SPEED AGILITY TRENDS IN CHILDREN ACCORDING TO GROWTH

New approach to assess speed-agility in children

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ABSTRACT

Background: Speed agility is considered as the whole assessment of speed of movement, agility and coordination. The 10x4m test has been broadly used to evaluate physical fitness

and overall health in children of developmental ages. A myriad of studies have investigated the ecology of speed-agility (SA). However, body dimensions are rarely appraised, and this is a weakness because body shapes are affected by growth.

Aim: This study aimed to model SA-specific allometric equations, and develop an approach objectively predictive for performance while controlling for maturity through age at peak height velocity (agePHV).

Subjects and methods: A total of 7317 (3627 girls) children aged 8–11 years were SA-tested. Multiplicative models with allometric body-size components, agePHV, and categorical differences, were implemented to evaluate SA performance.

Results: Model 1 accounted for body-size and shape only, whereas Model 2 included agePHV and Model 3 considered standing broad jump (SBJ) as a surrogate marker for explosive strength. An ectomorphic dominance was revealed across all the models.

Conclusion: The explosive strength resulted in influencing SA per height-to-weight ratio. Further, positive exponent of agePHV suggested that the late maturers were likely to show better SA performances. Predictive equations modelled on developmental factors are fundamental to scrutinise performances as valuable health and fitness outcomes in childhood.

Keywords: allometry, 4 × 10-m shuttle run test, children coordination, growth, speed-agility

Introduction

Physical fitness is a major health factor in children (Ortega et al. 2015a; Ruiz et al. 2011), and it is positively associated with present and future health-related outcomes such as risk for obesity, cardiovascular disease, skeletal health and mental health (Castro-Piñero et al. 2010; Ortega et al., 2008). Cardiorespiratory endurance and muscular strength are often referred to as health-related fitness and are usually associated with disease prevention and health promotion (Howley 2001). Conversely, balance, coordination, and speed-agility (SA) are described as

markers of physical fitness associated with enhanced performance in sports and motor skills (Howley, 2001). In particular, speed relates to the ability to perform a movement within a short period; agility relates to the ability to rapidly and accurately change the position/direction of the entire body in response to a stimulus. Balance involves the maintenance of equilibrium while stationary or moving (Haga 2008; Lubans et al. 2010).

In this framework, the physical fitness field test has become a useful and ecological tool to enforce health surveillance and monitor one's fitness status and behaviour (Ortega et al. 2015b; Giuriato et al. 2019).

In particular, the assessment of SA performance is strongly coupled to health (especially bone health) in young people (Ortega et al. 2008) and contributes to improve individual motor skills competence (Schmidt & Lee, 2005; Palou et al., 2019). Several studies claimed the reliability and validity of the 4x10 m shuttle-run test to measure SA in childhood using sponges to improve coordination (Ortega, et al. 2008; Ortega et al. 2015b; Sheppard & Young, 2006). The nervous system develops considerably in children from eight to ten (Malina & Bouchard, 1994), especially via an exercise-elicited cascade of neurological changes in the hippocampus, enhancing memory consolidation and skilled actions. In particular, short-term physical activity bouts selectively improve children's cognitive performance such as speed and accuracy (Donnelly et al. 2016).

For this reason, several youth fitness batteries (Castro-Piñero et al. 2010; Ortega, Artero, et al. 2008; Ruiz et al. 2011) have included SA evaluation from early childhood. From these studies, normative values for children and adolescents were created, suggesting that 50th percentiles could represent a valuable reference to properly establish the level of performance. Nevertheless, these batteries seemed to have some limitations. For example, with regards to the 4x10 m shuttle run test, Kolimechkov et al. (2019) showed a mean reduction of 0.4 s between 8 and 9 years, and 0.3 s between 10 and 11 years in girls, and a mean reduction of 0.5

