Received: 26 March 2020 | Revised: 6 July 2020 | Accepted: 3 August 2020

DOI: 10.1111/sms.13800

SPECIAL ISSUE ARTICLE

WILEY

Physical fitness spurts in childhood: A study in boys

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Abstract

This study aimed to (1) estimate age-at-mid-growth spurt (age-at-MGS) in Portuguese boys from two different regions—the Azores islands and Viana do Castelo, and (2) identify spurts in a variety of physical fitness (PF) components aligned by age-at-MGS in the two samples. A total of 176 (Azores, n = 91; Viana do Castelo, n = 85) boys aged 6 years old were followed annually to 10 years of age. Age-at-MGS and spurts in PF components (speed, explosive muscular strength, abdominal muscular strength, agility, and flexibility) were identified for each sample. The timing and intensities of the spurts were estimated using a non-smooth mathematical procedure. In Azorean boys, age-at-MGS occurred at 7.8 years (6.99 cm y^{-1}), whereas in Viana do Castelo it occurred at 7.9 years (6.20 cm y^{-1}). Spurt in speed was attained 12 months after the MGS in both samples (0.53 and 0.35 cm y^{-1} in Azores and Viana do Castelo, respectively), whereas spurts in explosive muscular strength and flexibility occurred 12 months before the MGS and at the MGS (Azores: 21.59 and 5.52 cm y^{-1} and Viana do Castelo: 14.12 and 2.5 cm y^{-1}, respectively). Agility and abdominal muscular strength peaked between 0 and 12 months after the MGS (Viana do Castelo: 0.37 m s^{-1} y^{-1} and 6.71 reps y^{-1} and Azores: 0.28 m s^{-1} y^{-1} and 19.36 reps y^{-1}, respectively). Results indicate that developmental spurts in explosive strength and flexibility occur before, or are coincident with, the mid-growth spurt in height, whereas spurts in speed, agility, and abdominal muscular strength occur after, or coincident with, the mid-growth spurt in height.

KEYWORDS

childhood, longitudinal, mid-growth spurt, motor performance

1 | INTRODUCTION

Physical fitness (PF) is widely accepted as the expression of the efficiency of a set of components such as strength, power, agility, and speed,[1] which altogether facilitate the acquisition of fundamental movement skills, including locomotor, object control, and balance skills.[2] Appropriate levels of PF, fundamental movement skills acquisition, and gross motor coordination promote healthy developmental trajectories.[3]

A very common and useful way of describing and interpreting how children and adolescents change their PF is to align them in chronological age groups.[4] Yet, it is also well known that adolescents vary in the timing and tempo of their biological maturation,[5] meaning that the interpretation of PF changes based on their biological status, or biological age, may be of a greater significance and far more encompassing than just describing chronological age-related changes.

The plotting of adolescent height velocity curves aligned by individual ages-at-peak height velocity (age-at-PHV) by Frank Shuttleworth[6] allowed for a better understanding of spurts in other bodily measurements,[5] and if these had interpretable sequences across populations.[7,8] This practice has also been transposed to PF research to best understand boys´ and girls´ developmental spurts in VO_{2max},[9] muscular strength,[10] and various other performance measures.[11] Notwithstanding the relevancy of these reports, adolescent boys' and girls' spurts and sequences vary across studies. Further, and so far as we know, no one has ever been able to report, from different samples from the same population, similar results. Further research in this area is required for putative explanations to be developed.

The practice of aligning distinct growth, physiological, and performance measures by biological age (eg, age-at-PHV, a well-known biological maturation marker) has previously been summarized by Beunen, Malina.[11] Such curves can be derived by numerous methodologies such as those described by the Preece-Baines model,[12] and the infancy, childhood, and puberty mathematical model (the ICP-model).[13] However, the disadvantage of using these models during childhood is that they only describe the adolescent growth spurt, with its most relevant parameter—the age-at-PHV. This is problematic as there is another spurt in statural growth, the mid-childhood growth spurt (MGS), first identified in 1915.[14] Recently, Butler, McKie, Ratcliffe[15] described its apparent cyclical nature using more flexible mathematical models.[16,17] The MGS refers to a relatively small and transient increase in growth velocity observed in most children, but not necessarily all, between 6 and 10 years.[14] The MGS has been shown to be governed by genetic factors.[18] In addition, available information concerning hormonal data strongly suggested that the MGS can also be considered as a biological age marker during childhood[19] in a similar way to the current practice of using age-at-PHV during adolescence.

In a recent report,[20] we investigated how different markers of children's gross motor coordination unfolded when children were aligned by age-at-MGS and found not only were there sex differences but also these markers had their own timing in terms of peak spurts. More specifically, we reported that in boys, spurts in walking backward and hopping on one leg were occurring 18 months before the MGS. In contrast, shifting platform occurred 12 months prior to the MGS and jumping sideways occurred 12 months after attainment of the MGS.

