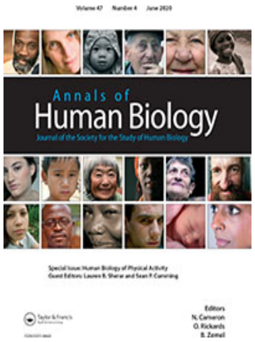

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RESEARCH PAPER

Patterns of physical performance spurts during adolescence: a cross-cultural study of Canadian, Brazilian and Portuguese boys

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ABSTRACT

Background: Data relating physical performance to the timing of the adolescent growth spurt are limited. **Aim:** This study identifies: (i) age-at-peak height velocity (APHV), (ii) physical performance spurt patterns aligned to APHV; and (iii) cross-cultural and time patterns in Canadian, Brazilian and Portuguese boys. **Subjects and methods:** A total of 512 boys (131 Canadian, 250 Portuguese and 131 Brazilian), 8–17 years of age were followed serially using longitudinal data. APHV was identified and five physical performance measures velocities [trunk extension (TE), trunk flexion (TF), standing long jump (SLJ), curl-ups (CU) and handgrip strength (HG)] were aligned at 6-month intervals, 4 years around the attainment of PHV. Velocities were estimated using a non-smooth mathematical procedure. **Results:** APHV was 13.9 ± 1.0, 13.4 ± 1.6 and 13.0 ± 0.8 years for Canadian, Brazilian and Portuguese boys, respectively. Maximal velocity in SLJ was attained between 12 and 6 months prior to PHV. For HG, peaks were attained 12–24 months after PHV. Maximal velocity in TE occurred between 12 and 0 months prior to PHV, while CU peaked between PHV and 6 months after PHV. **Conclusion:** Patterns of spurts in physical performance have remained relatively the same and do not appear to be influenced by cross-cultural differences.

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Physical performance; Spurts; Age-at-peak height velocity; Youth; cross-cultural

Introduction

Adolescence, the transition from childhood to adulthood, can also be viewed within the context of biological maturation (skeletal, sexual, somatic, dental, etc.) and is aligned with a growth spurt in height (Tanner 1962; Beunen et al. 1988). It represents the period of development when growth begins to accelerate prior to the attainment of maturity. Adolescence is an important time period in the growth process and is associated with a complex series of biological events (Ellison and Reiches 2012). They include, but are not limited to, changes in the nervous and endocrine systems, changes in size and body composition, as well as changes to the cardiorespiratory system and alterations in proportionality of body measurements (Tanner 1962; Beunen et al. 1988; Malina et al. 2015). All of these changes are likely to influence children's physical performance. This is important, as physical performance measures reflect concurrent and future health status (Ortega et al. 2008; IOM (Institute of Medicine) 2012).

Children develop and learn a variety of fundamental and specialised movement and skill patterns as they grow. Prior to entering adolescence, the development of basic movement patterns depends largely on a child's neuromuscular maturation, the effects of prior movement experiences, and the effects of normal growth and development (Haywood and Getchell 2009). On entering adolescence, learning and practice of skills are significant factors in physical performance competence (Robinson et al. 2015). Since performance measures often include tasks that require bursts of strength, power and speed, a child's maturity status also plays an important role in their physical performance competence. Further, it is well-known from cross-sectional and longitudinal studies (Malina et al. 2004; Dencker et al. 2006; Bai et al. 2016) that, on average, moderate-to-vigorous physical activity levels, as well as adequate milieus (the physical and built environments) positively affect physical performance levels. However, no information exists about their putative effects on physical performance spurts.

Although physical performance is an important factor in a child's healthy development, interpretation of its development in childhood has been confounded by differences in biological maturation. Adolescence is characterised by variability in timing, intensity and duration of the adolescent growth spurt (Tanner 1962; Roche and Sun 2003). In order to control for this variability, performance characteristics should be investigated using longitudinal data that are aligned with biological maturation (Beunen et al. 1988). However,

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differences during adolescence have been largely related to the timing and sequencing of physical performance levels, mostly using limited longitudinal data (Malina et al. 2004), and thus the impact of the variability in tempo and timing of maturation has been left uncontrolled.

One method to control for variability in biological maturation is to align individuals relative to the timing of the adolescent growth spurt in height [i.e., age at peak height velocity (APHV)], a measure of biological age, rather than chronological age (Kemper and Verschuur 1985; Baxter-Jones et al. 1993). Physical performance spurts have been previously reported for both VO_{2max} (Cunningham et al. 1984) and VO_{2peak} (Geithner et al. 2004), muscular strength (Carron and Bailey 1974; Kemper and Verschuur 1985), as well as other motor tests (Yagüe and De La Fuente 1998; Philippaerts et al. 2006). This is important as it is commonly accepted that boys advanced in their biological maturation tend to systematically outperform their late maturing peers in physical performance measures (Malina et al. 2004).

