

Effects of biological maturation and sport type on anthropometric and physical performance profiles in female youth athletes Aged 8–16 Years

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Abstract

Problem Statement: Given the structural differences among sports, it is important to examine how the multidirectional, open-skill, and decelerative demands of team sports alter maturity-related anthropometric and physical performance profiles in female athletes aged 8-16 years compared with individual sports. **Purpose:** This study evaluated the association of biological maturation and sport type on the anthropometric and physical performance profiles of 890 female athletes (aged 8–16 years) from team ($n = 314$) and individual ($n = 576$) sports. **Approach:** Participants were assessed for anthropometric measures (body height, body weight, sitting height, arm span, leg length) and physical performance characteristics (flexibility, speed, power, strength, agility, balance, and cardiorespiratory endurance). Maturity status was determined using years from peak height velocity (YPHV). A two-way factorial ANOVA examined differences between sport types across biological age groups (–3.5 to +2.5 YPHV). **Results:** The present study indicated that team sport athletes generally exhibited an advanced maturation status and larger anthropometric profiles. Flexibility and static balance demonstrated non-linear patterns across maturity groups. The pre-PHV stage was characterized by higher mean values in speed, change-of-direction speed (CODS), and power, particularly within individual sports. While team sport athletes showed higher mean speed profiles, the individual cohort exhibited significant maturity-associated variances. Additionally, team sport athletes, maintained higher mean values in explosive and strength-related capacities beyond PHV, while individual athletes demonstrated superior cardiorespiratory endurance and sustained strength enhancements. Notably, a concurrent medium effect of biological maturation and sport type was observed exclusively for cardiorespiratory endurance indicating that individual sports participation and biology jointly mediated performance in this specific capacity. Maturation heterogeneity peaked between ages 10–13, where athletes of identical chronological age were dispersed across three biological stages, with this substantial variability emerging at the age of 8 in individual sports and unexpectedly persisting until age 15 in team sports. In conclusion, biological maturation dominates anthropometric and physical performance differences, while the individual or team sports act as a minor modulator; this dominance is driven by a profound inter-individual biological heterogeneity that underscores the limitations of grouping youth female athletes solely by chronological age.

Keywords: academy level, childhood, adolescence, bio-banding, team sports, individual sports

Introduction

During childhood and adolescence, substantial physiological changes occur that significantly influence anthropometric characteristics and physical performance (Baxter-Jones et al., 2005). However, chronological age alone does not reflect developmental status, as children of the same age may differ significantly in their biological maturation (Sherar et al., 2007; Malina et al., 2015). The growth rate varies remarkably during puberty, resulting in considerable differences between athletes of the same chronological age group (Lloyd et al., 2014).

Biological maturation directly influences expression of height, body mass, sitting height, and limb length in both boys and girls (Albaladejo-Saura et al., 2022; Yapici et al., 2022). Peak height velocity (PHV), the period of maximum growth rate in stature during the adolescent growth spurt, is characterised by rapid changes in the bodies of young athletes, particularly in the relative growth of upper and lower limbs. These transient anthropometric discrepancies are frequently overlooked in athlete selection and classification processes, despite evidence suggesting that maturation-related differences tend to weaken in adulthood (Buchheit & Mendez-Villanueva 2014; Peña-González et al., 2018).

A well-documented consequence of biological maturation in youth sport is the selection bias favouring early maturing athletes (Towilson et al., 2022). Athletes approaching or experiencing PHV may temporarily display decrements in coordination, postural control, and neuromuscular efficiency due to their rapid growth (John et al., 2019; Steidl-Müller et al., 2020). Differences between early- and late-maturing individuals are

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particularly evident between 13 and 16 years of age and are commonly associated with variations in strength, power, and speed (Malina et al., 2004).

Adolescent biological maturation is associated with distinct variations in the physical, physiological, and metabolic profiles of youth athletes. These maturational differences are reflected in non-linear performance patterns across multiple athletic domains, including speed, change-of-direction speed (CODS), muscular strength, and aerobic capacity. Speed performance demonstrates non-linear configuration patterns influenced by both neural maturation and structural growth (Meyers et al., 2015; Towlson et al., 2018). Prior to puberty, improvements in speed are largely attributed to neuromuscular development, including enhanced motor control and coordination (Malina et al., 2004). A secondary acceleration phase often coincides with PHV, associated with increases in muscle size and development of fast-twitch fibres (Kumar et al., 2021). However, sex-specific differences have been identified in the literature (Valentza et al., 2026). More specifically, boys typically demonstrate continued improvements in speed after PHV, primarily due to increased muscle mass and anabolic hormonal responses (Meyers et al., 2015). In contrast, girls often exhibit relative stagnation or slight declines in sprint performance following PHV, potentially due to increases in body fat and differential hormonal influences (Emmonds et al., 2020; Baxter-Jones et al., 2005). Indeed, body fat has been reported to increase by approximately 50% during the three years following PHV in girls compared to approximately 12% in boys (Baxter-Jones et al., 2005).

Similarly, CODS performance profiles demonstrate non-linearly throughout childhood and adolescence (Chioldera et al., 2008; Eisenmann & Malina, 2003). While progress is observed in both sexes, maturation-related fluctuations often disrupt coordination in girls, particularly during periods of rapid growth (Emmonds et al., 2020). In female athletic profiling, it is well-established that the onset of the pubertal spurt marks a critical divergence in CODS trajectories. While male youths typically experience peak CODS development at approximately 13–14 years of age, coinciding with the timing of peak height velocity (Lloyd et al., 2014), females follow a distinct maturational path often characterized by performance plateaus or even decrements in neuromuscular capacities (Eisenmann & Malina, 2003). Although anthropometric factors such as body height and mass influence CODS in prepubertal populations (Fiori et al., 2020), this maturity-related 'window' may temporarily stall the linear progression of motor skills in girls, necessitating targeted strength and neuromuscular conditioning. In female athletes, periods surrounding biological maturation are characterized by significant physiological instability; while physical growth is present, hormonal shifts during maturation can negatively impact body composition, strength, and cardiorespiratory endurance (Malina et al., 2004). Specifically, increases in muscular strength are strongly driven by maturation-related structural changes, with peak gains typically occurring 1 to 1.5 years after peak height velocity (Manno, 2008). Unlike their male peers, who benefit from androgen-induced muscle hypertrophy (Dubois et al., 2012), adolescent girls experience estrogenic changes that may limit relative gains in lean muscle mass and alter movement mechanics, subsequently affecting power output and isometric force production (Chidi-Ogbolu & Baar, 2019).

Aerobic capacity in female also demonstrates substantial changes during adolescence, with growth patterns that differ significantly from those of their male peers (Armstrong & Welsman, 2019). Increases in absolute peak $\dot{V}O_2$ are evident in both sexes, however, rate and pattern of growth differ between sexes (Armstrong & Welsman, 2019). While differences in peak $\dot{V}O_2$ are partly attributable to chronological age and body size (Kemper & Verschuur, 1981), maturation status contributes beyond these factors (Armstrong et al., 1999). Notably, longitudinal data indicate that while boys show continuous increases until age 17, aerobic performance in girls tends to plateau between the ages of 10 and 13 (Armstrong & Welsman, 2019). This stabilization often occurs around the period of PHV, after which values typically decline relative to body mass due to maturity-related changes in body composition (Emmonds et al., 2020). Although factors such as muscle mass, stroke volume (SV_{max}), and arteriovenous oxygen difference ($a-vO_2diff_{max}$) are primary drivers of this sexual divergence (Armstrong & McManus, 2017; Armstrong & Welsman, 2019), a significant research gap remains.

