in a mixed-longitudinal study of growth, biological maturation, gross motor coordination, physical activity and physical fitness, body composition, and motivation for sport, conducted in the Azores Islands (Maia et al., 2003). The Azores archipelago is located in the middle of the Atlantic Ocean (latitude 37° e 40° N and longitude 25° e 31° W) and has 9 islands. Four of them (S. Miguel, Terceira, Faial and Pico) have ~80% of the total population of the archipelago. A stratified and random sample of 1159 subjects served as participants in this study. Data collection was initiated in 2002 with participants divided into four age-cohorts : cohort 1 from 6 to 10 years, *n*= 285; cohort 2 from 10 to 13 years, *n*= 277; cohort 3, from 13 to 16 years, *n*= 319; cohort 4, from 16 to 19 years, *n*= 278). The age cohorts had a one-year overlap and were followed consecutively over four years until 2007.

In the present paper we used data from cohort 1 comprising 180 children (90 girls) measured serially from 6.46 years (at baseline) to 9.46 years of age; all participants had complete data on anthropometry, body composition and motor performance. Between 2002 and 2007, Azorean schools did not have regular physical education classes nor any systematic sports programmesfor these children. Whenever possible, children participated in periodically organized physical activities, but not on a regular basis.

No statistically significant mean differences in anthropometry and PF tests were observed between those included in the present study and those excluded, i.e., those with missing data. The Azorean Government Board of Education and the Government Directorate of Sports approved the study and the Ethics Committee of the Faculty of Sport, University of Porto. Written informed consent was acquired from legal guardians for all participants.

Anthropometry

Height and weight were measured using standardized protocols (Lohman et al., 1988). Height was measured with a portable stadiometer (Siber Hegner, Switzerland) to the nearest 0.1 cm. Weight was measured to the nearest 0.1 kg with a portable Seca scale (Seca Optima 760, Germany).

Physical fitness

The following markers of PF were assessed: muscular strength, flexibility, running speed, agility, and aerobic capacity (Table 1). Prior to the assessments, children had 10 minutes of general warm-up, conducted by a physical education teacher. All tests were explained in detail and trial opportunities offered to the participants to understand the demands of each task. Tests were administered in the schools and followed the same order: Day 1 50-yard dash, handgrip strength, shuttle-run, standing long jump and 1-mile run/walk; Day 2 push-ups, trunk-lift, curl-ups and the 1-mile run/walk only for the batch of children who could not do it in day 1. Between tests and trial sufficient rest occurred. All measurements and tests occurred annually, during a 2-month period in September and October, to reduce potential seasonal variations.

Table 1. Physical fitness components, tests and batteries.

Component	Test	Battery
Performance-related fitness		
Muscular strength		
Static strength	Handgrip (kg^f)	EUROFIT (1988)
Explosive leg strength	Standing long jump (cm)	AAHPERD (1976)
Speed		
Running speed	50 yard dash ($m{\cdot}s^{-1}$)	AAHPERD (1976)
Agility		
Shuttle run	Shuttle run ($m{\cdot}s^{-1}$)	AAHPERD (1976)
Health-related physical fitness		
Muscular strength		
Abdominal strength	Curl-up (reps)	FITNESSGRAM (1994)
Upper body strength	Push-up (reps)	FITNESSGRAM (1994)
Flexibility		
Trunk extensor	Trunk lift (cm)	FITNESSGRAM (1994)
Aerobic capacity		
One mile run/walk	One mile run ($m{\cdot}min^{-1}$)	FITNESSGRAM (1994)

We used well-known and extensively described test batteries (AAHPERD, 1976; EUROFIT, 1988; FITNESSGRAM, 1994) to assess performance- and health-related fitness components:

Performance-related tests: (i) *Handgrip strength* (static strength; kg^f) was measured using a hand-held dynamometer (Takei Digital Grip Strength Dynamometer, Model T.K.K.5401, Tokyo, Japan). Participants squeezed the dynamometer gradually and continuously, for at least 5 seconds, and were encouraged to use maximum isometric effort. Two trials were allowed, separated by a 3-minute rest and the highest result recorded. (ii) *Standing long jump* (explosive leg strength; cm) was performed by having participants attempt to jump as far as possible, landing on both feet without falling backwards, with the distance covered measured; three trials were allowed and the longest result recorded. (iii) *50-yard dash* (speed; $m{\cdot}s^{-1}$) was completed by having participants run 50-yards as fast as possible and the time was measured in two trials, and the fastest result recorded. (iv) *Shuttle-run* (agility; $m{\cdot}s^{-1}$) was completed by having participants run as fast as possible from a starting line to a set of blocks on the floor placed 9 m away from the starting line; participants picked up a block and returned to the starting line, then return to pick up a second block, this was repeat until all blocks were retrieved. The time taken for the task was measured over two trials, and the fastest time recorded.

Health-related tests: (i) *Push-ups* (upper body strength; n) were assessed by having participants start with their hands and toes touching the floor, their arms at shoulder-width apart and their body and legs in a straight line, participants then lowered their body to a 90° elbow angle and performed as many repetitions as possible, with a maximum of 75 repetitions. The number of push-ups from a single trial were recorded. (ii) *Curl-ups* (abdominal strength and endurance; n) were performed by having participants begin by lying on their back, knees bent, feet flat on the floor, arms

Table 2. Mean constant velocities for height and physical fitness tests, aligned by age-at-MGS in boys. Bold numbers correspond to peak spurts.

