

The blueprint for athlete development in greece: developmental trajectories of Youth Athletes

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Abstract:

Problem Statement: Understanding the differences in the developmental trajectories of young athletes in team and individual sports is essential for supporting effective athlete development. **Purpose:** The aim of this study was to identify the developmental trajectories and rates of change in the anthropometric and physical performance characteristics of 2,191 academy competitive-level athletes (boys n = 1,046; girls n = 1,145) aged 6–16 years participating in team sports (basketball, handball, football, and volleyball) and individual sports (track and field, gymnastics, swimming, tennis, karate, judo, and fencing). **Approach:** Anthropometric (height, weight, sitting height, arm span, and leg length) and physical performance characteristics (stand-and-reach test, 20 m sprint, jump-and-reach test, handgrip strength, 20 m shuttle run test, star agility test, and stork balance stand test) were evaluated. Factorial ANOVA with Bonferroni correction for multiple comparisons was applied to anthropometric and physical performance characteristics to identify differences regarding age, gender and sport type. Statistical significance was set at $p \leq .05$, and effect size was estimated using η^2 . **Results:** The present study indicated that boys and girls performed similarly until early adolescence, after which boys displayed significantly greater gains in strength, sprinting, and power, while girls retained advantages in flexibility and balance. Differences between team and individual sports were generally small but age dependent. Team-sport participants (particularly girls) tended to outperform their peers in change of direction and shuttle-run tests from approximately 13 years onward. Athletes in individual sports displayed advantages in flexibility and balance at younger ages. **Conclusions:** The similar patterns across sport types before adolescence reinforce the idea that maturational status, rather than sport participation per se, drives early physical development.

Keywords: - anthropometry, physical performance, team sports, individual sports, academy level

Introduction

Understanding the developmental trajectories of young athletes is crucial for facilitating effective athlete development. Growth and maturation are complex and multifaceted processes influenced by both genetic and environmental factors (Georgiades et al., 2017). Even when athletes have similar opportunities and training environments their trajectories may differ significantly indicating that reaching at high-level in sport is not necessarily attainable for every individual (Barth et al., 2022). Interestingly, literature has shown that athletes with less favourable genetic predispositions can reach at high-level when supported by environments that foster holistic long-term development (Guth & Roth 2013; Georgiades et al., 2017). These findings demonstrate the idiosyncratic nature of athlete development highlighting the importance of a long-term focus approach. These trajectories can also be positioned within athlete development models such as the Long-Term Athlete Development (LTAD) (Balyi et al., 2013), the Developmental Model of Sport Participation (DMSP) framework (Côté & Fraser-Thomas, 2007), and the Youth Physical Development Model (YPDM) (Lloyd et al., 2015). These theoretical frameworks emphasise the interaction of growth, maturation, training experience, and training in nurturing the athletic potential. While such frameworks provide useful insights, researchers have suggested that they need to be considered when applied in various contexts instead of adopting an ‘one size fits all’ approach (Bailey & Collins, 2013). By unravelling the nature of developmental trajectories, sport systems can implement a more balanced and holistic approach that promotes long-term athlete welfare (Côté & Vierimaa, 2014).

During the early stages of the athlete development pathway, predictable patterns of growth can be observed in anthropometric and physiological characteristics, although the development rates may vary (Towilson et al., 2018). The relationship between maturation and these traits is dynamic and asynchronous (Towilson et al., 2018), while development is largely linear throughout childhood and mid-adolescence, nonlinear progression emerges around the pubertal growth spurt (De Miguel-Etayo et al., 2014; Golle et al., 2015; Towilson et al., 2018). Regarding anthropometric characteristics, significant sex-based differences do not appear to exist

between the ages of 11 and 13 (Beenakker et al., 2001). However, discrepancies in height and weight typically become evident after age 13 (Beenakker et al., 2001; Mendez-Rebolledo et al., 2022), with some research places this differentiation at age 14 for height and age 15 for weight (Temfemo et al., 2008).

Moreover, gender differences develop during this period, with boys typically demonstrating greater speed, strength, power and endurance, whereas girls tend to develop flexibility and balance at faster rates resulting in temporary performance advantages in these traits (De Miguel-Etayo et al., 2014; Woll et al., 2011). Specifically, a linear increase in muscle strength is observed in boys up to 13–14 years of age, followed by an accelerated growth phase extending to age 18. In contrast, for girls, the rate of development typically remains linear until age 15, reaching a stabilization point at approximately 16 years (Malina et al., 2004). Improvements in jumping performance emerge as early as age five (Viru et al., 1999), following a non-linear trajectory throughout the pubertal transition (Malina et al., 2004). By age 14, significant gender-based divergence in vertical jump metrics [squat jump (SJ) and countermovement jump (CMJ)] is firmly established, with boys exhibiting substantial superiority in explosive power (Martin et al., 2004; Temfemo et al., 2008). The peak rate of speed development in boys, occurs between ages 11.8 and 15.8, aligning with the period surrounding Peak Height Velocity (PHV; typically occurring at ~13.5–14.0 years) (Towlson et al., 2018).

Conversely, in females, biological maturation (estrogen-driven increases in fat mass) imposes significant mechanical and metabolic constraints (Malina et al., 2004), resulting in performance decreases after age 12.7 (Nagahara et al., 2019), particularly the disproportionate concentration in the lower body (Papai et al., 2012), hinders power production. On the other hand, literature indicates that change of direction speed (CODS) develops non-linearly during childhood and adolescence (Chiodera et al., 2008; Eisenmann & Malina, 2003; Vääntinen et al., 2011). Longitudinal data indicate substantial, continuous CODS gains in boys throughout the 11–16 age range, with particularly significant improvements observed between ages 13 and 16 before stabilizing after age 16 (Vääntinen et al., 2011). In contrast, female athletes follow a markedly different trajectory, typically reaching a performance plateau between ages 12 and 14 (Lloyd et al., 2013). While CODS gaps become statistically significant later, between ages 13 and 14 (Uzun et al., 2020). Furthermore, aerobic capacity is predominately age dependent for boys while girls are influenced by their age and body weight (Silva et al., 2012). This developmental trajectory initiates in early childhood (ages 6–9), where boys already demonstrate statistically significant superiority in cardiorespiratory endurance compared to girls (De Miguel-Etayo et al., 2014). The most pronounced physiological shifts occur as athletes transition into early adolescence, typically between ages 11–13 for girls and 13–15 for boys (Mirwald & Bailey, 1986). This growth rate in males only begins to decline between ages 16 and 18, aligning with the natural deceleration of somatic growth trajectories (Armstrong & Welsman, 2019c).

On the other hand, flexibility is influenced by gender demonstrating a decline in boys during mid-adolescence and slightly increasing in girls until it plateaus around the ages of 14–15 (Malina, 1994; Woll et al., 2011; Medeiros et al., 2013). As the youth athletes grow (post-adolescence), research has shown that the development curve follows a curvilinear trend (Tingelstad et al., 2025). While static balance develops until age 12, findings on adolescent superiority are conflicting, with some studies report comparable performance between children (ages 7–10) and early adolescents (ages 11–13) (Hatzitaki et al., 2002), while others identify a clear advantage driven by sensory maturation (Steindl et al., 2006). Empirical evidence shows a persistent female advantage in postural stability during childhood (ages 4–12), with significant gender differentiation emerging between ages 10 and 13 before stabilizing during later maturation (Khanna et al., 2015).