These sex-specific physiological alterations do not manifest uniformly across all athletic environments; rather, their distribution patterns appear to be mediated by the specific structural demands of team versus individual sports. In individual disciplines characterized by closed-loop, linear movement profiles or sustained energetic efficiency, a higher relative adiposity and a shifting centre of mass often observed within post-PHV cohorts can be negatively associated with linear acceleration and relative aerobic capacity profiles (Meyers et al., 2017; Armstrong & Welsman, 2019). Because individual endurance or sprint disciplines rely extensively on absolute physical and energetic efficiency, any post-PHV stagnation in relative $\dot{V}O_{2max}$ or relative lower-body strength directly lowers performance margins. Conversely, team sports rely heavily on multi-directional locomotion, where CODS and intermittent metabolic recovery are primary determinants of success (Chaabene et al., 2020).

Moreover, during the rapid growth phase surrounding PHV, female adolescents frequently face temporary disruptions in neuromuscular coordination and altered braking mechanics (Asimakidis et al., 2022). This phase of adolescent clumsiness is often associated with deceleration deficits, impacting the capacity to manage greater inertial forces during rapid turning manoeuvres, a vulnerability that may be further compounded

if differences in muscular strength profiles do not align with skeletal dimensions across maturity groups (Emmonds et al., 2020; Radnor et al., 2018). While performance profiles in individual disciplines present strict physical thresholds where metrics are highly sensitive to somatic variations, team sport contexts reflect multifaceted movement structures where specific physical performance differences across maturity groups are often hypothesized to be overshadowed by tactical or technical game demands (Freitas et al., 2022). Understanding how biological maturation interacts with speed, power, CODS, strength, and aerobic capacity in female youth populations across these distinct sporting contexts is critical for optimizing sport-specific training periodization (Lloyd & Oliver, 2012), refining talent identification models (Vaeyens et al., 2008), and implementing targeted injury-mitigation strategies unique to each athletic environment (Towlson et al., 2021). Therefore, further investigation is warranted to examine the influence of biological maturation on the anthropometrical and physical performance characteristics of young female athletes. While the independent effects of biological maturation on youth physical profiles are thoroughly documented, current frameworks heavily generalize youth development and overlook how specific sporting environments mediate these physiological pathways. The present study addresses this critical gap by evaluating whether the structural demands of team sports (characterized by multi-directional locomotion, open-skill complexity, and repetitive deceleration) alter the expression of maturity-associated anthropometric and physical performance profiles, differ than the linear environments of individual sports in female youth populations. Consequently, the purposes of the present study were: (a) to evaluate the impact of biological maturation status on the anthropometric profiles and physical performance characteristics of girls aged 8–16 years; (b) to investigate the interaction between biological maturation and sport type (individual vs. team sports) on the variance pattern of anthropometric and physical performance characteristics; and (c) to examine the percentage distribution of maturity categories across chronological ages in female athletes of different sporting backgrounds.

Methods

Participants and Study Design

To investigate the cross-sectional profiles of young athletes and evaluate the impact of biological maturation on anthropometric profiles and physical performance, a cross-sectional research design was employed. This approach focused on quantifying the rates of change in anthropometric and physical performance characteristics across a broad maturity spectrum, specifically spanning chronological ages from 8 to 16 years old. Participants were recruited from 22 sports academies across the Attica region, Greece, encompassing several municipalities within the Athens metropolitan area, through a random sampling method. By comparing diverse sporting backgrounds, the study aimed to isolate the influence of sport type (team vs. individual) and chronological age on anthropometric and physical performance characteristics.

A total of 890 female competitive-level athletes (team sports $n = 314$; individual sports $n = 576$) (skills level was determined according to the categorisations from Cobley et al. (2009) from Greek Sport Academies, aged 8–16 years participated in this study (Table 1). Participants were involved in a variety of team (basketball, handball, football, volleyball) and individual sports (track and field, gymnastics, swimming, tennis, karate, judo, fencing) across this age range. Following an established sports classification framework (Febrianty et al., 2024) the total cohort was stratified based on specific operational demands to systematically manage within-group heterogeneity. The study received institutional approval from the National and Kapodistrian University of Athens institutional review board and all participants provided written informed consent prior to their inclusion in the research.

Table 1. *Descriptive statistics of female youth athletes aged 8 -16 years old across individual and team sports, categorized by biological maturation groups*

Years from Peak Height Velocity (YPHV) N = 890		-3.5	-2.5	-1.5	-0.5	+0.5	+1.5	+2.5
Team sports	n	40	36	42	53	60	70	13
Individual sports	n	105	114	90	94	90	67	16

Anthropometric Measurements

Anthropometric measurements included body height (Ht), body mass (BM), sitting height (SH), leg length (LL), and arm span (AS). Ht and SH were measured to the nearest 0.1 cm using a Seca Alpha stadiometer (Seca, Birmingham, United Kingdom). BM was measured to the nearest 0.1 kg using a digital scale (Seca, Birmingham, United Kingdom). Leg length was calculated by subtracting sitting height from standing height as $LL = Ht - SH$. AS was defined as the distance between the tips of the middle fingers with arms abducted at 90°, elbows and wrists extended, and palms facing the wall.

Chronological Age

The chronological age of each participant was calculated to the nearest 0.01 year by subtracting the decimal year of birth from the decimal year of testing. For the creation of standardized age groups, participants were classified by their age at the time of measurement (e.g., all children aged 13.0–13.9 years were grouped as 13-year-olds).

Assessment of biological maturation and biological age

Physical growth and maturation were assessed using PHV as an indicator of somatic maturation, estimated from measurements of body mass, standing height, sitting height, and chronological age (Mirwald et al., 2002). Maturity offset was calculated to estimate the number of years from PHV (YPHV), representing time before or after the onset of peak growth (e.g., -3.5, -2.5, -1.5, -0.5, +0.5, +1.5, +2.5 years from PHV), using the following sex-specific predictive equation: Maturity offset = $-9.376 + 0.0001882 \times (\text{leg length} \times \text{sitting height}) + 0.0022 \times (\text{age} \times \text{leg length}) + 0.005841 \times (\text{age} \times \text{sitting height}) - 0.002658 \times (\text{age} \times \text{body mass}) + 0.07693 \times (\text{body mass} / \text{height})$. Biological age at PHV (APHV) was subsequently calculated relative to chronological age (CA) as: $\text{APHV} = \text{Chronological Age} - \text{YPHV}$. For example, among girls of the same chronological age, an individual who reaches PHV two years earlier than a peer would be classified as demonstrating earlier biological maturation.

Physical Performance Tests

Flexibility. Flexibility was tested using the stand-and-reach test (St&R) (Bös & Schlenker, 2011). Subjects were instructed to begin the test in a barefoot standing position on an elevated platform with their feet closed together. They were asked to bend over, using their maximal range of motion during expiration. During the test, knees, arms, and fingers were fully extended for at least two seconds. A measurement tape was attached to the platform with 100 cm corresponding to the upper level of the platform. Values above 100 cm indicate that the person was able to reach beyond the toes (i.e., good flexibility). Values below 100 cm indicate that the person could not reach the toes (i.e., limited flexibility). The best out of two trials (i.e., maximal reach distance) with a one-minute rest between trials was used for further data analysis.