The timing and intensity of physical performance spurts appears to vary within the same performance marker across studies from different countries. For example, in Belgian twins, VO_{2peak} coincided with APHV (Geithner et al. 2004), whereas in Canadian boys VO_{2max} occurred ~6 months after APHV (Mirwald et al. 1981). The peak spurt in standing long jump occurred 6 months before APHV in Brazilian boys (Silva et al. 2019), was coincident with APHV in Canadian boys (Ellis et al. 1975), but was found to plateau from APHV to 12 months post-PHV in both Spanish boys (Yagüe and De La Fuente 1998) and in Belgian boys (Philippaerts et al. 2006). Little is known about physical performance spurt patterns during adolescence. Further, so far no one has apparently investigated if a putative secular trend would emerge within physical performance spurts (Malafaya et al. 2015) given that a trend of decreasing age has occurred in APHV (Ali et al. 2000; Karlberg 2002; Aksglaede et al. 2008). If patterns of physical performance characteristics aligned to APHV have not changed, this would suggest patterns are related more to growth than environmental influences. Additionally, no report on physical performance spurts has ever been made across different countries varying in their human developmental index as well as their socio-cultural background. It is also unclear if an organised ordering exists in these spurts and if the patterns of spurts have changed over time. Hence the aims of this study were: (1) to estimate APHV for Canadian boys assessed in the 1960s and Portuguese and Brazilian boys assessed in the 2000s; and (2) to compare country-specific physical performance spurts when aligned to APHV.

Subjects and methods

Design and participants

Canada

The Canadian data come from the Saskatchewan Growth and Development Study (SGDS–1963 to 1973), a pure-longitudinal study of boys (Bailey 1968). All participants were measured annually for ten consecutive years, starting at 7 years of age. The sample consisted of 207 boys living in Saskatoon, Saskatchewan, Canada, and apart from their participation in regular physical education classes, the boys were not considered to be "athletes." Complete data on growth and physical performance tests spanning APHV were available in 131 boys and were used in the present report. The Human Developmental Index (HDI) was not available for the 1960s; however, in 2017 the HDI in Canada was 0.926. Informed consent was not required in the 1960s.

Portugal

The Portuguese data come from a research project studying growth and motor development in Azorean children and adolescents (Maia et al. 2003). In brief, a mixed-longitudinal design with four age cohorts of boys and girls starting at 6, 10, 13 and 16 years at baseline, followed consecutively for four years, was used. Annual assessments were performed. Each cohort comprised 250 subjects, 125 of each sex from the four main Azores islands (S. Miguel, Terceira, Faial and Pico) of the archipelago with an overall high HDI. In 2017 the HDI for Portugal was 0.847. All subjects were randomly recruited from schools, and their physical activity/sport participation practices were done within the school curriculum activities of their physical education classes. For the present analysis, male data from cohorts 2 and 3 were used from subjects for whom APHV was available and who had complete physical performance data. In total, 250 boys fulfilled these criteria. Informed consent was obtained from parents/legal guardians of all subjects. The Regional Government Board of Education approved the project, and ethical approval was obtained from the University of Porto Ethics Committee.

Brazil

The Brazilian data come from the Cariri Healthy Growth Study (Silva et al. 2012, 2013, 2016). Briefly, this study used a mixed-longitudinal design, utilising four overlapping age cohorts: 8, 10, 12, and 14 years at baseline. Participants were followed for three consecutive years with measurements taken at six-month intervals from 2006 through to 2009. The sample comprised 498 subjects (237 girls and 261 boys), recruited from the cities of Juazeiro do Norte, Crato and Barbalha. Cariri is a region in the state of Ceará, Brazil, characterised by a low HDI (PNUD 2015). Further, their exposure to diversified physical activities, as well as sport participation, was done within their physical education classes. Geo-climatic, socioeconomic and cultural characteristics are different from other Brazilian regions and the population is quite mixed due to immigration from other northeastern Brazilian states. In the present report participants for whom APHV was estimated (cohorts 2, 3 and 4), and who had physical performance test data were used. In total, 131 boys fulfilled these criteria. The procedures were approved by the Ethics Research Committee of the Medical School of Juazeiro do Norte, and by the school principals. Informed consent was obtained from parents.

Table 1. Physical performance tests used in Canada, Portugal and Brazil.

Location (Country)	Saskatchewan (Canada)	Azores Islands (Portugal)	Cariri Region (Brazil)
Variables	Height (cm)	Height (cm)	Height (cm)
	Trunk extension (cm)	Trunk lift (cm)	Trunk lift (cm)
	Trunk flexion (cm)	–	Sit-and-reach (cm)
	Standing long jump (cm)	Standing long jump (cm)	Standing long jump (cm)
	Bent knee sit-ups (n° of reps)	Curl-up (n° of reps)	Curl-up (n° of reps)
	Wrist flexion strength (Kg^f)	Handgrip strength (Kg^f)	Handgrip strength (Kg^f)

Measurements and tests

Canada

Height was measured with a wall-mounted stadiometer with a precision of 0.1 cm with subjects' heads positioned in the Frankfurt plane. Trunk flexion and trunk extension, standing long jump, bent knee sit-ups, and static wrist flexion (surrogate for handgrip) were performed by the participants (Table 1) and were described in the Saskatchewan Growth and Development Study Manual (Bailey 1968).