The multitude of differences can also be explained by the type of sport as this is another factor that has an impact on the development of skills such as cognitive-perceptual (Williams, 2000), tactical (Gabbett et al., 2007), technical (Duthie et al., 2005), and physiological (Cunningham et al., 2016; Read et al., 2016). In many cases, differences have been identified between athletes competing in individual sports and team sport athletes. For example, gymnasts demonstrated better balance compared to team sports athletes which is explained by their training practice and the nature of the sport itself (Bressel et al., 2007; Davlin, 2004; Matsuda et al., 2008). Similarly, football training supplemented with complex training (Thapa et al., 2021) or with different strength training programs can facilitate the improvement of CODS as this is an integral part of the sport (Hammami et al., 2017). Therefore, it could be argued that experiences in different sports can provide young athletes with important skills abilities that are transferable from one sport to another (Baker et al., 2003). Research suggests that the exposure to multiple sports and movement patterns during the early stages of development can facilitate the creation of broader motor, physical, and cognitive skills (Coutinho et al., 2015), that can be transferred to an athlete's primary sporting discipline at a later stage of their development (Collins et al., 2014). This highlights the interrelated link between growth, maturation, and sport-specific training in cultivating the development of key physical performance characteristics of young athletes. However, there is a notable research gap regarding the divergent developmental trajectories of anthropometric and physical performance characteristics between team and individual sports from childhood through mid-adolescence. Specifically, the exact period in which maturational development takes place, at what rate and which elements vary between young athletes, particularly between the ages of 11 to 16 years for boys and 10 to 15 years for girls, needs further investigation (De la Rubia et al., 2024).

Despite a considerable body of literature in the area, to the author's knowledge there are no studies available that examine the developmental trajectories of anthropometric and physical performance characteristics in Greek youth athletes. More specifically, the influence of gender differences, and sport type (team vs. individual) on growth patterns and physical performance characteristics remains underexplored. Current literature lacks evidence comparing whether existing growth norms are universally applicable or modulated by the distinct mechanical and neuromuscular demands of specific athletic contexts. This uncertainty extends to the developmental trajectories of power, speed, strength, flexibility, balance and aerobic capacity, while sex-based divergence after **age 12** is established, it remains unclear how the non-linear growth of physical performance characteristics from **age 6 to 16** is influenced by the training modalities inherent to each discipline, specifically whether the performance plateau in girls or the rapid acceleration in boys is a product of biological maturation or sporting environment. This gap is particularly significant in the Greek context, a relatively small nation that has nevertheless achieved considerable international sporting success. Nevertheless, there are no clear structured guidelines about the key characteristics of the pathways of development in Greece. Most of the existing research in talent development has been conducted in countries such as Scandinavia and the UK with organised and well-resourced systems, which may not be applicable to the Greek context due to cultural and infrastructural differences (Till & Baker, 2020).

However, there is still limited understanding regarding the extent to which biological maturation and sport-specific training contribute to the development of anthropometric and physical performance characteristics in youth athletes. Clarifying this gap is essential for developing evidence-based, context-specific talent development systems that move beyond generic international models. To address this gap, the present cross-sectional study aims to **identify developmental trajectories and rates of change** of anthropometric and physical performance characteristics in children and adolescents (6–16 years) participating in team and individual sports. By establishing age-specific benchmarks that account for the interaction between chronological age, sex, and sporting discipline, this research seeks to provide a comprehensive blueprint for youth sport development in Greece. Ultimately, these findings will inform more effective talent identification and development strategies.

Methods

Participants and Study Design

To investigate the developmental trajectories of young athletes, 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 developmental span, specifically from ages 6 to 16. 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 2,191 competitive-level athletes (boys $n = 1,046$; girls $n = 1,145$) participated in this study (see Table 1). Skill levels is determined according to the categorisations by Cobley et al. (2009). Participants were involved in a variety of team sports (basketball, handball, football, volleyball) and individual sports (track and field, gymnastics, swimming, tennis, karate, judo, fencing) across this age range. The study received institutional approval from the National and Kapodistrian University of Athens Institutional Review Board and all participants, along with their legal guardians, provided written informed consent prior to their inclusion in the research.

Table 1. Descriptive statistics of chronological age for male and female youth athletes (6–16 years old) across Individual and Team Sports.

Chronological age	6	7	8	9	10	11	12	13	14	15	16
Boys (N = 1046)											
Team sports	34	43	50	41	49	68	62	42	57	35	48
Individual sports	82	52	60	47	45	47	47	31	34	35	37
Girls (N = 1145)											
Team sports	31	44	31	34	34	32	40	41	35	31	38
Individual sports	94	78	68	99	95	56	82	61	50	38	35

Anthropometrical Measurements

Anthropometric measurements included standing height (Ht), body mass (BM), and arm span (AS). Ht was 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).

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).

Physical Performance Tests

Flexibility

Flexibility was tested using the stand-and-reach test (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.

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. 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. 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 8.5km 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.

Agility

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 (Figure 1). 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.

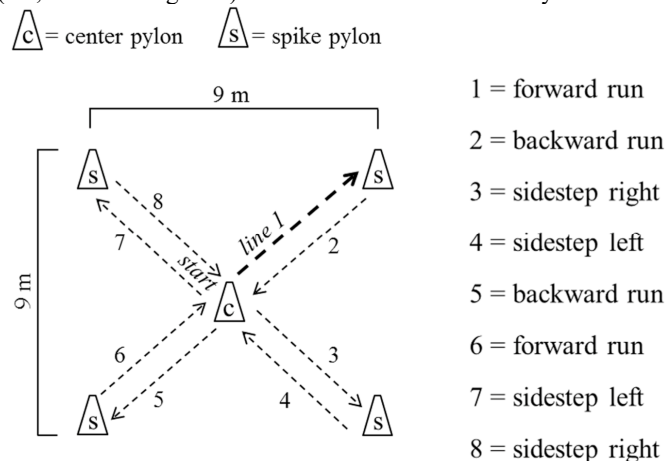


Figure 1. Schematic description of the Star agility run test (Golle et al., 2015)

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 (1979), to 0.01 s accuracy. Two trials per dominant leg were allowed with 3 min rest.

Statistical Analysis

Data analysed using SPSS version 29.0.2.0. To examine gender and type of sport differences (team vs. individual sports) across age groups (6–7, 7–8, 8–9, 9–10, 10–11, 11–12, 12–13, 13–14, 14–15, 15–16 years), factorial ANOVA with Bonferroni correction for multiple comparisons was applied to anthropometric and physiological characteristics. Statistical significance was set at $p \leq .05$, and effect size was estimated using η^2 .

Results

Body height

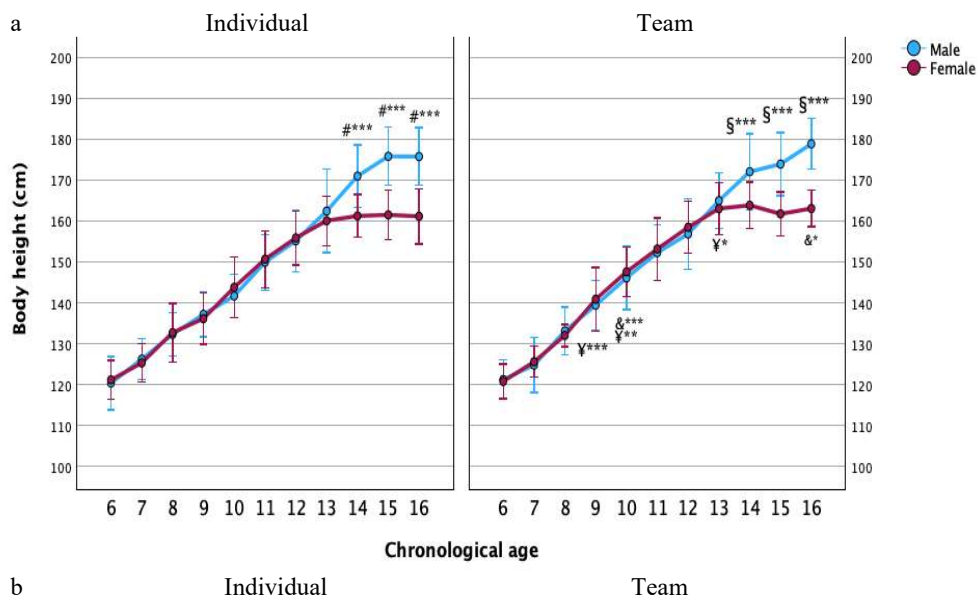
In team sports, boys and girls exhibited similar height values up to age 13. From ages 14 to 16, boys surpassed girls in height, with statistically significant differences observed at ages 14 [$F(1, 343) = 27.763$, $p < 0.001$, $\eta^2 = 0.08$], 15 [$F(1, 307) = 49.077$, $p < 0.001$, $\eta^2 = 0.14$], and 16 [$F(1, 289) = 129.086$, $p < 0.001$, $\eta^2 = 0.31$]. Similarly, in individual sports, boys and girls had comparable heights up to age 13, after which boys exceeded girls, with significant differences at ages 14 [$F(1, 343) = 36.417$, $p < 0.001$, $\eta^2 = 0.10$], 15 [$F(1, 307) = 75.303$, $p < 0.001$, $\eta^2 = 0.20$], and 16 [$F(1, 289) = 93.420$, $p < 0.001$, $\eta^2 = 0.24$] (as shown in Figure 2 *(a)*).