Static balance. Stork balance stand test was used to measure static balance. It was required to stand on the toes of one foot with their hands on their hips, and the other foot placed against the inner knee, holding the position for as long as possible. Static balance (SB) of the lower limbs was assessed with a stopwatch, following the protocol outlined by Johnson and Nelson (1969), to 0.01 s accuracy. Two trials per dominant leg were allowed with 3 min rest.

Triple hop test. Lower-extremity muscular power was assessed using the triple hop test for distance for the right (THR) and left (THL) legs (Stark, 2000). Participants were instructed to stand with one foot right behind the starting line and to jump three times with the same leg as far as possible and to land on both feet. Subjects were allowed to use arm swing during the tests. Two trials were performed for each leg with a one-minute rest between trials. The best trial in terms of maximal distance from the starting line to the landing point at heel contact for each leg was added and used for statistical analysis. Measurements were taken to the nearest centimetre using a tape measure. The test is also valid ($r = 0.74$ to 0.96) when compared with the standing long jump test in youth (Moll et al., 2012).

Jumping sideways (JS). Subjects were instructed to perform as many double-legged jumps as possible over a 2cm-wide marking within a 15-second timeframe (Bös & Schlenker, 2011). To ensure maximum performance, subjects are permitted to use an arm swing for momentum and balance. Scoring is based on the total number of successful jumps completed without touching the centre line; any jump that makes contact with the tape is considered an error and is excluded from the final count. The testing procedure consisted of two trials, separated by a one-minute rest.

Isometric strength. Handgrip strength (HGS) was assessed with a hand dynamometer (Baseline BIMS Digital Clinic Hand Dynamometer) recorded to the nearest 0.1 kg. Two attempts per hand were given with a one-minute rest.

Jump and Reach Test (JRT). The participant was required to have the right or left fingertips marked with chalk. They stood next to the wall at their right or left side, reached up as high as possible with their right or left hand and marked the wall while keeping their left or right arm down, accordingly and with both feet on the floor. The participants were asked to jump as high as possible, touching the wall again with their fingertips, and make a mark on the wall. The subject performed a fast downward movement to about 90° knee flexion and then a fast upward vertical movement and jumped as high as possible and made another mark at the peak of the jump (Harman et al., 1991). The jump height was assessed by measuring the difference between a person's standing reach and the height to which he or she can jump and touch. The vertical jump score is the difference between the two marks (recorded in centimetres). The athletes performed two jumps with 30s rest.

Sprint performance. A 20 m sprint was timed using a hand-held stopwatch (Casio HS -80TW, Japan), accurate to 0.01 s. Two trials were given with 3 min rest (Bös & Schlenker, 2011).

Aerobic capacity. Aerobic capacity was assessed using the 20 m shuttle run test (20mSRT). Subjects are required to run back and forth on a 20m course and must be at the 20m line while a sound signal is heard. The frequency of the sound signals increases in such way that running speed is increased by 0.5 km h^{-1} each minute from a starting point of 8.5 km h^{-1} . The maximum number of 20-meter shuttle runs a participant can complete was recorded before being unable to keep pace with the accelerating beeps (Léger et al., 1988). The last announced stage number and the cumulative distance are then used for analysis.

Star agility run test (SART). Agility was tested using the star agility run test (Golle et al., 2015). Participants were instructed to run in different running drills (e.g., forward, backward, side steps) from the centre to the edge

and back of a 9 x 9-m star-shaped field with four spikes. The spikes and the centre of the field were each marked with pylons (height: 30 cm). During the test, subjects had to touch the top of the pylons at each respective spike and when traversing the centre position. Time was taken with a hand-held stopwatch (Casio HS-80TW, Japan), accurate to 0.01 s. Subjects performed one practice trial and thereafter two test trials with a five-minute rest in between. The best trial (i.e., least running time) was used for further data analysis.

Statistical analysis

Data analysed using SPSS version 29.0.2.0. To examine the independent and interactive effects of biological maturation and sport type on anthropometric and physical performance variables, a series of two-way Factorial ANOVAs was conducted. Biological maturation was modelled as a categorical factor with athletes stratified into seven discrete annual maturity bands centred around predicted Years from Peak Height Velocity (-3.5, -2.5, -1.5, -0.5, +0.5, +1.5, and +2.5 YPHV), mirroring established chronological-biological tracking intervals used in youth athlete development (Till et al., 2013). Due to the unequal sample sizes within the stratified maturity by sport groups (ranging from $n = 13$ to $n = 114$), all models were executed using Type III Sum of Squares to eliminate statistical bias, account for unbalanced group cells, and preserve the mathematical integrity of the F-distribution. Statistical significance was set *a priori* at $p \leq .05$. To evaluate the practical meaningfulness of the findings, effect sizes were calculated using partial eta-squared (η_p^2) and interpreted as small (0.01), medium (0.06), or large (0.14) (Field, 2013). Where significant main effects or interaction benefits were identified, pairwise comparisons were resolved using (Bonferroni) post-hoc analyses with appropriate mathematical adjustments for multiple comparisons.

Results

Main effects of biological maturation

The two-way ANOVA revealed significant main effects for biological maturation (YPHV) across all measured variables $p < .001$. Large effect sizes were observed for chronological age ($\eta_p^2 = .94$), APHV ($\eta_p^2 = .64$), and all anthropometric dimensions ($\eta_p^2 = .61$ to $.82$). Moderate effect sizes were noted for neuromuscular performance profiles, including handgrip strength ($\eta_p^2 = .65$), single-leg triple hops ($\eta_p^2 = .31$), 20-m sprint ($\eta_p^2 = .31$), agility ($\eta_p^2 = .36$), and vertical jump ($\eta_p^2 = .27$). Conversely, biological maturation exerted a small effect on cardiorespiratory endurance ($\eta_p^2 = .08$) and flexibility ($\eta_p^2 = .03$).

Main effects of sport type

Significant differences between team and individual sports emerged across multiple variables ($p < .05$); however, the magnitude of these differences was uniformly small ($\eta_p^2 = .04$), with the sole exception of the shuttle-run endurance test, which demonstrated a small-to-moderate effect ($\eta_p^2 = .07$).

Interaction effects

Significant maturation - sport type interactions were found for body mass, arm span, non-dominant triple hop, agility, vertical jump, and shuttle-run performance ($p < .05$). Crucially, all observed interaction effects were small ($\eta_p^2 = .02$ to $.04$), indicating that variations across maturity groups remained largely independent of sport classification. Full statistical matrices and pairwise comparisons are provided in Table 2.