Portugal

Height was measured according to standard protocols using a portable stadiometer (Siber Hegner, Switzerland) with a precision of 0.1 cm with heads positioned in the Frankfurt plane. Physical performance was assessed using standardised tests, namely handgrip, standing long jump, curl-up, and trunk lift (Table 1). The first test was from the EUROFIT battery (Council of Europe and Committee of Experts on Sports Research 1993), the second was from the American Alliance for Health, Physical Education and Recreation (AAHPERD 1980), and the last two were from the Fitnessgram battery (Meredith and Welk 2004).

Brazil

Standardised protocols were used to measure height with a portable stadiometer (CARDIOMED® Welmy Model 220, Brazil) to the nearest 0.1 cm, with the head positioned in the Frankfurt plane. Physical performance was assessed using standardised tests, namely handgrip, standing long jump, sit-and-reach, curl-up, and trunk lift (Table 1). The first test was from the EUROFIT battery (Council of Europe and Committee of Experts on Sports Research 1993), the second and the third tests were from the American Alliance for Health, Physical Education and Recreation (AAHPERD 1980), and the last two tests were from the Fitnessgram battery (Meredith and Welk 2004).

Data quality control

Quality control followed the well-known rules concerning: (1) anthropometry data collection was done at the same time of the day, (2) training of field teams, (3) expert supervision during data collection, (4) test-retest intra-individual reliability for technical error of measurement in height measures (technical error of measurement: Canada = 0.5 cm; Brazil = 0.5 cm; Portugal = 0.4 cm) as well as ANOVA-based intraclass correlation coefficients for physical performance assessments: Canada ranged from 0.92 in standing long jump to 0.98 in sit-and reach; Brazil ranged from 0.87 in sit-and-reach to 0.96 in handgrip; Portugal ranged from 0.93 in trunk lift to 0.98 in standing long jump. Further, (5) correctness of data entry records, (6) data cleaning, and (7) normality checks were also done.

Statistical procedures

A modified non-smoothed polynomial method was used to fit individual velocity for height and physical performance tests. The methodology was identified by Van't Hof et al. (1976), and was described and used by Beunen et al. (1988) in their analysis of adolescent Belgian boys. Subsequently, this methodology was used by Yagüe and De La Fuente (1998) in Spanish boys and girls, and by Philippaerts et al. (2006) in Belgian male soccer players. A more general approach of this methodology was developed and previously used by Dos Santos et al. (2019) in Portuguese boys and girls, as well as by Silva et al. (2019) in Brazilian boys and girls.

Mean velocity curves, also called mean constant curves, were developed and defined in terms of time, i.e., months before and after APHV. However, measurements were taken every six-months in the Brazilian study, and annually in the Canadian and Portuguese studies, and the time span of valid data across studies was also different. For example, in the Canadian study we have velocities from –24 months APHV to +24 months after this peak, whereas in the Brazilian and Portuguese studies we have velocities from –18 to + 18 months.

Growth velocities were estimated using software developed by a mathematician and software programmer from the University of Porto. Graphical data were displayed using a cubic spline procedure (GraphPad Prism v(0).8). 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. ANOVA was also used and the alpha level was set at 5%.

Results

APHV values for Canadian, Brazilian and Portuguese boys were 13.9 ± 1.0, 13.4 ± 1.6 and 13.0 ± 0.8 years, respectively. Table 2 and Figure 1 present growth velocities in the three studies relative to APHV. The peak velocities were $9.92\ cm{\cdot}y^{-1}$ for Canadians, $8.49\ cm{\cdot}y^{-1}$ for Brazilians, and $8.17\ cm{\cdot}y^{-1}$ for Portuguese. Canadian boys' peak velocity

Table 2. Mean constant curve height velocities across countries.

	Months from PHV								
Height (cm·year^{-1})	−24	−18	−12	−6	0	6	12	18	24
Canada									
mean	5.01	5.82	6.51	8.13	**9.92**	8.16	6.39	5.12	3.41
n	*131*	*131*	*131*	*131*	*131*	*97*	*97*	*52*	*52*
Portugal									
mean	n/a	4.6	5.19	6.86	**8.17**	6.32	4.78	2.85	n/a
n		*24*	*39*	*39*	*51*	*27*	*27*	*11*	
Brazil									
mean	n/a	2.69	3.42	5.22	**8.49**	5.34	5.20	2.64	n/a
n		*9*	*33*	*84*	*131*	*79*	*42*	*10*	

n/a: not available. Bold numbers represent highest velocities.