Body mass

In team sports, boys and girls showed similar body mass up to age 13. From ages 14 to 16, boys exceeded girls in weight, with statistically significant differences at ages 14 [$F(1, 307) = 6.562$, $p = 0.011$, $\eta^2 = 0.02$], 15 [$F(1, 289) = 11.411$, $p < 0.001$, $\eta^2 = 0.04$], and 16 [$F(1, 289) = 49.995$, $p < 0.001$, $\eta^2 = 0.15$]. In individual sports, a similar pattern was observed: boys were heavier than girls from ages 14 to 16, with significant differences at ages 14 [$F(1, 307) = 9.301$, $p = .002$, $\eta^2 = .03$], 15 [$F(1, 289) = 43.330$, $p < 0.001$, $\eta^2 = 0.13$], and 16 [$F(1, 289) = 48.990$, $p < .001$, $\eta^2 = .15$] (as shown in Figure 2 *(b)*).

Girls participating in team and individual sports exhibited similar body mass between the ages of 6 and 9. From the age of 10 to 16, however, girls involved in team sports were heavier. The two-way ANOVA revealed statistically significant differences between team and individual sports at ages 10 [$F(1, 434) = 6.403$, $p = 0.012$, $\eta^2 = 0.02$], 11 [$F(1, 418) = 9.713$, $p = 0.002$, $\eta^2 = 0.02$], 12 [$F(1, 426) = 8.179$, $p = 0.004$, $\eta^2 = 0.02$], and 15 years [$F(1, 289) = 5.877$, $p = 0.016$, $\eta^2 = 0.02$].

An exception was observed at ages 6 and 7, where boys participating in individual sports were heavier than those in team sports, with a statistically significant difference at age 7 [$F(1, 450) = 5.513$, $p = 0.019$, $\eta^2 = 0.01$]. From ages 8 to 16, however, boys engaged in team sports demonstrated greater body weight compared to those in individual sports, with statistically significant differences found at ages 9 [$F(1, 420) = 4.875$, $p = 0.028$, $\eta^2 = 0.01$], 10 [$F(1, 434) = 8.746$, $p = 0.003$, $\eta^2 = 0.02$], 11 [$F(1, 418) = 12.422$, $p < 0.001$, $\eta^2 = 0.03$], and 12 years [$F(1, 398) = 4.713$, $p = 0.031$, $\eta^2 = 0.01$].



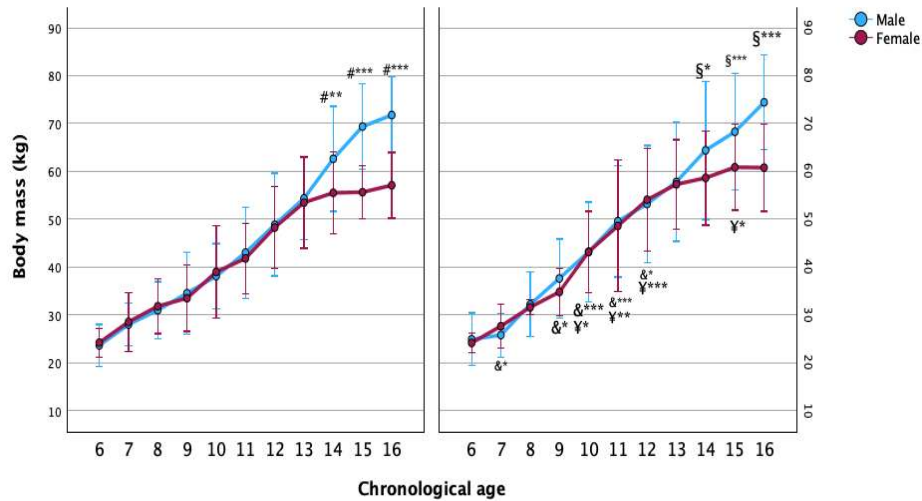


Figure 2. Differences between male and female athletes and between individual and team sports for (a) body height and (b) body mass. #: Differences between male and female athletes in individual sports, §: Differences between male and female athletes in team sports, &: Differences between team and individual sports for male athletes, ¥: Differences between team and individual sports for female athletes. Bonferroni adjustment: * p < 0.05, ** p < 0.01, *** p < 0.001.

Arm Span

In team sports, girls had greater arm span than boys between ages 9 and 12, whereas boys exceeded girls from ages 13 to 16, with significant differences from ages 14 to 16 [14: $F(1, 343) = 25.307$, $p < 0.001$, $\eta^2 = .07$; 15: $F(1, 307) = 57.294$, $p = 0.004$, $\eta^2 = .16$; 16: $F(1, 289) = 206.122$, $p < 0.001$, $\eta^2 = 0.42$]. In individual sports, girls had greater arm span from ages 10 to 12, while boys surpassed them from ages 13 to 16 [13: $F(1, 398) = 6.742$, $p = 0.010$, $\eta^2 = 0.02$; 14: $F(1, 343) = 34.015$, $p < 0.001$, $\eta^2 = 0.09$; 15: $F(1, 307) = 84.551$, $p < 0.001$, $\eta^2 = 0.22$; 16: $F(1, 289) = 175.813$, $p < 0.001$, $\eta^2 = .38$] (as shown in Figure 3).

The results of the analysis indicated that girls participating in individual sports exhibited greater arm span from ages 6 to 8, whereas from ages 9 to 14, girls involved in team sports surpassed those in individual sports. Significant differences were observed at ages 9 [$F(1, 420) = 10.478$, $p = 0.001$, $\eta^2 = 0.02$], 10 [$F(1, 434) = 7.495$, $p = 0.006$, $\eta^2 = 0.02$], and 13 [$F(1, 398) = 4.727$, $p = 0.030$, $\eta^2 = 0.01$]. At ages 15 and 16, girls participating in either team or individual sports showed similar mean values.

Among boys, those engaged in team sports demonstrated greater arm span from ages 8 to 16 (except at ages 6, 7, and 15) compared to those participating in individual sports. Significant differences were found at ages 10 [$F(1, 434) = 7.173$, $p = 0.008$, $\eta^2 = 0.02$] and 11 [$F(1, 418) = 4.225$, $p = 0.040$, $\eta^2 = 0.01$].