		Months from MGS						
Variables		−18	−12	−6	0	6	12	18
Height (cm·year^{-1})	mean	4.77	4.40	5.19	**6.20**	5.39	4.65	5.08
	n	*9*	*63*	*63*	*82*	*73*	*73*	*19*
Handgrip (kg^{f}·year^{-1})	mean	**2.81**	2.24	1.94	2.09	2.07	2.35	2.47
	n	*9*	*52*	*56*	*56*	*59*	*44*	*14*
Standing long jump (cm·year^{-1})	mean	5.34	**21.59**	13.49	16.04	13.35	16.15	13.22
	n	*7*	*28*	*40*	*34*	*44*	*29*	*12*
50 y dash (m·s^{-1}·year^{-1})	mean	0.39	0.39	0.33	0.41	0.40	**0.53**	0.36
	n	*6*	*35*	*46*	*41*	*50*	*40*	*11*
Shuttle-run (m·s^{-1}·year^{-1})	mean	0.18	0.21	0.17	0.19	0.19	**0.28**	0.18
	n	*2*	*24*	*30*	*30*	*33*	*22*	*15*
Curl-up (reps·year^{-1})	mean	1.97	4.16	9.66	15.01	12.17	**19.36**	9.19
	n	*5*	*40*	*45*	*41*	*41*	*28*	*9*
Push-up (reps·year^{-1})	mean	6.92	4.88	4.78	4.96	5.86	**9.40**	4.58
	n	7	41	43	46	39	32	8
Trunk-lift (cm·year^{-1})	mean	2.08	**5.52**	4.13	5.06	3.05	3.44	3.07
	n	*5*	*34*	*44*	*35*	*43*	*28*	*10*
One mile run/walk (m·min^{-1}·year^{-1})	mean	19.82	**18.41**	13.04	13.56	11.68	12.54	17.82
	n	*1*	*12*	*12*	*10*	*18*	*7*	*6*

A peak spurt in 1-mile run/walk (intensity = 19.81 m·min^{-1}·y^{-1}) was observed for one participant at 18 months before age-at-MGS. Therefore, we considered this intensity as the best estimate for a peak at 12 months before age-at-MGS.

Table 3. Mean constant velocities for height and physical fitness tests, aligned by age-at-MGS in girls. Bold numbers correspond to peak spurts.

		Months from MGS						
Variables		−18	−12	−6	0	6	12	18
Height (cm·year^{-1})	mean	4.68	4.44	5.28	**6.36**	5.64	4.91	5.09
	n	*23*	*61*	*62*	*88*	*65*	*64*	*26*
Handgrip (kg^{f}·year^{-1})	mean	1.86	1.84	1.71	1.98	1.84	**2.16**	2.05
	n	*22*	*53*	*58*	*67*	*59*	*45*	*21*
Standing long jump (cm·year^{-1})	mean	10.99	11.58	10.46	**15.36**	12.16	12.48	11.08
	n	*18*	*31*	*40*	*46*	*42*	*31*	*19*
50 y dash (m·s^{-1}·year^{-1})	mean	**0.41**	**0.40**	0.32	0.30	0.28	0.33	0.35
	n	*20*	*45*	*48*	*53*	*52*	*39*	*19*
Shuttle-run (m·s^{-1}·year^{-1})	mean	0.17	**0.22**	0.15	0.19	0.13	0.18	0.15
	n	*14*	*33*	*39*	*35*	*42*	*28*	*15*
Curl-up (reps·year^{-1})	mean	9.43	5.54	9.30	13.11	9.78	**14.15**	4.29
	n	*12*	*33*	*36*	*43*	*32*	*25*	*12*
Push-up (reps·year^{-1})	mean	4.26	4.18	**5.18**	4.65	2.85	2.86	3.48
	n	12	32	28	39	30	26	7
Trunk-lift (cm·year^{-1})	mean	3.06	4.11	3.75	**5.21**	3.65	4.59	4.85
	n	*17*	*32*	*39*	*43*	*35*	*20*	*17*
One mile run/walk (m·min^{-1}·year^{-1})	mean	11.16	**13.73**	9.54	11.97	9.26	11.60	6.11
	n	*7*	*8*	*15*	*14*	*20*	*12*	*6*

straight and parallel to the trunk, and complete as many curl-ups as possible, with a maximum of 75 repetitions. The number of curl-ups from a single trial were recorded; (iii) *Trunk-lift* (flexibility; cm) was performed by having participants lay in a prone position, and then get them to lift their trunk as far as they could, and the distance from the floor was measured. The distance from a single trial was recorded. (iv) *1-mile run/walk test* (aerobic capacity; min) was completed by having participants ran/walk 1609 meters and measure the time it took. The time from a single trial was recorded.

Data quality control

Data quality control was completed through various means. First, all assessment team members were systematically trained by the principal investigator of the study. Second, a pilot study was conducted, supervised by the principal investigator, to verify the quality of all data collection. Third, a series of routines were implemented in database management. Using *FileMakerPro* (FileMaker, Inc., USA) software, cross-checking of data entry and data elements, and automatic controls to ensure values were not outside known ranges. Fourth, in all weekly assessments, a random sample of 5–10 subjects were re-assessed for in-field reliability controls. Technical-error of measurement for girls was found to be 0.4 cm for height and 0.4 kg for weight. Further, ANOVA-based intraclass correlations (R) for PF tests in boys ranged from 0.72 (95%CI = 0.30–0.89) in 1-mile run/walk to 0.98 (95%CI = 0.96–0.99) in handgrip, and from 0.75 (95%CI = 0.36–0.90) in 1-mile run/walk to 0.98 (95%CI = 0.96–0.99) in standing long jump for girls.

