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Assessing the influence of chronological and skeletal age on selection and physical performance in South African youth football

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Abstract

This cross-sectional study examined potential selection-biases—specifically the Relative Age Effect (RAE) and maturation selection-bias—and explored how chronological age (CA) and skeletal age (SA) relate to physical performance in South African youth footballers. A total of 105 male players aged 10–18 years from two academies in the Western Cape province were assessed. Anthropometric data were collected, and SA was estimated using the BAUSport™ system. Performance outcomes included hip adduction and abduction strength (N), handgrip strength (kg), and standing broad jump (cm). Players were grouped into CA and SA percentile-bands across the full sample, and performance was compared using one-way Welch's ANOVA. Multiple linear regression was used to examine the predictive value of CA and SA on physical performance. RAE was evident, with more players born in the first half of the selection year. A key finding was the slightly delayed maturation profile in the sample, with an underrepresentation of early maturers—contrasting with trends that typically favour them. This suggests that RAE may have a stronger influence than early maturation on continued selection and participation. Both CA and SA were positively associated with performance, but SA emerged as the stronger predictor, particularly among younger players. However, performance differences plateaued at higher maturity levels. These findings highlight the influence of CA and SA on selection and performance in youth football. Considering maturity status into talent development strategies may promote more developmentally appropriate and equitable practices. The study provides important baseline data for future research in South African football.

Keywords

Anthropometry, biological maturation, relative age effect, soccer, talent development

Reviewer: Nuno André Nunes (Solent University, UK)

Introduction

In youth football (soccer), players are generally grouped by chronological age (CA) using fixed cut-off dates (e.g., 1 January–31 December in the South Africa), typically in one- or two-year bands.[1,2] Relative age effects (RAEs) arise from CA differences between players, favouring those born in the first half of the year.[1–3] RAEs are believed to be shaped by interacting factors such as environmental policies, physical and psychological development, and individual traits like birthdate and biological maturity.[2,4,5] RAEs are present from early childhood, tend to persist through adolescence, yet may lessen—or even reverse—at senior levels.[2,4,5] Players born in the second half of the year are often underrepresented in academy football, limiting their access to key developmental opportunities and high-quality learning environments.[6–8]

While RAE and maturation-related selection biases are often discussed together, they are distinct biases shaped by different processes.[3,7,9,10] CA groupings assume players of the same age are similarly developed, but while CA can be a useful proxy for psychological, social, and motor development, it is a poor indicator of physical maturity.[11]

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Biological maturation refers to the process of physical development toward adult form, commonly assessed through skeletal age (SA), which reflects an individual's maturity status, tempo, and timing.[12–14] SA is most commonly estimated by evaluating the development of bones in the left hand and wrist using radiographic reference standards, with alternative approaches such as ultrasonographic computerised methods also reported in the literature.[11–14] This provides an indicator of biological maturity that may be advanced or delayed relative to CA, as growth and maturing timing and tempo do not occur uniformly across individuals.[11–13,15] In youth football, players of the same CA can differ in SA by more than five years, resulting in large differences in height, strength, power, and endurance.[8,11,15] A key marker of this variation is age at peak height velocity (APHV)—the age at which the rate of growth is greatest during puberty.[12,16] Early-maturing male players, who reach PHV at a younger CA compared to their peers, typically demonstrate temporary advantages in size and athleticism.[6,12,16–18] These advantages emerge at the onset of puberty and are generally maintained through mid-to-late adolescence, increasing the likelihood of selection and retention in academy systems.[19,20]

Equally talented yet late-maturing male players are often overlooked due to their physical disadvantages, resulting in higher rates of deselection or voluntary withdrawal in favour of opportunities or activities where physical maturity plays a lesser role.[2,8,19] While some late-maturing players who remain in the system may possess or develop superior technical, tactical, or psychological skills—a phenomenon known as the "underdog effect"—only a small proportion are retained long enough for these attributes to be realised.[17,19,21] Although maturation is largely genetically driven, environmental factors such as chronic stress and inadequate nutrition can further delay development and impair physical growth and maturation.[16,22,23] Nutrition during childhood and early adolescence plays a critical role in shaping the timing and progression of puberty. Undernutrition has been consistently associated with delayed pubertal onset, prolonged maturation, and constrained gains in stature and lean mass, whereas excess adiposity has been linked to earlier pubertal timing in boys.[22–24] Although some catch-up growth may occur in late childhood or early adolescence, evidence suggests that sustained nutritional adversity—whether through chronic undernutrition or dysregulated energy balance—can limit biological catch-up and extend maturity-related differences between players of the same CA.[22,24]