Table 2. Tests of Between-Subjects Effects for Biological Maturation and Sport Type (Team vs. Individual) in Girls Aged 8–16

	Biological Maturation		Sport Type		Biological Maturation* Sport Type	
	<i>F</i> (<i>p</i>)	η^2	<i>F</i> (<i>p</i>)	η^2	<i>F</i> (<i>p</i>)	η^2
CA (years)	2288.34(***)	.94	4.19(*)	.01	.492(.81)	.003
APHV (years)	258.11(***)	.64	10.52(***)	.01	.430(.86)	.003
BM (cm)	283.23(***)	.66	36.32(***)	.04	4.17(***)	.03
Ht (cm)	629.15(***)	.81	9.83(**)	.01	1.86(.09)	.01
SH (cm)	652.43(***)	.82	4.60(*)	.01	1.25(.28)	.01
LL (cm)	227.68(***)	.61	6.53(*)	.01	1.35(.23)	.01
AS (cm)	446.10(***)	.75	1.34(.25)	.002	2.91(**)	.02
St&R (cm)	4.53(***)	.03	12.91(***)	.02	1.20(.31)	.01
HGS L (cm)	271.79(***)	.65	2.12(.15)	.002	1.87(.08)	.01
HGS R (cm)	294.03(***)	.67	5.26(*)	.01	1.77(.10)	.01
SB (sec)	1.62(.14)	.01	9.93(**)	.01	.31(.93)	.002
TH L (cm)	65.76(***)	.31	3.85(*)	.004	1.94(.07)	.01
TH R (cm)	65.42(***)	.31	.39(.53)	.00	2.62(*)	.02
JS (nr)	57.32(***)	.28	17.99(***)	.02	1.87(.08)	.01
20μ. (sec)	65.45(***)	.31	2.23(.14)	.003	1.03(.40)	.01
SART (sec)	82.31(***)	.36	6.62(**)	.01	2.80(*)	.02
JRT (cm)	52.81(***)	.27	1.59(.21)	.002	4.95(***)	.03
20mSRT (m)	12.79(***)	.08	61.05(***)	.07	5.62(***)	.04

Bonferroni adjustment: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

Partial Eta squared (η_p^2): Small ^(S) $\eta^2 = .01$ -.05, Medium ^(M) $\eta^2 = .06$ -.13, Large ^(L) $\eta^2 \geq .14$

Comparison of team and individual sports

Chronological age increased significantly across biological maturation categories for both team ($\eta_p^2 = .86$) and individual sports ($\eta_p^2 = .92$, $p < .001$). Two-way ANOVA revealed significant differences between sport types, though these variations consistently yielded small effect sizes ($\eta_p^2 = .01$). Specifically, biological age occurred earlier in team sport athletes at -0.5 YPHV ($p = .010$) and +0.5 YPHV ($p = .022$). For motor profiles, a maturity-dependent pattern emerged: individual-sport athletes outperformed team-sport athletes pre-PHV, whereas team-sport athletes excelled post-PHV. This shift was evident in the left single-leg triple hop at -2.5 YPHV ($p = .010$) versus +1.5 YPHV ($p = .009$), and in the vertical jump across -2.5 ($p = .003$), -1.5 ($p = .039$), and -0.5 YPHV ($p = .046$) versus +2.5 YPHV ($p = .002$). Full statistical indices are detailed in Table 3.

Percentage distribution of athletes by biological maturation within age categories

Team sports. Chi-square tests of independence revealed significant differences in the distribution of athletes across biological maturation categories (YPHV) within each chronological age group ($p < .05$). A clear maturational progression was observed with advancing chronological age: the dominant maturation status shifted from (-2.5) YPHV at age 9=.013, to (-2.5) and (-1.5) YPHV at age 10 $p < .001$, and (-0.5) YPHV at age 12 $p < .001$. This progression continued through early adolescence, with +0.5 YPHV becoming the predominant status at age 13, before clustering significantly at +1.5 YPHV by ages 15 and 16. Detailed frequency matrices and specific pairwise chi-square values are presented in Table 4.

Individual sports. Individual sports exhibited a parallel age-related progression in biological maturation, demonstrating highly significant distributional shifts within each chronological age cohort ($p < .001$). The dominant maturation status shifted systematically from (-3.5) YPHV at age 8, to (-2.5) YPHV at age 10, and (-1.5) YPHV by age 11. This biological advancement continued through early adolescence, with (-0.5) YPHV predominating at age 12, followed by a clear clustering at +0.5 YPHV at ages 13 and 14, and +1.5 YPHV by age 15. Complete pairwise chi-square matrices are detailed in Table 4.

Table 3. Anthropometric and physical fitness characteristics of youth female athletes (8-16 years old) by maturity offset group