Statistical analysis

We used the original methodology by Van't Hof et al. (1976) to estimate age-at-peak MGS, which has been extended and applied to Belgium boys (Beunen & Malina, 1988), Spanish boys and girls, (Yague, 1998) and Brazilian boys and girls (Silva et al., 2019). This methodology is valid for estimating the age-at-peak MGS if the following conditions are satisfied: (i) the presence of a real spurt, i.e., an increase in velocity, (ii) a specific slowdown of growth velocity after the peak, and (iii) the presence of reduced measurement error in all variables, i.e., reliable data. Failure to meet these assumptions implied that the MGS was not identified. Since each child has their own growth velocity curve as well as in all PF tests, mean constant curves were obtained for data aligned by age-at-peak MGS. Thus, the possibility to compute mean PF velocity values before and after age-at-peak MGS, i.e., −18, −12, −6, and +6, +12, +18 months from the mid-growth maximum velocity which is marked as 0. A generalization of the previous methodology was developed by a mathematician at the University of Porto, who developed the software to conduct all analyses. This methodology has been previously shown to be successful in identifying gross motor coordination and PF spurts in Portuguese children (Dos Santos et al., 2019; Guimarães et al., 2020; Pereira et al., in press). Mean velocity curves, also called mean constant curves, were developed and defined in terms of time, i.e., months before and after age-at-peak MGS. Although measurements were obtained each year, the method allows the estimation of individual velocities every six months. Graphical data were displayed using a cubic spline procedure as implemented in GraphPad Prism v.8.2.1. (Malina et al., 2004). A cubic spline employs interpolating cubic polynomials, which use information from neighbouring points to obtain a degree of global smoothness. The cubic spline was chosen over other curve fitting procedures because it maintains the integrity of the data without transforming or modifying the underlying growth characteristics. To test for differences in age-at-MGS as well as in PF spurts' intensities between boys and girls, a Student t-test was used with a significant level of 5%, and these analyses were done in IBM-SPSS v.27.

Results

Mean constant velocity curves for height and the PF tests are shown in Tables 2 and 3 and graphically illustrated in Figure 1. Age-at-peak MGS was identified in 82 boys (90%) and in 88 girls (98%). Furthermore, their timing was 7.80 ± 0.47 [95%CI: 7.698–7.902] years in boys and 8.00 ± 0.72 [95%CI: 7.850–8.150] years in girls and their intensity was 6.20 $cm{\cdot}y^{-1}$ and 6.36 $cm{\cdot}y^{-1}$, in boys and girls, respectively. Although age-at-MGS occurred significantly earlier in boys ($p = 0.04$; $d = 0.32$) the intensity was not statistically different ($p > 0.05$).

In general, no statistically significant differences ($p > 0.05$) were found in PF spurts' intensities between boys and girls, apart from the upper-body strength favouring boys ($p = 0.04$). Peaks in muscular strength markers (static, upper and lower body, explosive leg strength) occurred at different times with distinct intensities and sequences in both boys and girls. For handgrip strength, boys had their peak spurt 18 months before age-at-peak MGS (intensity = 2.81 $kg^{f}{\cdot}y^{-1}$), but girls had theirs 12 months after age-at-peak MGS with an intensity of 2.16 $kg^{f}{\cdot}y^{-1}$. Upper body and abdominal strength peaked differently in boys and girls: push-ups, 12 months after (intensity = 9.40

