**Titel: Physical Performance in Adolescent Academy Female Football Players: The Influence of Biological Maturation**

AALBORG UNIVERSITET
STUDENTERRAPPORT

**Tema: Kandidatspeciale**

**Projektperiode: 01/02/2025 - 02/06/2025**

**Uddannelse: Idræt**
**Projektgruppe:**
**HST-25-IDR-10-10105**

**Gruppemedlemmer:**
**Sebastian Axel Silberbauer Timmermann (20203054)**
**Viggo Bach Hilliard (20204521)**

**Vejleder: Mathias Vedsø Kristiansen**

**Eksterne Vejledere:**
**Rasmus Hallander Porse**
**Peter Kvorning Sand**

**Sideantal, Artikel: 28 (41.747 tegn)**
**Sideantal, Arbejdsblad: 36 (52.080 tegn)**
**Bilagsantal og -art: én PDF-fil**
**Afsluttet den: 01/06/2025**

**Synopsis:**

Biologisk modning har stor indflydelse på fysisk præstation i sprint, hop og retningsskift blandt drenge fodboldspillere. Formålet med nærværende projekt var at undersøge indflydelsen af biologisk modning, estimeret med procent af estimeret voksenhøjde, på hop, sprint, retningsskift og udholdenheds præstation blandt danske U13-U19 akademi pige fodboldspillere. 125 pigefodboldspillere fra tre forskellige danske fodboldakademier blev rekrutteret. Deltagernes højde, vægt og kronologiske alder og deres forældres højde blev indsamlet til brug i Khamis Roche metoden for at estimere procent af estimeret voksenhøjde. Derudover udførte deltagerne en 'counter movement jump' (CMJ), 30m sprint med 5m, 10m og 25m split tider, arrowhead højre og venstre samt en yo-yo intermittent recovery 1 (YYIR1) test. Deltagerne blev fordelt i prePHV (n = 17), circaPHV (n = 40) og postPHV (n = 68) baseret på procent af estimeret voksenhøjde. Resultaterne viste at postPHV sprintede hurtigere end prePHV i 10m og 30m sprint, var hurtigere i arrowhead højre end prePHV og hurtigere i arrowhead venstre end circaPHV og prePHV. PostPHV løb også længere i YYIR1 end både circaPHV og postPHV. Ingen forskel mellem grupperne blev observeret i CMJ, 5m og 25m sprint. Konklusionen for nærværende projekt er at biologisk modning har indflydelse på pigefodboldspilleres fysiske præstation i 10m og 30m sprint, retningsskifte og udholdenhed. Derudover kan det også konkluderes, at størrelsen af indflydelsen som biologisk modning har på pigers fysiske præstation, ikke er lige så stor som ved drenge.

# Physical Performance in Adolescent Academy Female Football Players: The Influence of Biological Maturation

Sebastian Axel Silberbauer Timmermann & Viggo Bach Hilliard
The Faculty of Medicine, Department of Health Science and Technology, Aalborg University, Aalborg, Denmark

Biological maturation has a large impact on the physical performance of adolescent male football players in sprinting, jumping and COD tests. The aim of this study was to investigate the influence of biological maturation, estimated by percentage of predicted adult height, on jump, sprint, COD and endurance performance among adolescent Danish U13-U19 female academy football players.

125 adolescent female football players were recruited from three different Danish football academies. The participants' height, weight, chronological age and their parents' height were collected for use in the Khamis Roche method to estimate %PAH. Furthermore, the participants performed a CMJ, 30m sprint with recorded 5m, 10m, and 25m split times, arrowhead right and left and a YYIR1 test as physical performance tests. The players were divided into prePHV (n = 17), circaPHV (n = 40) and postPHV (n = 68) based on %PAH.

The results showed that postPHV sprinted faster than prePHV in 10m and 30m sprint, were faster than prePHV in arrowhead right and were faster than prePHV and circaPHV in arrowhead left. PostPHV also performed better in YYIR1 than prePHV and circaPHV. No differences were observed in CMJ or 5m and 25m sprint between groups.

The conclusion of the present study is that biological maturation might influence 10m and 30m sprint, COD and endurance performance, but not 5m and 25m sprint and jumping, among adolescent Danish U13-U19 female academy football players. Furthermore, this study can conclude that the magnitude of the influence of biological maturation on physical performance is less in females compared to males.

**Key words:** Sprint, Jump, Change of Direction, Endurance, Predicted Adult Height, Predicted Adult Stature, Peak Height Velocity

# 1. Introduction

The influence of biological maturation has been well studied for adolescent males in multiple sports, where early maturing athletes generally outperform their late maturing counterparts in sprinting, jumping, change of direction (COD) abilities (Albaladejo-Saura et al., 2021; Read et al., 2017; Robles-Palazón et al., 2024; Rommers et al., 2019; Sellami et al., 2024; Yang & Chen, 2022), but not endurance (Albaladejo-Saura et al., 2021; Yang & Chen, 2022). For instance, a study by Sellami and colleagues (2024) found that post peak height velocity (PHV) football players performed better than prePHV players in tests of sprint, squat jump, countermovement jump (CMJ) as well as agility with and without a ball (Sellami et al., 2024). The fact that early maturing players possess increased physical attributes and physical performance has been shown to affect coaches and talent scouts' perception. Coaches and scouts perceive early maturing players to be better and more promising football players, than late maturing players (Cripps et al., 2016). This has created a maturational bias in football, where early maturing players are overrepresented in male football academies (Baxter-Jones et al., 2020; Hill et al., 2020; Johnson et al., 2017). Moreover, the players who are recruited into professional academies benefit from exposure to elite level coaching, sports science, medical support, training equipment and training facilities (Hill et al., 2020), giving them a further advantage compared to their late maturing counterparts.

Maturational bias has also been found in female football. A study by Sweeney and colleagues (2025), found a small maturational bias, favoring the early maturing players, in the female Irish U15 and U16 national teams, compared to the general population. Although there seems to be maturational bias in female football, the magnitude of the bias is not as substantial as in male football (Sweeney, Liam et al., 2025). The difference in magnitude of the maturational bias could be due to differences in biological maturation. In general, males gain increased fat free mass (FFM) and seem to accumulate less fat mass (FM) compared to females, which is advantageous to physical performance, hence the increased physical performance in early matured males (Read et al., 2017; Rommers et al., 2019; Sellami et al., 2024; Yang & Chen, 2022). Meanwhile, females accumulate more FM and less FFM compared to males (Malina, R. M. et al., 1988), which is disadvantageous to physical performance (Hunter & Senefeld, 2024). However, the literature on the influence of biological maturation on physical performance among female athletes is scarce, compared to males. The results of the few existing studies on female athletes are not consistent, as some studies find differences in physical performance between maturity groups, while others do not (Emmonds et al., 2020; Gryko et al., 2022; Gundersen et al., 2024; Söğüt et al., 2019). For instance, a study by Gundersen and colleagues (2024) found no correlation between bone age and physical performance in 40m sprint, 2000m run, standing long jump and push-ups for adolescent female athletes with different sport backgrounds. However, a study by Söğüt and colleagues (2019) found early maturing tennis players to be significantly stronger in hand grip strength than late maturing players but found no difference in an agility test. A Study by Gryko and colleagues (2022) found mixed results, with more mature basketball players in the U13 age group, performing better in standing vertical jump and vertical jump, but worse in 5m sprint and endurance than less mature players. These studies show no clear tendency regarding the influence of biological maturation on physical performance in female athletes. This is in stark contrast to male athletes, where there is a clear tendency for early maturing players outperforming late maturing players in sprinting, jumping and COD (Read et al., 2017; Rommers et al., 2019; Sellami et al., 2024; Yang & Chen, 2022). Furthermore, to the authors knowledge there are only one study investigating the influence of biological maturation on physical performance in female football players (Emmonds et al., 2020), whereas male football players are well studied (Albaladejo-Saura et al., 2021; Read et al., 2017; Robles-Palazón et al., 2024; Rommers et al., 2019; Sellami et al., 2024; Yang & Chen, 2022). The study by Emmonds and colleagues (2020) found some differences in physical performance between maturity groups (-2.5, -1.5, -0.5, +0.5, +1.5 and +2.5 years from PHV) in English adolescent female football players. However, they only compared consecutive (for example, -2.5 with -1.5 year from PHV and -1.5 with -0.5 year from PHV) maturity groups and not the least mature players with the most mature players (for example -2.5 with +2.5 year from PHV) (Emmonds et al., 2020). This means that changes in physical performance that might take longer to manifest, might not be evident in the study by Emmonds and colleagues (2020). Present study seeks to compare three different maturity groups with each other (prePHV, circaPVH and postPHV). This can give information for possible differences between the least and most mature players, which is not possible from the study by Emmonds and colleagues (2020).