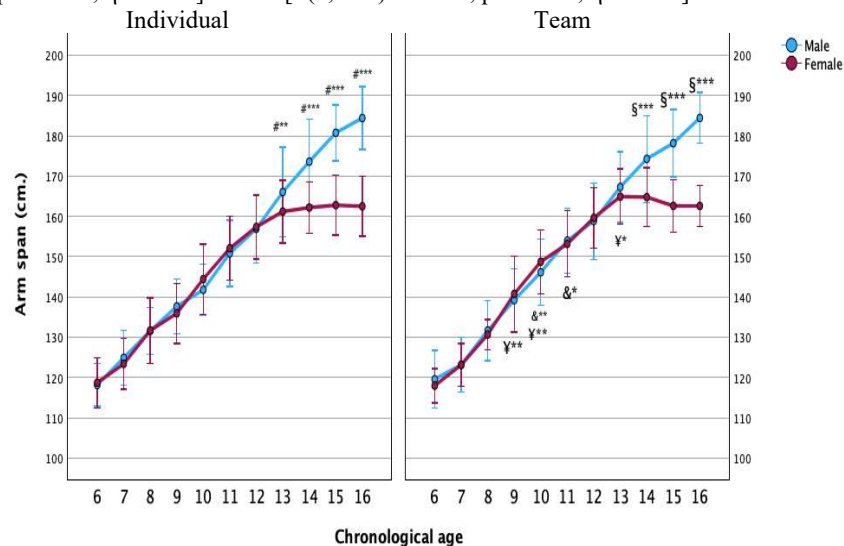


Figure 3. Differences between male and female athletes and between individual and team sports for arm span, #: Differences between male and female athletes in individual sports, §: Differences between male and female athletes in team sports, &: Differences between team and individual sports for male athletes, ¥: Differences between team and individual sports for female athletes. Bonferroni adjustment: * p < 0.05, ** p < 0.01, *** p < 0.001.

Flexibility

Analysis of variance revealed superior flexibility in girls compared to boys in team sports, with significant differences from ages 6 to 16 [6: $F(1, 450) = 25.940$, $p < 0.001$, $\eta^2 = 0.06$; 7: $F(1, 450) = 17.452$, $p < 0.001$, $\eta^2 = 0.04$; 8: $F(1, 418) = 6.662$, $p = 0.010$, $\eta^2 = 0.02$; 9: $F(1, 420) = 18.249$, $p < 0.001$, $\eta^2 = 0.04$; 10: $F(1, 434) = 10.862$, $p = 0.001$, $\eta^2 = 0.02$; 11: $F(1, 418) = 27.837$, $p < 0.001$, $\eta^2 = 0.09$; 12: $F(1, 426) = 22.272$, $p < 0.001$, $\eta^2 = 0.05$; 13: $F(1, 398) = 27.085$, $p < 0.001$, $\eta^2 = 0.06$; 14: $F(1, 343) = 11.111$, $p < 0.001$, $\eta^2 = 0.03$; 15: $F(1, 307) = 8.455$, $p = 0.004$, $\eta^2 = 0.03$; 16: $F(1, 289) = 10.253$, $p = 0.002$, $\eta^2 = 0.03$]. Similarly, in individual sports, girls outperformed boys in flexibility from ages 6 to 14 [6: $F(1, 450) = 49.722$, $p < 0.001$, $\eta^2 = 0.10$; 7: $F(1, 450) = 61.654$, $p < 0.001$, $\eta^2 = .12$; 8: $F(1, 418) = 32.594$, $p < 0.001$, $\eta^2 = 0.07$; 9: $F(1, 420) = 27.484$, $p < 0.001$, $\eta^2 = 0.06$; 10: $F(1, 434) = 25.039$, $p < 0.001$, $\eta^2 = 0.06$; 11: $F(1, 418) = 23.117$, $p < 0.001$, $\eta^2 = 0.05$; 12: $F(1, 426) = 47.924$, $p < 0.001$, $\eta^2 = 0.10$; 13: $F(1, 398) = 9.337$, $p = 0.002$, $\eta^2 = 0.02$; 14: $F(1, 343) = 7.083$, $p = 0.008$, $\eta^2 = 0.02$]. From ages 15 to 16, girls maintained superior performance, though the gap decreased (as shown in Figure 4 *(a)*).

The results of the analysis of variance showed that girls participating in individual sports demonstrated superior flexibility from ages 7 to 14 and at age 16 (except at ages 6 and 15) compared to girls engaged in team sports. Significant differences were observed at ages 10 [$F(1, 434) = 7.711$, $p = 0.006$, $\eta^2 = 0.02$] and 12 [$F(1, 426) = 6.931$, $p = 0.009$, $\eta^2 = 0.02$].

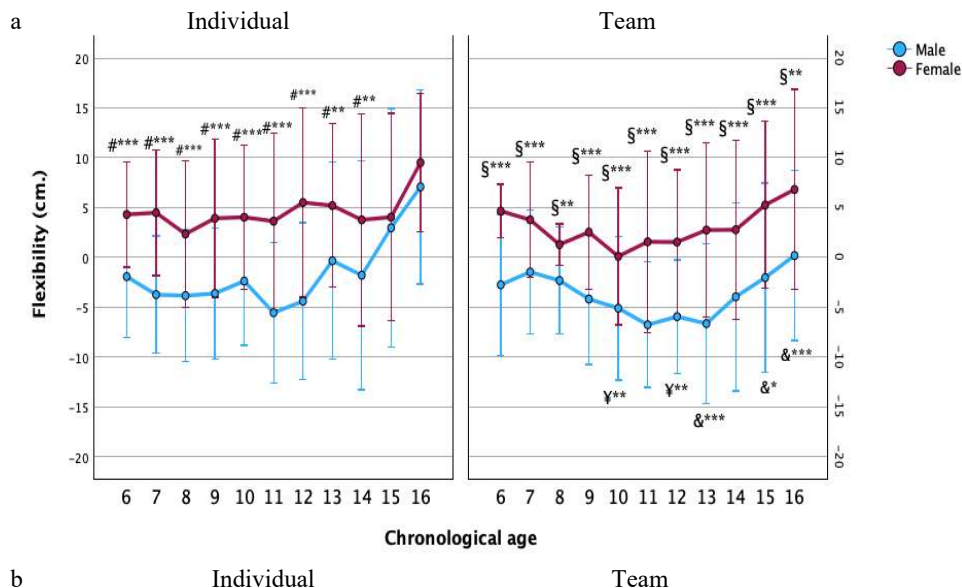
Similarly, boys participating in individual sports exhibited better flexibility at age 6 and from ages 9 to 16 (except at ages 7 and 8) compared to boys involved in team sports. Statistically significant differences were found at ages 13 [$F(1, 398) = 10.502$, $p = 0.001$, $\eta^2 = 0.03$], 15 [$F(1, 289) = 4.814$, $p = 0.029$, $\eta^2 = 0.02$], and 16 [$F(1, 289) = 10.917$, $p = 0.001$, $\eta^2 = 0.04$].

Static balance

In team sports, boys and girls showed similar single-leg balance at age 6. From ages 7 to 15, girls outperformed boys, whereas at age 16, boys showed superior performance. Significant differences were found for girls at ages 7 [$F(1, 450) = 6.568$, $p = 0.011$, $\eta^2 = 0.01$], 9 [$F(1, 420) = 5.976$, $p = 0.015$, $\eta^2 = 0.01$], and 11 [$F(1, 426) = 4.107$, $p = 0.043$, $\eta^2 = 0.01$], and for boys at age 16 [$F(1, 289) = 12.537$, $p < 0.001$, $\eta^2 = 0.04$]. In individual sports, girls outperformed boys from ages 6 to 15, while boys exceeded girls at age 16. Significant differences for girls were observed at ages 6 [$F(1, 450) = 4.123$, $p = 0.043$, $\eta^2 = 0.009$], 7 [$F(1, 450) = 4.744$, $p = 0.030$, $\eta^2 = 0.01$], 8 [$F(1, 418) = 5.891$, $p = 0.016$, $\eta^2 = 0.01$], 9 [$F(1, 420) = 9.212$, $p = 0.003$, $\eta^2 = 0.02$], 10 [$F(1, 434) = 17.661$, $p < 0.001$, $\eta^2 = 0.04$], and 14 [$F(1, 343) = 5.502$, $p = 0.020$, $\eta^2 = 0.02$], with boys surpassing girls at age 16 [$F(1, 289) = 25.541$, $p < 0.001$, $\eta^2 = 0.08$] (as shown in Figure 4 *(b)*).

The results of the analysis of variance indicated that girls participating in individual sports demonstrated better performance in single-leg static balance from ages 6 to 16 compared to girls involved in team sports, with statistically significant differences at ages 10 [$F(1, 434) = 13.545$, $p < 0.001$, $\eta^2 = 0.03$] and 12 [$F(1, 398) = 4.418$, $p = 0.036$, $\eta^2 = 0.01$] (as shown in Figure 4 *(b)*).