To our knowledge, no one has yet explored the possibility that such spurts may exist during children's PF development. Further, it is unknown if in different samples from the same population similar spurts could be identified. Specifically, it is unknown if the timing and tempo of such spurts were relatively alike within and between individuals. In any case, we also contend that these spurts may be linked to fundamental motor skill development. This is important as such spurts may increase the efficiency with which individuals perform daily activities. Further, it has been suggested that children's PF has positive links with health-related habits and behaviors, act synergistically with body weight status, and may attenuate the emergence of obesity in children.[21]

The aforementioned trajectories of growth, maturation, and motor development are continuous and intertwined. Although their sequences are apparently consistent among children, they differ considerably in terms of timing and tempo.[4] The identification of PF spurts during mid-childhood may provide relevant information for physical education teachers and sport coaches. This is particularly relevant during sensitive periods of a child's development when growth and maturation intertwine with patterns of differential change in PF components. This body of knowledge is essential to provide putative guidelines when developing and tailoring intervention programs. Such interventions should not just be based on a child's chronological age but also on their different growth and maturation statuses. Identification of the timing of PF spurts will enable those working with them to adjust individual programs to improve a child's motor development.

Hence, the aims of this paper were to (1) estimate the age of occurrence of the MGS (age-at-MGS) in Portuguese boys from two different regions—the Azores islands and Viana do Castelo, and (2) identify spurts in a variety of PF components aligned by age-at-MGS. Our hypotheses were as follows: (1) The mean age-at-MGS will be dependent on region, and (2) PF spurts aligned by age-at-MGS will be specific to each PF component but their pattern will be similar between regions.

2 | MATERIAL AND METHODS

2.1 | Participants

The current study sample was derived from two studies conducted in two regions of Portugal: Azores (islands) and Viana do Castelo (northern mainland). Table 1 compares participants' body size at 6 years of age, their sociodemographics, and some natural environment characteristics between Azores and Viana do Castelo. Height and weights at 6 years of age were similar between the populations. Although the Viana de Castelo population density was greater, family dimensions were similar as were parental educational levels. The Azores had a greater mean temperature but lower rainfall.

TABLE 1 Samples means at 6 years of age for body size, sociodemographic, and natural environmental characteristics in Azores and Viana do Castelo

	Azores	Viana do Castelo
	Mean ± SD	Mean ± SD
Sample characteristics		
Weight (kg)	24.1 ± 4.7	24.1 ± 4.3
Height (cm)	118.2 ± 5.0	120.1 ± 4.9
Body mass index (kg/m^2)	17.2 ± 2.4	16.6 ± 2.1
Sociodemographic characteristics		
Population density (people·km^2)	104.2	173.2
Mean family dimension (number of persons)	3.3	3.0
Education	%	%
<Grade 12	84.9	81.9
Grade 12/diploma/technical qualification	9.9	11.9
University level	5.2	6.2
Natural environmental characteristics		
Temperature (mean)	17.5	15.2
Number of days without rain	157	199

2.1.1 | Azores data

The Azores islands are located in the Atlantic ocean (between 36°-43° North latitude, and 25°-31° West longitude), and the data used in this report came from a mixed-longitudinal study (2002-2006) conducted in this region aiming to investigate the links between growth, body composition, biological maturation, motor performance, gross motor coordination, physical activity, motivation for sports, socioeconomic status, and school characteristics.[22] The study selected four age-cohorts, with an overlapping year, were measured annually and followed consecutively over 4-5 years (6-10; 10-13; 13-16; 16-19 years), with ~250 subjects per cohort (125 per sex). We used a random and proportional sample within each age group from the four main islands of the archipelago (S. Miguel, Terceira, Faial, and Pico) because they represent 80% of the total schooling population of the region. Data were obtained from cohort 1, from the original sample of 143 boys. Complete information for all variables was available in 91 participants (6.43 ± 0.30 years of age at baseline). Written informed consent was obtained from legal guardians, and the project was approved by the Ethics Committee of the University of Porto and school authorities.

2.1.2 | Viana do Castelo data

Viana do Castelo is located in the northern mainland of Portugal (41° 42′ North Latitude, and 8° 49′ Longitude), and the data originated from a longitudinal study (1997-2000) conducted in children aged 6 years who were followed consecutively until 10 years of age.[23] Similar to the Azorean study, data were randomly and proportionally selected from 15 schools of different Viana do Castelo parishes, with children assessed once per year.[24] The morphofunctional study of Viana do Castelo children[23] investigated their physical growth and PF. The original sample consisted of 472 children (239 boys). In the present analysis, complete data for all variables were available for 85 male participants (6.85 ± 0.36 years old at baseline). Written informed consent was obtained from legal guardians, and the project was approved by the Ethics Committee of the Polytechnic Institute of Viana do Castelo and school authorities.

2.2 | Azores and Viana do Castelo measurements

Height was measured with the child's head positioned in the Frankfurt plane, using a portable stadiometer (Siber Hegner for Azores and GPM model 101 for Viana do Castelo) to the nearest 0.1 cm.

