Biological maturity status and chronological age in young triathletes: a first approach to bio-banding in triathlon

Estado de madurez biológica y edad cronológica en jóvenes triatletas: una primera aproximación al bio-banding en triatlón

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Abstract

Introduction: The maturation process in young athletes has been widely studied due to its influence on sports performance and training responses. In endurance sports such as triathlon, understanding biological development is crucial for guiding athlete development and competition structuring.
Objective: The aim of this study was to investigate the correlation between biological age and chronological age, assess variations in maturity status within age groups, and determine whether bio-banding should be recommended for youth and junior triathlon.
Methodology: A cross-sectional study was conducted with 296 young triathletes of both sexes who participated in national, state, or regional multi-sport events in Brazil between 2022 and 2023. Biological maturity status was estimated using the percentage of predicted adult height (%PAH) and predicted age at peak height velocity (APHV).
Results: A strong correlation was observed between chronological age and biological age, suggesting that most young triathletes developed within expected standards. Both indicators were considered good estimators of maturity, although the predicted age at peak height velocity appeared to better reflect intra-group variation. The results are consistent with previous studies that support the use of non-invasive maturity indicators in youth sports. The application of these indicators contributes to a more equitable interpretation of performance and training potential across maturity stages.
Conclusions: It is concluded that age grouping remains an appropriate method for organizing youth triathlon competitions. However, bio-banding emerges as a strategic alternative for planning training and guiding talent identification, considering biological maturity and its influence on performance.

Keywords

Adolescent; bio-banding; biological maturity; chronological age; triathlon.

Resumen

Introducción: El triatlón juvenil y junior presenta desafíos en la agrupación de atletas debido a las diferencias en la madurez biológica. El bio-banding ha sido propuesto como estrategia para mejorar la equidad en la competición, aunque su aplicación en este deporte aún es limitada.
Objetivos: Investigar la correlación entre la edad biológica y la edad cronológica, evaluar las variaciones en el estado de madurez dentro de los grupos de edad y determinar si se debe recomendar el bio-banding para competiciones de triatlón juvenil y junior.
Metodología: Participaron 296 jóvenes triatletas de ambos sexos que compitieron en eventos multideportivos en Brasil entre 2022 y 2023. El estado de madurez biológica se determinó mediante el porcentaje de madurez biológica prevista (%PAH) y la edad prevista a la velocidad máxima de altura (APHV).
Resultados: Se encontró una fuerte correlación entre %PAH y APHV, indicando que la mayoría de los triatletas se desarrollan dentro del rango esperado. Ambos indicadores se consideraron buenos estimadores de madurez, siendo el APHV el que reflejó con mayor precisión las variaciones en las etapas de madurez.
Conclusiones: La agrupación por edades se confirmó como una estrategia eficaz para organizar competiciones de triatlón. El bio-banding se presenta como una alternativa viable para diseñar planes de entrenamiento y orientar la selección y desarrollo de jóvenes triatletas, considerando su madurez y relación con el rendimiento competitivo. Sin embargo, debido a la naturaleza transversal del estudio, existen limitaciones para comprender completamente el desarrollo longitudinal de los atletas.

Palabras clave

Adolescente; bio-banding; edad cronológica; madurez biológica; triatlón .

Introduction

Chronological age is a criterion commonly used to group young athletes into categories, identify talented individuals, and design training guidelines (Ferriz-Valero et al., 2020). In youth and junior triathlon events, competitive categories are grouped according to chronological age: 8–9, 10–11, 12–13, 14–15, and 16–17 years (World Triathlon, 2020). Although age intervals are small to promote a fairer and more balanced competitive environment, it is important to bear in mind that children of the same chronological age may vary in biological maturity, with some individuals maturing earlier or later than others (Cumming et al., 2017).

Maturity-related differences in body size become apparent at 6 or 7 years of age. These differences continue to increase as the child grows, peaking during adolescence due to individual variations in the timing and rate of the growth spurt (Malina et al., 2005). Maturational differences may confer athletic advantages resulting from greater size, strength, speed, and power output, particularly among 11- to 14-year-old boys (Malina et al., 2015). Such an advantage does not seem to occur in girls (Ferriz-Valero et al., 2020), although early maturers tend to be taller and heavier and experience a more intense growth spurt during puberty (Malina et al., 2015).