	Team sports (N = 314)							Individual sports (N = 576)						
YPHV	-3.5 n = 40	-2.5 n = 36	-1.5 n = 42	-0.5 n = 53	+0.5 n = 60	+1.5 n = 70	+2.5 n = 13	-3.5 n = 105	-2.5 n = 114	-1.5 n = 90	-0.5 n = 94	+0.5 n = 90	+1.5 n = 67	+2.5 n = 16
Chronological age	8.88 ± 0.36	10.04 ± 0.38	11.10 ± 0.57 ^{***}	12.38 ± 0.65 ^{***}	13.83 ± 0.64 ^{***}	15.56 ± 0.70	16.48 ± 0.41	8.96 ± 0.49	9.99 ± 0.61 ^{***}	11.24 ± 0.60	12.34 ± 0.48 ^{***}	13.97 ± 0.58 ^{***}	15.60 ± 0.60	16.61 ± 0.25 ^{***}
Biological age (APHV)	12.29 ± 0.21	12.48 ± 0.33	12.74 ± 0.42	12.83 ± 0.53	13.90 ± 0.50 ^{***}	14.04 ± 0.53	14.25 ± 0.34	12.37 ± 0.38	12.56 ± 0.48 ^{***}	12.81 ± 0.50 ^{***}	13.03 ± 0.43 ^{***}	13.48 ± 0.46 ^{***}	14.19 ± 0.50	14.36 ± 0.21
BM (cm)	31.42 ± 1.77	37.03 ± 5.32 ^{***}	42.23 ± 5.42 ^{***}	55.00 ± 10.0 ^{***}	57.52 ± 8.36	60.67 ± 9.24	69.32 ± 9.39	30.42 ± 3.97	36.05 ± 5.91 ^{***}	42.30 ± 7.06	49.10 ± 7.83 ^{***}	55.31 ± 8.76	56.95 ± 6.37	58.16 ± 7.76
Ht (cm)	132.23 ± 3.0 ^{***}	143.47 ± 5.0 ^{***}	148.77 ± 4.19 ^{***}	158.45 ± 4.50 ^{***}	163.26 ± 5.26	163.02 ± 5.27	167.35 ± 2.92	132.38 ± 4.80	140.36 ± 5.35 ^{***}	149.09 ± 5.0 ^{***}	156.80 ± 5.16 ^{***}	160.83 ± 4.0 ^{***}	161.15 ± 6.0 ^{***}	167.00 ± 5.66 ^{***}
SH (cm)	68.40 ± 0.93	73.12 ± 3.13	75.65 ± 2.45 ^{***}	80.62 ± 3.42 ^{***}	83.68 ± 2.92 ^{***}	85.31 ± 2.58 ^{***}	87.46 ± 2.94	68.48 ± 2.78	71.92 ± 2.51 ^{***}	75.70 ± 2.85 ^{***}	80.51 ± 2.77 ^{***}	82.85 ± 2.41 ^{***}	84.21 ± 2.69 ^{***}	87.28 ± 1.35 ^{***}
LL (cm)	63.83 ± 2.65	70.34 ± 3.75	73.12 ± 3.05 ^{***}	77.83 ± 4.44 ^{***}	79.57 ± 4.31	77.71 ± 3.96	80.08 ± 2.05	63.89 ± 3.38	68.44 ± 4.04 ^{***}	73.39 ± 4.09 ^{***}	76.30 ± 3.99 ^{***}	77.98 ± 3.88 ^{***}	76.94 ± 4.69	79.73 ± 5.84
AS (cm)	130.84 ± 3.79	144.10 ± 7.0 ^{***}	148.90 ± 5.79 ^{***}	159.51 ± 5.06 ^{***}	164.84 ± 6.97 ^{***}	163.99 ± 6.09	164.89 ± 6.49	131.34 ± 5.74	140.61 ± 6.54 ^{***}	150.73 ± 6.76 ^{***}	158.08 ± 6.92 ^{***}	162.04 ± 6.0 ^{***}	162.27 ± 6.89	167.75 ± 7.77 ^{***}
S&R (cm)	1.20 ± 2.23	1.78 ± 7.26	0.11 ± 7.65	2.24 ± 7.36	2.51 ± 9.17	5.68 ± 9.15	6.50 ± 8.96	3.08 ± 7.64	4.95 ± 7.36 ^{***}	2.98 ± 7.88 ^{***}	5.65 ± 9.40 ^{***}	4.76 ± 9.48 ^{***}	4.64 ± 9.98	11.06 ± 4.78
HGS L (cm)	12.51 ± 1.75	16.37 ± 3.93	18.63 ± 3.89	23.44 ± 4.42	25.85 ± 3.17 ^{***}	27.78 ± 5.37	26.88 ± 3.43	12.62 ± 2.70	15.39 ± 2.71 ^{***}	17.94 ± 3.11 ^{***}	22.18 ± 3.71 ^{***}	24.64 ± 3.82 ^{***}	26.15 ± 4.13	29.51 ± 4.42 ^{***}
HGS R (cm)	13.28 ± 1.84	16.17 ± 3.89 ^{***}	19.39 ± 4.26 ^{***}	25.16 ± 4.80	27.27 ± 3.14	29.15 ± 5.11	29.28 ± 3.15	13.36 ± 2.62	15.91 ± 2.75 ^{***}	19.03 ± 3.09 ^{***}	23.37 ± 4.10 ^{***}	25.74 ± 3.96 ^{***}	27.10 ± 4.08	30.11 ± 4.81
SB (sec)	3.93 ± 2.13	5.25 ± 3.54	6.59 ± 6.64	5.51 ± 4.44	6.78 ± 5.73	6.83 ± 6.26	6.10 ± 3.67	5.64 ± 5.14	8.51 ± 11.98 ^{***}	7.53 ± 11.87 ^{***}	8.23 ± 9.99 ^{***}	8.85 ± 11.12	8.06 ± 8.27	9.72 ± 6.39 ^{***}
THL (cm)	315.75 ± 35.13	334.17 ± 60.76	379.64 ± 63.45	414.53 ± 57.40	425.42 ± 68.82	443.86 ± 57.41	440.77 ± 49.24	326.00 ± 65.93	366.62 ± 60.21 ^{***}	383.28 ± 59.32	427.82 ± 60.42 ^{***}	427.94 ± 59.05	426.72 ± 64.14	463.75 ± 45.15
THR (cm)	317.75 ± 34.29	343.19 ± 61.41	387.98 ± 61.68	426.98 ± 59.39	434.67 ± 67.85	452.93 ± 59.10	451.54 ± 40.59	330.62 ± 61.47	372.94 ± 57.68 ^{***}	389.89 ± 65.92	433.46 ± 59.94 ^{***}	427.11 ± 62.55	425.90 ± 66.78	456.87 ± 24.42
JS (m)	32.88 ± 3.62	35.53 ± 4.33	39.05 ± 4.95	40.09 ± 5.34	42.08 ± 6.44	44.20 ± 6.31	45.00 ± 4.49	30.87 ± 6.41	34.46 ± 5.96 ^{***}	36.64 ± 5.57 ^{***}	39.37 ± 5.22 ^{***}	41.11 ± 4.89	39.64 ± 5.64	43.19 ± 1.94
20μ (sec)	4.30 ± 0.21	4.15 ± 0.39	3.97 ± 0.33	3.78 ± 0.26	3.68 ± 0.31	3.60 ± 0.30	3.63 ± 0.33	4.21 ± 0.43	4.03 ± 0.37 ^{***}	3.94 ± 0.31	3.70 ± 0.28 ^{***}	3.66 ± 0.27	3.66 ± 0.28	3.63 ± 0.08 ^{***}
SART (sec)	23.63 ± 2.21	21.71 ± 1.64	20.68 ± 1.89	19.43 ± 1.50 ^{***}	18.63 ± 1.40	18.43 ± 1.47	18.22 ± 0.64	23.12 ± 3.03	21.65 ± 2.15 ^{***}	20.97 ± 1.98	19.72 ± 1.54 ^{***}	19.62 ± 1.86	19.61 ± 1.69	18.95 ± 0.93
JRT (cm)	21.85 ± 2.55	23.19 ± 5.65	25.24 ± 5.72	27.96 ± 5.59	32.72 ± 6.57 ^{***}	36.29 ± 7.94 ^{***}	34.54 ± 5.32	24.02 ± 6.33	26.85 ± 6.30 ^{***}	27.71 ± 7.27 ^{***}	30.16 ± 6.40 ^{***}	31.41 ± 6.69	32.85 ± 6.23	33.44 ± 7.02
20mSRT (m)	495.00 ± 165.78	499.44 ± 198.48	485.24 ± 158.90	485.28 ± 198.00	603.67 ± 206.03	666.86 ± 277.11	612.31 ± 222.94	538.48 ± 220.01	597.19 ± 262.07 ^{***}	606.44 ± 227.68 ^{***}	757.87 ± 374.36 ^{***}	648.22 ± 250.84	745.37 ± 270.61	1087.50 ± 220.29 ^{***}

Bonferroni adjustment: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$

Partial Eta squared (η_p^2): Small (^S) $\eta_p^2 = .01$ -.05, Medium (^M) $\eta_p^2 = .06$ -.13, Large (^L) $\eta_p^2 \geq .14$

Team sport: ^oSignificant difference from previous maturity offset

Individual sport: [@]Significant difference from previous maturity offset

Difference between team and individual sports between similar maturity offset: [&]

Table 4. Chi-Square Test of Independence for the Percentage Distribution of Biological Maturation Categories Across Chronological Ages in Female Individual and Team Sport Athletes

Chronological age	Team sports								Individual sports							
	n	-3.5	-2.5	-1.5	-0.5	+0.5	+1.5	+2.5	n	-3.5	-2.5	-1.5	-0.5	+0.5	+1.5	+2.5
8.0-8.9	31	31 (100%)							60	53 (88.3%)	7 (11.7%) @1***					
9.0-9.9	32	9 (28.1%)	23 (71.9%) O1*						99	51 (51.5%)	48 (48.5%)					
10.0-10.9	34		13 (38.2%)	19 (55.9%)	2 (5.9%) O2**, O1***				95	1 (1.1%)	56 (58.9%) @1***	37 (38.9%) @1***, @2*	1 (1.1%)			
11.0-11.9	32			19 (59.4%)	13 (40.6%)				56		3 (5.4%)	43 (76.8%) @2***	10 (17.9%)			
12.0-12.9	40			4 (10%)	28 (70%) O3***	8 (20%) O4***			82			9 (11%)	70 (85.4%) @3***	3 (3.7%) @4***		
13.0-13.9	41				10 (24.4%)	29 (70.7%) O4**	2 (4.9%) O4*, O3***		61			1 (1.6%)	13 (21.3%) @1***	47 (77%) @3.5, @4***		
14.0-14.9	35					20 (57.1%)	15 (42.9%)		50					38 (76%)	12 (24%) @5***	
15.0-15.9	31					3 (9.7%)	26 (83.9%) O5***	2 (6.5%) O6***	38					2 (5.3%)	36 (94.7%) @5***	
16-16.9	38						27 (71.1%)	11 (28.9%) O6**	35						19 (54.3%)	16 (45.7%)