Physical fitness (Table 2) was assessed using the following tests taken from the Fitnessgram battery,[25] the American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD) battery,[26] and the Eurofit battery[27]: (1) Speed was obtained via a 50 yard dash (Azores data) and 50 m dash (Viana do Castelo data), where participants ran this distance in the shortest time possible; (2) explosive muscular strength was assessed with standing long jump tests (both Azores and Viana do Castelo data) where participants jumped as far as possible from a standing position; (3) abdominal muscular strength was assessed via curl-up test

TABLE 2 Motor performance components and tests used in Azores and Viana do Castelo studies

Azores tests	Motor performance components	Viana do Castelo tests
50 yard dash	Speed	50 m dash
Standing long jump	Explosive muscular strength	Standing long jump
Curl-ups	Abdominal muscular strength	Sit-ups
4 × 9 m shuttle run	Agility	4 × 10 m shuttle run
Trunk lift	Trunk extensor/hamstring flexibility	Sit-and-reach

TABLE 3 Mean constant curves for height and motor performance velocities aligned by age-at-MGS of Azorean and Viana do Castelo boys (peak velocities are in bold)

Variables		Months from MGS −18	−12	−6	0	6	12	18
Azores								
Height (cm y^{-1})	mean	4.77	4.40	5.19	**6.20**	5.39	4.65	5.05
	n	*9*	*63*	*63*	*82*	*73*	*73*	*19*
50 yard dash (m s^{-1} y^{-1})	mean	0.39	0.39	0.33	0.41	0.40	**0.53**	0.36
	n	*6*	*35*	*46*	*41*	*50*	*40*	*11*
Standing long jump (cm y^{-1})	mean	5.34	**21.59**	13.49	16.04	13.35	16.15	13.22
	n	*7*	*28*	*41*	*34*	*44*	*29*	*12*
Curl-ups (reps y^{-1})	mean	1.97	4.16	9.66	15.01	12.17	**19.36**	9.19
	n	*5*	*40*	*45*	*41*	*41*	*28*	*9*
Shuttle run (m s^{-1} y^{-1})	mean	0.18	0.21	0.17	0.19	0.19	**0.28**	0.18
	n	*2*	*24*	*30*	*30*	*33*	*22*	*15*
Trunk lift (cm y^{-1})	mean	2.05	**5.52**	4.13	5.06	3.05	3.44	3.07
	n	*5*	*34*	*44*	*35*	*43*	*28*	*10*
Viana do Castelo								
Height (cm y^{-1})	mean	4.95	4.21	5.55	**6.99**	5.62	4.25	4.98
	n	*17*	*25*	*25*	*85*	*68*	*68*	*60*
50 m dash (m s^{-1} y^{-1})	mean	0.31	**0.35**	0.27	0.29	0.28	**0.35**	0.27
	n	*17*	*18*	*20*	*54*	*56*	*35*	*47*
Standing long jump (cm y^{-1})	mean	12.24	**14.05**	10.09	**14.12**	11.90	9.48	6.90
	n	*15*	*17*	*20*	*63*	*59*	*44*	*42*
Sit-ups (reps y^{-1})	mean	4.60	4.84	3.71	**6.71**	5.87	**6.14**	4.62
	n	*14*	*14*	*20*	*60*	*59*	*45*	*44*
Shuttle run (m s^{-1} y^{-1})	mean	0.33	0.31	0.25	**0.37**	0.31	0.24	0.18
	n	*16*	*23*	*18*	*74*	*65*	*61*	*41*
Sit-and-reach (cm y^{-1})	mean	1.52	0.91	2.01	**2.5**	1.81	1.88	1.37
	n	*7*	*9*	*6*	*24*	*23*	*19*	*4*

where participants correctly performed as many curl-ups as possible (with a maximum of 75 repetitions)—Azores data, and via sit-ups where participants correctly performed as many sit-ups as possible in 30 seconds—Viana do Castelo data; (4) agility was assessed with the shuttle run test—all participants ran as fast as possible from the starting line 9 m (Azores data), and 10 m (Viana do Castelo data) away where two small wooden blocks were placed, picked-up one of the blocks, returned to the starting line, placed the block on the line, and then repeated the route; (5) flexibility was assessed with the trunk lift test, with children lying in a prone position, lifted the trunk as much as he/she could (Azores data); in Viana do Castelo the sit-and-reach test was used, with children sitting on the floor with legs stretched out straight ahead without shoes, with the palms facing downwards, and the hands on top of each other or side by side, the participant reached forward along the measuring line as far as he/she could.

2.3 | Data analysis

The MGS in stature was estimated separately in each sample, as well as the occurrence of PF spurts with tests aligned by age-at-peak MGS. We adapted the methodology initially developed by Van't Hof, Roede, Kowalski,[28] later applied to growth and PF of Belgium boys who were followed annually from 12 to 18 years,[11] as well as in Spanish youth.[29] This methodology remains valid during the MGS, if the following conditions are satisfied: (1) the presence of a real spurt, that is, an increase in velocity, (2) a specific slowdown of growth velocity after the peak, and (3) the presence of reduced measurement error in all variables, that is, reliable data. If these assumptions were not met, a MGS was not identified. Given that each individual child has his/her own height growth velocity curve as well as in all PF tests, mean constant curves were obtained for PF data aligned by age-at-MGS. Hence, the possibility to compute mean PF velocity values before and after age-at-MGS, that is, −18, −12, −6, and +6, +12, +18 months from the mid-growth maximum velocity is marked as 0. A generalization of the methodology was developed by a University of Porto mathematician, who also developed the software to conduct all analyses. This generalization was successfully applied to identify spurts in children's gross motor coordination.[20] Graph pad Prism v8 software was used to produce all figures.