Boys showed similar values between team and individual sports at age 6 (team > individual). However, from ages 7 to 16, boys participating in individual sports exhibited better balance performance compared to those in team sports, with statistically significant differences at ages 11 [$F(1, 426) = 4.227$, $p = 0.040$, $\eta^2 = 0.01$], 14 [$F(1, 343) = 16.462$, $p < 0.001$, $\eta^2 = 0.05$], and 16 [$F(1, 289) = 12.709$, $p < 0.001$, $\eta^2 = 0.04$].



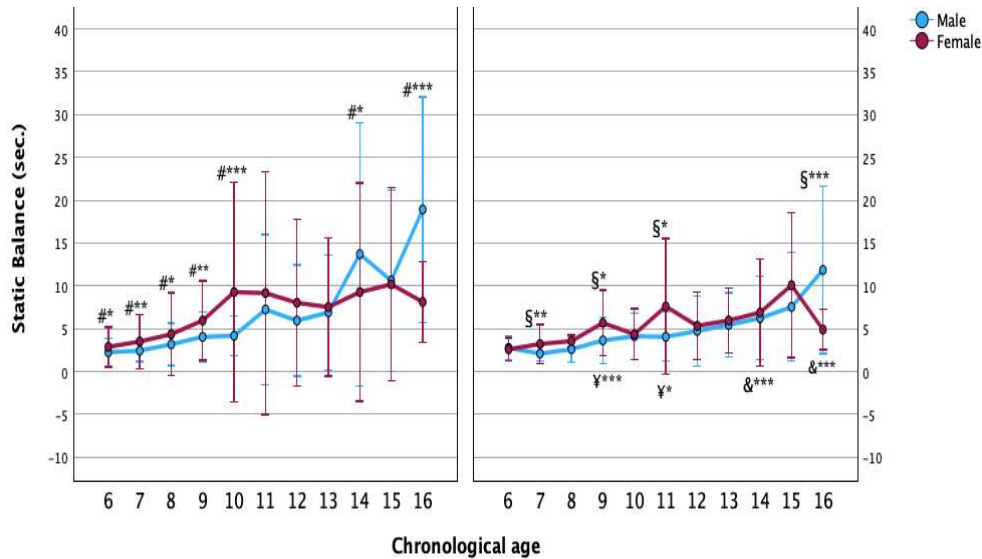


Figure 4. Differences between male and female athletes and between individual and team sports for (a) flexibility and (b) static balance, #: Differences between male and female athletes in individual sports, \$: Differences between male and female athletes in team sports, &: Differences between team and individual sports for male athletes, ¥: Differences between team and individual sports for female athletes. Bonferroni adjustment: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Handgrip strength test – left hand

In team sports, boys and girls had comparable left-hand grip strength at ages 6 to 8. Between ages 9 and 11, girls outperformed boys, while from age 12 onward, boys exhibited higher strength up to age 16. Analysis of variance revealed significantly better performance in boys at ages 14 [$F(1, 343) = 49.194$, $p < 0.001$, $\eta^2 = 0.12$], 15 [$F(1, 307) = 34.538$, $p < 0.001$, $\eta^2 = 0.10$], and 16 [$F(1, 289) = 81.613$, $p < 0.001$, $\eta^2 = 0.22$]. In individual sports, boys and girls showed similar performance from ages 6 to 12, with boys outperforming girls from ages 13 to 16 [13: $F(1, 398) = 7.568$, $p = 0.006$, $\eta^2 = 0.02$; 14: $F(1, 343) = 37.848$, $p < 0.001$, $\eta^2 = 0.10$; 15: $F(1, 307) = 57.667$, $p < 0.001$, $\eta^2 = 0.16$; 16: $F(1, 289) = 104.648$, $p < 0.001$, $\eta^2 = 0.27$] (as shown in Figure 5 *(a)*).

The results of the analysis of variance indicated that girls participating in team sports demonstrated better performance from ages 9 to 15 compared to girls involved in individual sports. Significant differences were observed at ages 9 [$F(1, 420) = 7.637$, $p = 0.006$, $\eta^2 = 0.02$], 10 [$F(1, 434) = 6.617$, $p = 0.010$, $\eta^2 = 0.02$], 11 [$F(1, 418) = 5.878$, $p = 0.016$, $\eta^2 = 0.01$], and 13 [$F(1, 398) = 4.431$, $p = 0.036$, $\eta^2 = 0.01$] (as shown in Figure 5 *(a)*).

In contrast, boys showed similar values between team and individual sports from ages 6 to 15, whereas at age 16, boys participating in individual sports demonstrated better performance compared to those in team sports, with a statistically significant difference [$F(1, 289) = 5.179$, $p = 0.024$, $\eta^2 = 0.02$].

Handgrip strength test– right hand

In team sports, boys and girls showed similar performance from ages 7 to 11, while boys surpassed girls from ages 12 to 16. Significant differences were observed at ages 6 [$F(1, 450) = 4.744$, $p = 0.030$, $\eta^2 = 0.01$] and 13–16 [13: $F(1, 398) = 4.729$, $p = 0.030$, $\eta^2 = 0.01$; 14: $F(1, 343) = 49.571$, $p < 0.001$, $\eta^2 = 0.13$; 15: $F(1, 289) = 51.037$, $p < 0.001$, $\eta^2 = 0.15$; 16: $F(1, 289) = 92.330$, $p < 0.001$, $\eta^2 = 0.24$] (see Figure 7). In individual sports, boys and girls had similar right-hand grip performance from ages 6 to 12, with boys significantly outperforming girls from ages 13 to 16 [13: $F(1, 398) = 7.496$, $p = 0.006$, $\eta^2 = 0.02$; 14: $F(1, 343) = 47.267$, $p < 0.001$, $\eta^2 = 0.12$; 15: $F(1, 289) = 60.410$, $p < 0.001$, $\eta^2 = 0.17$; 16: $F(1, 289) = 115.436$, $p < 0.001$, $\eta^2 = 0.29$] (as shown in Figure 5 *(b)*).

The results of the analysis of variance indicated that girls participating in team and individual sports exhibited similar performance at ages 6 and 7, whereas from ages 8 to 16, girls involved in team sports demonstrated better performance. Significant differences were observed at ages 10 [$F(1, 434) = 7.073$, $p = 0.008$, $\eta^2 = 0.02$] and 13 [$F(1, 398) = 8.650$, $p = 0.003$, $\eta^2 = 0.02$] (as shown in Figure 5 *(b)*).

Boys showed similar values between team and individual sports from ages 6 to 8. From ages 9 to 15, boys participating in team sports achieved better performance, with statistically significant differences observed at age 13 [$F(1, 398) = 3.897$, $p = 0.049$, $\eta^2 = 0.01$]. At age 16, boys involved in individual sports demonstrated slightly better performance, although the difference was not statistically significant.