s between 9 to 11 years in boys. This stratification would help primary surveillance (Lovecchio et al., 2019; Lovecchio et al., 2020; Tomkinson et al., 2007; Valarani et al., 2020). However, it would not be as accurate as needed for training evaluation or developmental analysis. Childhood is a crucial age in which 4x10 m shuttle run performance increases slowly, approximately by 1.5-2% per year (Kolimechkov et al., 2019). Moreover, at the age of 8-11, children's performance in agility tests depends on body mass and height (Id et al. 2020) but not on the index summarising these two variables (i.e. body mass index; BMI); therefore, BMI cannot be considered as an accurate indicator of the actual performance (Lovecchio et al., 2019a; Giuriato et al., 2020). Indeed, growth has a misaligned pattern (Gonzalez et al., 2017): height increases by 3-4% per year and mass by 8-10% (Cole and Lobstein, 2012). Furthermore, the traditional ratio of speed/body mass, commonly accepted to scale for body mass, frequently produces artefacts, being a body dimensionless index (Welsman & Armstrong, 2008; Welsman, 2019). The stratification of performance according to social condition (Lovecchio et al., 2015) or BMI categories (Lovecchio & Zago, 2019) could be an alternative. However, this would result in a non-robust analysis due to performance variations during growth phases (Armstrong & Welsman, 2019; Van Praagh & Doré; 2002). Some studies have attempted to model the development of various athletic characteristics, including maturation and anthropometry (non-linear relationship; Carnevale Pellino et al., 2020; Towlson et al., 2018) applying classic polynomial regression models. However, these analytical approaches do not necessarily consider transition points in the maturity-physicality relationship, and the regression parameters are not directly interpretable (Towlson et al., 2017). To overcome these pitfalls it is necessary to scale for actual maturity differences and determine the role of body size (allometric model) on performance (Doré et al. 2005). Indeed, scaling aims to produce a "size free" variable (Meylan et al., 2014).

In this framework, a polynomial model might appraise each component of maturation: body size, structure or composition (Nevill et al., 2009). In light of this, allometric analysis becomes the most appropriate approach since it is the best method of scaling when physical outcomes are assessed during growth (Bustamante et al., 2015; Cunha et al., 2011; Meylan et al., 2014; Nevill et al., 2009; dos Santos et al., 2016; Valente-dos-Santos et al., 2014). Further, some authors applied scaling methods when dealing with SA (Negra et al., 2014; Silva et al., 2016; Bustamante Valdivia et al., 2015).

Additionally, the evaluation process should also account for the "age-distance" (at the peak of maturity). Predicted maturity offset is defined as the time before or after peak height velocity (PHV). PHV influences speed and power results throughout growth (Giuriato et al., 2020). While the strength outcome depends on the physiological determinants' developmental stage, the peak of strength corresponds to PHV. Particularly, absolute values of specific "strength actions", such as jumping, are differently positioned into the peak-performance-velocity curves of PHV (Beunen & Malina, 1988; Sherar et al., 2005). For all these reasons, it is crucial to control maturity (Mirwald et al., 2002). Thus, this study aims at determining the ideal body shape and allometric equations to assess SA performance assessment in children of different height, mass, sex, age, maturity and strength of lower limb. Predictive equations will enact an accurate and robust surveillance, adjusted according to paediatric developmental stages, in children aged 8-11.

Subjects and methods

Participants and study design

This cross-sectional study involved a total of 7317 (3627 girls) children aged 8–11 years recruited from 37 North East Italian primary schools (368 classes from third, fourth, and fifth grades). Descriptive statistics in table 1. Children with known chronic cardiac, respiratory,

neurological, or musculoskeletal disease were not recruited. All the described measures were taken during the regular Physical Education lessons at school (8.00-12.00 AM). The study protocol, including each feature of the experimental design, was approved by the schools' ethical board in accordance with the "World Medical Association Declaration of Helsinki" as revised in 1983.

Procedure

Data collection included demographic/anthropometric information (gender, age, mass, height) measured before the test sessions using standardised techniques and are shown in Table 1. Height was measured using a portable stadiometer with a precision of ± 1mm (Stadiometer Seca 213, Intermed S.r.l. Milan, Italy), with children in an upright position, bare feet placed slightly apart, arms extended, and head positioned in the Frankfort plane. Body mass was assessed using a beam scale with a precision of ± 100g (Seca 813, Intermed S.r.l. Milan, Italy), with children in light clothing, without shoes, and stood upright in the centre of the platform of the mass scale. We calculated the age of the children from the birth date and subsequently rounded down values.

The SA was evaluated using the 4 × 10 m shuttle run test (Oja & Jurimae; 1997; Niederer et al., 2011). This test consisted of running and turning as fast as possible between two parallel lines (10 m apart), where children had to exchange sponges when crossing the lines (4 times × 10 m) (Ortega et al., 2008). The result was measured with a stopwatch (Kalenjy, Onstart 710, Lille, France) to the nearest 0.1 s by a trained rater (Vicente-Rodríguez et al., 2011). The best of two attempts was recorded in seconds. A higher score indicated a worse performance. Before starting the test, evaluators performed an example to ensure that the children understood the test correctly.

The explosive leg strength of the children was measured by a standing broad jump (SBJ) test: a practical, time-efficient and low cost field-test widely adopted in the school or gym context (Lovecchio et al., 2019b; Lovecchio & Zago, 2019; Ruiz et al., 2011; Tomkinson et al., 2007). Every child jumped for distance from a standstill. During the jumps performance, the children were asked to bend their knees with their arms in front of them, parallel to the ground, then swing both arms, push off vigorously and jump as far as possible. The test was performed three times, scored in centimetres, and the best value was recorded. The score was obtained by measuring the distance between the last heel-mark and the take-off (Ortega et al., 2015). Fitness assessment was performed twice so systematic error was nearly null for both tests (Ortega et al., 2008).