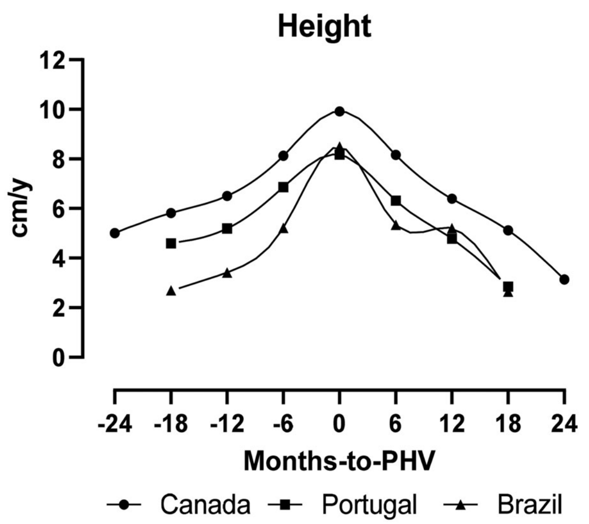

Figure 1. Height velocities aligned by APHV in Canadian, Portuguese and Brazilian boys.

was significantly higher ($p < 0.01$) than Brazilian and Portuguese peers. Average adult height for Canadian boys was 177.80 ± 6.45 cm (Mirwald et al. 1981), whereas for Brazilian boys it was 166.82 ± 5.83 cm at 17 years, and for Portuguese boys 175.65 ± 6.58 cm at 18 years.

Table 3 and Figure 2 show physical performance spurts across the three countries for all tests. For trunk extension/trunk lift (trunk extensor flexibility), there is an acceleration from 3.63 cm·y^{-1} (24 months before APHV) to 4.14 cm·y^{-1} (coincident with APHV) in Canadian boys, from 5.89 cm·y^{-1} (18 months before APHV) to 7.00 cm·y^{-1} (12 months before APHV) in Portuguese boys, and from 5.29 cm·y^{-1} (18 months before APHV) to 7.59 cm·y^{-1} (12 months before APHV) in Brazilian boys. In trunk flexion/sit-and-reach (hamstring flexibility), increases were from 1.70 cm·y^{-1} (24 months before APHV) to 2.67 cm·y^{-1} (12 months after APHV) in Canadian boys, whereas Brazilians reached their peak 12 months before APHV (8.42 cm·y^{-1}), and then velocities decreased. In the standing broad/long jump (explosive muscular strength) a fluctuation is observed in Canadian boys' spurts–they reached their peak spurt 12 months before APHV (14.94 cm·y^{-1}), then the velocity declined, and increased again coincident with APHV (14.92 cm·y^{-1}). In Brazilian boys there was an acceleration from 20.78 cm·y^{-1} (18 months before APHV) to 28.54 cm·y^{-1} (6 months before APHV), whereas in Portuguese boys the curve accelerated from 16.73 cm·y^{-1} (18 months before APHV) to 22.25 cm·y^{-1} (12 months before APHV). For bent knee sit-ups/curl-ups (muscular strength and endurance of the abdominal muscles), both Canadian and Portuguese boys reached their peak spurt coincident with APHV (4.95 and 19.88 reps·y^{-1}, respectively), whereas in Brazilians there was an increase from 12.57 reps·y^{-1} (18 months before APHV) to 13.09 reps·y^{-1} (6 months after APHV). In wrist flexion/handgrip strength (static muscular strength), estimated peak spurts were 14.3 Kg^{f}·y^{-1} (24 months after APHV) in Canadian boys, 6.12 and 6.14 Kg^{f}·y^{-1} coincident and 12 months after APHV, respectively, in Portuguese boys, and in Brazilian boys the peak spurt was 8.18 Kg^{f}·y^{-1} and occurred 12 months after APHV.

Discussion

This study estimated APHV for Canadians assessed in the 1960s as well as Portuguese and Brazilian boys assessed in the 2000s and compared country specific physical performance spurts aligned by APHV. Once aligned by APHV, physical performance spurts showed similarities in timing between the populations but differences in intensity. Given the cross-cultural nature of the present study as well as time, nature of the data, and the specificities of the methodologies, the discussion was framed around three issues: substantive, methodological, and data-driven results.

Substantive

Notwithstanding the unquestionable relevance of the information one gets when aligning physical/motor performance or anthropometric longitudinal data on APHV, there are always issues related to the fact that no formal theory exists that can be empirically tested. Nor is there a substantive body of hypotheses that posit, *a priori*, what will be found, or putative explanations grounded in a network of mechanisms linking physiology, biomechanics, motor learning and control, as well as neuro-motor development. What is available are empirical results emerging from the specifics of each study methodology. In 1988, (Beunen and Malina 1998) wrote an extensive summary of available data from different studies conducted in different countries on height and fat mass, VO_{2max}, muscular strength, and physical performance. In their summary, they tackled a few of the problems and provided "coherent trends" of: (1) if studies were longitudinal or mixed-longitudinal; (2) if sample sizes varied substantially;

Table 3. Physical performance mean constant curves velocities aligned by APHV in each country.