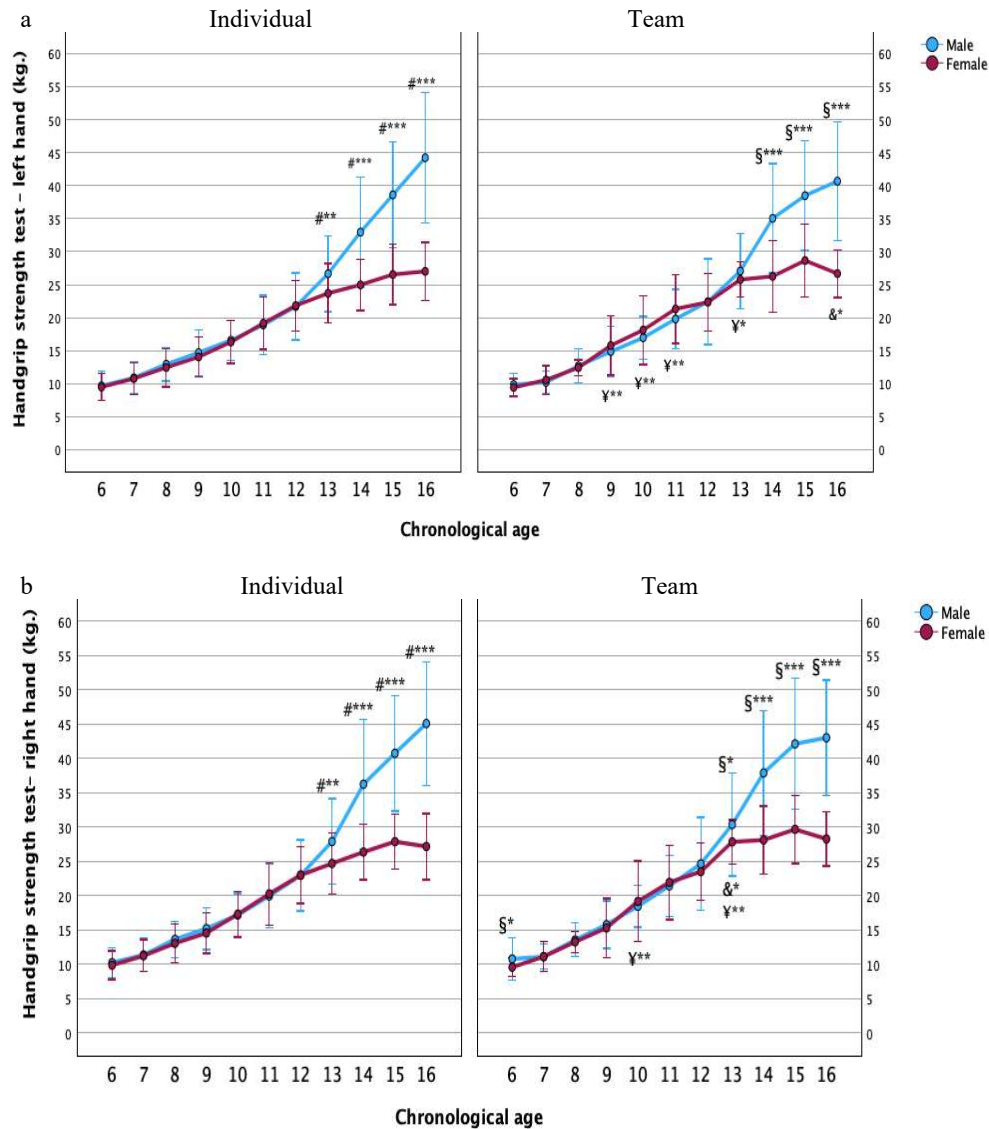


Figure 5. Differences between male and female athletes and between individual and team sports for handgrip strength test (a) left hand and for (b) right hand, #: Differences between male and female athletes in individual sports, \$: Differences between male and female athletes in team sports, &: Differences between team and individual sports for male athletes, ¥: Differences between team and individual sports for female athletes. Bonferroni adjustment: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

20m sprint

In team sports, boys and girls showed similar 20 m sprint performance at ages 7 to 10. Girls outperformed boys at ages 11 and 12, while boys demonstrated superior performance from ages 13 to 16. Two-way ANOVA revealed significantly better performance in boys at age 6 [$F(1, 450) = 5.585$, $p = 0.019$, $\eta^2 = 0.01$] and ages 13–16 [13: $F(1, 343) = 5.356$, $p = 0.021$, $\eta^2 = 0.02$; 14: $F(1, 307) = 19.823$, $p < 0.001$, $\eta^2 = 0.06$; 15: $F(1, 289) = 27.110$, $p < 0.001$, $\eta^2 = 0.09$; 16: $F(1, 289) = 62.530$, $p < 0.001$, $\eta^2 = 0.18$]. In individual sports, girls performed better at ages 11 and 12, while boys outperformed girls at all other ages, with significant differences from ages 14 to 16 [14: $F(1, 307) = 26.562$, $p < 0.001$, $\eta^2 = 0.08$; 15: $F(1, 289) = 38.023$, $p < 0.001$, $\eta^2 = 0.12$; 16: $F(1, 289) = 48.919$, $p < 0.001$, $\eta^2 = 0.16$] (as shown in Figure 6 *(a)*).

Similar performances were recorded among girls participating in team and individual sports from the age of 6 to 16 years in the 20 m sprint test. The two-way ANOVA revealed no statistically significant differences. Likewise, boys showed similar performances between team and individual sports from the ages of 7 to 10 and 13 to 16 years, with significantly better performances observed in team sports at age 6 [$F(1, 450) = 7.150$, $p = 0.008$, $\eta^2 = 0.02$], and in individual sports at ages 11 [$F(1, 426) = 5.965$, $p = 0.015$, $\eta^2 = 0.01$] and 12 years [$F(1, 398) = 5.638$, $p = 0.018$, $\eta^2 = 0.01$] (as shown in Figure 6 *(a)*).

Star agility test

In team sports, girls outperformed boys at age 6 and from ages 9 to 12, whereas boys were superior at all other ages. ANOVA revealed significantly better performance for boys at ages 14 [F(1, 307) = 24.596, $p < 0.001$, $\eta^2 = 0.07$], 15 [F(1, 289) = 23.731, $p < 0.001$, $\eta^2 = 0.08$], and 16 [F(1, 289) = 71.547, $p < 0.001$, $\eta^2 = 0.20$]. In individual sports, girls showed superior agility at ages 6, 10, 11, and 12, with a significant difference at age 6 [F(1, 450) = 8.458, $p = 0.004$, $\eta^2 = 0.02$]. Boys outperformed girls at ages 7–9 and 13–16, with significant differences from ages 13 to 16 [13: F(1, 343) = 7.993, $p = 0.005$, $\eta^2 = 0.02$; 14: F(1, 307) = 30.302, $p < 0.001$, $\eta^2 = 0.09$; 15: F(1, 289) = 35.710, $p < 0.001$, $\eta^2 = 0.11$; 16: F(1, 289) = 52.423, $p < 0.001$, $\eta^2 = 0.15$] (as shown in Figure 6 * (b) *).

Girls participating in team sports showed better performances at age 6 and from ages 9 to 16, with statistically significant differences at ages 13 [F(1, 343) = 10.465, $p = 0.001$, $\eta^2 = 0.03$], 14 [F(1, 307) = 11.785, $p < 0.001$, $\eta^2 = 0.03$], 15 [F(1, 289) = 8.300, $p = 0.004$, $\eta^2 = 0.03$], and 16 years [F(1, 289) = 10.571, $p = 0.001$, $\eta^2 = 0.04$]. Boys participating in team sports demonstrated better performances from ages 6 to 9, at age 11, and from ages 13 to 16, with statistically significant differences at ages 6 [F(1, 450) = 5.515, $p = 0.019$, $\eta^2 = 0.01$], 14 [F(1, 307) = 7.615, $p = 0.006$, $\eta^2 = .02$], 15 [F(1, 289) = 4.352, $p = 0.038$, $\eta^2 = 0.02$], and 16 years [F(1, 289) = 16.593, $p < 0.001$, $\eta^2 = 0.05$] (as shown in Figure 6 * (b) *).