As a result of maturational bias in male football, initiatives to combat this bias have been made and adopted by national football teams and academies (DBUFuture; Cumming et al., 2017, 2018; Malina, Robert M. et al., 2019). These are initiatives such as bio-banding and FUTURE national teams, where players are matched by biological maturation instead of chronological age (DBUFuture; Malina, Robert M. et al., 2019; Sweeney, L. et al., 2024). Bio-banding has been shown to successfully create more homogenous groups, regarding anthropometric measures and physical performance (MacMaster et al., 2021). Furthermore, Premier League academy players experience bio-banding as positive (Cumming et al., 2018). Both early and late maturing players experience greater opportunities to develop and utilize skills and attributes (technical, tactical, physical and psychological) during bio-banded games, and recommend their academies to continue to use bio-banding (Cumming et al., 2018). Future national teams and bio-banding has had a positive influence on male football and has therefore also been introduced in female football as well (DBUFuture). However, the lack of scientific evidence for bio-banding, FUTURE national teams and similar initiatives in female athletes is scarce. As illustrated above, the biological maturation of females and males is different (Handelsman et al., 2018; Hunter & Senefeld, 2024; Malina, R. M. et al., 1988), and the biological maturation of females seem to influence physical performance differently than for males (Emmonds et al., 2020; Gryko et al., 2022; Gundersen et al., 2024; Söğüt et al., 2019). This poses a risk of potentially implementing ineffective or inappropriate practices in female football. The initiatives are most likely being adopted by the female academies and national teams, because they lack knowledge of how biological maturation influences physical performance in female football players.

Therefore, the aim of this study is to investigate the influence of biological maturation, estimated by percentage of predicted adult height, on jump, sprint, COD and endurance performance among adolescent Danish U13-U19 academy female football players.

## 2. Methods and Materials

### 2.1 Experimental Design

In this cross-sectional study female football players were recruited from three Danish football academies (Kolding If, Fortuna Hjoerring & AaB).

The date of testing from each academy was performed by Kolding IF between the 11th of January and 15th of February 2025, Fortuna Hjoerring the 21st of January 2025 and AaB between the 27th of July and 10th of August 2024. The data was either collected by retrieving it directly from the academy or assisting with the physical performance testing at the academy. The physical performance tests included CMJ, sprint (5m, 10m, 25m and 30m), arrowhead right and left and Yo-yo intermittent recovery test 1 (YYIR1) in that order by all academies. All physical performance tests were administered in an indoor court with appropriate footwear. AaB completed all the physical tests, while Kolding IF did not include the arrowhead test and Fortuna Hjoerring performed a 20m sprint split time instead of a 25m sprint split time and did not record 5m split times. As Fortuna Hjoerring were the only academy to record 20m sprint split time, the results from that test were excluded.

## 2.2 Participants

125 participants were recruited and were 11.0-17.6 years old (13.5 ± 1.4 years), had a bodyweight of 30.8-82.9 kg (51.7 ± 9.1 kg) and were 140.0-188.0 cm tall (163.5 ± 7.6 cm). The inclusion criteria were that they played for a Danish football academy and played for the U13-U19 teams. The exclusion criterias were no available anthropometric data (height, weight, parents height, age), if they had done none of the physical tests (CMJ, Sprint, Arrowhead or YYIR1) or were injured and therefore unable to do the physical tests. Written informed consent was retrieved from participants (above 18 years), the parents or the legal guardians of the participants (below 18 years). If the data were retrieved from an academy, a data processing agreement was made with the academy, instead of retrieving written informed consent from participants.

## 2.3 Measurements

### 2.3.1 Biological Maturation

Biological maturation was estimated using the Khamis Roche method for percentage of predicted adult height (%PAH) (Khamis & Roche, 1994). To calculate %PAH, bodyweight, height and age of the participant as well as mid-parent height (height(father)+height(mother) / 2) is required. Height was measured using either a stadiometer (Aab: Seca 217) or measuring tape (Kolding IF: Measuring tape, Fortuna Hjoerring: Stanley measuring tape) and bodymass was measured with either a personal scale (Aab: MPK 200K-1P) or a standard bathing scale (Kolding IF: EKS bathing scale, Fortuna Hjoerring: Beurer 180 BF). The age of the participants on the day of testing was calculated to the nearest half year by their birth date and the date of testing. The heights of the parents were self-reported and adjusted using an equation from Epstein and colleagues (1995). The participants were then distributed into three groups, prePHV (Corresponding to 84-89%PAH), circaPHV (Corresponding to 90-93%PAH) or postPHV (Corresponding to 94-100%PAH) dependent on %PAH (Cumming et al., 2017; Malina, Robert M. et al., 2019).

#### 2.3.2 Warmup

The participants performed a warmup before each physical test. Kolding IF had a standardized protocol which the participants followed. Fortuna Hjoerring had a trainer who was in charge of the warm-up. In Aab, the participants performed a self-administered warmup.

For the CMJ, Kolding IF performed light jogging, skipping for height, hip ab- and adduction, more light jogging, dynamic stretches (toes → heel → groin → hamstrings), three jumps with 50%, 70% and 90% of max, before the test. Fortuna Hjoerring performed light jogging, skipping, light jumping and three test jumps with focus on technique before the test. For the sprint, Kolding IF performed light jogging, long jump running, cross-run, sidesteps, COD, run, progressive run and progressive backwards run before the test. Fortuna Hjoerring performed light jogging, progressive runs and knee lifts, before the test. Kolding IF did not perform the Arrowhead right and left test as mentioned above (section 2.1). For the Arrowhead right and left test Fortuna Hjoerring performed light jogging, skipping and COD running for four rounds around the cones (two right, two left), before the test. For the YYIR1 test, all participants of both Kolding IF and Fortuna Hjoerring performed two to three light jogging rounds back and forth of the marked area.

AaB performed a self-administered general warm-up including jogging, dynamic stretching, sprinting and jumping. While waiting for the next test, the participants were told to keep warm by doing light activity. Before doing each test, the participant performed the test two to three times at lower intensity as warm up for the specific test and familiarization.

#### 2.3.3 Countermovement Jump

For the CMJ, Kolding IF and AaB used Microgate Optojump (Microgate Optojump, Microgate Srl Via Waltraud Gebert Deeg, 3e 39100 - Bolzano - Italy) and Fortuna Hjoerring used Eleiko Sport (Eleiko sport RS232). Jump height was collected in centimeters, estimated by flight time during the CMJ. Each participant was tested individually and received a standardized introduction to the test beforehand. During the test, the participant was required to place their hands on their hips and maintain the position throughout the jump. They were instructed to squat to a self-selected depth and speed, with the objective of achieving maximal jump height. Additionally, they were instructed not to tuck their knees to increase flight time but maintain relative stiffness. Each participant was given three consecutive attempts to optimize their jump performance with a rest period of 10-12 seconds after each jump. The highest jump achieved for each participant was recorded as the final test result.