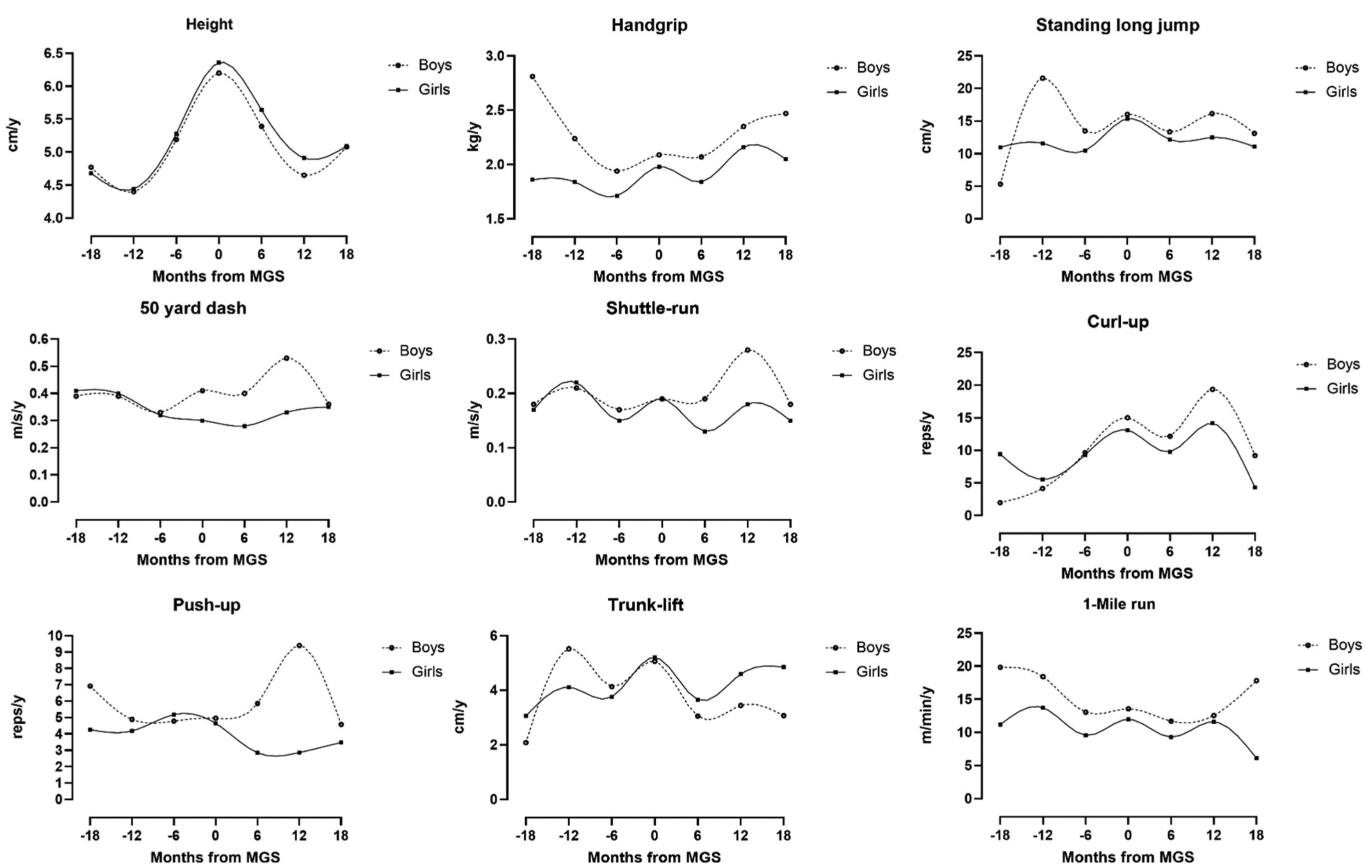

Figure 1. Mean constant velocity curves for height and physical fitness tests in boys and girls, aligned on height mid-growth spurt.

reps·y^{-1}), and 6 months (intensity = 5.18 reps·y^{-1}) before age-at-peak MGS, respectively; curl-ups, 12 months after age-at-peak MGS, with an intensity of 19.36 reps·y^{-1} (boys) and 14.15 reps·y^{-1} (girls). For explosive leg strength (standing long jump), boys' peak was at 12 months (intensity = 21.59 cm·y^{-1}) before age-at-peak MGS, but in girls, it was coincident with age-at-peak MGS (intensity = 15.36 cm·y^{-1}).

For running speed, boys´ peak spurt (0.53 m·s^{-1}·y^{-1}) was identified at 12 months after age-at-peak MGS, but in girls, it was earlier and had similar intensity, i.e., 18 (0.41 m·s^{-1}·y^{-1}), and 12 (0.40 m·s^{-1}·y^{-1}) months before age-at-peak MGS. For the shuttle run, the timing of peak spurts occurred at 12 months before age-at -peak MGS in girls, and 12 months after in boys, and their intensity was relatively similar, i.e., 0.22 m·s^{-1}·y^{-1} and 0.28 m·s^{-1}·y^{-1}, respectively.

For flexibility, the peak spurt was at 12 months before age-at-peak MGS with an intensity of 5.52 cm·y^{-1} in boys, whereas in girls was coincident with age-at-peak MGS (intensity = 5.21 cm·y^{-1}). Aerobic capacity peaked 12 months before age-at-peak MGS in both sexes (intensity = 18.41 m·min^{-1}·y^{-1} and 13.73 m·min^{-1}·y^{-1}, for boys and girls, respectively).

Finally, boys' and girls' peak spurt sequences are shown in Figure 2. In boys, the sequence is: (i) before age-at-peak MGS – aerobic capacity, static strength, explosive leg strength, and flexibility; (ii) after age-at-peak MGS – abdominal strength, upper body strength, agility, and speed, whereas in girls, it is: (i) before age-at-peak MGS – speed, agility, aerobic capacity, and upper body strength; (ii) coincident with age-at-peak MGS – explosive leg strength and flexibility; (iii) after age-at-peak MGS – abdominal strength and static strength.

Discussion

This study showed sex differences in children's PF spurts with their associated timings, intensities, and sequences. Age-at-peak MGS was identified in 90% and 98% of Azorean boys and girls, respectively. Similar results were previously reported by Butler et al. (1990) in British children (100% in boys and 98.2% in girls), and by Gasser et al. (1985) in Swiss children (93% in boys and 82% girls). However, in contrast Towne et al. (2008) only found a spurt in 79% and 36% of American boys and girls, respectively. Although it has been suggested that the MGS may not be observed in all children or that some may experience a cyclical growth pattern during their childhood (Butler et al., 1990), there is compelling evidence supporting the MGS as a genuine biological phenomenon or an individual characteristic (Muhl et al., 1992; Robertson, 1915; Towne et al., 2008). Indeed, the MGS occurs not only in height but also in other anthropometric measures (Gasser et al., 1993; Meredith, 1981; Tameron & Cameron, 1980). Furthermore, Towne et al. (2008) revealed that 37% of the total variation in MGS in height was accounted for by genetic factors and identified genetic markers for the MGS in chromosomes 12 and 17.

Timing and intensity of MGS were relatively similar in the Portuguese boys and girls presented here (see Tables 2 and 3). These results are consistent with some previous studies, but not all. For example, Butler et al. (1990) identified the peak MGS at 7.0 years in boys with an intensity of 6.7 cm·y^{-1}, while girls peaked at 6.7 years with an intensity of 6.8 cm·y^{-1}. Gasser et al. (1985) reported similar values for the timing in both sexes (7.5 years, boys; 7.7 years, girls) and an intensity of 6.4 cm·y^{-1} for both boys and girls.