3 | RESULTS

Mean constant curve height and PF velocities aligned by age-at-MGS are presented in Table 3 and displayed graphically in Figure 1. The assumptions of the MGS models were met in 90% of the Azorean sample and 100% in the Viana do Castelo sample. In Azorean boys, the MGS was identified to be occurring at 7.8 years, whereas in the Viana do Castelo boys it was at 7.9 years. No significant differences were found between the two samples ($P > .05$). Further, at the MGS occurrence the velocity was 6.99 cm y^{-1} in Viana do Castelo boys, while in Azorean boys it was 6.20 cm y^{-1}. These were statistically significant differences (95% CI for the difference: 0.49 to 1.09 cm; $t(165) = 5.14$, $P < .01$). As noted, the number of available data points for each test within each location differed but followed a relatively similar pattern. The lowest are found at the time extremes (−18 months and +18 months) and the highest are within a twelve-month boundary around age-at-MGS. In speed, Azorean boys had their spurt (0.53 m s^{-1} y^{-1}) 12 months after the MGS, whereas in Viana do Castelo boys two similar spurts (0.35 m s^{-1} y^{-1}) were identified at −12 months from MGS and 12 months after. In the explosive muscular strength (standing long jump), Azorean boys had their spurt (21.59 cm y^{-1}) at −12 months

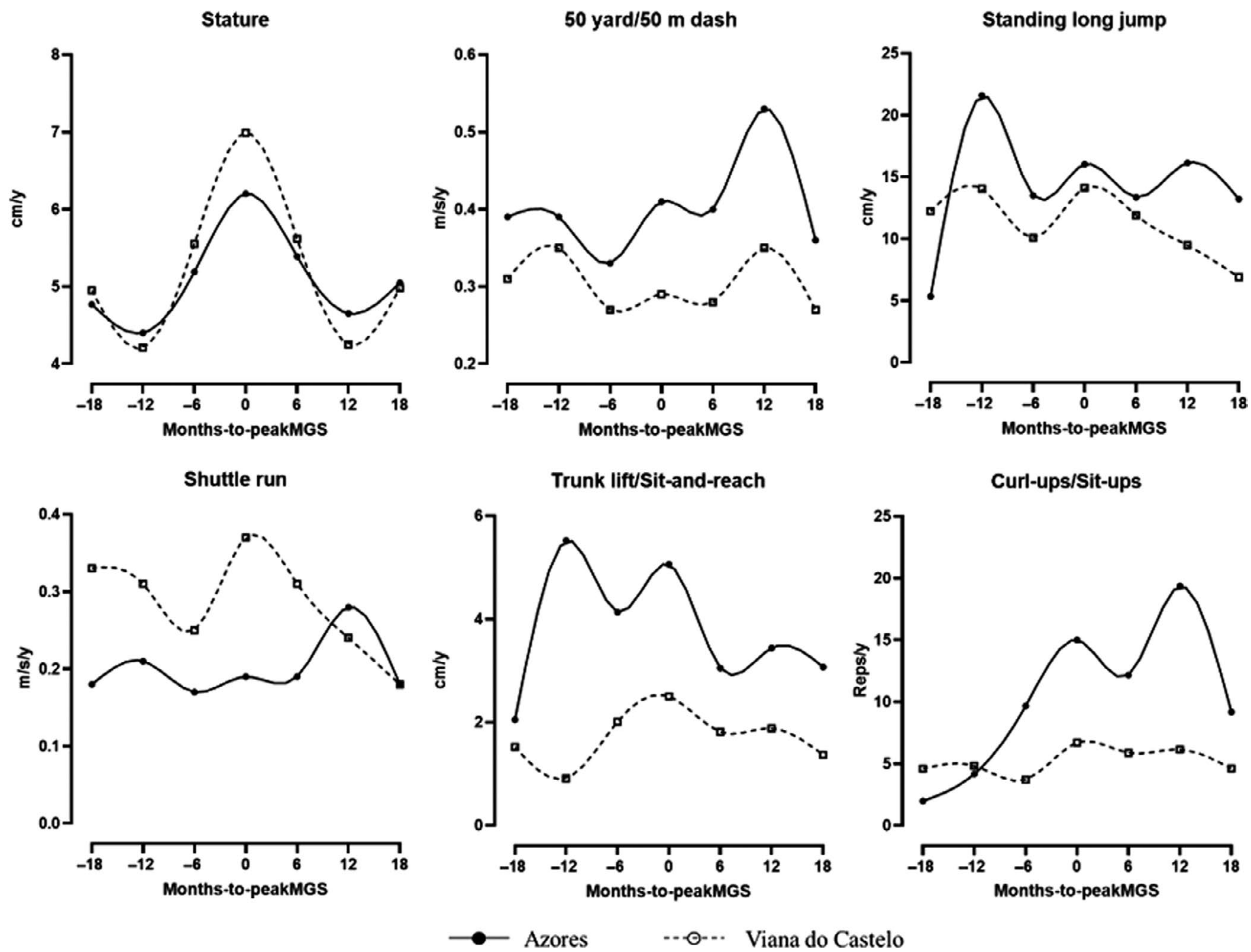

FIGURE 1 Mean constant velocity curves for height and all physical fitness tests in Azorean (continuous line/filled circle) and Viana do Castelo boys (dashed line/open circle)