### 2.3.4 Sprint

For the sprint test, photocells (Microgate Witty, used by Kolding IF and Aab, and Eleiko sport RS232 used by Fortuna Hjoerring) were placed at 5m, 10m, 25m and 30m from the start line and at a height of 80 centimeters. Each participant was given three attempts with a rest period of two to four minutes (waiting time in queue) before the next attempt. The starting position was set at one meter from the first set of photocells and the participants was required to remain in contact with the floor until takeoff. The participants were advised to initiate the test at their own discretion. Timing commenced as soon as the participants passed through the first set photocells, with split times recorded at each respective distance as previously specified. The sprint and split times were measured in seconds. The fastest individual 5m, 10m and 25m split times and 30m sprint times (fastest split time(s) does not have to be from the same 30m sprint trial) for each participant was recorded as the final test result.

### 2.3.5 Arrowhead Right and Left

The setup for the arrowhead test is illustrated on Figure 1. In this test, only one set of photocells were applied at the START/FINISH (black dots). The participants (grey dot) were to start at START/FINISH position and sprint to cone A. From there, the participant either had to run around cone C (arrowhead right) or cone D (arrowhead left). Afterwards the

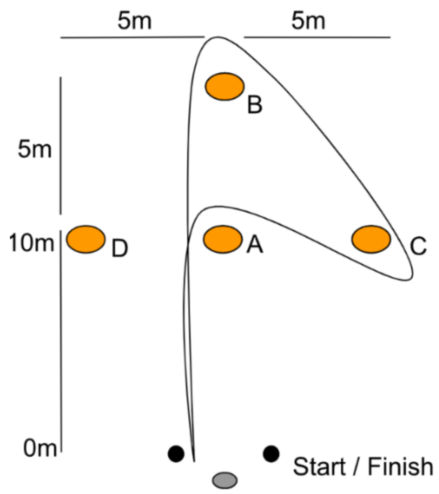


*Figure 1 shows the layout of the arrowhead test. Orange dots represent the cones the players must run around. Black dots represent timing gates. Grey dot represents the players start and finish position.*

participant sprinted to cone B and back again towards the START/FINISH through the photocells to stop the time. In total, each participant completed four trials. Two trials around the right side: START → A → C → B → FINISH followed by two trials around the left side: START → A → D → B → FINISH. Participants had a rest period consisting of three to four minutes before each trial (waiting time in queue). The completion time was measured in seconds. The fastest time for arrowhead right and left was recorded as the final test result.

#### 2.3.6 Yo-Yo Intermittent Recovery Test Level 1

All age groups from U13-U19 completed the YYIR1 (The 1 in YYIR1 refers to level 1, which determines the start and incremental speed increase throughout the test) (Krustrup et al., 2003). The test requires the participants to run 2x20 meters, 20 meters down to a turning point and 20 meters to return, where there is a five meter recovery zone. After each shuttle of 2x20 meters, the participants had a 10 second rest period, in the recovery zone before the next shuttle.

An audio file designed for the test was used on a loudspeaker so everyone could hear. It was designed to make beeping sounds when the test started, when they should pass the 20 meter mark and yet again, when they returned to the start line. Afterwards there was a beeping sound per second for 10 seconds until the next shuttle started. As the test progressed, the speed gradually increased, which was provided by the audio file to ensure the participants were prepared. The participants were given a warning if they failed to clear the 2x20 meters within the allocated time. If a second warning were given or the participant did not complete the shuttle, they were eliminated. The total distance, in meters, was recorded at the point of the elimination of a participant. All participants had one attempt for this test.

### 2.4 Statistical Analysis

The data analysis was initially conducted in Microsoft Excel (Microsoft® Excel® for Microsoft 365 MSO, Version 2504), where the self-reported heights of the parents were adjusted and %PAH of the participants were calculated. The participants were then divided into their respective groups based on %PAH. The data were then transferred to SPSS statistics (IBM SPSS Statistics version 29.0.0.0 (241), IBM Corporation, Armonk, NY, US) where the statistical analysis was conducted. To test for the assumption of homogeneity of variance, the Levene’s test for equality of variances was conducted. If there was homogeneity of variance, a One-way Analysis of Variances

(ANOVA) with a Tukey-Kramer post-hoc analysis were conducted to test for differences between the three groups. If there was heterogeneity of variance, Welch's ANOVA with a Games-Howell post hoc analysis were conducted. Statistical significance was set at $p \leq 0.05$ for all statistical tests. The One-way ANOVA is robust to data that deviates from normal distribution (Driscoll, 1996; Schmider et al., 2010), therefore normality of data was not assessed. For significant pairwise differences the effect size was calculated using Cohen's d. Effect sizes were interpreted according to the following intervals: small = 0.2, moderate = 0.5 and large = 0.8 (McGough & Faraone, 2009).

## 3. Results

| | PrePHV (N = 17) | CircaPHV (N = 40) | PostPHV (N = 68) |
|---|---|---|---|
| Chronological Age (years) | 12.1 ± 0.5 | 13.1 ± 0.5 * | 14.9 ± 1.2 * † |
| Body Mass (kg) | 38.7 ± 5.6 | 49.9 ± 4.9 * | 55.9 ± 8.3 * † |
| Height (cm) | 151.3 ± 6.4 | 162.8 ± 4.2 * | 166.9 ± 5.9 * † |

*Table 1 shows descriptive values (mean ± standard deviation) for chronological age, body mass and height. Chronological age is measured in years, body mass in kilograms and height in centimeters. PrePHV consists of 17 participants, circaPHV consists of 40 participants and postPHV consists of 68 participants.*

** = significantly different from prePHV ($p \leq 0.05$).*

*† = significantly different from circaPHV ($p \leq 0.05$).*

There was a statistical significant difference in chronological age between the groups, as assessed by Welch's $F$ (2, 52.583) = 118.741, $p < 0.001$. With postPHV being older than circaPHV (Mean difference (MD) = 1.85, 95% CI [1.47; 2.23], $p < 0.001$, Cohens d = 1.9) and prePHV (MD = 2.86, 95% CI [2.42; 3.31), $p < 0.001$, Cohens d = 3.0) as well as circaPHV being older than prePHV (MD = 1.02, 95% CI [0.66; 1.38], $p < 0.001$, Cohens d = 2.0), as assessed by Games-Howell post hoc. The effect sizes show a large difference in age between the three groups.

A statistical significant difference in body mass was also observed between the groups, as assessed by Welch's $F$ (2, 47.482) = 51.247, $p < 0.001$. With postPHV being heavier than circaPHV (MD = 6.0, 95% CI [3.0; 9.0], $p < 0.001$, Cohens d = 0.9) and prePHV (MD = 17.2, 95% CI [13.1; 21.3], $p < 0.001$, Cohens d = 2.4) as well as circaPHV being heavier than prePHV (MD = 11.2, 95% CI [7.3; 15.1], $p < 0.001$, Cohens d = 2.1), as assessed by Games-Howell post hoc. The effect sizes show a large difference in body mass between the groups.

A difference in height between the groups was observed to be of statistical significance, One-way ANOVA $F(2, 122) = 54.287$, $p < 0.001$. Tukey-Kramer post hoc showed that postPHV were taller than circaPHV (MD = 4.1, 95% CI [1.5; 6.7], $p < 0.001$, Cohens d = 0.8) and prePHV (MD = 15.6, 95% CI [12.0; 19.2], $p < 0.001$, Cohens d = 2.5) and circaPHV being taller than prePHV (MD = 11.5, 95% CI [7.7; 15.3], $p < 0.001$, Cohens d = 2.1). The effect sizes show a large difference in height between the groups.