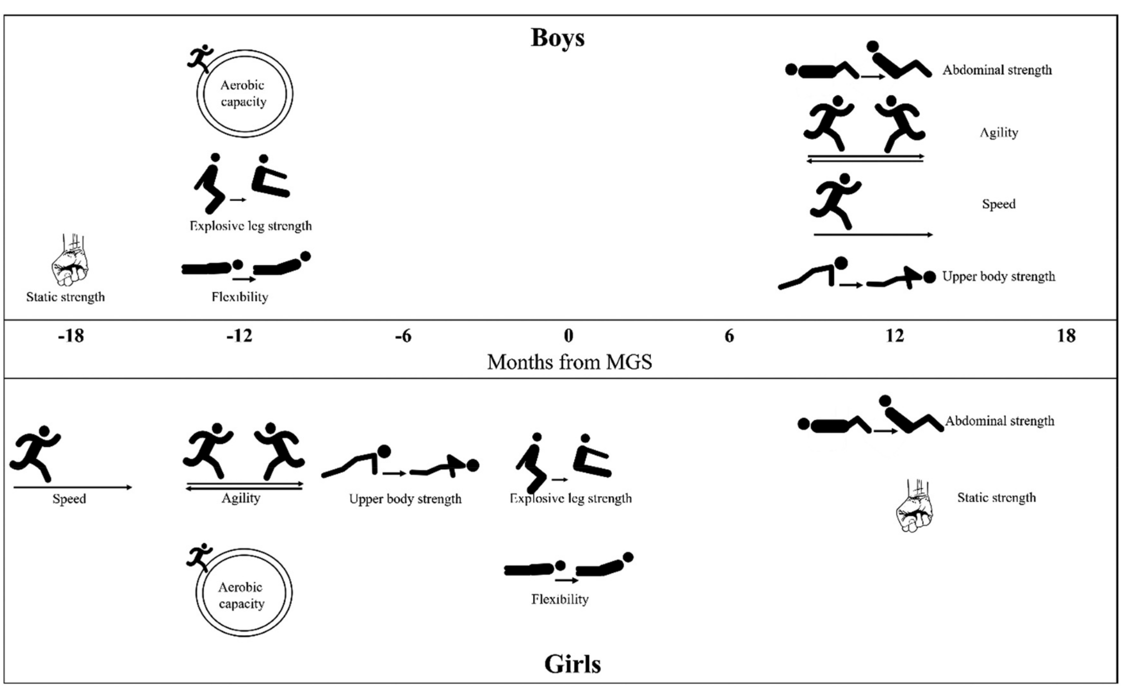

Figure 2. Physical fitness peak spurts' sequences in boys and girls.

Contrarily, Towne et al. (2008) found a substantial sex difference in timing (6.3 years in boys and 4.8 years in girls), although with similar values for intensity: 6.6 cm·y^{-1} and 6.9 cm·y^{-1} in boys and girls, respectively. These discrepancies may reflect biological variation, differences in the measurement frequency within each study, mathematical models used, and sample characteristics.

We explored spurts in PF components relative to the age-at-peak MGS. The landscape on which children of both sexes unfold their PF components varied in timing, intensity, and sequence. Unfortunately, we could not identify any previous studies to compare our results. Even data from adolescent growth spurts in muscular strength, motor performance, and aerobic power aligned on age-at PHV in both boys and girls do not show clear trends (Beunen & Malina, 1988; Mirwald & Bailey, 1986; Silva et al., 2019; Yague, 1998). This, of course, poses difficulties when interpreting our results. In our study, the timing of PF spurts aligned on age-at-peak MGS revealed sex differences in most components (except for aerobic capacity and abdominal strength) as well as in the MGS sequences. Yet, the intensity does not vary between the sexes, apart from upper body strength favouring boys, where the average gain of boys (9.4 reps·year^{-1}) was about twice as much as that of girls (5.2 reps·year^{-1}). This difference probably reflects boys' more significant gains in upper-arm strength, but data applying scaling procedures to longitudinal changes in muscular strength during childhood are not available (Malina et al., 2004).

Spurts in muscular strength components varied in timing, suggesting that they are independent of each other and that children's growth and maturation may influence, differently, their development in boys and girls. In static and explosive strength, boys peaked before age-at-peak MGS, while in the upper body and abdominal strength peaks occurred after age-at-peak MGS. On the other hand, girls peaked in upper body strength before age-at-peak MGS. Yet, the MGS in explosive strength coincided with age-at-peak MGS, while static and abdominal strength spurts occurred after age-at-peak MGS. A putative explanation for different peaks in static and explosive strength may be due to differences in body composition. The maximum velocity of fat-free mass in boys (data not shown) occurred earlier (spurt coincident with the peak MGS in height) than in girls (spurt is reached 12 months after the peak MGS). Hence, static and explosive strength may depend more on body composition than the upper body and abdominal strength. Furthermore, it has been suggested that muscular strength is highly influenced by neuromuscular capacity, which allows the production of muscular force and changes in non-neuromotor factors such as variations of the biomechanical properties of the musculoskeletal system (Korff & Jensen, 2008).

Regarding running speed and agility components, the timing of peak spurts in boys occurred after age-at-peak MGS. However, girls peaked before age-at-peak MGS. Given the motor demands underlying these PF components, the sex differences may be explained by the non-synchronic growth velocities of the legs versus the trunk. Indeed, girls tend to reach the maximal velocity, on average, three-quarters of a year later for the trunk than for the legs, while boys reach it half-a-year later (Gasser et al., 1991). Moreover, given the neuromuscular demands involved in speed and agility components (Enoka, 2008), these results suggest that girls tend to develop neuromuscular abilities earlier than boys do.

For flexibility, boys peaked before age-at-peak MGS, while girls' spurt coincided with peak MGS. However, velocities in this component between 6 to 10 years were highly erratic in both sexes. Muscle and tendon tissue extensibility and passive dorsiflexion angles are responsible for efficient movement in trunk-lift tasks and depend on a set of proprioceptive mechanisms associated with bone, muscle, and joint structure (Lee et al., 2006; McHugh et al., 1998). During childhood, the rate of bone growth in both sexes is not parallel to that of the ligamentous and capsular tissues (Alter, 1996) and this may explain the difference in timing of the spurt. These results also suggest that after attainment of MGS, there may be an increase in muscle-tendon tightness over the joint and a faster bone growth than muscle growth and stretching capacity. This may explain the lower rate of change in the flexibility component after age-at-peak MGS.