It is essential to consider maturational aspects during adolescence in the context of sports, as variations in physical structure may significantly influence performance. These emerging issues have garnered the attention of the scientific community (Cripps, Hopper, & Joyce, 2016; Eisenmann, Till, & Baker, 2020). Ferriz-Valero et al. (2020), based on a performance analysis of young triathletes according to relative age, suggested alternatives to chronological age grouping in an attempt to create a fairer competition system. Grouping athletes by biological age could be an interesting strategy for competition and training, ensuring young athletes are appropriately exposed to the demands of the sport for specific capacities, such as muscle strength and power (Cripps et al., 2016; Lloyd et al., 2014; Rogol, Cumming, & Malina, 2018).

Bio-banding has been proposed as an alternative to the chronological grouping of young athletes (Rogol et al., 2018). This method consists of categorizing athletes based on physical and maturational characteristics rather than chronological age, with the aim of reducing competitive inequalities generated by differences in size and maturity (Abbott et al., 2019; Baxter-Jones et al., 2020; Cumming et al., 2017; Malina et al., 2015; Towlson et al., 2024). Application of bio-banding in soccer, for instance, has had positive effects on talent development (Arroyo-Moya, 2023; Barrett et al., 2022; Cumming et al., 2017b; Ludin et al., 2022; Massa et al., 2022), holistic development (Abbott et al., 2019; Bradley et al., 2019; Cumming et al., 2017; Malina et al., 2019), and performance and training load management (Cumming et al., 2017; Gundersen et al., 2022; Ludin et al., 2022; Malina et al., 2019; Meylan et al., 2010).

Different methods can be used to categorize young individuals according to biological age or maturity status. The gold standard is bone age measurement, which, although efficient, is costly and requires exposing athletes to radiation. Non-invasive anthropometric methods have been developed to estimate somatic maturity in an economical, practical, and safe manner (Beunen, Rogol, & Malina, 2006; Malina et al., 2019).

Considering that anthropometric characteristics may attenuate the effect of chronological age on the performance of young athletes, bio-banding based on anthropometric variables could serve as an alternative to chronological grouping (Giudicelli et al., 2021). This approach may aid in tailoring training and competition routines to the developmental stages of young competitors.

Despite advances in other sports, such as soccer, the adoption of bio-banding in triathlon is still in its infancy. The absence of criteria that consider the maturational stage can compromise not only the fairness of competitions but also the development of sports and the retention of talent. Young athletes who mature late may be systematically disadvantaged, which can result in demotivation, early withdrawal from the sport, and underutilization of athletic potential. Therefore, understanding the maturational variability within age categories in triathlon is essential to propose adjustments to the grouping criteria and promote a fairer and more formative competitive environment. This research seeks to contribute to filling this gap, providing a first approach to bio-banding in the context of triathlon. The aims were to investigate the correlation between biological age and chronological age, assess variations in maturity status within age groups, and determine whether bio-banding should be recommended for youth and junior triathlon competitions. Our hypothesis is that there will be a moderate correlation between biological age and chronological age, and the 10–11 and 12–13 year age groups will be the categories with the greatest variations in maturity status of the athletes.

Method

Design, participants and ethics

This cross-sectional study was conducted with a convenience sample of young triathletes of both sexes who competed in national, state, or regional multi-sport events (triathlon, duathlon, or aquathlon) in Brazil between 2022 and 2023. The sample initially included 401 athletes. Of these, 105 were excluded for the following reasons: missing anthropometric data (n = 21), diagnosis of a growth-related condition (n =15), and lack of information on the height of biological parents (n = 69). Thus, the final sample comprised 296 young triathletes. Individuals had to meet the following inclusion criteria to participate in the study: (i) being a registered triathlete, (ii) being enrolled in and completing one of the multi-sport events from the 2022 and 2023 seasons during which data collection took place, and (iii) being aged between 8 and 15 years. In our sample calculations, considering the correlation test with an alpha value of 0.05, a power of 0.8, and a moderate effect size (r = 0.3), 84 athletes would be necessary. Considering the chi-square test with 6 degrees of freedom, an alpha value of 0.05, a power of 0.8, and a moderate effect size (w = 0.3), 152 athletes would be necessary. Therefore, our sample size seems to be sufficient. All study procedures were approved by the Human Research Ethics Committee at Santa Catarina State University (protocol No. 5.715.986). The athletes and their legal guardians were informed about the research and agreed to participate by signing, respectively, an assent form and an informed consent form.