before age-at-peak MGS, but Viana do Castelo boys had two peaks at −12 months (14.05 cm y^{-1}) and coincident with age-at-MGS (14.12 cm y^{-1}). Sit-ups/curl-ups' (abdominal muscular strength) peaks manifested 12 months after age-at-MGS in Azoreans (19.36 reps y^{-1}), while Viana do Castelo boys showed two similar peaks, one coincident with age-at-MGS (6.71 reps y^{-1}) and the other 12 months after it (6.14 reps y^{-1}). Peaks in agility are apparent at age-at-MGS in Viana do Castelo boys (0.37 m s^{-1} y^{-1}) and 12 months after it in Azoreans (0.28 m s^{-1} y^{-1}). Flexibility peak spurts are different in Azoreans (−12 months before age-at-MGS, 5.52 cm y^{-1}) from Viana do Castelo boys (2.5 cm y^{-1} coincident with age-at-MGS).

4 | DISCUSSION

In the present study, we examined the timing, tempo, and sequence of the MGS aligned to a variety of PF components. To our knowledge, this is the first time that such spurts and sequences have been identified in Portuguese children, and in doing so, we believe that these results provide useful information for physical education teachers and sport coaches to better understand the development of children's PF during their school years. During mid-childhood, one of the main aims is to provide ample opportunities for children to develop their fundamental motor skills. In addition, it is important to improve their PF levels, that is, extend their motor repertoire while engaging in physical activities and sport. Importantly, those working with children during this time need to be aware that sensitive periods, or windows of opportunity, for each PF component are present and thus a need to consider the joint effects of differential physical growth and biological maturation are required. Hence, it is expected that those working with children will provide children with enriching learning opportunities and provide environments that prompt the timely development of these components. The age-at-MGS was identified in all Viana do Castelo children and in 90% of the Azorean children. This may due to the fact that the MGS may not be experienced by all children,[30] or that some may have experienced two or three spurts, as argued by Butler, McKie, Ratcliffe.[15] Another explanation is that annual measurements may have limited the estimation of the MGS, although previously Gasser, Kneip, Binding, Prader, Molinari[31] accurately determined MGS in boys and girls who participated in the First Zürich Longitudinal Growth Study through annual measurements from 24 months to 9 years.

The timing of the MGS was relatively similar in both Portuguese samples (~7.8 years), but the peak was significantly higher in children from Viana do Castelo compared to Azores (6.9 vs 6.2 cm y^{-1}, respectively). Similar values have been identified in Scottish[19] (7.0 years, peak = 6.7 cm y^{-1}), Swiss[31] (7.7 years, peak = 6.4 cm y^{-1}) and US[23] (6.2 years, peak = 6.6 cm y^{-1}) children. On the face of it, we contend that the slight differences of timing and intensity of the MGS may reflect real biological variation, sampling specificities, or the use of distinct mathematical methods to estimate these performance characteristics. It has also been suggested that the MGS is linked to a cascade of hormonal factors,[32] but care must be taken when linking this growth event to adrenarche (the physiological increase of adrenal androgen secretion) in healthy children.[33]

Aside from the small differences in age-at-MGS among groups, we found that spurts in explosive muscular strength and flexibility occurred before or were coincident with age-at-MGS, whereas in abdominal strength and agility they took place at the same time or after age-at MGS. Additionally, in the speed component, Azorean boys' spurts occurred after age-at MGS, whereas in Viana do Castelo had two similar spurts—one before and one after age-at MGS.

Unfortunately, we were unable to locate any other study reporting PF spurts during childhood using biological age as their reference frame,[34-36] which makes it impossible to make any comparisons with the existing literature. In any case, previous chronological age-based results from either cross-sectional or longitudinal data showed successive mean increases, or positive mean differences in all PF components across time, which may suggest that their unfolding may be somewhat synchronous.[34-36] Yet, PF development aligned by age-at-MGS showed a different picture. We can only speculate that the differences in the timing and intensity of spurts may have occurred due to differences in physiological, hormonal, and neuromuscular mechanisms. The difference could also be linked to disparities in the refinement of motor skills and their kinematics.

Previous studies examining the mechanisms associated with explosive muscular strength development, more specifically those involved in the standing long jump (SLJ), have suggested that during childhood, muscular strength is strongly influenced by neuromuscular capacity allowing for rapid production of muscular force. In one such study, Waugh, Korff, Fath, Blazevich[37] showed that age-related increases in tendon stiffness combined with muscle activation rate accounted for 61% of the rate of force development, highlighting the role of both neural and mechanical development of rapid force production during childhood. In line with the above, Fernandez-Santos, Gonzalez-Montesinos, Ruiz, Jiménez-Pavón, Castro-Piñero[38] showed that both the take-off distance and the take-off speed in a kinematic analysis of the standing long jump (SLJ) accounted for most of the variation in the SLJ in children aged 6 to 12 years. It seems that to attain success, children need to develop their levels of proficiency in the coordination of leg and arm action simultaneously.[39] However, although the relationship between these parameters has not been addressed, studies indicate that around 6 and 7 years of age children have the potential to perform SLJ proficiently.[40] More specifically, given that children from 6 to 7 years show proficiency in performing the SLJ in terms of quality of movement this may affect a higher development rate before or coinciding with the MGS. These results agree with previous studies describing a strong relationship between FMS proficiency PF development.[41,42]