*p ≤ .05, **p ≤ .01, ***p ≤ .001

Team sports: ^OSignificant difference between different maturity offset groups (coding for the maturity offset groups: -3.5 = 1, -2.5 = 2, -1.5 = 3, -0.5 = 4, +0.5 = 5, +1.5 = 6, +2.5 = 7 [for example, difference between -3.5 and -1.5 (O1), or between -2.5 and -1.5 (O2)])

Individual sports: [@]Significant difference between different maturity offset groups (similar approach as in team sports)

Discussion

The present study aimed to: (a) examine the influence of biological maturation status on anthropometric and physical performance characteristics in girls aged 8–16 years; (b) investigate the interaction between biological maturation and sport type (individual vs. team sports); and (c) determine the percentage distribution of biological maturation categories across chronological ages. The findings provide a large-scale descriptive mapping of how biological maturation influences anthropometric and physical performance profiles in female youth athletes. Crucially, our findings demonstrate that biological maturation exerts a dominant influence across nearly all anthropometric and performance variables, with exceptions limited to static balance and flexibility, whereas the independent effect of sport type is considerably more subtle. Furthermore, although the interaction between maturation and sport type achieved statistical significance within specific metrics, namely body mass, arm span, triple jump R, CODS, jump and reach test, and cardiorespiratory endurance, these effects were uniformly small. Consequently, while these significant interactions prove that maturational differences are not identical across sporting contexts, the small magnitude of the effects suggests that the sporting environment acts as a minor modulating factor rather than a primary driver of variance.

Anthropometric characteristics

Maturity-associated variations in body size align closely with baseline biological timelines rather than being shaped by the type of sport practiced. Our findings indicate that biological maturation was strongly associated with anthropometric characteristics around the peak height velocity window (-0.5 and +0.5 YPHV) in female youth athletes, with team sport participants demonstrating a statistically earlier APHV at both maturity status. Furthermore, female team sport athletes consistently exhibited higher values in several anthropometric dimensions compared to their individual sport counterparts across multiple maturity statuses. This advanced maturation observed in team sports aligns with recognized systemic selection biases that favour physically mature female athletes (de la Rubia et al., 2024; Patel et al., 2020). In disciplines where body height and leg length are critical performance determinants, such as basketball and volleyball, advanced biological maturation often emerges as a contributing factor for the selection of female athletes into development programs (Leyhr et al., 2024). For instance, contemporary evidence from elite youth volleyball suggests that up to 69% of the variance in structural metrics, such as body height, body mass, and sitting height, can be explained by maturity-associated physical characteristics (Cular et al., 2025).

However, although team sports tend to select early-maturing girls for a distinct competitive advantage (Koziel et al., 2024), we found that this athletic environment merely modulates anthropometric profiles across different maturity groups rather than inducing a profound, sport-driven remodelling of somatic growth. Because the sport-type interactions in this cohort were consistently minimal, these variations represent a minor phenotypic modulation rather than a structural biological shift. Given our cross-sectional design, these differences reflect specific maturity-associated stratification rather than definitive, long-term growth trajectories.

Consequently, the structural demands of a sport function merely as a secondary filter that slightly modifies group distribution profiles. The athletic environment does not overwrite the dominant biological trajectory of female adolescence; natural biological development remains the primary driver of anthropometric characteristics, leaving external sporting factors to play a minor, descriptive role (Malina et al., 2015).

Interaction between biological maturation and sport type

The interaction between biological maturation and sport type revealed that physical performance characteristics varied across the distinct maturity groups, rather than following a strict linear progression. Rather than showing a continuous step-like ascent, the cross-sectional performance profiles displayed fluctuating patterns, characterized by marked differences between certain maturity statuses and comparative stability in others, particularly surrounding the PHV window. The data suggest that while the type of sport introduces minor adjustments to an athlete's physical profile, the overarching performance variances remain fundamentally anchored to the primary, large-scale effects of biological maturation.

Regarding the flexibility profiles in girls, performance demonstrated a non-linear pattern across maturity groups, which may reflect the emerging complexity of neuromuscular control during female adolescence (Malina et al., 2004). Notably, the findings of the present study display distinct patterns from the longitudinal trends reported by Castro-Piñero et al. (2013) concerning late adolescence; while those authors reported a stabilization of flexibility during later growth stages (14–17 years old), our cross-sectional maturity cohorts demonstrate higher mean values in the more biologically advanced groups. Of particular interest are the periods of flexibility stabilization in relation to biological maturation. In team sport athletes, performance plateaus are confined to a narrow window surrounding PHV (± 0.5 years), whereas individual sport athletes exhibited a prolonged period of lower performance variation extending up to 1.5 years post-PHV. Similarly, static balance performance demonstrated non-linear differences across the investigated maturity groups, which could theoretically align with the transient phenomenon of adolescent clumsiness, where rapid anthropometric growth is often associated with temporary disruptions in motor coordination (Malina et al., 2004). Nevertheless, given the small statistical magnitudes for sport type, these non-linear differences across maturity stages reflect minor anthropometric and physical variations rather than profound neuromuscular reorganizations.

The pre-PHV stage was characterized by higher mean values in speed, CODS, and power, particularly among individual-sport athletes. These findings support the consensus identifying the pre-adolescent phase as a critical window for neuromuscular development (Lloyd et al., 2014). When comparing maturity groups, performance disparities narrowed as athletes approached PHV. Several variables plateaued or exhibited diminished cross-sectional differences; this stabilization trend was most notable among individual sport athletes (e.g., St&R, SB, THR & THL, SART, and 20mSRT). This pattern may reflect the neuromuscular adjustments required during periods of rapid somatic growth (Lloyd et al., 2014). Subsequently, lower mean values in most physical capacities were observed post-PHV (approximately +1.5 YPHV), which might tentatively support the hypothesis that rapid linear growth may temporarily outpace motor coordination and proprioceptive control. While team sport athletes demonstrated consistently lower speed performance across maturity groups, individual sport athletes exhibited substantial performance fluctuations between the investigated categories. Within the latter, an initial sprint peak was identified early, between -3.5 YPHV (8.96 years) and -2.5 YPHV (9.99 years), whereas the most substantial performance surge occurred during the pre-PHV stage, between -1.5 YPHV (11.24 years) and -0.5 YPHV (12.54 years). This discrepancy suggests that speed in female individual sport athletes is strongly linked to biological readiness and the neuromuscular maturation that typically precedes the PHV threshold (Lloyd & Oliver, 2012). Conversely, the lack of biological confirmation in team sports may be attributed to the multidimensional nature of training stimuli, which are typically less focused on isolated linear speed and instead introduce more varied physical demands. Consequently, performance improvements in team-based disciplines appear to reflect a broader integration of chronological age, training volume and multi-directional competitive exposure rather than being solely defined by specific biological milestones (Meyers et al., 2017). Additionally, speed differences between team and individual sports were independent of sport classification. This pattern is consistent with previous cross-sectional evidence regarding chronological differences in youth sports (Velentza et al., 2026), suggesting that performance variations align primarily with a dominant biological timeline that uniformly shapes sprint performance regardless of athletic background.