	Months from PHV								
Variables	–24	–18	–12	–6	0	6	12	18	24
Saskatchewan (Canada)									
Trunk extension (cm·year^{-1})									
mean	3.63	3.30	3.76	4.06	**4.14**	3.35	2.96	1.95	4.07
n	*79*	*93*	*80*	*53*	*50*	*25*	*21*	*5*	*3*
Trunk flexion (cm·year^{-1})									
mean	1.70	1.78	1.99	1.87	1.99	2.62	**2.67**	0.50	0.68
n	*27*	*32*	*29*	*30*	*29*	*12*	*12*	*3*	*3*
Standing broad jump (cm·year^{-1})									
mean	12.82	13.37	**14.94**	13.75	**14.92**	12.47	7.72	10.52	8.95
n	*104*	*103*	*95*	*61*	*59*	*29*	*29*	*7*	*7*
Bent knee sit-ups (reps·year^{-1})									
mean	3.63	3.24	3.99	3.78	**4.95**	3.50	3.35	3.00	4.08
n	*73*	*59*	*42*	*37*	*28*	*12*	*10*	*1*	*1*
Wrist flexion (Kg^{f}·year^{-1})									
mean	6.31	6.59	8.14	7.69	8.43	6.57	7.59	8.17	**14.3**
n	*101*	*103*	*93*	*59*	*54*	*27*	*24*	*6*	*6*
Azores Islands (Portugal)									
Trunk lift (cm·year^{-1})									
mean	n/a	5.89	**7.00**	3.79	2.56	1.30	2.03	0.52	n/a
n		*14*	*14*	*15*	*9*	*7*	*2*	*3*	
Standing long jump (cm·year^{-1})									
mean	n/a	16.73	**22.25**	13.78	16.09	12.46	12.8	13.25	n/a
n		*21*	*4*	*33*	*29*	*22*	*17*	*10*	
Curl-ups (reps·year^{-1})									
mean	n/a	13.1	14.69	17.75	**19.88**	13.13	11.6	10.63	n/a
n		*13*	*18*	*20*	*25*	*13*	*9*	*7*	
Handgrip strength (Kg^{f}·year^{-1})									
mean	n/a	2.32	3.29	4.27	**6.12**	5.59	**6.14**	4.29	n/a
n		*24*	*31*	*37*	*43*	*25*	*24*	*9*	
Cariri Region (Brazil)									
Trunk lift (cm·year^{-1})									
mean	n/a	5.29	**7.59**	5.66	4.81	2.13	2.30	n/a	n/a
n		*10*	*23*	*36*	*39*	*22*	*11*		
Sit-and-reach (cm·year^{-1})									
mean	n/a	n/a	**8.42**	2.39	3.26	3.73	n/a	n/a	n/a
n			*7*	*10*	*8*	*8*			
Standing long jump (cm·year^{-1})									
mean	n/a	20.78	22.07	**28.54**	22.34	20.86	17.28	n/a	n/a
n		*9*	*30*	*57*	*61*	*34*	*15*	*4*	
Curl-ups (reps·year^{-1})									
mean	n/a	12.57	11.62	9.8	12.13	**13.09**	4.35	1.99	n/a
n		*7*	*19*	*29*	*32*	*15*	*4*	*1*	
Handgrip strength (Kg^{f}·year^{-1})									
mean	n/a	2.23	1.48	2.92	3.63	7.98	**8.18**	5.85	n/a
n		*19*	*45*	*85*	*95*	*65*	*32*	*18*	

n/a: not available. Bold numbers represent highest velocities.

(3) if mathematical models used to estimate APHV were different; (4) if the number of time points in each study varied; and (5) if studies identified a similar APHV in boys or in girls, and if the same occurred in physical performance variables. For example, they reported a similar age-at-peak for arm-pull static strength in Belgian boys as well as in Dutch boys and girls, using both means and medians; Geithner et al. (2004) identified a peak for VO_{2peak} coincident with APHV in Belgian twins, a result not reported by Mirwald et al. (1981) or Kobayashi et al. (1978) in Japanese boys. Similar discrepancies can be found in other reports related to physical performance (Yagüe and De La Fuente 1998; Philippaerts et al. 2006). In summary, what this means, in our view, is the following: sometimes data from different studies are consistent in the peaks they identify, whereas at other times they are not for reasons related to study design and methodology. Yet, by no special reason can we claim that some results are "right," and others are "wrong." They are just sample and methods' specific.