Anthropometric measurements

Close to or on the day of the competition, participants completed an online questionnaire used for sample characterization. Subsequently, participants underwent an anthropometric assessment. Wearing light clothing, the triathletes were instructed to remove their shoes for the measurement of body weight, standing height, and sitting height. Each variable was measured twice and averaged. A third measurement was taken if the difference between measurements was greater than 0.4 cm or 0.1 kg. Body weight was recorded using a portable scale (100 g resolution). Height was measured using an Avanutri® AVA-305 portable stadiometer (1.0 mm accuracy) and a non-slip base. Sitting height (head-trunk height) was recorded in centimeters using a compact Sanny® ES-2040 stadiometer and a 50 cm high wooden box (Freitas Junior, 2018). Lower limb length was calculated by subtracting sitting height from standing height. Measurements were collected by a senior evaluator and two auxiliary evaluators. Auxiliary evaluators were trained by the senior evaluator, and assessments began when the senior evaluator judged that the auxiliary evaluators were ready. The reliability of anthropometric measurements was calculated using the Intraclass Correlation Coefficient (ICC2,1). Mass, height, and sitting height showed a perfect ICC2,1 of 1.0.

Chronological age and parental height

Chronological age was calculated from the date of birth reported by participants in the characterization questionnaire. The height of biological parents, collected in the self-report questionnaire completed by the parents, was used for calculation of the mean parental height, following the procedures adopted by Giudicelli et al. (2021). The questionnaire included a question about the height of the biological father and that of the biological mother.

Biological maturity

Biological maturity was estimated using two somatic indicators, namely percentage of predicted adult height (%PAH) and predicted age at peak height velocity (APHV).

%PAH: The equation proposed by Khamis & Roche (1994) was used to calculate PAH from current height, body weight, and mean parental height. The equation comprises the following terms: current height (x1) and weight (x2) of young athletes at the time of data collection, mean parental height (x3), and the decimal age (x4) of young athletes. PAH (y) is given by a linear equation whose m values are obtained from a reference table for each X variable, based on the chronological age of athletes. The b parameter is a constant term that can be read directly from the table. Thus, PAH is estimated using the following equation (Eq. $y = mx_1 + mx_2 + mx_3 + mx_4 + b$ (1)

Eq. (1) can also be written as:

$$\text{PAH} = \text{Height} + \text{Body weight} + \text{Mean parental height} + \text{Age} + b \qquad (2)$$

After the calculation of individual PAH values, it was possible to determine %PAH, by dividing the current height by the PAH and multiplying by 100, as shown below (Eq. 3):

$$\%\text{PAH} = (\text{Current height}/\text{Predicted height}) \times 100 \qquad (3)$$

The coefficients of the Khamis–Roche method, expressed in inches and pounds, were converted to the metric system (centimeters and kilograms). %PAH is an indicator of somatic maturity at the time of measurement. This metric has been increasingly used for the categorization of juvenile athletes. The developmental stage of individuals can be classified according to %PAH values, as follows: prepubertal or pre-PHV (<88%), pubertal (88%–95%), and post-pubertal or post-PHV (>95%) (Monasterio et al., 2023).

APHV: The parameter was estimated by calculating maturity offset (MO), using the formula of Mirwald et al. (2002). The following anthropometric data were used: height, sitting height, lower limb length, body weight, and chronological age. The data were applied to specific equations for boys (Eq. 4) and girls (Eq. 5) (Mirwald et al., 2002). The formula gives the distance, in years, that the subject is from the PHV, being negative when the PHV has not yet been reached. Thus, maturity status can be classified according to MO values, as follows: prepubertal or pre-PHV, MO < −1; pubertal, MO ≥ −1 or MO ≤ +1; and post-pubertal or post-PHV, MO > +1. These stages are determined according to chronological and biological ages (Lloyd, et al., 2014; Malina et al., 2015).

MO = -9.236 + [0.0002708(Lower limb length × Sitting height)] − [0.001663(Chronological age × Lower limb length)] + [0.007216 (Chronological age × Sitting height)] + [0.02292(Body weight/height × 100)] (4)

MO = -9.376 + [0.0001882(Lower limb length × Sitting height)] + [0.0022(Chronological age × Lower limb length)] + [0.005841(Chronological age × Sitting height)] − [0.002658(Chronological age × Body weight)] + [0.07693 (Body weight/Height × 100)] (5)

The method for determining maturity status according to APHV estimation is non-invasive and feasible. Although it does not provide a time indicator, it does provide an indicator of development between individuals to allow comparisons between groups of biological maturity (pre-pubertal, pubertal, and post-pubertal). According to Mirwald et al. (2002), the validity coefficient between skeletal age and maturity deviation is 0.83, suggesting an acceptable result to determine maturity stage.