In contrast, team sport athletes tended to demonstrate higher mean scores in explosive and strength-related capacities beyond PHV, suggesting that sport-specific training demands may extend or influence periods of adaptation. Specifically, for the vertical jump (JRT), the peak occurred later in team sport athletes, with an initial surge identified between -0.5 and +0.5 YPHV (13.83 years), followed by a secondary peak between +0.5 and +1.5 YPHV (15.56 years). Regarding horizontal power (TH L or R and JS), team sport athletes exhibited an initial peak between -2.5 and -1.5 YPHV (10.04 years). Notably, a secondary performance surge was recorded exclusively for the dominant (right) lower limb between -1.5 and -0.5 YPHV (12.38 years). Conversely, in individual sport athletes, higher mean power values in both the horizontal and vertical axes manifested significantly earlier than in team sports, with marked descriptive differences noted between -3.5 and -2.5 YPHV

(8.96 years). These findings suggest that the maturational timing of power development is axis-specific across maturity groups, while slightly modulated by the sport-specific mechanical demands.

This later, localised performance peak observed in team sport athletes (± 0.5 YPHV), compared to the premature surge in individual sports, suggests a more distributed performance pattern across maturity brackets, rather than an altered biological alignment. Although the continuous jumping and landing demands of team-based disciplines such as volleyball and basketball, may provide multifaceted training stimulus during the pubertal transition (Faigenbaum et al., 2013); and the systematic exposure to high volumes of plyometric patterns in team sports (Lloyd et al., 2011; Zhu et al., 2025) appears to offset potential performance regressions associated with adolescent clumsiness; our statistical indicators prove that the sporting environment functions merely as a secondary filter rather than a primary driver. Individual sport athletes may rely on early neural adaptations (Lloyd & Oliver, 2012) that display comparative stability in later maturity stages, whereas the sporting environment in team disciplines slightly shifts the descriptive expression of physical performance across female youth maturity cohorts without rewriting baseline biological growth timelines. Ultimately, while individual and team sports present distinct descriptive variations in speed and power across maturity cohorts, these patterns are ultimately governed by a dominant biological timeline rather than sport-specific training demands.

Regarding CODS, similar mean values were observed in both team and individual sport athletes during the early stages, characterized by two distinct peak periods (-3.5 to -2.5 YPHV and -1.5 to -0.5 YPHV). These findings align with prior evidence suggesting that CODS performance improves progressively before and during puberty in girls (Lloyd et al., 2013). Such variations are frequently hypothesized to reflect enhanced neuromuscular control and the optimization of intra- and inter-muscular coordination resulting from central nervous system maturation during the pre-pubertal period (Viru et al., 1999). However, a diverging trend emerged thereafter. In team sport athletes, higher mean performance values were maintained beyond the +0.5 YPHV stage (13.83 years), albeit at a diminishing rate. In contrast, the individual sports cohort experienced an early performance plateau between -0.5 and +1.5 YPHV, before showing higher performance scores at the +2.5 YPHV milestone. This divergence could be attributed to the specialized nature of team sports, which necessitates the systematic integration of complex motor, cognitive, and perceptual-cognitive stimuli (Mann et al., 2007). Continuous exposure to explosive multidirectional actions and strength-oriented training may attenuate the temporary performance constraints typically associated with rapid maturation (Moran et al., 2018; Retzepis et al., 2025). Consequently, these maturity-specific profiles suggest that while neuromuscular maturation dictates early performance, the multidimensional stimuli of team sports may provide a stabilizing effect on motor efficiency during post-pubertal stages.

Furthermore, the higher performance scores and later plateau patterns observed across the older team sport athletes contrasting with earlier findings in female youth cohorts (Emmonds et al., 2020), likely reflect differences in training volume, competitive structure, and long-term athletic development pathways. Regular engagement with variable movement patterns may enable team sport athletes to maintain neuromuscular proficiency, potentially mitigating the performance stagnations often observed in more standardized or closed-skill training environments (Albaladejo-Saura et al., 2021; Lloyd & Oliver, 2012). Ultimately, while sport-specific demands induce these localized variations, baseline biological maturation remains the primary anchor of CODS variance across the entire sample. Ultimately, while sport-specific stimuli and training volumes modulate these localized variations, baseline biological maturation remains the primary anchor governing physical profiling across all female youth cohorts.

Regarding isometric handgrip strength, the findings indicate that both team and individual sport athletes exhibited synchronized maturational peaks between -1.5 and -0.5 YPHV (11.10-12.38 years for team sports and 11.24-12.54 years for individual sports, respectively). This convergence suggests that isometric strength is influenced by the morphological and hormonal shifts preceding the PHV period (Malina et al., 2004; Vaeyens et al., 2006). Notably, while the onset of this peak (-1.5 YPHV) aligns with international literature, its completion at -0.5 YPHV occurred prematurely compared to previous data placing the maximal strength increment between +0.5 and +1.0 YPHV (Ford et al., 2011; Meyers et al., 2015). Additionally, in team sport athletes, higher mean values were maintained until the +0.5 YPHV stage, followed by a performance plateau after +1.5 YPHV. In contrast, the individual sports cohort demonstrated higher mean strength values extending up to the +2.5 YPHV. This continued upward trend post-PHV, particularly in individual athletes, likely reflects the influence of specialized training stimuli and the specific isometric strength demands inherent to these disciplines (Friedmann, 2007; Retzepis et al., 2025). Notably, these differences challenge traditional perspectives (Malina et al., 2004), which posited that female muscular development is strictly limited during puberty due to the comparatively lower anabolic effect of oestrogens. Furthermore, our findings diverge from reports suggesting that female strength performance typically stabilizes around age 14 (Armstrong & van Mechelen, 2023). Instead, the present study demonstrates that while biological maturation remains the primary driver behind these continuing higher strength profiles. While the athletic environment should not be seen as a major factor that changes natural growth, regular sports training helps maximize biological potential (Lloyd & Oliver, 2012). It

slightly modifies fitness profiles across different maturity groups, ensuring that strength characteristics do not plateau early, while the basic biological development of female youth remains primary.

In contrast to the uniform cardiorespiratory endurance profiles observed across maturity groups in team sports, individual sport groups presented distinct variation, characterized by higher mean scores in pre-PHV and late post-PHV categories. This cross-sectional pattern suggests that variations in female aerobic capacity are not a mere by product of biological maturation (Malina et al., 2004), but are likely associated with the specialized training demands of individual disciplines. Furthermore, these maturity-specific differences indicate that cardiorespiratory profiles in females display structural variations even in post-pubertal cohorts (Armstrong & Welsman, 2019; Tomkinson et al., 2019). Conversely, higher body mass and adiposity in team sport cohorts during and after PHV may explain their stabilized aerobic performance scores (Silva et al., 2012). Within this context, cardiorespiratory endurance demonstrates a distinct baseline pattern where both sport classification and biological maturation concurrently shape the physical profile (Armstrong & Welsman, 2019; Emmonds et al., 2020). In conclusion, both the sport environment and biological maturation status introduce moderate modifications in shaping the cardiorespiratory capacity profiles across female youth cohorts.