In a review of the research related to flexibility, assessed with different tests, Dantas et al[43] reported that this PF component is affected by a set of proprioceptive mechanisms linked with the relationships between bone, muscle, and joint structure. During childhood, the rate of bone growth is not parallel to that of the ligamentous and capsular tissues.[44] A possible explanation for a peak before/coincident and lower spurt change after age-at-MGS might be due to an increase in muscle-tendon tightness over the joint and a faster bone growth compared to muscles growth and stretching capacity.

Speed and agility are components of PF highly dependent on neuromotor mechanisms. Notwithstanding, performance in speed is related to the capacity of the fast-straight sprint and agility involves running and turning (shuttle) at maximum speed.[4] According to Sheppard, Young[45] a better performance in these motor tests depends on physical demands (muscle strength), cognitive processes (motor learning), and technical skills (biomechanics). The development of muscle strength and other physiological functions (eg, myelination) seems to be more closely related to biological age than chronological age. It has also been reported that speed and agility are a product of stride length and frequency.[46] The complexity of these intertwined mechanisms affecting performance in speed and agility linked to the accelerated growth of the body extremities (eg, arms and legs) can act as constraints in the motor developmental process,[47] requiring children to need more time to adapt to changes in body mass and acquire motor competence in certain skills.

For abdominal muscular strength, a neuromotor control of the hip extensors and flexors, pelvis, rectus, trunk, and spinal muscles are expected to occur. A related factor to the expression of muscular strength in children is the development of the nervous system. As the nervous system develops, children tend to improve their postural control.[48] Our results might indicate that these neuromotor demands for abdominal muscular strength may have a spurt coincident/after age-at-MGS and explain higher growth velocity in this component during this period.

In summary, our results illustrate the importance of understanding the intricate relationships between growth, maturation, and PF development during mid-childhood. More specifically, we showed that the MGS is an important biological marker in identifying putative sensitive periods of the development of children's PF. The period between 6 and 10 years of age appears to be a transitive period, marked by a higher degree of plasticity in neuromuscular function, which supports a concurrent development of PF components along with other motor skills coincident with the first spurt in stature. Explosive muscular strength and flexibility spurts occur between twelve months prior to MGS and the attainment of MGS, in contrast, speed, abdominal muscular strength, and agility spurts occur at MGS to 12 months after MGS attainment. Although putative sensitive periods for PF development are usually related to chronological age, future research is expected to scrutinize the combined effects of both chronological and biological age, as well as body size on motor proficiency during middle childhood. These results may heighten sports´ coaches and physical educators' awareness regarding alleged sensitive or windows of opportunity for developing children's PF within a lifespan perspective. Further, physical education teachers and sport coaches need to always consider the intertwined bonds between growth and maturation that shape children's motor development. Thus, a more accurate knowledge regarding the "what," "why," and "when" children are capable, or not, to perform PF tasks in terms of patterned movements and skills, requires a focus on their underlying processes rather than PF results alone. This way such professionals will be more equipped to provide adequate learning environments and conditions linked to children's intra- and inter-individual differences. This in turn will allow for more adequate positive instructional feedback that can impact children's development of healthy trajectories. This study is not without limitations. First, we only focused on apparently healthy and normal growing and developing boys. Second, two different samples from the same country were used (mainland and Azores islands). Although they were not representative of all Portuguese regions, in each study children were randomly and proportionally selected from regional schools and islands. Hence, care must be taken when trying to generalize the results. Further, we also caution readers for putative differences among children of the two regions, although to address this differential issue a completely distinct approach would be required in terms of aims and hypothesis as well as in the statistical analysis, based on the multilevel model, with its manifold testing strategies.

Third, in the same PF components, different tests were used to assess them, but this was contingent on data availability as well as on how each study operationalized their PF assessments. Fourth, we only have assessments of PF at yearly intervals. It is possible that using half-year assessments would provide a more accurate estimation of PF spurts. However, over short intervals of assessment a learning effect in performing each test could occur which makes it difficult to distinguish between the test-retest effects and the true change. In the future, we suggest replicating this study with larger samples including girls to verify if timing and intensity in each spurt are sex-specific. Further, we encourage to also consider lifestyle behaviors (eg, physical activity levels) as well as environmental characteristics (eg, urban *versus* rural samples) to investigate whether differences in spurts' timing and intensity depend on them. Finally, we hearten interested researchers to also include longitudinal data on fundamental movement skills to attest if their putative spurts are coincident, or not, with PF spurts.