Data analysis and statistical processing

Pearson (parametric data) and Spearman (non-parametric data) correlation tests were performed to assess the association between chronological age and %PAH and between chronological age and APHV. The assumptions of data normality and homoscedasticity were verified using the Kolmogorov–Smirnov test and the scatter plot of standardized residuals against standardized predicted values, respectively (Field, 2020). Correlation coefficients lower than 0.1 were considered negligible; between 0.1 and 0.4, weak; between 0.4 and 0.7, moderate; between 0.7 and 0.9, strong; and greater than 0.9, very strong (Schober & Schwarte, 2018).

The association between age groups and maturity stage was determined using the χ^2 test. The proportions were compared between maturity stages for each age category by means of Z tests for pairwise comparisons with Bonferroni correction (MacDonald & Gardner, 2020). The strength of associations was determined using Cramer's V test.

The age category with the greatest variation in maturity status was identified based on the coefficient of variation (CV) of the proportion of maturity status within each age group. In this case, the lower the CV, the greater the variation in maturity status.

The next step aimed to assess whether the classification of the proposed maturity stages reflected the variation in %PAH and APHV within each age group. For this, analysis of the residuals of a simple linear regression model was carried out for each age category. Chronological age was treated as the predictor variable and %PAH and APHV as dependent variables. The independence of residuals and the absence of discrepant values were confirmed by the Durbin–Watson test and analysis of standardized residuals and standardized predicted values, respectively (Field 2020). The standard deviation of residuals (root mean square error, RMSE) of the model was calculated by age group. The higher the RMSE, the greater the variation of the dependent variable around the value predicted by the model.

For all statistical tests, a value of $p < 0.05$ was deemed significant. Statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) software version 20.0.

Results

The sample comprised 296 triathletes (182 boys and 114 girls). Table 1 presents the characteristics of study participants in the total sample and stratified by sex.

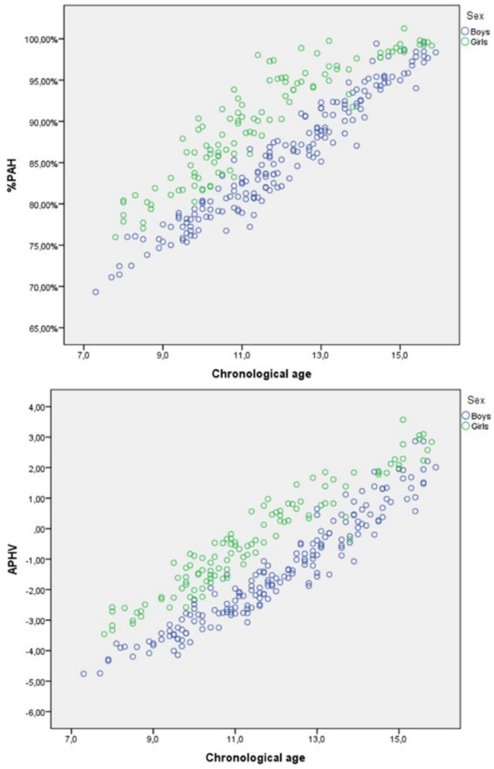
Table 1. Participant characteristics

Variable	Boys	Girls	Total
	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	12 (2)	11.5 (2.1)	11.8 (2)
%PAH (%)	85.6 (7.2)	90 (6.7)	87.3 (7.3)
APHV (years)	−1.4 (1.8)	−0.4 (1.7)	−1 (1.8)
Body weight (kg)	44.9 (13.1)	42.9 (12.7)	44.2 (13)
Standing height (cm)	153 (14)	149 (11)	151 (13)
Seating height (cm)	130 (7)	129 (7)	130 (7)
Mean parental height (cm)	170 (6)	170 (5)	170 (6)
Training length (months)*	20 (15.5)	18.3 (15.6)	19.4 (15.5)
Age category	*n* (%)	*n* (%)	*n* (%)
8–9 years	32 (17.6)	24 (21.1)	56 (18.9)
10–11 years	58 (31.9)	45 (39.5)	103 (34.8)
12–13 years	53 (29.1)	28 (24.6)	81 (27.4)
14–15 years	39 (21.4)	17 (14.9)	56 (18.9)
Maturity stage (%PAH)	*n* (%)	*n* (%)	*n* (%)
Pre-pubertal	47 (25.8)	7 (6.1)	54 (18.2)
Pubertal	113 (62.1)	74 (64.9)	187 (63.2)
Post-pubertal	22 (12.1)	33 (28.9)	55 (18.6)
Maturity stage (APHV)	*n* (%)	*n* (%)	*n* (%)
Pre-pubertal	114 (62.6)	46 (40.4)	160 (54.1)
Pubertal	48 (26.4)	44 (38.6)	92 (31.1)
Post-pubertal	20 (11.0)	24 (21.1)	44 (14.9)
Menarche		*n* (%)	
Yes		44 (38.6)	
No		70 (61.4)	
		Mean (SD)	
Age at menarche (years)		11.4 (1)	