Methodologically

Available reports using APHV as a suitable marker to identify spurts in physical/motor performance vary in their sample sizes, subject's origin, duration of the study, measurement frequency, and in statistical methods. For example, Yagüe and De La Fuente (1998) sampled Spanish children from the Menorca Islands, Philippaerts et al. (2006) used Belgian boys playing soccer from Ghent, and Beunen et al. (1988) sampled from Leuven, whereas Kemper and Verschuur (1985) used Dutch subjects, and Silva et al. (2019) recruited from a northeast Brazilian region. The Saskatchewan Growth and

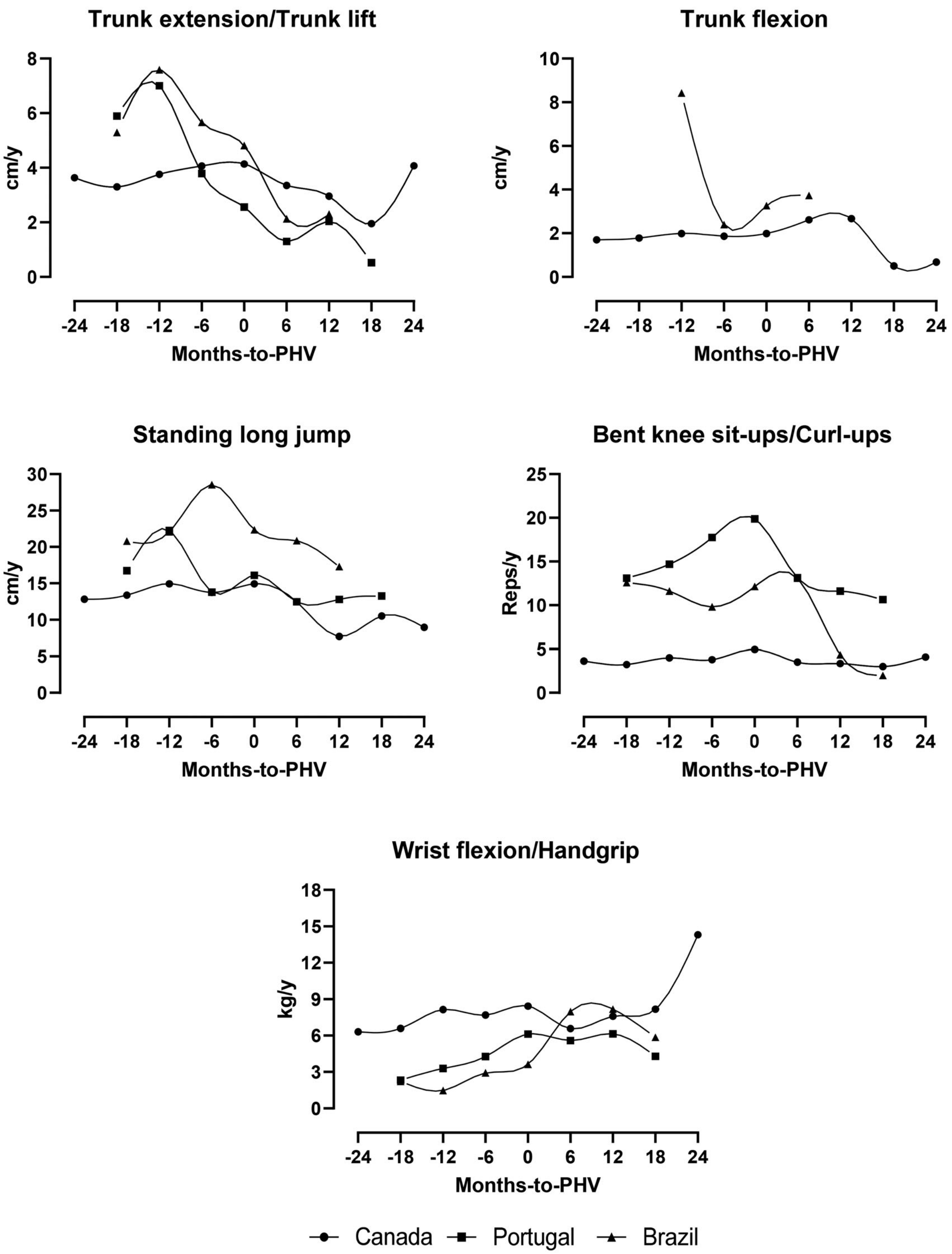

Figure 2. Physical performance velocities aligned by APHV in Canadian, Portuguese and Brazilian boys.

Development Study originally sampled 207 boys, but only used 131 for analysis, whereas in the Spanish study the total sample comprised 509 boys and 453 girls, but the final sample in their analysis only comprised 28 boys and 38 girls. Similar trends were observed in the other reports as valid data to be successfully modelled varied substantially from the original sample size, and are different for different physical/motor performance markers [see, for example, Philippaerts et al. (2006), Kobayashi et al. (1978), or Geithner et al. (2004)].