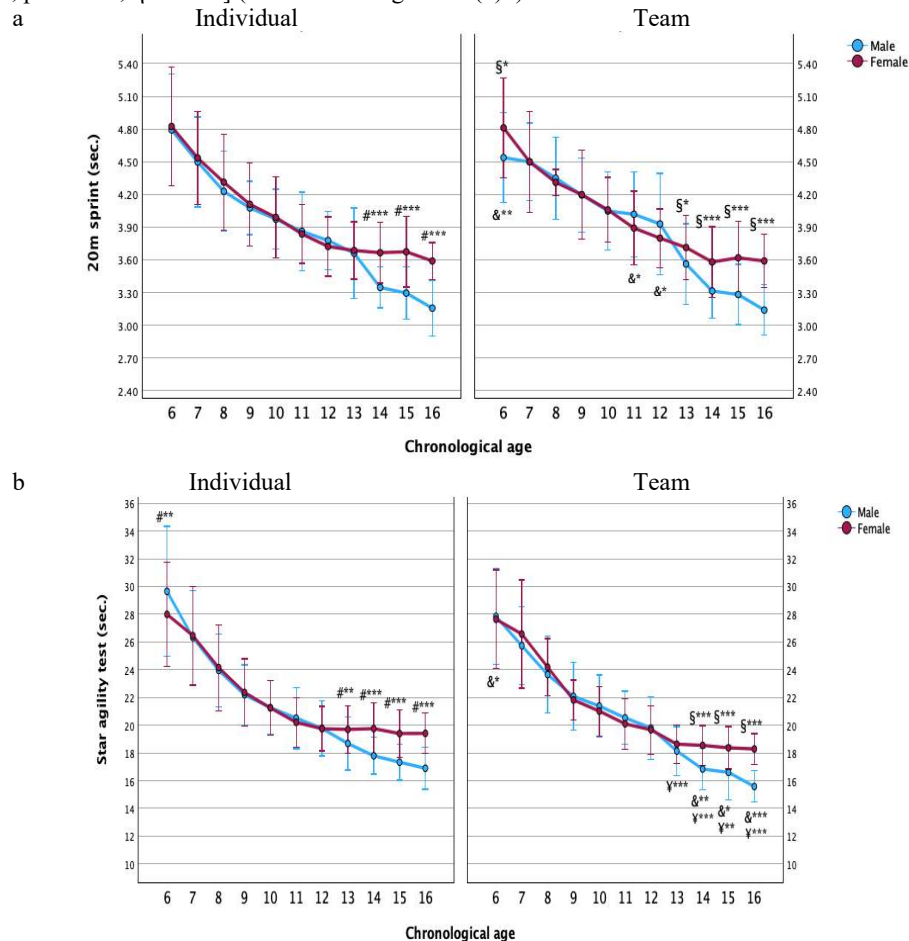


Figure 6. Differences between male and female athletes and between individual and team sports for (a) 20m sprint and for (b) star agility test, #: Differences between male and female athletes in individual sports, §: Differences between male and female athletes in team sports, &: Differences between team and individual sports for male athletes, ¥: Differences between team and individual sports for female athletes. Bonferroni adjustment: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Jump-and-reach test

In team sports, girls outperformed boys in countermovement vertical jump at ages 6–9, while boys exceeded girls from ages 10 to 16. ANOVA revealed significant differences for boys at ages 11 [F(1, 418) = 5.095, $p = 0.025$, $\eta^2 = 0.01$], 14 [F(1, 307) = 14.627, $p < 0.001$, $\eta^2 = 0.05$], 15 [F(1, 289) = 13.965, $p < 0.001$, $\eta^2 = 0.05$], and 16 [F(1, 289) = 68.886, $p < 0.001$, $\eta^2 = 0.19$]. In individual sports, girls outperformed boys from ages 6 to 10, showed similar performance at ages 11 and 12, and boys outperformed girls from ages 13 to 16, with significant differences at ages 14–16 [14: F(1, 307) = 21.966, $p < 0.001$, $\eta^2 = 0.07$; 15: F(1, 289) = 36.024, $p < 0.001$, $\eta^2 = .011$; 16: F(1, 289) = 107.360, $p < 0.001$, $\eta^2 = 0.27$] (as shown in Figure 7 * (a) *).

Girls participating in team sports at ages 6, 7, and from 13 to 16 years showed better performances compared to girls in individual sports. A statistically significant difference was observed at age 14 [$F(1, 307) = 4.313$, $p = 0.039$, $\eta^2 = 0.01$]. In contrast, girls involved in individual sports demonstrated better performances at the remaining ages (8, 9, 10, 11, and 12), with significantly better results at ages 9 [$F(1, 420) = 4.022$, $p = 0.046$, $\eta^2 = 0.009$] and 10 [$F(1, 434) = 9.417$, $p = 0.002$, $\eta^2 = 0.02$]. The analysis revealed no statistically significant differences between team and individual sports for boys (as shown in Figure 7 *(a)*).

20m shuttle run test

In team sports, boys covered greater distances than girls in the shuttle run test from ages 6 to 16 (except age 7). Significant differences were observed from ages 10 to 16 [10: $F(1, 4134) = 12.043$, $p < 0.001$, $\eta^2 = 0.03$; 11: $F(1, 418) = 10.313$, $p = 0.001$, $\eta^2 = 0.02$; 12: $F(1, 426) = 9.906$, $p = 0.002$, $\eta^2 = 0.02$; 13: $F(1, 398) = 30.433$, $p < 0.001$, $\eta^2 = 0.07$; 14: $F(1, 343) = 56.174$, $p < 0.001$, $\eta^2 = 0.14$; 15: $F(1, 289) = 59.574$, $p < 0.001$, $\eta^2 = 0.17$; 16: $F(1, 289) = 87.207$, $p < 0.001$, $\eta^2 = 0.123$]. In individual sports, boys covered greater distances from ages 6 to 16 (except age 7), with significantly better performance from ages 13 to 16 [13: $F(1, 398) = 12.890$, $p < 0.001$, $\eta^2 = 0.03$; 14: $F(1, 343) = 40.057$, $p < 0.001$, $\eta^2 = 0.11$; 15: $F(1, 289) = 50.269$, $p < 0.001$, $\eta^2 = 0.15$; 16: $F(1, 289) = 30.749$, $p < 0.001$, $\eta^2 = 0.10$] (as shown in Figure 7 *(b)*).

According to the results of the analysis of variance, girls participating in team sports showed better performance in the shuttle run distance at ages 6 and 7, while from ages 8 to 16, girls in team sports covered greater distances, with statistically significant differences at ages 10 [$F(1, 434) = 8.359$, $p = 0.004$, $\eta^2 = 0.02$], 11 [$F(1, 434) = 12.385$, $p < 0.001$, $\eta^2 = 0.03$], 12 [$F(1, 426) = 10.599$, $p = 0.001$, $\eta^2 = 0.02$], and 16 years [$F(1, 289) = 10.410$, $p = 0.001$, $\eta^2 = 0.04$]. The analysis revealed no statistically significant differences between team and individual sports for boys (as shown in Figure 7 *(b)*).