In particular, all tests were conducted by a team of ten tutors of the Sport Science Faculty during the scheduled Physical Education classes. The presence and collaboration of the curricular Physical Education teachers were guaranteed at any time to meet the confidence of the students (Ceccarelli et al., 2020).

Data analysis

The biological maturation (MO) was estimated through the somatic maturation method proposed by Moore et al. (2015). This formula was chosen for the low number of measurements (age, height), minimising bias.

This method estimates MO from stature and chronological age using an algorithm, providing the result offset in years to peak height velocity (PHV). In brief, the MO was determined using a specific formula for girls and boys:

$$\text{Maturity offset for girls (years)} = -7.709133 + (0.0042232 \times (\text{age} \times \text{height}))$$

$$\text{Maturity offset for boys (years)} = -7.999994 + (0.0036124 \times (\text{age} \times \text{height}))$$

Then, the age of PHV (agePHV) was determined by subtracting the maturity offset from the chronological age. Participants were classified as late, early, or on-time through the one standard deviation from the mean of ~~SD method derived from~~ the current sample.

Statistical Methods

The multiplicative model with allometric body-size components of body mass (M) and height (H), was used to identify the most appropriate body size and shape characteristics (Eq.1) associated with the physical performance variable SA (4x10m). The model is similar to that used to predict Greek children's physical performance variables (Nevill et al., 2009).

$$Y = a \cdot M^{k1} \cdot H^{k2} \cdot \varepsilon \quad (1)$$

The model (Model 1) has the advantage of having proportional body size components and a multiplicative error that assumes, ε will increase proportionally with the physical performance variable Y (see Figure 1a, b). The model (Eq.1) can be expanded to incorporate maturity (using AgePHV) (reported as Model 2) plus leg strength (SBJ test) (reported as Model 3) , and categorical differences (e.g., sex, age),incorporated as fixed factors, in the physical performance variable SA.

$$Y = a \cdot M^{k1} \cdot H^{k2}\, SBJ^{k3} \cdot \exp(b \,.\, agePHV) \,.\, \varepsilon \quad (2)$$

The model (Eq. 2) can be linearized with a log transformation (Eq.3). A linear regression analysis or analysis of covariance (ANCOVA) on Ln(Y) (note that $Ln=\log_e$) can then be used to estimate the unknown parameters of the log-transformed model:

$$Ln(Y)= Ln(a) + k1 \cdot Ln(M)+k2 \cdot Ln(H) +k3 \cdot Ln(SBJ)+ b \cdot agePHV + Ln(\varepsilon) \quad \text{(Eq. 3)}$$

Other categorical differences within the population, e.g. sex orage, can be explored by allowing the constant intercept parameter 'Ln(a)' to vary for each group by introducing them as fixed factors (plus possible interactions) within an ANCOVA (note that the terms Ln(M), Ln(H), Ln(SBJ) and agePHV in Eq. 3 are the covariates used in the ANCOVA). The significance level was set at $P<0.05$.

****Figure 1a near here****

****Figure 1b near here****

Results

Descriptive statistics for all subjects are reported in Table 1.

Speed agility 4x10m test (Model 1)

Agility performance expressed through the 4x10m test revealed a mean value (SD) of 13.69 sec (1.62) and 14.18 sec (1.49) for boys and girls, respectively.

The estimated parameters from the multiplicative model relating log-transformed 4x10m SA to the body-size components in Eq.1 (Model 1), are given in Table 2a.

****Table 2a near here****

The model 1 (Eq.1) relating the 4x10m Speed Agility to the body-size components was:

$$\text{Speed Agility (m.sec}^{-1}) = a \cdot M^{-0.178} \cdot H^{0.583}$$

These exponents suggest the optimal body-shape associated with 4x10m SA is to be taller (H exponent=0.583) but with lighter body mass (M exponent=-0.178), that is a subject with an ectomorphic body shape.

Fitting Model 1 (Eq.1) revealed significant differences in the constant 'a' parameter (table 2a) due to sex (P<0.001), and age (P<0.001) but with a non-significant age x sex (P= .320) interaction (Figure 2a).

****Figure 2a here****

Speed agility 4x10m test incorporating Age at PHV (Model 2)

The estimated parameters from the multiplicative model relating log-transformed 4x10m SA to the body-size components in Eq.2, incorporating AgePHV, are given in Table 2b.