The original mathematical methodology proposed by Hof et al. (1976), and described in Beunen et al. (1988), was applied to annual data; however, the current study estimated six-month velocities. Yagüe and De La Fuente (1998) used six-month data, as well as in the Brazilian study (2019), but in Portugal and Canada only annual data were available. Consistent with the method, we only showed six-month velocities and used different month intervals as per the age range of each study, i.e., from –24 to +24 in Canada but from –18 to +18 in Brazil and Portugal. In contrast, a

Spanish study (Yagüe and De La Fuente (1998) used a reference frame from −16 to +16 for boys, whereas in the study by Philippaerts et al. (2006) on Ghent boys, −18 to +18 was used in their Figures 3 and 4, but then from −12 to + 12 was used in their Table 3. It is also important to state that there is substantial variation in all tests used to mark different physical performance components as seen, for example in Yagüe and De La Fuente (1998) or in Philippaerts et al. (2006). A similar situation occurred in the present study and this may have repercussions in the identifications in the timing and intensity of each physical performance spurt.

Data-driven results

Canadian boys reached their PHV later than their Portuguese and Brazilian peers. Since the Canadians were assessed between 1963 and 1973, the Portuguese between 2002 and 2006, and the Brazilians between 2006 and 2009 these age differences suggest a putative secular trend in APHV even though these samples belong to populations with distinct life and socioeconomic histories as well as different genetic backgrounds. A similar tendency is seen when we consider the estimated APHV in British boys (14.1 y) (Tanner et al. 1966), Swedish boys (14.1 y) (Lindgren 1978) and Swiss boys (13.9 y) (Largo et al. 1978) in comparison to Spanish boys (13.0 y) measured 20–30 years later (Yagüe and De La Fuente 1998). Similarly, in youth soccer the average APHV of Danish (Froberg et al. 1991) and Welsh (Bell 1993) players was ~14.2 y, but 13–15 years later Philippaerts et al. (2006) reported 13.8 y in Belgian players. This is also in line with secular trends on APHV found in Japan (Ali et al. 2000), and in Denmark (Aksglaede et al. 2008).

Peak spurts in trunk extension/trunk lift (trunk extensor flexibility) occurred coincident with APHV in Canadians, whereas in Portuguese and Brazilian boys it occurred 12 months before APHV. Although we were not able to locate any study reporting on trunk extension/trunk lift peak spurts, which makes other comparisons difficult, we believe that these discrepancies may be explained by at least two factors: (1) the trunk extension and trunk lift were assessed using relatively different protocols; and (2) although the test measures trunk extensor flexibility, its execution requires some level of strength from the *erector spinae* muscles (*spinalis, longissimus and iliocristalis*) with *glutaeus maximus* and *hamstrings* fixing the position of the lower part of the body (pelvis and lower limbs). It is possible that the different conditions of the Canadian protocol had a putative limiting effect when exerting strength of the *erector spinae* muscles to lift the head upward and backward as far as possible, and thus hindering the spurt intensity.

For the trunk flexion/sit-and-reach (hamstring flexibility), the Canadian boys reached their peak 12 months after APHV while the Brazilian ones reached it 12 months before APHV. This different timing pattern is also present in previous studies. For example, it occurred 8 months after APHV in Spanish boys (Yagüe and De La Fuente 1998) and 12 months after APHV in young Belgian soccer players (Philippaerts et al. 2006). In contrast, data from the Leuven Growth Study of Belgian Boys indicated that "if there is a spurt in flexibility, it probably occurs somewhat before PHV, and probably is more coincident with the adolescent spurt in leg length" (Beunen et al. 1988). In a different vein, Grosser et al. (1989) suggested that a possible sensitive period in flexibility development may occur between 8/9 and 12/13 years old in boys. We also contend that differences in the measurement protocols, together with differences in the timing of leg and arm lengths´ spurts play important roles in the variation seen in the timing and intensity flexibility spurts.

Results for the standing broad/long jump (explosive muscular strength) indicate that Canadian and Portuguese boys had their peak 12 months before APHV, whereas the Brazilians had their peak at 6 months before APHV. Comparable results were also reported in Belgian young soccer players since they peaked 18 months before and coincident with APHV (Philippaerts et al. 2006). In terms of training methodology, Grosser et al. (1989) suggested that children can start their training in explosive strength at 7–8 years of age, i.e., prior to APHV. Indeed, they also indicate that this is a great window of opportunity to begin their display in this specific type of strength which is also consistent with data from meta-analysis reported by Behringer et al. (2011). In addition, and given the coordinative task structure of the standing long jump, Starosta and Hirtz (1990) also suggested this age as a putative sensitive period for gross motor coordination training/development. In contrast to these results and suggestions, Yagüe and De La Fuente (1998) found a peak in Spanish boys coincident with APHV followed by a plateau during the 12 months after APHV, and Beunen et al. (1988), using vertical jump, reported a peak 6 months after APHV in Belgian boys. Again, we contend that these discrepancies may be linked to the distinctive designs of the studies, peculiarities of testing methodologies, as well as specificities of both skills (horizontal versus vertical jump). It is also possible that putative differences across countries in the sequences and intensities of peak spurts in trunk height and/or leg length may have a contribution to these dissimilarities. Yet, one has to keep in mind that there is a wide variation in the timing, intensity and sequences of peak spurts of body dimensions (Bergman and Gorcy 1984; Busscher et al. 2011; Geithner 2013).