Legend. SD= standard deviation; *n*= absolute frequency; %= relative frequency; %PAH= percentage of predicted adult height; APHV= predicted age at peak height velocity; * length of triathlon training (*n* = 156).

Spearman's correlation test demonstrated a strong correlation between chronological age and %PAH (rho = 0.853 [CI95% = 0.82–0.88], $p < 0.001$) and between chronological age and APHV (rho = 0.863 [CI95% = 0.83–0.89], $p < 0.001$). Chronological age explained 72.5% of the variance in %PAH (rho2 = 0.725) and 74.2% of the variance in APHV (rho2 = 0.742). When the sample was stratified by sex, correlations became stronger. For boys, the rho coefficient was 0.97 (CI95% = 0.96–0.98) for correlations between chronological age and %PAH and between chronological age and APHV ($p < 0.001$). For girls, the rho value was 0.93 (CI95% = 0.90–0.95) for the correlation between chronological age and %PAH ($p < 0.001$) and 0.96 (CI95% = 0.94–0.97) for the correlation between chronological age and APHV ($p < 0.001$). Correlations between chronological age, %PAH, and APHV are depicted in Figure 1.

Figure 1. Correlation between chronological age, percentage of predicted adult height (%PAH), and predicted age at peak height velocity (APHV).



The results of the χ^2 test indicated an association of 63.7% between age category and maturity status based on %PAH ($\chi^2[6] = 240.460$; $p < 0.001$; Cramer's $V = 0.637$) and of 62.3% between age category and maturity status based on APHV ($\chi^2[6] = 230.114$; $p < 0.001$; Cramer's $V = 0.623$). The age groups with the smallest variation in proportions, that is, the greatest variation in maturity status, were 8–9 years and 14–15 years according to %PAH and 12–13 years according to APHV, as demonstrated by CV values (Table 2). According to the RMSE values for %PAH and APHV predicted by linear regression, the classification of maturity status by APHV seems to better reflect the variation of its respective continuous variable within age categories (i.e., the age category with the lowest CV for maturity status corresponds to the age category with the highest RMSE).

Table 2. Association between age category and biological maturity stages

Age category (years)	Pre-puberty	Puberty	Post-puberty	CV (%)	RMSE
	n (%)	*n* (%)	*n* (%)		
		%PAH			(%)
8–9	39^{a} (69.6)	17^{b} (30.4)	0^{b} (0)	1.05	3.39
10–11	15^{a} (14.6)	85^{a} (82.5)	3^{b} (2.9)	1.29	4.35
12–13	0^{a} (0)	68^{b} (84)	13^{b} (16)	1.34	4.02
14–15	0^{a} (0)	17^{a} (30.4)	39^{b} (69.6)	1.05	1.96
		APHV			(years)
8–9	55^{a} (98.2)	1^{b} (1.8)	0^{b} (0)	1.69	0.76
10–11	81^{a} (78.6)	22^{b} (21.4)	0^{c} (0)	1.22	0.89
12–13	23^{a} (28.4)	50^{b} (61.7)	8^{a} (9.9)	0.79	0.98
14–15	1^{a} (1.8)	19^{b} (33.9)	36^{c} (64.3)	0.94	0.70

Legend. ^{abc} Different letters in a row indicate significantly different values ($p < 0.05$). n= absolute frequency; %= relative frequency; %PAH= percentage of predicted adult height; APHV= predicted age at peak height velocity; CV= coefficient of variation; RMSE= root mean square error (standard deviation of residuals between estimated and predicted values for each age category [predictor, chronological age; dependent variable= %PAH or APHV]).

In our subsequent calculations, considering the alpha of 0.05, sample size and effect size found, the statistical power of the Pearson correlation test and the chi-square test was equal to 1.0 in all analyses.

Discussion

There was a strong correlation between chronological age and %PAH and between chronological age and APHV. Chronological age explained 74.2% and 72.5% of the variance in %PAH and APHV, respectively. Thus, in a sports context, most young athletes develop within the average range, and chronological age is correlated to biological age. However, there is a small group of young individuals who deviate from the average. This small group will either be behind in development or ahead of their chronological age.