****Table 2b near here****

The model 2 (Eq.2) relating the 4x10m speed agility to the body-size components was:

$$\text{Speed agility (m.sec}^{-1}) = a \cdot M^{-0.174} \cdot H^{1.03} \cdot \exp(0.104 \cdot \text{agePHV})$$

The model suggests the optimal body-shape associated with 4x10m is to be taller (1.03) but with lighter body mass (-0.174), indicating a subject that tends to have an ectomorphic body shape. The model also identified that having an older agePHV (0.104) or being a late maturer is also associated with faster SA.

Fitting Model (Eq.2) revealed significant differences in the constant 'a' parameter (table 2b) due to sex (P<0.001) and age (P<0.001), together with a significant interaction for age x sex (P=0.002). No interaction between sex x agePHV was found (P= 0.310) (Figure 2b).

****Figure 2b here****

Speed agility 4x10m test incorporating SBJ (surrogate for Leg Strength) (Model 3)

The estimated parameters from the multiplicative model relating log-transformed 4x10m speed agility to the body-size components in Eq.1, incorporating agePHV and lower limb strength through the SBJ test, are given in Table 2c.

****Table 2c near here****

The model 3 (Eq.2) relating the 4x10m speed agility to the body-size components was:

$$\text{Speed agility (m.sec}^{-1}) = a \cdot M^{-0.047} \cdot H^{0.317}\ SBJ^{0.342} \cdot \exp(0.048 \cdot \text{agePHV})$$

The model suggests the optimal body-shape associated with 4x10m SA is to be tall (0.317) and with a low body mass (-0.047), indicating a subject that tends to have an ectomorphic body shape. The model also identified that having an older agePHV (0.048) i.e., being a late mature and having a greater lower limb strength SBJ (0.342) is also associated with faster SA.

Fitting Model 3 (Eq.2) revealed significant differences in the constant 'a' parameter (table 2c) due to sex (P<0.001) and age (P<0.001), together with a non-significant interaction for age x sex (P= .757), AgePHV (p<.001). No interaction between sex x agePHV was found (P= 0.718) (Figure 2c).

****Figure 2c here****

Discussion

An allometric modelling approach was used to identify and analyse optimal body size and shape characteristics associated with the SA test (4x10m). Generally, boys outperformed girls at all ages, not only in absolute terms but also when adjusting for body size/shape and agePHV. The results of the current study are aligned with Nevill et al, (2021), in which performance was not significantly associated with PHV, and was negative in girls. Consistently, in our study, a negative parameter *b* in female x agePHV (see Table 2 b,c), indicated that girls'performances

in speed agility were worse than males when adjusted per maturity state. Furthermore, no agePHV x sex interaction (see model 2 b,c) was registered, revealing a large variability in the performance. Moreover, the trend is contrary in other types of performance (i.e. explosive strength; Lovecchio et al, 2019a), in which girls outperformed boys.

In Model 1, through parameter *b* of Height and Mass, it was found that the height-to-body mass ratio fitted the optimal relationship between SA performance and body shape. Considering that the exponent of height was positive (.58), while the one of mass was negative (-.17), a tendency to an ectomorphic body shape could be inferred. In line with these pieces of evidence, Valente-dos-Santos (2014) reported that agility performance based on multilevel models indicated that as much as a 1-kg increase in fat-free mass was associated with improved agility performance by 5%. These findings were obtained when body size, body composition and skeletal age were controlled in 10-to 18-year-old boys. Morerover, the positive exponents in height in Model 1, 2, and 3, are in line with Nevill et al, (2021), who found similar results (i.e. positive height exponent) in sprint speed, jump, and change of direction performance, highlighting that the successful body size/shape in these tests was to be tall and lightweight. By including agePHV in the model, the tendency to ectomorphic body shape was confirmed. Furthermore, agePHV influenced the performance in the SA test (Figure 2b). In the third model, a measure of lower limb strength (SBJ) was incorporated in addition to agePHV. As a result, this expression of strength changed the trend of SA (Figure 2c). The ratio of trunk length to leg length can also potentially influence motor performance, accounting for individual differences in sprinting speed (Dintiman and Ward, 2011). This could explain our findings concerning body shape associated with SA. On the other hand, the low variance (~21%) of the SA performance remained unchanged despite maturity, suggesting it to be an independent factor. In this view, Nevill et al, (2021), found no significant interaction between SA test (Illinois agility test) and PHV, confirming (as the present results) that late maturers perform better in drills with change