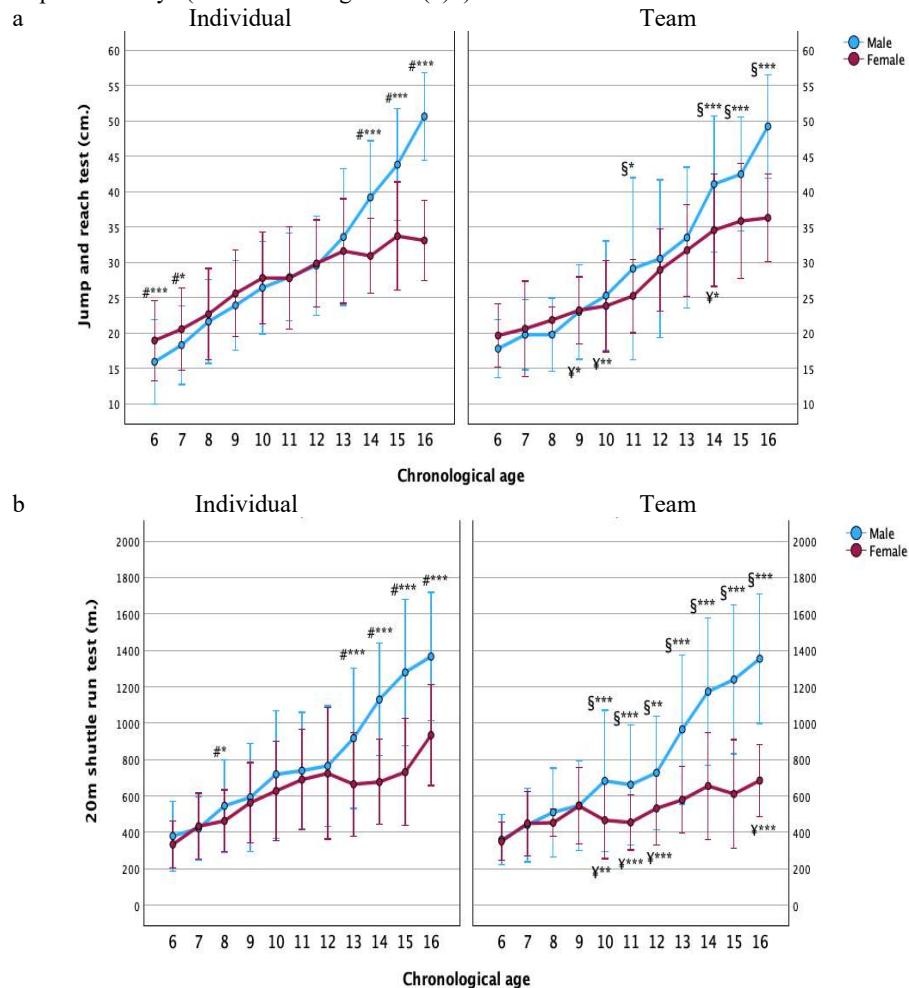


Figure 7. Differences between male and female athletes and between individual and team sports for (a) jump and reach test and for (b) 20m shuttle run test, #: Differences between male and female athletes in individual sports, \$: Differences between male and female athletes in team sports, &: Differences between team and individual sports for male athletes, ¥: Differences between team and individual sports for female athletes. Bonferroni adjustment: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Discussion

The present study aimed to examine the developmental trajectories of anthropometric and physical performance characteristics in Greek children and adolescents aged 6–16 years who participated in team and individual sports. Both genders showed progressive improvements in most anthropometric and performance variables with age. Boys and girls performed similarly until early adolescence, after which boys displayed significantly greater gains in strength, sprinting, and power, while girls retained advantages in flexibility and balance. Differences between team and individual sports were generally small but age dependent. A unique finding of this study is the distinct divergence in performance profiles based on sport type and age. Team-sport participants, particularly girls, tended to outperform their peers in change-of-direction and shuttle-run tests from approximately 13 years onward. Conversely, athletes in individual sports displayed clear advantages in flexibility and balance at younger ages. However, the modest effect sizes observed suggest that biological maturation and cumulative training exposure exert a significantly stronger influence on physical performance than the specific type of sport itself.

The age-related improvements observed are consistent with existing evidence showing that neuromuscular coordination, strength, and aerobic capacity develop linearly through childhood and accelerate around the onset of puberty (Malina et al., 2004; Golle et al., 2015; Towlson et al., 2018). While the discrepancies between genders around the ages of 12–13 coincides with peak height velocity and the associated hormonal and morphological changes (Armstrong & Welsman, 2019; Beunen & Malina, 2008). Moreover, temporary plateaus in speed and agility, particularly among girls around 12–14 years old, reflect growth-related disruptions in coordination and strength-to-mass ratio that have been documented elsewhere (Le Gall et al., 2007; Rumpf & Cronin, 2012). Another unique finding of this study is that during pre-adolescence, physical performance characteristics are remarkably similar between team and individual sports, suggesting that maturational status—not sport participation—is the primary driver of early physical development. As adolescents mature, however, training exposures become more sport-specific and begin to shape performance in distinct ways. For example, the frequent multidirectional accelerations and intermittent demands typical of invasion team sports like football, handball, volleyball or basketball likely reinforce the superior sprint and agility outcomes among team-sport athletes in mid-adolescence. On the contrary the technical precision and movement control emphasised in gymnastics may explain the stronger balance and flexibility observed in individual-sport athletes. The sport-type differences revealed in this study are likely the results of two overlapping mechanisms: (a) the training ecology of each sport, and (b) selection pressures that shape who remain within each sport. Team sports expose participants to repeated high-intensity and reactive tasks that stimulate neuromuscular adaptations relevant to speed and agility (Hung et al., 2025; Lloyd et al., 2016b). On the other hand, individual sports tend to focus on movement efficiency and technical precision. These ecological distinctions may explain why team sport athletes outperformed their peers in agility and power measurements from early adolescence onwards, while those in individual sports maintained an advantage in flexibility.

Selection bias may further contribute to these contrasts. For example, taller and stronger athletes are often selected or retained in team sports such as basketball, volleyball or football (Gaurav et al., 2010; Milić et al., 2017; Reilly et al., 2000), whereas ‘smaller’ or lighter athletes are more common in gymnastics (Ackland et al., 2003). In swimming, the selection bias favour taller athletes who present with disproportionately long arms and large hands/feet (Alves et al., 2022). Consequently, the anthropometric profiles that differentiate sport types are not merely training outcomes but also reflections of the selection system. Nonetheless, the generally small effect sizes observed suggest that these physical performance characteristics only explain a small part of the variation in performance.

The results align closely within the Developmental Model of Sport Participation (DMSP) (Côté & Fraser-Thomas, 2007) and Long-Term Athlete Development (LTAD) (Balyi et al., 2013) frameworks, which highlight the value of early diversification followed by gradual specialisation. The limited differences between sport types during childhood (6–12 years) suggest that taking part in multiple activities can support the development of broad motor skills that transfer across sports (Schmidt & Wrisberg, 2008). The clearer distinctions that emerge from 13 years onwards may mark the onset of sport-specific specialization, when training volumes and competition loads increase and performance demands become more targeted (Moesch et al., 2011; Hornig et al., 2016). Viewed through the Youth Physical Development Model (YPDM) (Lloyd & Oliver, 2012), these findings reinforce the need to plan training based on biological rather than chronological age. The period surrounding PHV represents both an opportunity and a vulnerability since athletes experience rapid neuromuscular development but are also prone to temporary decreases in coordination and increased risk of injury risk. As such, coaches need to appropriately adjust training loads and focus on technical accuracy and consistency during this phase which can facilitate long-term development.

From a practical perspective, these findings reinforce the idea that young athletes can benefit from varied and age-appropriate movement experiences during childhood. Exposure and participation in a range of sports between 6 and 12 years old seems to provide a strong base of motor competence that supports later specialisation. Around and after PHV, training should become more individualised, considering each athlete’s maturity status and the specific demands of their sport.

Female youth athletes, who typically display greater flexibility and balance, may benefit from a progressive emphasis on strength and power development to counter the declines in speed and jump performance often observed during puberty. Male youth athletes, who generally exhibit more rapid strength gains, require continued focus on mobility and movement quality to reduce the risk of overuse injuries associated with accelerated growth. Incorporating biological maturity assessments into talent identification systems can help mitigate selection biases favouring early mature athletes and ensure the retention of late-developing athletes with long-term potential.

Conclusion

Ultimately, this study reshapes our understanding of youth development by demonstrating that biological maturation, rather than early specialization, is the true engine of physical performance. By revealing that sport-type differences only crystallize in mid-adolescence, these findings challenge the "start young, start specialized" narrative and instead champion early diversification as a scientifically sound foundation. These results unambiguously shift the focus from chronological age to biological readiness, reinforcing the critical importance of diversified sport experiences in childhood and maturity-sensitive training throughout adolescence. Fundamentally, this study advocates for an approach to athlete development that categorically values long-term growth and well-being over immediate, sport-specific performance. While the ecological validity of this large-scale study provides a robust mapping of the Greek youth sport landscape, it also serves as a compelling call to action. Moving beyond cross-sectional observations toward longitudinal tracking—incorporating maturity offset and training load—will be essential to fully master the intricate interplay between biological growth, sport type, and athletic performance. Furthermore, integrating psychosocial assessments would facilitate a more holistic understanding of development, ensuring that we nurture not just the athlete's physical potential, but the well-being of the individual as a whole.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors didn't use of AI in the writing of the article.

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