There were no statistical significant differences in CMJ performance between prePHV (28.1 ± 3.5 cm), circaPHV (29.8 ± 3.8 cm) and postPHV (29.4 ± 4.1 cm), One-way ANOVA $F(2, 120) = 1.009$, $p = 0.386$.

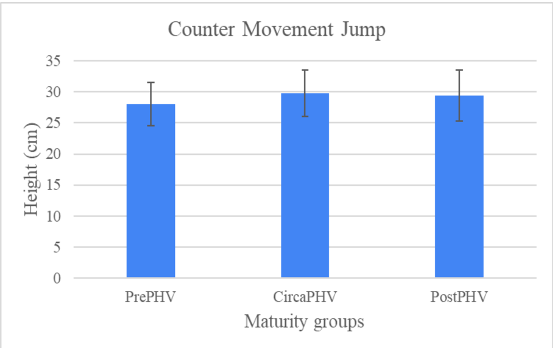


*Figure 2 shows the results of the CMJ test from prePHV (N =16), circaPHV (N = 40) and postPHV (N = 67). The Y-axis shows jump height in centimeters, and the X-axis shows the three different maturity groups. Error bars show the standard deviation.*

No statistical significant differences were observed in 5m sprint times between prePHV (1.1 ± 0.07 s), circaPHV (1.08 ± 0.08 s) and postPHV (1.09 ± 0.08 s), as assessed by One-way ANOVA $F(2, 88) = 0.371$, $p = 0.691$.

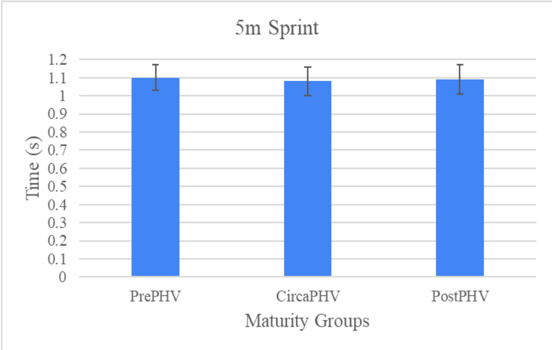


*Figure 3 shows the results of the 5 meter sprint from prePHV (N =14), circaPHV (N = 31) and postPHV (N = 46). The Y-axis shows the time in seconds, and the X-axis shows the three different maturity groups. Error bars show the standard deviation.*

There was a statistical significant difference in 10m sprint times between the groups, One-way ANOVA $F(2, 108) = 3.768$, $p = 0.026$. Tukey-Kramer post hoc showed that postPHV (1.87 ± 0.09 s) had faster 10m sprint times than prePHV (1.94 ± 0.12 s) (MD = 0.07, 95% CI [0.01; 0.13], $p = 0.026$, Cohens $d = 0.66$), but no pairwise difference between circaPHV (1.89 ± 0.08 s) and any of the two other maturity groups in 10m sprint times. The effect size shows a moderate difference in 10m sprint time between prePHV and postPHV.

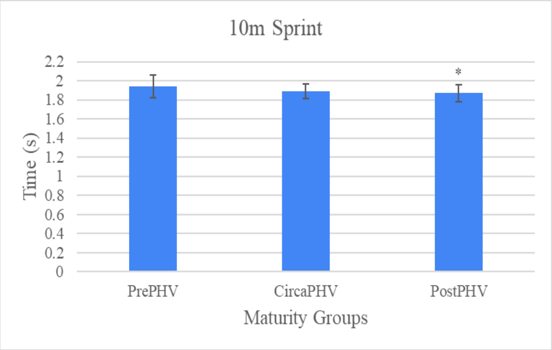


*Figure 4 shows the results of the 10 meter sprint from prePHV (N =17), circaPHV (N = 39) and postPHV (N = 55). The Y-axis shows the time in seconds, and the X-axis shows the three different maturity groups. Error bars show the standard deviation.*

** = Significantly different from prePHV ($p \leq 0.05$).*

No statistical significant differences were observed in 25m sprint times between prePHV (4.06 ± 0.51 s), circaPHV (3.98 ± 0.32 s) and postPHV (3.99 ± 0.29 s), Welch's $F(2, 31.030) = 0.120$, $p = 0.888$.

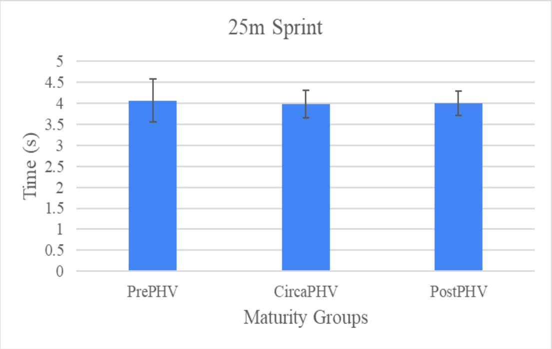


*Figure 5 shows the results of the 25 meter sprint from prePHV (N =14), circaPHV (N = 31) and postPHV (N = 46). The Y-axis shows the time in seconds, and the X-axis shows the three different maturity groups. Error bars show the standard deviation.*

A statistical significant difference was observed between the groups 30m sprint times, One-way ANOVA F (2, 118) = 3.248, p = 0.042. With postPHV (4.72 ± 0.23 s) being faster than prePHV (4.89 ± 0.29 s) (MD = 0.16, 95% CI [0.01; 0.32], p = 0.034, Cohens d = 0.65), no pairwise differences were observed between circaPHV (4.77 ± 0.22 s) and any of the two other maturity groups. The effect size shows a moderate difference in 30m sprint time between prePHV and postPHV.

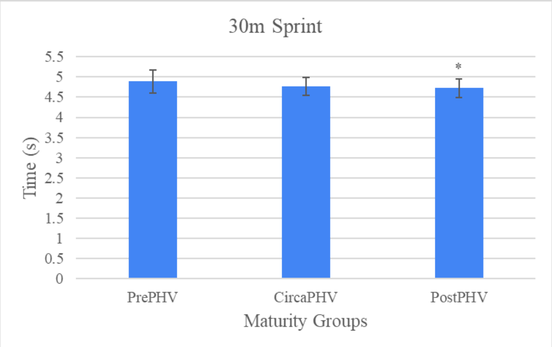


*Figure 6 Shows the results of the 30 meter sprint test from prePHV (N =17), circaPHV (N = 40) and postPHV (N = 64). The Y-axis shows the time in seconds, and the X-axis shows the three different maturity groups. Error bars show the standard deviation.*

** = significantly different from prePHV (p ≤ 0.05).*

There was a statistical significant difference in arrowhead right times between the groups, One-way ANOVA F (2, 80) = 3.775, p = 0.027. With postPHV (8.85 ± 0.38 s) having faster times for arrowhead right than prePHV (9.13 ± 0.38 s) (MD = 0.29, 95% CI [0.03; 0.56], p = 0.027, Cohens d = 0.74), as assessed by Tukey-Kramer post hoc. No difference was observed between circaPHV (8.96 ± 0.26 s) and any of the two other maturity groups. The effect size shows a moderate difference in arrowhead right time between prePHV and postPHV.