Peak spurts in bent knee sit-ups/curl-ups (muscular strength and endurance of the abdominal muscles) occurred coincident with APHV in Canadians and Portuguese, and 6 months after APHV in Brazilians. Similarly, Belgian young soccer players had peak performance coincident with APHV (Philippaerts et al. 2006). In contrast, Spanish boys peaked 16 months before APHV, and Beunen et al. (1988) did not find a clear peak in their data. Although we anticipate that these discrepancies may be associated with differences in testing protocols across studies, the bulk of results show a putative pattern of maximum velocities occurring around APHV, which is in line with the suggestions made by Grosser et al. (1989) that a suitable age to start this type of strength training is around 13–15 years of age.

For the wrist flexion/handgrip strength (static muscular strength), both Portuguese and Brazilian boys attained their peak spurt 12 months after APHV, whereas the Canadian boys reached it 24 months after APHV. This timing is consistent with the arm pull strengths reported by Kemper and Verschuur (1985) and Beunen et al. (1988), who reported the spurt occurring 12 and 6 months after APHV in Dutch and Belgian boys, respectively. This occurring pattern after APHV suggests that maximal static strength spurts are linked not only to body weight spurt (and substantial increases in muscle mass), but also to increases in circulating testosterone (Round et al. 1999).

This study is not without limitations. Firstly, although we used a set of similar physical components across the studies, differences in testing are expected and this most probably influenced the results. Secondly, even if the temporal gap between studies, ~40 years, may be considered as a limitation, it may also be viewed as a strength due to the fact that an eventual secular trend in spurts may have been identified. Yet, and since we are dealing with data from different studies done at different time points, it would probably be somewhat difficult to use the same tests given researchers interests, even if the same physical performance components are being assessed. For example, in the Netherlands (Kemper and Verschuur 1985) or in Belgium (Beunen et al. 1988; Philippaerts et al. 2006), as well as in Spain (Yagüe and De La Fuente 1998), different tests were used to measure the same physical performance components, and by no means did this prevent them from using each other's data to best interpret theirs. Thirdly, across countries, no consistent and similar information is available concerning objective environmental characteristics and/or children and adolescents lifestyle behaviours that could be useful in providing a more encompassing explanation for some of our findings. In no papers we consulted was such information available, nor had authors tried to incorporate this information whatever the physical performance or physiological variable used. Finally, it could be argued that higher levels of physical activity/sports participation may have an effect on the timing and/or intensity of physical performance spurts. Since no such data are available across Canada, Brazil and Portugal, nothing can be said about this possibility. In fact, there is no study available that has ever tested this hypothesis, but we have some indirect evidence. Even if the test structure of the study by Yagüe and De La Fuente (1998) in Spanish non-sportive boys is different from that of Philippaerts et al. (2006) in Belgian soccer players (2006), we can use a similar test as an example–the standing long jump. In the Spanish sample the peak was 21 cm·y^{-1} at APHV as well as at 4 months and 8 months after APHV, but the reported peak was 22 cm·y^{-1} 12 months after PHV, i.e., a difference of just + 1 cm. In the Belgium sample, the peak is coincident at APHV, 10.5 cm·y^{-1}, but then other peaks of 10.1 cm·y^{-1} and 10.1 cm·y^{-1} occur at 6 and 12 months after APHV, i.e., a difference of just 0.4 cm. The biggest question is how to explain that in soccer players the peak was just 10.5 cm·y^{-1}, when in non-sporting Spanish boys it was 21 cm·y^{-1}. Another line of evidence comes from Canadian longitudinal aerobic power of active ($n = 14$) versus non-active ($n = 11$) boys (Mirwald et al. 1981); the age at the aerobic power spurt was at 14.5 y versus 14.0 y, for active and non-active boys, and the intensity of the spurt was 0.57 versus 0.53 l·min-1·y^{-1}, respectively.

In conclusion, Canadian, Portuguese and Brazilian boys show a putative secular trend in APHV. Our study also reveals a relatively similar pattern in physical performance peaks which seems to be independent of this secular trend. Apart from hamstring flexibility, the identified sequence, having APHV as a pivoting biological marker, showed that explosive muscular strength peaks prior to PHV, trunk extensor flexibility peaks just before or at PHV, abdominal muscular strength and endurance peaks at or just after the attainment of PHV, and static muscular strength peaks tend to occur post PHV. We believe that the present information may be of interest to coaches of young athletes as well as physical education teachers to better grasp the intertwined links between rapid growth, maturation timing and tempo and development of physical performance across childhood and puberty. Finally, we recommend that future reports include data from both boys and girls, consider information on objective physical activity and sport participation, and other biological variables like hormonal data, as well as putative contextual variables that might be useful to provide a better understanding of these spurts, their intensities, and sequences. This will require relatively complex designs following children living in the same country but from different socio-economic conditions, with systematic differences in their physical activity/sports participation practices, and studying in schools whose conditions are distinct.

Disclosure of interest

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

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