For aerobic capacity, boys and girls peaked before age-at-peak MGS. Aerobic capacity reflects the maximum rate that the respiratory, cardiovascular, and muscular systems can take in, transport, and use oxygen during exercise (Caspersen et al., 1985). Nonetheless, body composition, mainly body fat, also influences this component given the body displacement demands involved in this task (1-mile run/walk). The fact that boys and girls reach their minimum velocity of fat mass 12 months before age-at-peak MGS (data not shown), may explain their similar timings in the aerobic capacity spurt.

Finally, when interpreting the sequences of the MGS in PF components (see Figure 1), apart from putative influences of genetic and biological underlying mechanisms, there is also room to consider the critical roles of behavioural and cultural factors in explaining sex differences. Undoubtedly, children's growth and PF development do not occur in a social vacuum (Beunen & Malina, 1988), but within a variety of environmental conditions, namely home, neighbourhood, rearing style, interactions with siblings and peers, and opportunities for outdoor play and physical activity, among others (Freitas et al., 2018). Furthermore, it is known that boys and girls engage in different games and activities that may influence their physical fitness development in different ways. For example, whereas girls become more involved in cooperative activities, boys tend to engage in competitive games (Garcia, 1994). Additionally, differences in motor performance between boys and girls have also been reported in other domains of their motor development, namely in their fundamental movement skills. Available reports highlight that cultural factors lead boys to outperform girls in object control skills (Barnett et al., 2010; O' Brien et al., 2016; Foulkes et al., 2015; Hardy et al., 2010). Also, these studies shed some light on an important aspect – boys and girls may react differently to similar stimuli. The finding suggests that teachers and coaches should incorporate different strategies in their physical education classes and sports training sessions to accommodate developmental differences in girls and boys.

Limitations

This study is not without limitations. Firstly, the sample is from four Azorean Islands and our findings cannot be generalized to the total Portuguese population. Secondly, the sample size is relatively small. Yet, we are not aware of any other studies that tackle the issue of PF spurts aligned by age-at-peak MGS, nor have investigated children's PF development with sample sizes of substantially greater magnitudes. Thirdly, it is also possible that we could more precisely estimate age-at-MGS and PF spurts with six-month assessments. More frequent fitness assessments would probably lead to a re-testing effect that may lead to more proficient results but could induce greater difficulty in separating skill from performance. This study also has several strengths. Data were collected carefully with rigorous quality control measures. Moreover, a robust mathematical approach was used to identify the MGS and PF spurts when aligned by age-at-peak MGS. The list of fitness tests covered both health- and performance-related fitness components. Finally, the study novelty is high given this is the first time that sex differences in children's PF spurts are described.

Conclusions

In conclusion, we found a similar MGS in height in boys and girls at ~8 years of age. However, the timing and sequences of health- and performance-related PF spurts differed between boys and girls (but not their intensities). Boys and girls peaked at similar ages for abdominal strength and aerobic capacity for health-related PF components. However, differences were found in upper body strength and flexibility. For speed and agility, boys reached their peak later than girls. However, in static and explosive strength, the inverse occurred: boys peaked earlier than girls. These findings are important for motor development researchers to grasp how and why children differ in their PF spurts and respond differently to stimuli provided in physical education classes and sports training sessions. Furthermore, these findings may also be helpful when designing more effective programs providing equal, varied, and enriching learning opportunities for all children to develop their PF and fundamental movement skills. Future studies should consider: (1) whether or not children's extracurricular sports or physical activity participation affect the timing, intensity and sequence of PF spurts; (2) using other samples from different sociodemographic contexts to best understand the putative impacts of nature and nurture and their interaction in PF development during children's engagement in primary school years and initiation in sports participation; (3) linking PF spurts with fundamental motor skills development, as well as a putative synchronicity with motor coordination development.

Acknowledgments

We wish to thank all children, school teachers and parents for their participation. Further, in the Azorean study we acknowledge the support from the Azorean Regional Department of Physical Education and Sport.

The results of the current study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The authors received no funds for covering costs to publish in open access.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

ORCID

Sara Pereira http://orcid.org/0000-0002-4661-3879
Carla Santos http://orcid.org/0000-0003-4607-7292
Go Tani http://orcid.org/0000-0002-6517-5472
Duarte Freitas http://orcid.org/0000-0001-6642-3370
Fernando Garbeloto http://orcid.org/0000-0001-8024-909X
Eduardo Guimarães http://orcid.org/0000-0001-5344-9344
Leah E. Robinson http://orcid.org/0000-0002-9016-648X
Adam Baxter-Jones http://orcid.org/0000-0003-0430-0556
Peter T. Katzmarzyk http://orcid.org/0000-0002-9280-6022
José Maia http://orcid.org/0000-0002-3273-0046

References

EUROFIT: Handbook for the eurofit tests of physical fitness. (1988). Committee for the Development of Sport, Council of Europe.

AAHPERD. (1976). *Youth fitness test manual*. American Alliance for Health, Physical Education & Recreation and Dance.

Alter, M. J. (1996). *Science of flexibility*. Human Kinetics.