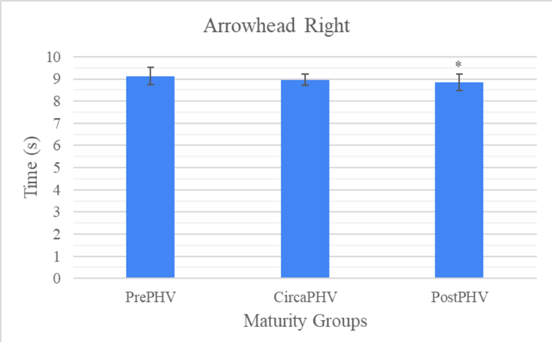


*Figure 7 shows the results of the arrowhead right from prePHV (N =12), circaPHV (N = 28) and postPHV (N = 43). The Y-axis shows the time in seconds, and the X-axis shows the three different maturity groups. Error bars show the standard deviation.*

** = Significantly different from prePHV (p ≤ 0.05).*

Statistical significant differences were also observed in the arrowhead left times between the groups, One-way ANOVA F (2, 80) = 6.247, p = 0.003. With postPHV (8.85 ± 0.38 s) being faster than prePHV (9.23 ± 0.42 s) (MD = 0.38, 95% CI [0.09; 0.67], p = 0.006, Cohens d = 0.95) and circaPHV (9.06 ± 0.33 s) (MD = 0.22, 95% CI [0.00; 0.43], p = 0.047, Cohens d = 0.6), but no difference between prePHV and circaPHV. The effect sizes show a large difference in arrowhead left time between prePHV and postPHV and a moderate difference between circaPHV and postPHV.

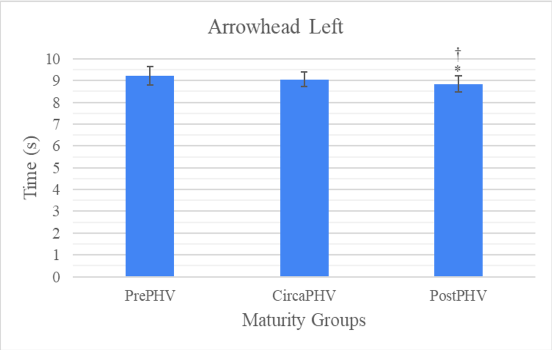


*Figure 8 shows the results of the arrowhead left from prePHV (N =17), circaPHV (N = 39) and postPHV (N = 55). The Y-axis shows the time in seconds, and the X-axis shows the three different maturity groups. Error bars show the standard deviation.*

** = significantly different from prePHV (p ≤ 0.05).*

*† = significantly different from circaPHV (p ≤ 0.05).*

A statistical significant difference was observed in running distance in the YYIR1 test between groups, Welch's F (2, 43.678) = 11.269, p < 0.001. With postPHV (1109.8 ± 380.4 m) performing than prePHV (774.1 ± 351.6 m) (MD = 335.7, 95% CI [93.2; 578.2], p = 0.005, Cohens d = 0.92) and circaPHV (830.8 ± 265.2 m) (MD = 279.1, 95% CI [126.7; 431.5], p < 0.001, Cohens d = 0.85), but no difference between circaPHV and prePHV, as assessed by Tukey-Kramer post hoc. The effect sizes show a large difference in running distance in the YYIR1 test between postPHV and prePHV, as well as postPHV and circaPHV.

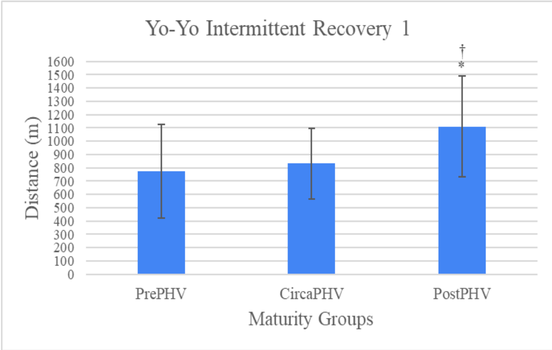


*Figure 9 shows the results of the YYIR1 test from prePHV (N =17), circaPHV (N = 39) and postPHV (N = 63). The Y-axis shows the distance in meters, and the X-axis shows the three different maturity groups. Error bars show the standard deviation.*

** = significantly different from prePHV (p ≤ 0.05).*

*† = significantly different from circaPHV (p ≤ 0.05).*

## 4. Discussion

The aim of this study was to investigate the influence of biological maturation, estimated by percentage of predicted adult height, on jump, sprint, COD and endurance performance among adolescent Danish U13-U19 academy female football players. This was done by dividing 125 participants from three different football academies into prePHV, circaPHV & postPHV based on %PAH. Results showed that postPHV had faster sprint times in the 10m and 30m sprint. PostPHV also had faster running times than prePHV in the arrowhead right and left tests, as well as postPHV being faster than circaPHV in arrowhead left. Furthermore, it was observed that postPHV performed better than pre- and circaPHV in the YYIR1 test.

No significant differences were found between the groups for the CMJ, 5m sprint and 25m sprint test. Furthermore, the results showed that postPHV were the tallest, heaviest and oldest, followed by circaPHV and then by prePHV.

Biological maturation will, as described, have an immense impact on physical performance for males in tests such as CMJ, sprint and COD (Albaladejo-Saura et al., 2021; Read et al., 2017; Robles-Palazón et al., 2024; Rommers et al., 2019; Sellami et al., 2024; Yang & Chen, 2022), but not endurance (Albaladejo-Saura et al., 2021; Yang & Chen, 2022). Studies on the influence of biological maturation in adolescent males have found postPHV players to perform better than circaPHV and prePHV, as well as circaPHV to perform better than prePHV in CMJ, sprint and COD or agility (Albaladejo-Saura et al., 2021; Robles-Palazón et al., 2024; Sellami et al., 2024). Furthermore, the difference between maturity groups have been observed to be of mostly large magnitude (Robles-Palazón et al., 2024). This contrasts with the present study, where postPHV adolescent females were found to perform better than prePHV in, 10m and 30m sprint, arrowhead right and arrowhead left, as well as better than circaPHV in arrowhead left. No differences between groups were observed in CMJ or 5m and 25m sprints in the present study. The magnitude of the difference in arrowhead right was moderate, arrowhead left was moderate to large, and 10m and 30m were moderate. This indicates a difference in the influence of biological maturation on physical performance in adolescent males and females. Adolescent males seem to perform vastly better as they mature, while females do not seem to experience gains in physical performance to the same degree. This is most likely due to the differences in biological maturation in males and females. During puberty, males will gain increased FFM, and a lesser amount of FM compared to females. FFM is beneficial to physical performance, hence the large increases in physical performance during biological maturation in males (Albaladejo-Saura et al., 2021; Read et al., 2017; Robles-Palazón et al., 2024; Rommers et al., 2019; Sellami et al., 2024; Yang & Chen, 2022). In opposition to this, females will gain a lesser amount of FFM but accumulate more FM than males, which is disadvantageous to physical performance (Hunter & Senefeld, 2024; Malina, R. M. et al., 1988). This can explain the differences observed in physical performance gains between males and females, especially regarding physical performance tests, such as CMJ and sprint, with high demands to relative strength.

Regarding endurance, present study found large differences between postPHV and circaPHV, as well as postPHV and prePHV in YYIR1 performance, while the consensus on males seems to be that there is no difference in endurance between maturity groups (Albaladejo-Saura et al., 2021; Yang & Chen, 2022). In a systematic review and meta-analysis by Albaladejo-Saura and colleagues (2021), they reported that four articles found differences in the yo-yo test between some male maturity groups, while four found no difference. However, the meta-analysis showed no differences in yo-yo performance between maturity groups for males (Albaladejo-Saura et al., 2021). This could be due to training variables having a larger impact on endurance performance than biological maturation (Albaladejo-Saura et al., 2021).