of direction (SA test) (See table 2c). Furthermore, once lower limb strength was added to the model, the variance increased (up to ~48%). Agility performance is complex and is affected by several factors. Jeffreys et al. (2011) stated that the agility expression limits are mainly due to three factors: organismic, tasks, and environmental. Sheppard and Young (2006) reported that SA and change of direction performances foresee physical demands (strength and conditioning), cognitive processes (motor learning) and technical skills (biomechanics). This multifactorial performance could be at the origin of the explanation of our study results, underlining that late maturers, with a low centre of grativity, are favoured in such trails. Figueiredo et al. (2009), through a cross-sectional study based on multiple linear regressions models, indicated that chronological age and stature positively affected SA performance while adiposity was a neg-effector, accounting for 34% of the variance in the shuttle run test in subjects aged 11–12 years. This variance, after that, decreased to 24% for adolescents of 13–14 years. Also, resistance training had a small effect on linear sprint performance and SA. The lower outcomes might be justified by the complex nature of these qualities, with various determinants contributing to the performance level (Lesisnski et al., 2016). Agility depends on perceptual factors and rapid changes of direction, which is again influenced by movement technique, leg muscle quality and straight sprinting speed (Young et al., 2002). Furthermore, muscle strength seemed to be the sole factor contributing to agility.

In Model 3, including agePHV and SBJ, maturity positively influenced speed agility performance through chronological age. Thus, later maturing youth appeared to perform better in SA. These results could be crucial in research of talent, suggesting that agility should be assessed during adolescence as a surrogate marker of strength spurs. SBJ values were positively associated with SA performance, implying that increases in explosive strength and maturity are responsible for improved SA performance. Furthermore, the results confirmed that being tall

and linear (ectomorphic body shape), could be predictive of the performance in change of direction and SA.

Lastly, by including strength performance, the *r* squared variance increased at .485, proposing lower limb strength as a determinant factor for the agility performance.

Conclusion

In boys and girls aged 8-11, the optimal body shape for agility performance tended to be ectomorphic, pointing toward low fat mass as a positive effector. Scouting and coaching should focus on late maturers, especially when SA and change of direction are fundamental in a sports discipline. Furthermore, the expression of lower limb strength affected agility. In this perspective, the developed models including height, mass (first model) and agePHV (second model) described a trend fitting parallel to strength expression. This study may provide valid inference when investigating group differences, especially regarding maturity state.

References

Bustamante Valdivia, A., J. Maia, and A. Nevill. 2015. "Identifying the Ideal Body Size and Shape Characteristics Associated with Children's Physical Performance Tests in Peru." Scandinavian Journal of Medicine & Science in Sports 25(2): e155–65.

Castro-Piñero, J. et al. 2010. "Criterion-Related Validity of Field-Based Fitness Tests in Youth: A Systematic Review." British Journal of Sports Medicine 44(13): 934–43.

Ceccarelli, Gabriele et al. 2020. "BMI and Inverted BMI as Predictors of Fat Mass in Young People: A Comparison across the Ages." Annals of Human Biology: 1–7.

Cole, T. J., and T. Lobstein. 2012. "Extended International (IOTF) Body Mass Index Cut-Offs for Thinness, Overweight and Obesity." Pediatric Obesity 7(4): 284–94.

Cunha, Giovani et al. 2011. "Effect of Biological Maturation on Maximal Oxygen Uptake and Ventilatory Thresholds in Soccer Players: An Allometric Approach." Journal of Sports Sciences 29(10): 1029–39.

Donnelly, Joseph E et al. 2016. 48 Med Sci Sport Exerc Atividade Física, Aptidão, Função Cognitiva e Conquista Acadêmica Em Crianças: Uma Revisão Sistemática.

Doré, E. et al. 2005. "Gender Differences in Peak Muscle Performance during Growth." International Journal of Sports Medicine 26(4): 274–80.

Giuriato, M, Lovecchio N, Fugiel J, Lopez-Sanchez G.F., Pihu M, Emeljanovas A. 2020. Enjoyment and Self-Reported Physical Competence According to BMI: International Study in European Primary School Children. 60 (7):1049-55.

Giuriato M, Pugliese L, Biino V, Bertinato L, La Torre A, Lovecchio N. Association between motor coordination, body-mass index, and sports participation in children 6-11 years old. Sport Science for Health, 15 (1): 463-468; 2019

Malina RM, Bouchard C, Bar-Or O. Growth, Maturation, and Physical Activity. Human Kinetics; 2th edition, 2003

Haga, M. 2008. "The Relationship between Physical Fitness and Motor Competence in Children." Child: Care, Health and Development 34(3): 329–34.

Howley, E. T. 2001. "Type of Activity: Resistance, Aerobic and Leisure versus Occupational Physical Activity." Med Sci Sports Exerc. 33(6 Suppl):S364-9; discussion S419-20.

Fiori F, Bravo G, Parpinel M, Messina G, Malavolta R, Lazzer S (2020) Relationship between body mass index and physical fitness in Italian prepubertal schoolchildren. PLoS ONE 15(5): e0233362.