There are challenges in dealing with both early and late maturing athletes. For instance, it may be difficult to identify talented late maturers and guide them throughout development. Additionally, early maturing athletes must be optimally challenged and trained to develop technical and tactical skills, as their physical advantages (size, speed, strength) may disappear by late adolescence (Albaladejo-Saura et al., 2022; Almeida-Neto et al., 2022). Providing a realistic view of current performance through the monitoring of data on maturity status and providing guidance to professionals, athletes, and families are important, as recommended by Eisenmann et al. (2020).

In line with these findings, Albaladejo-Saura et al. (2022) observed that, among a sample of 48 volleyball players, 33 were classified as having average APHV, 8 were classified as early maturers, and 7 as late maturers. Guimarães, et al. (2019) found that 92.7% of basketball players were correctly classified in their original groups. Figueiredo et al. (2009) reported that 52% of soccer players (boys) aged 11-12 years were on-time maturers, 20% were late maturers, and 29% were early maturers. In the 13-14 years age group, 63% were on-time, 31% were early, and 6% were late maturers (Figueiredo et al., 2009).

Malina et al. (2005), in studying a sample of 582 young soccer players from two Michigan communities in 2000 and 2001, classified 405 (69.6%) as on-time/average, 154 (25.5%) as early, and only 23 (3.9%) as late maturers. The percentage of boys classified as average was highest in the small sample of boys aged 9.0 years (88.0%) and ranged from 60.9% to 76.3% in boys aged 9.5 to 13.5 years (Malina et al., 2005). The percentage of on-time maturers was lowest among 14-year-old boys (58.8%) (Malina et al., 2005). By contrast, the percentages of early maturing athletes were lower among younger boys, aged 9.0 (12%) and 9.5 (15.9%) years, and ranged from 22.4% to 41.2% between 10.0 and 14.0 years (Malina et al., 2005). Spearman correlations between chronological age and late, on-time, and early maturers in each age group were -0.42 ($p = 0.098$), -0.34 ($p = 0.152$), and 0.61 ($p = 0.022$) (Malina et al., 2005). The direction of correlations suggests a decline in the percentages of athletes classified as late and on-time maturers with age, and an increase in athletes classified as early maturers (Malina et al., 2005).

These findings differ from those of Sellés et al. (2016) who reported that 70.8% of the sample were ahead of their chronological age with regard to growth. Similarly, Malina, Bouchard & Bar-Or (2004) found that young soccer players were, on average, advanced in skeletal maturity compared with chronological age.

The results support that selective processes in competitive environments should be carried out with caution during puberty. When necessary, biological maturity level should be analyzed together with its relationship with chronological age. This approach should be adopted to avoid creating erroneous expectations in young athletes who matured early and to avoid excluding late-maturing individuals from selection and monitoring processes (Miranda et al., 2019).

Vieira et al. (2023) investigated how Brazilian triathlon coaches identify talent and the importance of different factors and indicators for the development of young triathletes. It was found that almost half of the interviewed coaches ($n = 17$, 45.9%) use some procedure to detect talent in triathlon (Vieira et al., 2023). The most frequent methods were physical/motor test batteries and simulations of triathlon events (Vieira et al., 2023). Seven coaches (41.2%) evaluated performance in competitions (Vieira et al., 2023). It is noteworthy that only 3 of the 17 coaches assessed biological maturity when evaluating potential triathlon athletes (Vieira et al., 2023). When these indicators or procedures are not considered together, the selection of promising young athletes may be conducted inadequately (Miranda et al., 2023). It is important to caution in talent identification programs; favoring individuals who excel can discourage those who do not, ultimately resulting in the abandonment of sports (Cuba-Dorado et al., 2020).

It is common to group young athletes based on age and weight in combat sports (e.g., boxing, judo, taekwondo, and wrestling), as extreme size mismatches can affect competitive equity and athlete safety (Albuquerque et al., 2016; Cumming et al.; 2017). In soccer, great progress has been made in research on biological maturity, its relationship with chronological age, and the implications on sports development (Abbott et al. 2019; Arroyo-Moya 2023; Bradley et al. 2019; Cumming et al. 2018; Figueiredo et al. 2009; Gundersen et al. 2022; Leyhr et al. 2020; Ludin et al. 2022; Malina et al. 2024; Massa et al. 2022; Meylan et al. 2010; Thurlow 2022).