The present study found no difference in CMJ performance between groups. This is in line with a study by la Rubia and colleagues (2024), who found no difference in CMJ performance between maturity groups in female youth handball players. Again, this could be due to the increased FM and lesser increased FFM females accumulate during puberty (Hunter & Senefeld, 2024; Malina, R. M. et al., 1988), resulting in less relative strength compared to males. Furthermore, the postPHV participants in the present study are significantly older than circaPHV and prePHV and possibly have had more training and test experience. Even with the possible increased training and test experience, the postPHV participants still do not perform better than prePHV and circaPHV. This further supports that the lack of gains in relative strength, during female puberty, is a likely explanation to the results of the present study. A Study by Emmonds and colleagues (2020) found contrasting results compared to present study. They observed likely differences in CMJ performance from -2.5 to -0.5 years from PHV and possibly to most likely differences between +0.5 to +2.5 years from PHV (Emmonds et al., 2020). The differing results between present study and the study by Emmonds and colleagues (2020) could be due to different cohorts or means of estimating biological maturation. Even though both study cohorts are adolescent female academy football players, the cohorts might differ on training experience, quantity and/or quality. The participants in Emmonds and colleagues (2020) are reported to have pitch-based sessions two to three times of 90 minutes per week plus one to two strength and conditioning sessions of 30-60 minutes per week. However, the training experience, quantity and quality of participants in present study are unknown. The participants in Emmonds and colleagues (2020) might therefore have more training experience, training quantity and/or training quality, especially regarding strength and conditioning training. Strength training is an important factor in improving both absolute and relative strength, with the latter being important for CMJ performance. Therefore, the potential increased strength training for participants in the study by Emmonds and colleagues (2020), might explain why they find more mature players to perform better in CMJ, while present study finds no differences between maturity groups.

Regarding sprint performance, the present study found no differences in 5m and 25m sprint but found postPHV to be faster than prePHV in 10m and 30m sprint. The lack of relative strength gains during female puberty, as discussed in the CMJ section, could explain why no differences were observed in the 5m sprint. Relative strength in lower extremities is an important factor when accelerating, this is due to the requirement of overcoming one's own body mass during acceleration (Comfort et al., 2012). However, the fact that no differences were observed in either the 5m or 25m sprint, with differences observed in the 10m and 30m sprint, could be due to differences in sample sizes. As described in the methods section, one of the academies did not record the 5m or 25m split times, hence the difference in sample size.

PostPHV performing better than prePHV in the 10m and 30m sprint is in line with the study by Emmonds and colleagues (2020). They observed that more mature English adolescent female football players had faster 10m and 30m sprint times than less mature players (Emmonds et al., 2020). Emmonds and colleagues (2020) observed the largest increases in 30m sprint times to happen between -2.5 and +0.5 years from PHV. The faster sprint times for postPHV than prePHV in the present study, could be due to postPHV being taller and therefore most likely having longer legs (Meyers et al., 2015). Meyers and colleagues (2015) showed strong relationships between standing height and leg length and stride length, as well as stride length strongly relating to sprint speed in adolescent boys. Faster sprint times in the 10m and 30m sprint for postPHV may also be due to physiological and neurophysiological changes (Meyers et al., 2015), such as increased muscle-tendon stiffness (Rumpf et al., 2013), reduced antagonist cocontraction (Frost et al., 1997), increased muscle thickness (Abe et al., 2001; Kumagai et al., 2000; Monte & Zamparo, 2019) and fascicle length (Abe et al., 2001; Kumagai et al., 2000). However, these variables would also contribute to increased CMJ as well as 5m and 25m sprint performance, which is not observed in the present study, why they may not be leading factors for increased 10m and 30m sprint performance.

The results showed faster arrowhead right times for postPHV compared to prePHV, as well as faster arrowhead left times for postPHV compared to both circaPHV and prePHV. This is consistent with findings from Emmonds and colleagues (2020), who found more mature players to perform better in the 505 test. However, a study by Söğüt and colleagues (2019) found no difference between early and late maturing tennis players in a hexagon agility test. The differences in the results could be due to the chosen test, means of measurement or participants with different sports backgrounds. The study by Söğüt and colleagues (2019) used a stopwatch as a measurement tool, which means there could be measurement errors from the person operating the stopwatch. This limitation is not present with the use of timing gates, as used in the present study as well as the study by Emmonds and colleagues (2020). The increased COD performance observed in the present study could be due to physiological and neurophysiological changes during puberty, as discussed in the sprint section above. However, as CMJ and 5 meter sprint performances do not seem to increase between maturity groups in the present study, the physiological and neurophysiological changes may only play a trivial role in the increased COD performance for the postPHV group. The more likely explanation for improved COD performance in the postPHV group is better technical COD performance. COD requires a high degree of technical ability where posture, lean, foot placement and adjustment of steps are all important components to execute a good technical COD (Dos'Santos et al., 2017). As the postPHV group is older than circaPHV and prePHV and most likely have more experience with football practice and COD, as well as possibly more test experience, they may therefore have better technical abilities for COD.

The results for the YYIR1 test showed that postPHV covered a greater distance than circaPHV and prePHV. This may be true, since players in the postPHV group are older, and potentially have more training experience than the other groups. Given that football is largely characterized by intermittent workload (Datson et al., 2014), the potential increased training experience of postPHV players may explain the differences observed. To support this, a study by Wright and colleagues (2016) found postPHV female football players to moderately increase their YYIR1 test results after an eight week mixed-methods high intensity interval training. Furthermore, they found the prePHV change in YYIR1 performance to be unclear (Wright et al., 2016). This could indicate that postPHV players benefit more from training than the prePHV players. During puberty the size of the heart (Janz et al., 2000) and lungs (Mahmoud et al., 2018; Nève et al., 2002) increase, hence greater stroke volume, cardiac output and more oxygen uptake can be expected during physical endurance tests, such as YYIR1, and therefore possibly better performance.

Other studies measuring physical endurance and biological maturation in females have found contrasting results (Emmonds et al., 2020; Gryko et al., 2022; Gundersen et al., 2024). The study by Emmonds and colleagues (2020) observed that +0.5 years from PHV likely ran further in YYIR1 than -0.5 years from PHV, with only unclear differences between +0.5 and +1.5 years from PHV as well as +1.5 and +2.5 years from PHV. The study by Emmonds and colleagues (2020) only compared consecutive groups, hence it is unknown as to whether there were differences between the most (+1.5 and +2.5) and least (-1.5 and -2.5) maturity groups in the study. Furthermore, a study by Gundersen and colleagues (2024) found no linear relationship between bone age and 2000m run times.

A limitation of the present study was estimating biological maturation by using the Khamis Roche method. This method is a noninvasive, reliable, convenient (Khamis & Roche, 1994) and recognized method, when a longitudinal approach is not an option (Cumming et al., 2017; Malina, Robert M. et al., 2019). The accuracy of the Khamis Roche method is expressed by using 90% error bounds. The 90% error bounds provide the range within the actual adult stature, for 90% of girls with the same predictor variables (height, body mass and mid-parent height), lies (Khamis & Roche, 1994). The average 90% error bound for females is 4.25 ± 1.64 centimeters (Khamis & Roche, 1994). Furthermore, the Khamis Roche method utilizes height, body mass, mid-parent height and chronological age. The football academies included in the present study used different means of measuring height and body mass, which potentially can reduce the validity of the Khamis Roche method. The height of the parents was self-reported, which is a less valid, although more feasible, method of collecting height since people often overestimate their own height (Epstein et al., 1995). The self-reported heights of the parents were adjusted to obtain a more valid and correct height of the parents.