Kolimechkov S,Petrov L, Alexandrova A. 2019. Alpha-Fit Test Battery Norms for Children and Adolescents from 5 to 18 Years of Age Obtained by a Linear Interpolation of Existing European Physical Fitness References. European Journal of Physical Education and Sport Science 5(4): 1–14.

Lovecchio, Nicola et al. 2015. "Urban and Rural Fitness Level: Comparison between Italian and Croatian Students." Perceptual and Motor Skills 120(2): 367–80.

Lovecchio N, Novak D, Sedlacek J, Hamar P, Milanovic I, Radisavljevic-Janic S, Emeljanovas A, Eid L, Zago M Physical fitness for sedentary students: a common trend from six European countries. J Sports Med Phys Fitness. 2019b; 59(8):1389-1396.

Lovecchio, Nicola, Matteo Giuriato, Matteo Zago, and Alan Nevill. 2019a. "Identifying the Optimal Body Shape and Composition Associated with Strength Outcomes in Children and Adolescent According to Place of Residence: An Allometric Approach." Journal of Sports Sciences 37(12): 1434–41.

Lovecchio, Nicola, and Matteo Zago. 2019. "Fitness Differences According to BMI Categories: A New Point of View." The Journal of Sports Medicine and Physical Fitness 59(2): 298–303.

Lubans, David R. et al. 2010. "Fundamental Movement Skills in Children and Adolescents: Review of Associated Health Benefits." Sports Medicine 40(12): 1019–35.

Meylan, César M. P., John B. Cronin, Jon L. Oliver, and Michael C. Rumpf. 2014. "Sex-Related Differences in Explosive Actions During Late Childhood." Journal of Strength and Conditioning Research 28(8): 2097–2104.

Meylan, Cesar Marius, John Cronin, Will G. Hopkins, and Jonathan Oliver. 2014. "Adjustment of Measures of Strength and Power in Youth Male Athletes Differing in Body Mass and Maturation." Pediatric Exercise Science 26(1): 41–48.

Mirwald, Robert L., Adam D.G. Baxter-Jones, Donald A. Bailey, and Gaston P. Beunen. 2002. "An Assessment of Maturity from Anthropometric Measurements." Medicine and Science in Sports and Exercise 34(4): 689–94.

Moore, S. A., McKay, H. A., Macdonald, H., Nettlefold, L., Baxter-Jones, A. D. G., Cameron, N., & Brasher, P. M. A. (2015). Enhancing a somatic maturity prediction model. Medicine and Science in Sports and Exercise, 47(8), 1755–1764

Negra, Y., Chaabène, H., Hammami, M., Khlifa, R., Gabbett, T., & Hachana, Y. (2016). Allometric scaling and age-related differences in change of direction speed performances of young soccer players. Science & Sports, 31(2), e19-e26.

Nevill, A, Tsiotra G, Tsimeas P, and Koutedakis Y. 2009. "Allometric Associations between Body Size, Shape, and Physical Performance of Greek Children." Pediatric Exercise Science 21(2): 220–32.

Nevill AM, Negra Y, Myers TD, Duncan MJ, Chaabene H, Granacher U. Are Early or Late Maturers Likely to Be Fitter in the General Population?. Int J Environ Res Public Health. 2021;18(2):497. Published 2021 Jan 9. doi:10.3390/ijerph18020497

Ortega FB, Artero EG, Ruiz JR, et al. Reliability of health-related physical fitness tests in European adolescents. The HELENA Study. Int J Obes (Lond). 2008;32 Suppl 5:S49-S57.

Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: a powerful marker of health. Int J Obes (Lond). 2008;32(1):1-11.

Ortega FB, Cadenas-Sánchez C, Sánchez-Delgado G, et al. Systematic review and proposal of a field-based physical fitness-test battery in preschool children: the PREFIT battery. Sports Med. 2015;45(4):533-555.

Ruiz JR, Castro-Piñero J, España-Romero V, et al. Field-based fitness assessment in young people: the ALPHA health-related fitness test battery for children and adolescents. Br J Sports Med. 2011;45(6):518-524.

Dos Santos FK, Nevill A, Gomes TN, et al. Differences in motor performance between children and adolescents in Mozambique and Portugal: impact of allometric scaling. Ann Hum Biol. 2016;43(3):191-200.

Tomkinson GR, Olds TS, Borms J. Who are the Eurofittest? Med Sport Sci. 2007;50:104-128

Towlson, C., S. Cobley, G. Parkin, and R. Lovell. 2018. "When Does the Influence of Maturation on Anthropometric and Physical Fitness Characteristics Increase and Subside?" Scandinavian Journal of Medicine and Science in Sports 28(8): 1946–55.