Barnett, L. M., van Beurden, E., Morgan, P. J., Brooks, L. O., & Beard, J. R. (2010). Gender differences in motor skill proficiency from childhood to adolescence: A longitudinal study. *Research Quarterly for Exercise and Sport*, *81*(2), 162–170. https://doi.org/10.1080/02701367.2010.10599663

Berkey, C. S., Reed, R. B., & Valadian, I. (1983). Midgrowth spurt in height of Boston children. *Annals of Human Biology*, *10*(1), 25–30. https://doi.org/10.1080/03014468300006151

Beunen, G., & Malina, R. M. (1988). Growth and physical performance relative to the timing of the adolescent spurt. *Exercise and Sport Sciences Reviews*, *16*, 503–540. https://doi.org/10.1249/00003677-198800160-00018

Boas, F. (1892a). The growth of children. *Science*, *19*(483), 256–257. https://doi.org/10.1126/science.ns-19.483.256

Boas, F. (1892b). The growth of children. *Science*, *19*(485), 281–282. https://doi.org/10.1126/science.ns-19.485.281

Boas, F. (1892c). The growth of children. *Science*, *20*(516), 351–352. https://doi.org/10.1126/science.ns-20.516.351

Bock, R. D., & Thissen, D. (1980). Statistical problems of fitting individual growth curves. In F. E. Johnston, A. F. Roche, & C. Susanne (Eds.), *Human physical growth and maturation: Methodologies and factores* (pp. 265–290). Plennum Press.

Butler, G. E., McKie, M., & Ratcliffe, S. G. (1990). The cyclical nature of prepubertal growth. *Annals of Human Biology*, *17*(3), 177–198. https://doi.org/10.1080/03014469000000952

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health reports (Washington, D.C.: 1974)*, *100*(2), 126–131.

Cole, T. J. (2020). Tanner's tempo of growth in adolescence: Recent SITAR insights with the Harpenden Growth Study and ALSPAC. *Annals of Human Biology*, *47*(2), 181–198. https://doi.org/10.1080/03014460.2020.1717615

Dos Santos, M. A. M., Baxter-Jones, A., Reyes, A. C., Freitas, D., Henrique, R. S., Chaves, R. N., Bustamante, A., Tani, G., Katzmarzyk, P. T., & Maia, J. (2019). Are there gross motor coordination spurts during mid-childhood? *American Journal of Human Biology: The Official Journal of the Human Biology Council*, *31*(4), e23251. https://doi.org/10.1002/ajhb.23251

Enoka, R. M. (2008). *Neuromechanics of human movement* (4 ed.). Human Kinetics.

FITNESSGRAM. (1994). *The prudencial fitnessgram test administratics manual*. The Cooper Institute for Aerobics Research.

Foulkes, J. D., Knowles, Z., Fairclough, S. J., Stratton, G., O'Dwyer, M., Ridgers, N. D., & Foweather, L. (2015). Fundamental movement skill of presschool children in Northwest England. *Perceptual and Motor Skills*, *121*(1), 260–283. https://doi.org/10.2466/10.25.PMS.121c14x0

Freitas, D. L., Lausen, B., Maia, J. A., Gouveia, É. R., Antunes, A. M., Thomis, M., Lefevre, J., & Malina, R. M. (2018). Skeletal maturation, fundamental motor skills, and motor performance in preschool children. *Scandinavian Journal of Medicine & Science in Sports*, *28*(11), 2358–2368. https://doi.org/10.1111/sms.13233

Garcia, C. (1994). Gender differences in young children's interactions when learning fundamental motor skills. *Research Quarterly for Exercise and Sport*, *65*(3), 213–225. https://doi.org/10.1080/02701367.1994.10607622

Gasser, T., Kneip, A., Binding, A., Prader, A., & Molinari, L. (1991). The dynamics of linear growth in distance, velocity and acceleration. *Annals of Human Biology*, *18*(3), 187–205. https://doi.org/10.1080/03014469100001522

Gasser, T., Muller, H. G., Kohler, W., Prader, A., Largo, R., & Molinari, L. (1985). An analysis of the mid-growth and adolescent spurts of height based on acceleration. *Annals of Human Biology*, *12*(2), 129–148. https://doi.org/10.1080/03014468500007631

Gasser, T., Ziegler, P., Kneip, A., Prader, A., Molinari, L., & Largo, R. H. (1993). The dynamics of growth of weight, circumferences and skinfolds in distance, velocity and acceleration. *Annals of Human Biology*, *20*(3), 239–259. https://doi.org/10.1080/03014469300002672

Geithner, C. A., Thomis, M. A., Vanden Eynde, B., Maes, H. H., Loos, R. J., Peeters, M., Claessens, A. L., Vlietinck, R., Malina, R. M., & Beunen, G. P. (2004). Growth in peak aerobic power during adolescence. *Medicine and Science in Sports and Exercise*, *36*(9), 1616–1624. https://doi.org/10.1249/01.MSS.0000139807.72229.41

Guimarães, E., Baxter-Jones, A. D. G., Pereira, S., Garbeloto, F., Freitas, D., Janeira, M. A., Tani, G., Katzmarzyk, P. T., Silva, S., Bailey, D. A., Mirwald, R. L., & Maia, J. (2020). Patterns of physical performance spurts during adolescence: A cross-cultural study of Canadian, Brazilian and Portuguese boys. *Annals of Human Biology*, *47*(4), 346–354. https://doi.org/10.1080/03014460.2020.1781928

Hardy, L. L., King, L., Farrell, L., Macniven, R., & Howlett, S. (2010). Fundamental movement skills among Australian preschool children. *Journal of Science and Medicine in Sport*, *13*(5), 503–508. https://doi.org/10.1016/j.jsams.2009.05.010

Korff, T., & Jensen, J. L. (2008). Effect of relative changes in anthropometry during childhood on muscular power production in pedaling: A biomechanical simulation. *Pediatric Exercise Science*, *20*(3), 292–304. https://doi.org/10.1123/pes.20.3.292

Lee, P. J., Rogers, E. L., & Granata, K. P. (2006). Active trunk stiffness increases with co-contraction. *Journal of Electromyography and Kinesiology*, *16*(1), 51–57. https://doi.org/10.1016/j.jelekin.2005.06.006

Lejarraga, H. (2012). Growth in infancy and childhood: A pediatric approach. In C. Noël, and B. Barry (Eds.), *Human growth and development*. Academic Press. 23-56.