However, in the present study it is observed that there are clear differences in chronological age, height and body mass between all three groups, with large effect sizes. This can indicate that the use of the Khamis Roche method, self-reported parental height, as well as the academies using different means of measuring height and body mass, may only have had trivial influence on the results of the present study. This study does not include training experience, which can be an important factor that could help explain the differences in physical performance observed (or not observed) between the three groups. However, it would be difficult to obtain valid information regarding training experience, quality and quantity from the academies and players.

Furthermore, as shown in the method and results there is a considerable variation in the number of participants included in each test and each group, which may also have influenced the findings. Results that may have been influenced are the tests where higher p-values and lower effect sizes have been observed. This is among others regarding the 30m sprint where a p-value of 0.042 has been observed.

## 5. Conclusion

The aim of this study was to investigate the influence of biological maturation, estimated by percentage of predicted adult height, on jump, sprint, COD and endurance performance among adolescent Danish U13-U19 academy female football players. The results showed no differences in CMJ, 5m and 25m sprint performances between groups. PostPHV were observed to sprint moderately faster than prePHV in the 10m and 30m sprint. Furthermore, the results showed that postPHV was moderately faster in the arrowhead right than prePHV. In the arrowhead left, postPHV were observed to be moderately faster than circaPHV and much faster than prePHV. Furthermore, postPHV covered a considerably greater distance in the YYIR1 test than circaPHV and prePHV.

The conclusion of the present study is that biological maturation might influence 10m and 30m sprint, COD and endurance performance, but not 5m and 25m sprint and jumping, among adolescent Danish U13-U19 female academy football players. Furthermore, the magnitude of the influence from biological maturation on physical performance is less in female football players compared to males.

## 6. Practical implications

The findings of the present study have practical implications for talent identification and selection as well as training within female football academies. Females do not appear to experience greater increases in explosive power or relative strength with maturation, but there is evidence to suggest that aerobic endurance tends to improve with maturation. Furthermore, the sprint and COD ability will only increase moderately. This differs significantly from what is observed in males, where large increases in jumping, sprinting and COD is observed during biological maturation. This should be taken into consideration when developing and implementing initiatives for talent programmes for adolescent female football players.

Furthermore, the findings from this study can suggest academies to rethink how to train female football players and redesign specific training practices. Bio-banding might be inappropriate when jumping or acceleration are key elements in football training or games. However, it might be appropriate to implement, when endurance, sprint or COD are key elements. FUTURE national teams might still be appropriate, as less mature players might struggle against more mature players, especially in the later stages of football matches. This is because less mature players might lack endurance compared to more mature players, as well as their sprinting and COD abilities not being as developed.

# References

Abe, T., Fukashiro, S., Harada, Y., & Kawamoto, K. (2001). Relationship between sprint performance and muscle fascicle length in female sprinters. *Journal of Physiological Anthropology and Applied Human Science, 20*(2), 141–147. 10.2114/jpa.20.141

Albaladejo-Saura, M., Vaquero-Cristóbal, R., González-Gálvez, N., & Esparza-Ros, F. (2021). Relationship between Biological Maturation, Physical Fitness, and Kinanthropometric Variables of Young Athletes: A Systematic Review and Meta-Analysis. *International Journal of Environmental Research and Public Health*, *18*(1), 328. 10.3390/ijerph18010328

Baxter-Jones, A. D. G., Barbour-Tuck, E. N., Dale, D., Sherar, L. B., Knight, C. J., Cumming, S. P., Ferguson, L. J., Kowalski, K. C., & Humbert, M. L. (2020). The role of growth and maturation during adolescence on team-selection and short-term sports participation. *Annals of Human Biology, 47*(4), 316–323. 10.1080/03014460.2019.1707870

Comfort, P., Bullock, N., & Pearson, S. J. (2012). A Comparison of Maximal Squat Strength and 5-, 10-, and 20-Meter Sprint Times, in Athletes and Recreationally Trained Men. *Journal of Strength and Conditioning Research*, *26*(4), 937–940. 10.1519/JSC.0b013e31822e5889

Cripps, A. J., Hopper, L. S., & Joyce, C. (2016). Coaches' perceptions of long-term potential are biased by maturational variation. *International Journal of Sports Science & Coaching*, *11*(4), 478–481. 10.1177/1747954116655054

Cumming, S. P., Brown, D. J., Mitchell, S., Bunce, J., Hunt, D., Hedges, C., Crane, G., Gross, A., Scott, S., Franklin, E., Breakspear, D., Dennison, L., White, P., Cain, A., Eisenmann, J. C., & Malina, R. M. (2018). Premier League academy soccer players' experiences of competing in a tournament bio-banded for biological maturation. *Journal of Sports Sciences, 36*(7), 757–765. 10.1080/02640414.2017.1340656

Cumming, S. P., Lloyd, R. S., Oliver, J. L., Eisenmann, J. C., & Malina, R. M. (2017). Bio-banding in Sport: Applications to Competition, Talent Identification, and Strength and Conditioning of Youth Athletes. *Strength & Conditioning Journal, 39*(2), 34–47. 10.1519/ssc.0000000000000281

Datson, N., Hulton, A., Andersson, H., Lewis, T., Weston, M., Drust, B., & Gregson, W. (2014). Applied Physiology of Female Soccer: An Update. *Sports Medicine, 44*(9), 1225–1240. 10.1007/s40279-014-0199-1

*DBUFuture* . Retrieved May 23, 2025, from https://www.dbusjaelland.dk/turnering/ungdom-u13-u19/talentudvikling/talentudvikling-drenge/future/

de la Rubia, A., Kelly, A. L., García-González, J., Lorenzo, J., Mon-López, D., & Maroto-Izquierdo, S. (2024). Biological maturity vs. relative age: Independent impact on physical performance in male and female youth handball players. *Biology of Sport, 41*(3), 3–13. 10.5114/biolsport.2024.132999

Dos'Santos, T., Thomas, C., Jones, P. A., & Comfort, P. (2017). Mechanical Determinants of Faster Change of Direction Speed Performance in Male Athletes. *The Journal of Strength & Conditioning Research, 31*(3), 696–705. 10.1519/JSC.0000000000001535

Driscoll, W. C. (1996). Robustness of the ANOVA and Tukey-Kramer statistical tests. *Computers & Industrial Engineering, 31*(1), 265–268. 10.1016/0360-8352(96)00127-1

Emmonds, S., Scantlebury, S., Murray, E., Turner, L., Robsinon, C., & Jones, B. (2020). Physical Characteristics of Elite Youth Female Soccer Players Characterized by Maturity Status. *Journal of Strength and Conditioning Research, 34*(8), 2321–2328. 10.1519/JSC.0000000000002795

Epstein, L. H., Valoski, A. M., Kalarchian, M. A., & McCurley, J. (1995). Do children lose and maintain weight easier than adults: a comparison of child and parent weight changes from six months to ten years. *Obesity Research, 3*(5), 411–417. 10.1002/j.1550-8528.1995.tb00170.x

Frost, G., Dowling, J., Dyson, K., & Bar-Or, O. (1997). Cocontraction in three age groups of children during treadmill locomotion. *Journal of Electromyography and Kinesiology, 7*(3), 179–186. 10.1016/S1050-6411(97)84626-3

Gryko, K., Adamczyk, J. G., Kopiczko, A., Calvo, J. L., Calvo, A. L., & Mikołajec, K. (2022). Does predicted age at peak height velocity explain physical performance in U13-15 basketball female players? *BMC Sports Science, Medicine & Rehabilitation, 14*(1), 21. 10.1186/s13102-022-00414-4

Gundersen, H., Kvammen, K. M. N., Vestbøstad, M., Rygh, C. B., & Grendstad, H. (2024). Relationships between bone age, physical performance, and motor coordination among adolescent male and female athletes. *Frontiers in Sports and Active Living, 6*, 1435497. 10.3389/fspor.2024.1435497