Towlson, Chris et al. 2017. "Relative Age, Maturation and Physical Biases on Position Allocation in Elite-Youth Soccer." International Journal of Sports Medicine 38(3): 201–9.

Vicente-Rodríguez, Germán et al. 2011. "Interrater Reliability and Time Measurement Validity of Speed-Agility Field Tests in Adolescents." Journal of Strength and Conditioning Research 25(7): 2059–63.

Welsman, JR, N Armstrong - Paediatric, and undefined 2008. "Interpreting Exercise Performance Data in Relation to Body Size." Oxford University Press Oxford, UK.

Young WB, James R, Montgomery I. Is muscle power related to running speed with changes of direction? J Sports Med Phys Fitness 2002;42:282–8.

Jeffreys I. A Task-Based Approach to Developing Context-Specific Agility. Strength and conditioning journal 2011, 33(4):52-59

Lesinski M, Prieske O, Granacher U. Effects and dose-response relationships of resistance training on physical performance in youth athletes: a systematic review and meta-analysis. Br J Sports Med. 2016;50(13):781-795.

Figueiredo A J , Goncalves C E , Coelho-e-Silva M J , Malina R M . Youth soccer players, 11-14 years: maturity, size, function, skill and goal orientation Ann Hum Biol 2009 ; 36 : 60 – 73)

Valente-dos-Santos J, Coelho-e-Silva MJ, Duarte J, et al. Allometric multilevel modelling of agility and dribbling speed by skeletal age and playing position in youth soccer players. Int J Sports Med. 2014;35(9):762-771.

Dintiman G and Ward R. Encyclopedia of sport speed. Kill Devil Hills, NC: The National Association of Speed And Explosion, 2011

Schmidt RA and Lee TD, Motor control and Learning, Human Kinetics; 2005

Sheppard JM, Young WB. Agility literature review: classifications, training and testing. J Sports Sci. 2006Sep;24(9):919-32.

Sherar LB, Mirwald RL, Baxter-Jones AD, Thomis M. Prediction of adult height using maturity-based cumulative height velocity curves. J Pediatr. 2005;147(4):508-514.

Silva, S., Bustamante, A., Nevill, A., Katzmarzyk, P. T., Freitas, D., Prista, A., & Maia, J. (2016). An Allometric Modelling Approach to Identify the Optimal Body Shape Associated with, and Differences between Brazilian and Peruvian Youth Motor Performance. PloS one, 11(3), e0149493.

Valarani F, Giuriato M, Puci MV, Vandoni M, Codella R, Lovecchio N. Cardiorespiratory fitness assessment using the PREFIT test in Italian children: a preliminary dataset. J Sports Med Phys Fitness. 2020 May;60(5):709-712

Palou, P., Muntaner-Mas, A., Cantallops, J., Borràs, P. A., Labayen, I., Jiménez-Pavón, D., Dorado García, C., Moliner-Urdiales, D., Rodríguez Pérez, M. A., Rojo-Tirado, M. A., Cadenas-Sanchez, C., Ortega, F. B., & Vidal-Conti, J. (2019). A Single Question of Parent-Reported Physical Activity Levels Estimates Objectively Measured Physical Fitness and Body Composition in Preschool Children: The PREFIT Project. Frontiers in psychology, 10, 1585.

Giuriato M, Nevill A, Kawczynski A, Lovecchio N. Body size and shape characteristics for Cooper's 12 minutes run test in 11-13 years old Caucasian children: an allometric approach. J Sports Med Phys Fitness. 2020 Mar;60(3):417-421

Gonzalez MC, Correia M, Heymsfield SB. 2017. A requiem for BMI in the clinical setting. Curr Opin Clin Nutr Metab Care 20(5):314–321

Armstrong, N and Welsman, J. Sex-Specific Longitudinal Modeling of Short-Term Power in 11- to 18-Year-Olds. Med Sci Sports Exerc 51: 1055–1063, 2019.

Van Praagh, E and Doré, E. Short-term muscle power during growth and maturation. Sport. Med. 32: 701–728, 2002.

Welsman J. Reflecting on Field Performance Tests of Pediatric Aerobic Fitness: After 30 Years, It Really Is Time to Move on. Pediatr Exerc Sci. 2019 May 1;31(2):191-193

Oja L, Jurimae T. Assessment of motor ability of 4- and 5-year- old children. Am J Hum Biol. 1997;9(5):659–64.

Niederer I, Kriemler S, Gut J, et al. Relationship of aerobic fitness and motor skills with memory and attention in preschoolers (Ballabeina): a cross-sectional and longitudinal study. BMC Pediatr. 2011;11:34.