Lohman, T. G., Roche, A. F., & Martorell, R. (1988). *Anthropometric standardization reference manual*. Human kinetics books Champaign.

Maia, J. A. R., Lopes, V. P., Silva, R. G., Seabra, A., Morais, F. P., Fonseca, A. M., Cardoso, M., Prista, A., & Freitas, D. L. (2003). *Um olhar sobre crianças e jovens da região autónoma dos Açores. Implicações para a Educação Física, Desporto e saúde*. DREFD-RAA & FCDEF-UP.

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation and physical activity*. Human Kinetics.

McHugh, M. P., Kremenic, I. J., Fox, M. B., & Gleim, G. W. (1998). The role of mechanical and neural restraints to joint range of motion during passive stretch. *Medicine and Science in Sports and Exercise*, *30*(6), 928–932. https://doi.org/10.1097/00005768-199806000-00023

Meredith, H. V. (1981). An addendum on presence and absence of a mid-childhood spurt in somatic dimensions. *Annals of Human Biology*, *8*(5), 473–476. https://doi.org/10.1080/03014468100005311

Mirwald, R. L., Bailey, D. A., Cameron, N., & Rasmussen, R. L. (1981). Longitudinal comparison of aerobic power in active and inactive boys aged 7.0 to 17.0 years. *Annals of Human Biology*, *8*(5), 405–414. https://doi.org/10.1080/03014468100005231

Mirwald, R. L., & Bailey, D. A. (1986). *Maximal aerobic power*. Sports Dynamics.

Muhl, A., Herkner, K. R., & Swoboda, W. (1992). [The mid-growth spurt–a pre-puberty growth spurt. Review of its significance and biological correlations]. *Padiatrie und Padologie*, *27*(5), 119–123. https://pubmed.ncbi.nlm.nih.gov/1437227/

O' Brien, W., Belton, S., & Issartel, J. (2016). Fundamental movement skill proficiency amongst adolescent youth. *Physical Education and Sport Pedagogy*, *21*(6), 557–571. https://doi.org/10.1080/17408989.2015.1017451

Pereira, S., Garbeloto, F., Guimarães, E., Santos, C., Baxter-Jones, A., Tani, G., Freitas, D., Bustamante, A., Katzmarzyk, T. P., & Maia, J. (in press). Physical fitness spurts in childhood: A study in boys. *Scandinavian Journal of Medicine & Science in Sports*, *31*(1), 47–55. https://doi.org/10.1111/sms.13800.

Robertson, T. B. (1915). Studies of the growth of man 1. The pre- and post-natal growth of infants. *The American Journal of Physiology*, *37*(1), 1–42. https://doi.org/10.1152/ajplegacy.1915.37.1.1

Rowland, T. W. (2005). *Children´s exercise physiology*. Human Kinetics.

Rutenfranz, J. (1986). Longitudinal approach to assessing maximal aerobic power during growth: The European experience. *Medicine and Science in Sports and Exercise*, *18*(3), 270–275. https://doi.org/10.1249/00005768-198606000-00003

Shuttleworth, F. K. (1937). Sexual maturation and the physical growth of girls age six to nineteen. *Monographs of the Society for Research in Child Development*, *2*(5), 5. https://doi.org/10.2307/1165417

Silva, S., Mendes, H., Freitas, D., Prista, A., Tani, G., Katzmarzyk, P. T., Baxter-Jones, A. D. G., Valdivia, A. B., & Maia, J. (2019). Development of physical performance tasks during rapid growth in Brazilian children: The cariri healthy growth study. *International Journal of Environmental Research and Public Health*, *16*(24), 5029. https://doi.org/10.3390/ijerph16245029

Stützle, W., Gasser, T., Molinari, L., Largo, R. H., Prader, A., & Huber, P. J. (1980). Shape-invariant modelling of human growth. *Annals of Human Biology*, *7*(6), 507–528. https://doi.org/10.1080/03014468000004641

Tameron, J. M., & Cameron, N. (1980). Investigation of the mid-growth spurt in height, weight and limb circumferences in single-year velocity data from the London 1966-67 growth survey. *Annals of Human Biology*, *7*(6), 565–577. https://doi.org/10.1080/03014468000004681

Tanner, J. M. (1962). *Growth at adolescence* (5th ed.). Blackwell Scientific Publications.

Towne, B., Williams, K. D., Blangero, J., Czerwinski, S. A., Demerath, E. W., Nahhas, R. W., Dyer, T. D., Cole, S. A., Lee, M., Choh, A. C., Duren, D. L., Sherwood, R. J., Chumlea, W. C., & Siervogel, R. M. (2008). Presentation, heritability, and genome-wide linkage analysis of the midchildhood growth spurt in healthy children from the Fels Longitudinal Study. *Human Biology*, *80*(6), 623–636. https://doi.org/10.3378/1534-6617-80.6.623

Van't Hof, M. A., Roede, M. J., & Kowalski, C. J. (1976). Estimation of growth velocities from individual longitudinal data. *Growth*, *40*, 217–40. https://pubmed.ncbi.nlm.nih.gov/976767/

Yague, P. H, & De La Fuente JM. (1998). Changes in height and motor performance relative to peak height velocity: A mixed-longitudinal study of Spanish boys and girls. *American Journal of Human Biology: The Official Journal of the Human Biology Council*, *10*(5), 647–660. https://doi.org/10.1002/(SICI)1520-6300(1998)10:5<647::AID-AJHB11>3.0.CO;2-8