5 | PERSPECTIVE

The study findings suggest a mid-growth spurt in stature is observed in boys at ~8 years of age and this is considered an important biological developmental milestone. Moreover, there is an association between the timing of this spurt and peak velocities occurring in different physical fitness components. Motor development programs targeted for children could consider this information. It was found that explosive muscular strength and flexibility developmental spurts occurred before or were coincident with the MGS; spurts in speed, agility, and abdominal muscular strength occurred after or coincident with MGS. Our results suggest that these fitness components can potentially be integrated in physical education and sports programs for children aged 6-8 years given what is now known from evidence-based research. Indeed, physical education teachers and sports coaches should design adequate programs encouraging muscular strength and flexibility development at early ages, that is, before or coincident with children's peak spurt (≤8 years old), as these periods encompass fruitful windows of opportunity for developing these PF components. Furthermore, a variety of motor tasks linking speed, agility, and abdominal muscular strength can also be emphasized after or coincident with the children's peak spurt (≥8 years old) given that it is known that no harm is to be expected in the growing musculo-skeletal system. However, future studies need to explore the impact of such early interventions on children's physical fitness and motor competence.

ACKNOWLEDGEMENTS

We 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, and in the Viana do Castelo study the support from the City Hall. Additionally, we thank Dr Luis Paulo Rodrigues for making the Viana do Castelo data available to us, and we express our gratitude to the anonymous reviewers for their comments and suggestions that substantially improved the paper. Finally, this report is dedicated to the memory of the late Professor Gaston Beunen, Katholieke Universitei Leuven.

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REFERENCES

1. Bouchard C, Shephard RJ. Physical activity, fitness, and health: the model and key concepts. In: Bouchard C, Shephard RJ, Stephens T, eds. *Physical activity, fitness, and health: international proceedings and consensus statement*. Champaign, IL: Human Kinetics Publishers; 1994:77-88.
2. Comeau M, Bouchard D, Levesque C, et al. Association between functional movements skills and health indicators in children aged between 9 and 12 Years Old. *Int J Environ Res Public Health*. 2017;14(9):1010. https://doi.org/10.3390/ijerph14091010
3. Robinson LE. Motor development, a field with a bright future. *Kinesiol Rev*. 2018;7(2):115-122.
4. Malina RM, Bouchard C, Bar-Or O. *Growth, maturation and physical activity*. Champaign, IL: Human Kinetics; 2004.
5. Tanner JM. *Growth at Adolescence*, 5th edn. Oxford: Blackwell Scientific Publications; 1962.
6. Shuttleworth FK. Sexual maturation and the physical growth of girls age six to nineteen. *Monogr Soc Res Child Dev*. 1937;2(5):i-253.
7. Geithner CA, Satake T, Woynarowska B, Malina RM. Adolescent spurts in body dimensions: average and modal sequences. *Am J Hum Biol*. 1999;11(3):287-295.
8. Satake T, Malina RM, Tanaka S, Kikuta F. Individual variation in the sequence of ages at peak velocity in seven body dimensions. *Am J Hum Biol*. 1994;6(3):359-367.
9. Mirwald RL, Bailey DA, Cameron N, Rasmussen RL. Longitudinal comparison of aerobic power in active and inactive boys aged 7.0 to 17.0 years. *Ann Hum Biol*. 1981;8(5):405-414.
10. Carron AV, Bailey DA. Strength development in boys from 10 through 16 years. *Monogr Soc Res Child Dev*. 1974;39(4):1.
11. Beunen G, Malina RM. Growth and physical performance relative to the timing of the adolescent spurt. *Exerc Sport Sci Rev*. 1988;16:503-540.
12. Preece MA, Baines MJ. A new family of mathematical models describing the human growth curve. *Ann Hum Biol*. 1978;5(1):1-24.
13. Karlberg J. A biologically-oriented mathematical model (ICP) for human growth. *Acta Paediatr Scand Suppl*. 1989;350:70-94.
14. Robertson TB. Studies of the growth of man 1. The pre- and post-natal growth of infants. *Am J Physiol*. 1915;37(1):1-42.
15. Butler GE, McKie M, Ratcliffe SG. The cyclical nature of prepubertal growth. *Ann Hum Biol*. 1990;17(3):177-198.
16. Bock RD, du Toit SHC, Thissen D. *AUXAL: Auxological Analysis of Longitudinal Measurements of Human Stature*. Chicago, IL: SSI; 1994.
17. Gasser T, Muller HG, Kohler W, Prader A, Largo R, Molinari L. An analysis of the mid-growth and adolescent spurts of height based on acceleration. *Ann Hum Biol*. 1985;12(2):129-148.
18. Towne B, Williams KD, Blangero J, et al. Presentation, heritability, and genome-wide linkage analysis of the midchildhood growth spurt in healthy children from the Fels Longitudinal Study. *Hum Biol*. 2008;80(6):623-636.
19. Muhl A, Herkner KR, Swoboda W. The mid-growth spurt–a pre-puberty growth spurt. Review of its significance and biological correlations. *Padiatr Padol*. 1992;27(5):119-123.