Lovecchio N, Giuriato M, Carnevale Pellino V, Valarani F, Codella R, Vandoni M. Italian Physical Fitness Decline: A True Fact or a Mindset? A 10-Year Observational Perspective Study. Int J Environ Res Public Health. 2020; 30;17(21):8008

Carnevale Pellino V, Giuriato M, Ceccarelli G, Codella R, Vandoni M, Lovecchio N, Nevill AM. Explosive Strength Modeling in Children: Trends According to Growth and Prediction Equation. Applied Sciences. 2020; 10(18):6430.

579 Table 1. Descriptive statics (Mean ± SD) per sex (girls, boys) and years (8-11).
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	Age (years)	n	Height (cm)	Body mass (kg)	4x10m (sec)
Girls	**8**	799	127.76 5.80	27.70 5.58	14.91 1.49
	9	1060	133.59 6.40	31.39 7.14	14.46 1.43
	10	1199	144.51 7.49	39.00 8.85	13.48 1.21
	11	757	140.19 6.75	36.21 7.78	13.85 1.31
Boys	8	932	128.97 6.02	29.02 6.27	14.44 1.56
	9	1131	134.39 6.17	32.15 6.44	13.91 1.64
	10	1184	139.72 6.28	36.31 8.05	13.34 1.38
	11	725	143.82 6.45	39.20 8.74	12.89 1.38

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Table 2a. The estimated parameters from the multiplicative model relating log transformed 4x10m agility speed (Ln(Speed Agility)) to the body-size components in Eq.1 (Model 1).

Parameters	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	-1.109	0.144	-7.674	0.000	-1.392	-0.825
LnMass (k1)	-0.178	0.007	-24.018	0.000	-0.192	-0.163
LnHeight (k2)	0.583	0.033	17.900	0.000	0.519	0.646
Sex (Girls)	-0.049	0.005	-9.643	0.000	-0.059	-0.039
Years (8.0)	-0.103	0.005	-18.668	0.000	-0.113	-0.092
Years (9.0)	-0.070	0.005	-14.219	0.000	-0.080	-0.060
Years (10.0)	-0.031	0.005	-6.597	0.000	-0.040	-0.022

Boys (age 11) are taken as the reference/baseline group from which girls and other age groups are compared.

Table 2b. The estimated parameters from the multiplicative model relating log transformed 4x10m agility speed (Ln(Speed Agility)) to the body-size components and agePHV in Eq.2 (Model 2)

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	-4,722	0.317	-14.875	0.000	-5.345	-4.100
LnMass (k1)	-0.174	0.007	-23.780	0.000	-0.189	-0.160
LnHeight (k2)	1.030	0.048	21.619	0.000	0.937	1.124
Sex (Girls)	0.082	0.011	7.165	0.000	0.060	0.104
Years (8.0)	0.041	0.013	3.309	0.001	0.017	0.066
Years (9.0)	0.021	0.009	2.425	0.015	0.004	0.038
Years (10.0)	0.008	0.006	1.495	0.135	-0.003	0.019
agePHV (years)	0.104	0.008	12.749	0.000	0.088	0.120
Girls*agePHV	-0.009	0.009	-1.101	0.310	-0.027	0.009

Boys (age 11) are taken as the reference/baseline group from which girls and other age groups are compared.

Table 2c. The estimated parameters from the multiplicative model relating log transformed 4x10m agility speed (Ln(Speed Agility)) to the body-size components, agePHV and SBJ in Eq.2 (Model 3).

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Intercept	-2,577	0.261	-9.878	0.000	-3.089	-2.066
LnMass	-0.047	0.006	-7.489	0.000	-0.060	-0.035
LnHeight	0.317	0.040	7.832	0.000	0.238	0.396
Sex (Girls)	0.035	0.009	3.777	0.000	0.017	0.054
Years (8.0)	0.011	0.010	1.090	0.276	-0.009	0.031
Years (9.0)	0.003	0.007	0.384	0.701	-0.011	0.017
Years (10.0)	0.005	0.005	1.150	0.250	-0.004	0.014
agePHV (years)	0.048	0.007	7.060	0.000	0.034	0.061
LnSBJ	0.342	0.005	62.780	0.000	0.331	0.353
Girls*agePHV	-0.003	0.007	-0.362	0.718	-0.017	0.012

Boys (age 11) are taken as the reference/baseline group from which girls and other age groups are compared.

Figure 1a

Figure 1a. The association between speed-agility ($m.s^{-1}$) and height for girls

Figure 1b

Figure 1a. The association between speed-agility ($m.s^{-1}$) and height for boys

Figure 2a Estimated marginal means of 4x10m per sex (boys, girls)
Figure 2b Estimated marginal means of 4x10m per sex (boys, girls) and Maturity Offset
Figure 2c Estimated marginal means of 4x10m per sex (boys, girls), Maturity Offset, and explosive strength (SBJ)