Handelsman, D. J., Hirschberg, A. L., & Bermon, S. (2018). Circulating Testosterone as the Hormonal Basis of Sex Differences in Athletic Performance. *Endocrine Reviews*, *39*(5), 803–829. 10.1210/er.2018-00020

Hill, M., Scott, S., Malina, R. M., McGee, D., & Cumming, S. P. (2020). Relative age and maturation selection biases in academy football. *Journal of Sports Sciences*, *38*(11-12), 1359–1367. 10.1080/02640414.2019.1649524

Hunter, S. K., & Senefeld, J. W. (2024). Sex differences in human performance. *The Journal of Physiology*, *602*(17), 4129–4156. 10.1113/JP284198

Janz, K. F., Dawson, J. D., & Mahoney, L. T. (2000). Predicting heart growth during puberty: The Muscatine Study. *Pediatrics*, *105*(5), E63. 10.1542/peds.105.5.e63

Johnson, A., Farooq, A., & and Whiteley, R. (2017). Skeletal maturation status is more strongly associated with academy selection than birth quarter. *Science and Medicine in Football*, *1*(2), 157–163. 10.1080/24733938.2017.1283434

Khamis, H. J., & Roche, A. F. (1994). Predicting adult stature without using skeletal age: the Khamis-Roche method. *Pediatrics*, *94*(4 Pt 1), 504–507. https://pubmed.ncbi.nlm.nih.gov/7936860/

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Pedersen, P. K., & Bangsbo, J. (2003). The Yo-Yo Intermittent Recovery Test: Physiological Response, Reliability, and Validity. *Medicine & Science in Sports & Exercise*, *35*(4), 697. 10.1249/01.MSS.0000058441.94520.32

Kumagai, K., Abe, T., Brechue, W. F., Ryushi, T., Takano, S., & Mizuno, M. (2000). Sprint performance is related to muscle fascicle length in male 100-m sprinters. *Journal of Applied Physiology (Bethesda, Md.: 1985), 88*(3), 811–816. 10.1152/jappl.2000.88.3.811

MacMaster, C., Portas, M., Parkin, G., Cumming, S., Wilcox, C., & Towlson, C. (2021). The effect of bio-banding on the anthropometric, physical fitness and functional movement characteristics of academy soccer players. *PLoS ONE, 16*(11)10.1371/journal.pone.0260136

Mahmoud, O., Granell, R., Tilling, K., Minelli, C., Garcia-Aymerich, J., Holloway, J. W., Custovic, A., Jarvis, D., Sterne, J., & Henderson, J. (2018). Association of Height Growth in Puberty with Lung Function. A Longitudinal Study. *American Journal of Respiratory and Critical Care Medicine, 198*(12), 1539–1548. 10.1164/rccm.201802-0274OC

Malina, R. M., Bouchard, C., & Beunen, G. (1988). Human Growth: Selected Aspects of Current Research on Well-Nourished Children. *Annual Review of Anthropology, 17*(1), 187–219. 10.1146/annurev.an.17.100188.001155

Malina, R. M., Cumming, S. P., Rogol, A. D., Coelho-E-Silva, M. J., Figueiredo, A. J., Konarski, J. M., & Kozieł, S. M. (2019). Bio-Banding in Youth Sports: Background, Concept, and Application. *Sports Medicine (Auckland, N.Z.), 49*(11), 1671–1685. 10.1007/s40279-019-01166-x

McGough, J. J., & Faraone, S. V. (2009). Estimating the size of treatment effects: moving beyond p values. *Psychiatry (Edgmont (Pa.: Township)), 6*(10), 21–29. https://pubmed.ncbi.nlm.nih.gov/20011465/

Meyers, R. W., Oliver, J. L., Hughes, M. G., Cronin, J. B., & Lloyd, R. S. (2015). Maximal sprint speed in boys of increasing maturity. *Pediatric Exercise Science, 27*(1), 85–94. 10.1123/pes.2013-0096

Monte, A., & Zamparo, P. (2019). Correlations between muscle-tendon parameters and acceleration ability in 20 m sprints. *PloS One, 14*(3), e0213347. 10.1371/journal.pone.0213347

Nève, V., Girard, F., Flahault, A., & Boulé, M. (2002). Lung and thorax development during adolescence: relationship with pubertal status. *The European Respiratory Journal, 20*(5), 1292–1298. 10.1183/09031936.02.00208102

Read, P. J., Oliver, J. L., De Ste Croix, M. B. A., Myer, G. D., & Lloyd, R. S. (2017). Hopping and Landing Performance in Male Youth Soccer Players: Effects of Age and Maturation. *International Journal of Sports Medicine, 38*(12), 902–908. 10.1055/s-0043-114009

Robles-Palazón, F. J., McMahon, J. J., Ayala, F., & Comfort, P. (2024). Things to keep in mind when selecting physical assessments in youth soccer: Correlations between test performances, interlimb asymmetries, and effects of maturation. *PloS One, 19*(6), e0305570. 10.1371/journal.pone.0305570

Rommers, N., Mostaert, M., Goossens, L., Vaeyens, R., Witvrouw, E., Lenoir, M., & D'Hondt, E. (2019). Age and maturity related differences in motor coordination among male elite youth soccer players. *Journal of Sports Sciences, 37*(2), 196–203. 10.1080/02640414.2018.1488454

Rumpf, M. C., Cronin, J. B., Oliver, J. L., & Hughes, M. G. (2013). Vertical and leg stiffness and stretch-shortening cycle changes across maturation during maximal sprint running. *Human Movement Science, 32*(4), 668–676. 10.1016/j.humov.2013.01.006

Schmider, E., Ziegler, M., Danay, E., Beyer, L., & Bühner, M. (2010). Is it really robust? Reinvestigating the robustness of ANOVA against violations of the normal distribution assumption. *Methodology: European Journal of Research Methods for the Behavioral and Social Sciences, 6*(4), 147–151. 10.1027/1614-2241/a000016

Sellami, M., Makni, E., Moalla, W., Tarwneh, R., & Elloumi, M. (2024). Effect of maturation level on normative specific-agility performance metrics and their fitness predictors in soccer players aged 11–18 years. *BMC Sports Science, Medicine and Rehabilitation, 16*(1)10.1186/s13102-024-00855-z

Söğüt, M., Luz, L. G. O., Kaya, Ö B., Altunsoy, K., Doğan, A. A., Kirazci, S., Clemente, F. M., Nikolaidis, P. T., Rosemann, T., & Knechtle, B. (2019). Age-and maturity-related variations in morphology, body composition, and motor fitness among young female tennis players. *International Journal of Environmental Research and Public Health, 16*(13)10.3390/ijerph16132412

Sweeney, L., Sinkunas, L., & Lundberg, T. R. (2024). Physical and perceptual demands of youth international team match-play in traditional and aged-matched future teams for biologically late maturing soccer players. *Ann Hum Biol, 51*(1), 2437164. 10.1080/03014460.2024.2437164

Sweeney, L., Lundberg, T. R., Sweeney, C., Hickey, J., & MacNamara, Á. (2025). Biological maturity but not relative age biases exist in female international youth soccer players relative to the general population. *Biology of Sport*, *42*(2), 249–256. 10.5114/biolsport.2025.144411

Wright, M. D., Hurst, C., & Taylor, J. M. (2016). Contrasting effects of a mixed-methods high-intensity interval training intervention in girl football players. *Journal of Sports Sciences*, *34*(19), 1808–1815. 10.1080/02640414.2016.1139163

Yang, S., & Chen, H. (2022). Physical characteristics of elite youth male football players aged 13-15 are based upon biological maturity. *PeerJ*, *10*, e13282. 10.7717/peerj.13282