20. Dos Santos MAM, Baxter-Jones A, Reyes AC, et al. Are there gross motor coordination spurts during mid-childhood? *Am J Hum Biol*. 2019:e23251.
21. Stodden DF, Goodway JD, Langendorfer SJ, et al. A developmental perspective on the role of motor skill competence in physical activity: an emergent relationship. *Quest*. 2008;60(2):290-306.
22. Maia JAR, Lopes VP, Silva RG, et al. Um olhar sobre crianças e jovens da região autónoma dos Açores. *Implicações para a Educação Física, Desporto e saúde*. Porto: DREFD-RAA & FCDEF-UP; 2003.
23. Rodrigues LP, Sá C, Bezerra P, Saraiva L. *Estudo morfofuncional da criança Vianense*. Viana do castelo: Câmara Municipal de Viana do castelo; 2006.
24. Cole TJ. Optimal design for longitudinal studies to estimate pubertal height growth in individuals. *Ann Hum Biol*. 2018;45(4):314-320.
25. FITNESSGRAM. *The Prudencial Fitnessgram Test Administratics Manual*. Dallas, TX: The Cooper Institute for Aerobics Research; 1994.
26. AAHPERD. *The AAHPERD Physical Best Program*. Reston, VA: AAHPERD; 1988.
27. EUROFIT. *Handbook for the Eurofit Tests of Physical Fitness*. Rome: Committee for the Development of Sport, Council of Europe; 1988.
28. Van't Hof MA, Roede MJ, Kowalski CJ. Estimation of growth velocities from individual longitudinal data. *Growth*. 1976;40:217-240.
29. Yagüe PH, La Fuente D, Manuel J. Changes in height and motor performance relative to peak height velocity: a mixed-longitudinal study of Spanish boys and girls. *Am J Hum Biol*. 1998;10(5):647-660.
30. Tanner JM, Cameron N. Investigation of the mid-growth spurt in height, weight and limb circumferences in single-year velocity data from the London, 1966–67 growth survey. *Ann Hum Biol*. 1980;7(6):565-577.
31. Gasser T, Kneip A, Binding A, Prader A, Molinari L. The dynamics of linear growth in distance, velocity and acceleration. *Ann Hum Biol*. 1991;18(3):187-205.
32. Johnston FE. Somatic growth of the infant and preschool child. In: Falkner F, Tanner JM, eds. *Postnatal Growth Neurobiology*. Boston, MA: Springer, US; 1986:3-24.
33. Remer T, Manz F. The midgrowth spurt in healthy children is not caused by adrenarche. *J Clin Endocrinol Metab*. 2001;86(9):4183-4186.
34. Roth A, Schmidt S, Seidel I, Woll A, Bös K. Tracking of physical fitness of primary school children in trier: A 4-year longitudinal study. *Biomed Res Int*. 2018;2018:1-10.
35. Golle K, Muehlbauer T, Wick D, Granacher U. Physical fitness percentiles of German children aged 9–12 years: findings from a longitudinal study. *PLoS One*. 2015;10(11):e0142393.
36. Rodrigues LP, Leitão R, Lopes VP. Physical fitness predicts adiposity longitudinal changes over childhood and adolescence. *J Sci Med Sport*. 2013;16(2):118-123.
37. Waugh CM, Korff T, Fath F, Blazevich AJ. Rapid force production in children and adults: mechanical and neural contributions. *Med Sci Sports Exerc*. 2013;45(4):762-771.
38. Fernandez-Santos JR, Gonzalez-Montesinos JL, Ruiz JR, Jiménez-Pavón D, Castro-Piñero J. Kinematic analysis of the standing long jump in children 6- to 12-years-old. *Meas Phys Educ Exerc Sci*. 2018;22(1):70-78.
39. Haywood NM, Getchell N. *Life Span Motor Development*, 5th edn. Champaign, IL: Human Kinetics; 2009.
40. Branta C, Haubenstricker J, Seefeldt V. Age changes in motor skills during childhood and adolescence. *Exerc Sport Sci Rev*. 1984;12:467-520.
41. Stodden D, Langendorfer S, Roberton MA. The association between motor skill competence and physical fitness in young adults. *Res Q Exerc Sport*. 2009;80(2):223-229.
42. Stodden DF, Gao Z, Goodway JD, Langendorfer SJ. Dynamic relationships between motor skill competence and health-related fitness in youth. *Pediatr Exerc Sci*. 2014;26(3):231-241.
43. Dantas E, Daoud R, Trott A, Nodari R, Conceição M. Flexibility: components, proprioceptive mechanisms and methods. *Biomed Hum Kinet*. 2011;3:39-43.
44. Alter MJ. *Science of flexibility*. Champaign, IL: Human Kinetics; 1996.
45. Sheppard JM, Young WB. Agility literature review: classifications, training and testing. *J Sports Sci*. 2006;24(9):919-932.
46. Mero A, Komi PV, Gregor RJ. Biomechanics of sprint running. *Sports Med*. 1992;13(6):376-392.
47. Newell KM. Coordination, control and skill. In: Goodman D, Wilberg RB, Franks IM, eds. *Advances in Psychology*, vol. 27. North-Holland; 1985:295-317.
48. Sa C, Boffino CC, Ramos RT, Tanaka C. Development of postural control and maturation of sensory systems in children of different ages a cross-sectional study. *Braz J Phys Ther*. 2018;22(1):70-76.

How to cite this article: Pereira S, Garbeloto F, Guimarães E, et al. Physical fitness spurts in childhood: A study in boys. *Scand J Med Sci Sports*. 2021;31(Suppl. 1):47–55. https://doi.org/10.1111/sms.13800