Ultimately, the present study provides a large-scale descriptive mapping that underscores biological maturation as the primary and dominant driver shaping the anthropometric and physical performance profiles of female youth athletes. Concurrently, the independent influence of sport type and its interaction with maturation status present highly selective, minor modulations characterized by small statistical effect sizes across nearly all examined variables. The sole exception is cardiorespiratory endurance, where both biological maturation and sport type demonstrate a medium effect size, highlighting a greater contextual sensitivity of cardiorespiratory profiles to specific training environments. Given the cross-sectional nature of this investigation, these differences reflect maturity-associated stratification rather than definitive growth timelines. Consequently, these non-linear variations must be interpreted with caution. They should not be overextended as definitive developmental trajectories, long-term athlete pathways, or profound physiological stabilizers during the pubertal transition (Moran et al., 2018). Instead, the evidence indicates that while the biological maturation status remains the primary driver shaping physical profiles in female youth athletes, the distinct physical and mechanical demands of team and individual disciplines function merely as minor modulating factors. While regular sports training plays a critical role in maximizing biological potential (Lloyd & Oliver, 2012), the athletic environment ultimately modifies specific anthropometric and physical performance profiles only slightly, without fundamentally altering or restructuring the natural biological growth of female adolescents.

Variability in biological maturation across chronological ages

The percentage distribution analysis revealed substantial inter-individual heterogeneity in biological maturation, which emerges as early as age 8 in individual sports and age 9 in team sports. Notably, athletes of the same chronological age were distributed across multiple YPHV stages, with differences reaching two or more biological years within the same age group. While the critical window of maximal diversity is identified between ages 10 and 13, this variability unexpectedly persists through mid-adolescence, as evidenced by the maturational spread observed at age 15 in team-based disciplines. This finding reinforces existing literature suggesting that biological maturation does not follow a uniform or linear pattern relative to chronological age (Malina et al., 2004). The high variability observed during early and mid-adolescence highlights the limitations of age-grouped training and competition structures that overlook substantial biological differences among athletes of the same chronological age. Furthermore, the distribution patterns further suggest that the period of maturational differences extends beyond traditionally cited PHV windows in girls (e.g., Tanner et al., 1966) and continue into mid-adolescence. Such sustained developmental variation supports the critical value of continued biological monitoring beyond the onset of puberty to ensure appropriate athletic progression (Till et al., 2017).

Limitations

This study has several limitations that warrant acknowledgment. First, the cross-sectional design precludes definitive causal inferences regarding developmental trajectories; however, establishing this comprehensive baseline across a wide maturity spectrum offers a valid framework for generating longitudinal hypotheses.

Second, estimating biological maturation via the Mirwald equation introduces known precision limitations at the individual level, particularly in females (Malina et al., 2012). Nevertheless, this methodological uncertainty was heavily mitigated by our substantial sample size ($N = 890$), which minimizes individual-level residual errors (Hopkins et al., 2009), and our use of discrete annual maturity cohorts (from -3.5 to +2.5 YPHV) rather than continuous, hyper-sensitive modelling (Till et al., 2013). This structural approach ensures that group-level classifications remain statistically robust.

Third, the binary classification of team vs. individual sports introduces within-group heterogeneity in training demands and physical profiles, potentially confounding sport-specific training effects with biological maturation. To control for this, sport groupings were structured around established locomotor taxonomies (Febrianty et al., 2024), and our models utilized Type III Sum of Squares to protect statistical integrity against unequal cell sizes and data skewing.

Finally, unmeasured confounding variables, such as precise training loads, chronological training age, and baseline hormonal status, were not controlled. Future research should utilize longitudinal designs with repeated measures and combine predictive equations with direct somatic or skeletal validation to further refine these interactions.

Practical implications

The results of the current study support the implementation of maturity specific profiling within female youth athlete evaluation models. The substantial variability within maturity groups indicates that designing training sessions based solely on chronological age may be insufficient and potentially counterproductive. To address this, practitioners should adopt **bio-banding strategies** (Malina et al., 2019), which can reduce maturity-related selection bias, ensure equitable competition, and enhance long-term athlete development (Cumming et al., 2017). Practitioners should give particular attention to the period around -0.5 to +0.5 YPHV. During this period of rapid somatic growth, the risk of adolescent clumsiness and associated injury is heightened due to temporary disruptions in neuromuscular coordination (Lloyd et al., 2014). Consequently, training programmes during this window should emphasise movement quality, neuromuscular control, and progressive load management rather over maximal performance outputs. While team sports may offer a multidimensional stimulus that stabilizes performance during the pubertal transition, individual sport athletes demonstrate distinct physical profiles in both strength and cardiorespiratory endurance.

Furthermore, coaches should recognize that, in female sports, physical performance profiles are driven primarily by biological maturation rather than the type of sport. The sporting environment acts only as a minor filter, causing minimal variations across maturity groups. Rather than viewing the athletic environment as a primary driver that alters baseline growth, coaches should interpret sport-specific demands as a secondary refining filter of physical performance in youth female athletes. Regular biological monitoring non-invasive tracking tools should therefore extend beyond the onset of puberty and continue through mid-adolescence to ensure that training and competitive tasks are aligned with the athlete's actual maturational status (Lloyd et al., 2016; Myer et al., 2013). Future longitudinal research incorporating hormonal markers and precise training-load monitoring would strengthen our understanding of the complex interactions between maturation and performance.

Conclusion

Biological maturation represents a primary and central determinant shaping the anthropometric characteristics and physical performance profiles in female youth academy athletes, whereas sport type played a minor, selective role. The descriptive differences, earlier maturation and greater body size in team sport athletes appear to reflect both natural biological fluctuations and maturity-related selection dynamics within youth sport systems. Physical performance profiles followed non-linear, maturity-dependent trajectories, including temporary disruptions around PHV and sport-specific adaptations across adolescence. This maturational heterogeneity emerges as early as ages 8–9, reaches its absolute peak during the critical window of 10–13 years, where same-age athletes are simultaneously dispersed across different biological stages, and unexpectedly persists until age 15 within team disciplines. Beyond immediate field applications, this study challenges the foundational design of youth sports by demonstrating, across a large cohort of 890 athletes, that biological maturation exerts a primary influence on anthropometry and physical performance, whereas the distinct effects of sport type remain secondary and limited in magnitude.

Consequently, grouping athletes strictly by birth year creates an ineffective system that leads to a major loss of athletic talent, wasted financial investments in academy infrastructure and an inadequate framework for evaluating, ranking or even guiding athlete development in female youth sports. The empirical evidence provided herein serves as a direct catalyst for reform, allowing sports organizations to shift from chronological age to biological tracking to optimize talent retention and reduce injury-related dropouts.

Although the present cross-sectional design inherently provides a static snapshot of maturational distribution rather than tracking individual growth velocities over time, its profound utility lies in mapping systemic macro-trends and identifying the critical age windows where organizational interventions are most urgently required. Taken together, these findings support the systemic integration of maturity-informed training, evaluation, and talent identification practices. While the implementation of bio-banding and individualized progression strategies presents a proven, credible, and applicable solution to reduce maturity-related bias, further longitudinal research is necessary to validate these cross-sectional benchmarks and strengthen long-term athlete development pathways. Advancing the field through multi-year longitudinal designs that incorporate hormonal markers and precise training-load tracking will provide the youth sport industry with robust predictive modelling tools, ultimately allowing athletic organizations to construct highly efficient, injury-resilient, and sustainable developmental pathways that maximize the athletic longevity of youth female athletes.

Author Contributions

CrediT: **Elisavet Velentza**: Conceptualization, Supervision, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Writing – original draft, Writing - review & editing; **Charilaos Tsolakis**: Conceptualization, Supervision, Validation, Writing – review & editing; **Maria Maridaki**:

Conceptualization, Supervision, Validation; **Georgios Andronikos**: Conceptualization, Supervision, Validation; **Nikolaos Apostolidis**: Conceptualization, Supervision, Validation.

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