There is similar evidence in other sports. Albaladejo-Saura et al. (2022) analyzed the biological maturity status, anthropometric characteristics, and performance in physical fitness tests of adolescent volleyball players. The authors determined which variables better predict performance and concluded that there are significant differences in anthropometric and physical condition between individuals at different stages of biological maturity; and those at more advanced stages of maturity had better performance (Albaladejo-Saura et al., 2022). Almeida-Neto et al. (2022) analyzed the influence of biological maturity on performance and aerobic and anaerobic power among rowing athletes. It was concluded that advanced biological maturity influences anaerobic and sports performance in young rowers of both sexes (Almeida-Neto et al., 2022).

To the best of our knowledge, there is no study providing preliminary data on the relationship between biological age, chronological age, and athlete performance in triathlon. Ferriz-Valero et al. (2020), without assessing biological age, analyzed the effect of relative age on performance. The authors observed that triathletes born in the first half of the year showed superior performance (although not statistically significant) to triathletes born in the second half of the year (Ferriz-Valero et al., 2020). Furthermore, older male triathletes were found to perform significantly better than younger triathletes in the 13-14 years and 15-17 years age groups (Ferriz-Valero et al., 2020). By contrast, older female triathletes did not perform significantly better than younger athletes (Ferriz-Valero et al., 2020).

Hill et al. (2020) demonstrated that young soccer players (U10, U14, and U15 age groups) at more advanced stages of biological maturity were associated with more positive evaluations by coaches. Individual differences in maturity status are not calendar dependent (Cumming et al., 2017). In a single chronological year (e.g., 11.0-11.99 years or 13.0-13.99 years), late, average, and early maturers are observed in each birth trimester (Cumming et al., 2017).

Individual differences in biological maturity have an impact on psychological constructs that are important drivers of motivated behavior and resilience in sports, such as self-perception of physical competence (Cumming et al. 2018; Eisenmann et al. 2020). When not considered, individual differences in growth and maturity can promote competitive inequality and increased risk of injury, especially for athletes who are constitutionally small and/or late maturing (Cumming et al., 2017).

Gundersen et al. (2022) confirmed the influence of biological maturity on the success of young soccer players aged 14-15 years, demonstrating a significant relationship between maturity status and key parameters of physical performance, such as maximum speed, distance traveled at high speed, performance in 40 m sprint, and countermovement jump. Figueiredo et al., (2009), in a study with 159 Portuguese male soccer players, analyzed variations in size, function, sport-specific ability, and goal orientation associated with differences in biological maturity status in two age groups, 11-12 years (n = 87) and 13-14 years (n = 72). Using the Fels method, the authors classified athletes as late, on-time, and early maturers (Figueiredo et al., 2009). The results showed that late, on-time, and early maturers were well represented among 11-12-year-olds, but late-maturing boys were underrepresented among 13-14-year-olds (Figueiredo et al, 2009). Early maturers were taller and heavier than on-time and late maturers (Figueiredo et al., 2009). However, athletes with different maturity statuses did not differ in functional capabilities, soccer-specific competencies, or goal orientation, with few exceptions (Figueiredo et al., 2009).

The relative mismatch and variation in biological maturity among children of the same chronological age, even among early and late maturers, suggest limitations in the use of this parameter as a determinant for global exercise prescription in young athletes (Lloyd et al., 2014). It is necessary to understand biological maturity in young athletes to distinguish whether maturity or exposure to regular physical training is responsible for the observed changes in physical performance and injury risk (Lloyd et al., 2014).

Many studies consider the use of chronological age ranges or age groups in competitions to be limited (Abbott et al., 2019; Bradley et al., 2019; Cumming et al., 2017). In general, only average data are published. Distribution across maturity stages by chronological age group is not commonly reported, and some studies are limited to selected samples, e.g., pre-pubescent or precocious pubertal individuals (Malina et al., 2015). The literature has proposed changes in the organization of competitive groups with the aim of neutralizing differences that benefit more developed athletes, especially for triathletes close to peak growth velocity, that is, 13-14-year-old boys and 11-12-year-old girls (Ferriz-Valero et al., 2020; Mirwald et al., 2002).

Towlson et al. (2024) observed that secondary schoolchildren at different stages of maturity are often grouped by chronological age, resulting in large variations in physical, behavioral, emotional, and educational development. In sports, this is particularly relevant, given that involvement, enjoyment, and attitudes in sports are influenced by the perception of competence and relationship, which can be impaired by variations in maturity (Towlson et al., 2024).

A strength of the current study was the use of a large and heterogeneous sample, allowing for a comprehensive and representative analysis of the data. Furthermore, the use of somatic maturity estimates based on anthropometric measurements is advantageous in the context of young athletes. These measurements are less time-consuming, suitable for large samples, and less invasive; do not require technical equipment; and are appropriate for cross-sectional studies. The adopted methods have been widely used in bio-banding, being validated in most related studies (Cumming et al., 2017; Malina et al., 2019; Massa et al., 2022; Miranda et al., 2019). In practical terms, the inclusion of these simple and accessible measures of maturation assessment can help adapt training loads, adjust performance expectations, and promote a more equitable and safer environment for athletes with different maturational profiles. Furthermore, monitoring maturation can help to avoid early exclusions of young talents with late maturation and offer appropriate challenges to those who mature early, preventing stagnation in technical and tactical development. In this way, more individualized sports policies and practices that are sensitive to maturational differences can favor the retention, well-being and long-term performance of young athletes.

However, it is necessary to consider some methodological limitations. Given the cross-sectional nature of the study, the data comprised measures collected at a single time point, which may limit the understanding of the longitudinal development of athletes. The use of somatic maturity estimates, although advantageous, is still incipient in research on the development of young athletes, deserving attention from all stakeholders. Interpretations may be limited and subject to measurement error. In addition, the methods were derived from specific populations, mainly North American Caucasians, which limits the validity of prediction-based equations in youth sports settings and in brazilian population. However, they are widely applied in international research with young athletes from diverse backgrounds (Miranda et al., 2019; Monasterio et al., 2024; Sullivan et al., 2023). Their use in the present study was based on their non-invasive nature, practicality, and frequent adoption in scientific literature to estimate biological maturity in sports contexts. Another factor is the use of parents' self-reported height, which can influence the calculation of predicted adult height, despite being a common practice in most studies.

To ensure the best estimate of biological maturity status with the proposed equations, it is necessary to take measurements with care, particularly that of sitting height. The amplification of measurement errors by prediction equations is an important limitation of any method, particularly when a measure directly influences the number of independent variables (Mirwald et al., 2002). There is also a significant sex bias in the literature, with a disproportionate lack of research on female athletes. This fact may impact on the differential dynamics between sexes.

Another limitation is that there was no control for variables such as nutritional status and socioeconomic level, which could influence growth and maturation. However, since all participants were involved in triathlon projects with a minimum support structure and systematic monitoring, a relative homogeneity in these conditions is assumed, which may have attenuated the impact of these variables on the results.

Conclusions

The analysis revealed a strong correlation between chronological age and %PAH, as well as between chronological age and APHV. Thus, most young triathletes tended to develop within the average range, with a significant correlation between chronological and biological age. However, it is important to pay attention to young people who mature early or late, so that they are not excluded from monitoring and selection processes in the sports environment.

A significant and strong association between age category and biological maturity status was identified, regardless of the method used (%PAH or APHV). This finding suggests that both %PAH and APHV were good indicators of maturity status. The largest variations in maturity status were observed in the age groups 8–9 and 14–15 age groups when measured by %PAH, and in the 12–13 age group when measured by APHV. However, unlike %PAH, APHV cut-off values for maturity status seemed to provide classifications that better reflect variation in the quantitative variable (APHV).

Children and adolescents are traditionally grouped by chronological age. Changes in this grouping method could impact the entire sports structure. The results of this study suggest that it may not be necessary to modify the competitive categories of triathlon, as chronological age showed a good correlation with biological age, with little variation within competitive age categories. Bio-banding appears to be a strategic alternative for designing training plans and guiding the selection and development of promising young triathletes by taking into account their maturity stage and its association with competitive results.

Monitoring biological age may be beneficial in minimizing negative outcomes resulting from inequalities in physical attributes influenced by maturational aspects. This approach may contribute to the holistic development of young triathletes. In the sports context, such as youth and junior triathlon, it may be appropriate to measure, classify, and interpret biological age in association with chronological age to avoid the creation of unrealistic expectations in early- maturing athletes. Once biological maturity has been reached, it becomes possible to make more prudent decisions, equalize competition, increase the chances of success, and potentially reduce the incidence of dropouts.

Future studies should consider the use of a longitudinal design to confirm the current results and assess possible anthropometric changes over time. Tracking individual growth trajectories would allow for a better understanding of how biological maturation influences performance and selection processes. Furthermore, triathlon competitions could group young athletes by both chronological and biological age within the existing structure, representing an opportunity for expansion and inclusion.

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