Despite football's popularity in South Africa, research related to talent identification and the influence of relative age and maturation upon player selection and performance is limited. Understanding this relationship is important, as South Africa employs a structured framework for youth football development, which serves as a foundation for international success.[25] Youth development begins with organised local and national competitions, starting at the U12 level, with subsequent tournaments providing pathways to international competitions at U17 and U20 levels. To standardise competition, a two-year age grouping policy is commonly applied, categorising players into brackets such as U12, U14, U16, and U18. Within these age groups, regular trials are conducted to identify promising players for specialised coaching, preparing them for advanced competition levels. In recent years, the introduction of the DStv Diski Challenge (DDC) has created a transitional platform for U21 players, functioning as an apprenticeship league rather than a fully professional competition. This initiative bridges the gap between youth competitions and professional leagues, offering players opportunities to refine their skills and transition into the professional ranks, either in South Africa's Premier Soccer League or National First Division or through international club opportunities.

In light of the preceding discussion, the present study aims to address three key objectives: (1) examine the presence and magnitude of relative age and maturation selection biases in male South African academy players, (2) investigate differences in physical performance outcomes across age groups, comparing relatively older vs younger players in terms of both CA and SA, and (3) analyse the linear relationships between both SA and CA with physical performance outcomes. The findings aim to advance understanding of these relationships, offering insights to support talent development strategies for South African youth football.

Methods

Study design

A cross-sectional, quantitative study design was employed to investigate the relationship between CA and SA and physical performance among adolescent football players. This study involved retrospective analysis of de-identified data extracted from a larger research database project that focused on growth, maturation, and development among South African youth athletes. This manuscript was prepared in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for cross-sectional studies.[26]

Sample

Data were exported from an existing research database, and all players included (n = 105; aged 10–18 years) met eligibility criteria relevant to the study question and had complete data available. All players were grouped into four age categories (U12: n = 28; U14: n = 29; U16: n = 28; U18: n = 20) and participated in structured training programmes (3–4 sessions per week) led by qualified coaches, competing within their respective age groups in the same academy league structure in the Western Cape province, ensuring comparable exposure to coaching, training load, and competitive opportunities. Coaches were not provided with information on players' SA during academy selection, meaning that any observed differences in maturity were not explicitly influenced by SA knowledge.

Ethics

This study was conducted in accordance with the Declaration of Helsinki and received ethical approval from the Stellenbosch University, Health Research Ethics Committee [Ethics Reference Number: S23/10/250 (PhD)]. Written informed consent from parents or guardians and assent from players were obtained as part of the original research database protocol [Ethics Reference No: B22/02/001]. For this secondary analysis, a waiver of additional consent was granted, as only de-identified data were used, and this use of data was outlined in the database consent and assent forms.

Procedures

All procedures were conducted between April and May 2023, at the start of the season, and followed standardised protocols to ensure consistency across assessments. Measurements were carried out at each club's respective training facility prior to scheduled training sessions or matches.

Anthropometry

Anthropometric measurements included height (cm), body mass (kg), and body mass index (BMI), calculated as body mass divided by height squared (kg/m^2).[27] All assessments followed the International Standards for Anthropometry Assessments (ISAK) guidelines.[27] Participants wore minimal clothing (t-shirt and shorts) and removed their shoes. For body mass, they stood still on a calibrated digital scale (Seca 813, Seca GmbH, Hamburg, Germany). For height, they stood upright with heels together against a portable stadiometer (Seca 213, Seca GmBH, Hamburg, Germany), looking straight ahead. They were instructed to take a deep breath, hold the position, and remain still until the measurement was taken.[25] Two measurements were recorded (mean used for analysis), with a third taken if discrepancies exceeded 0.4 cm or 0.4 kg (median used).

Age and biological maturation

RAEs were examined based on players' birth quarters (Q1: January to March; Q2: April to June; Q3: July to September; Q4: October to December), while CA was calculated as the difference between the date of assessment and the participants' birth dates.[11] Biological maturation was assessed using the BAUSport™ system (SonicBone Medical Ltd, Israel), which estimates SA by measuring bone density at three sites on the left hand: the distal radius and ulna, the metacarpals, and the proximal third phalanx.[13,14] This system uses ultrasound technology to estimate SA, offering a safe and accurate alternative to traditional approaches using radiographs.[13,14] An examination of test-retest reliability in the target population (18 players aged 10.7–17.9 years) indicated a Standard Error of Measurement (SEM) of 0.19 years for SA. Maturation timing was classified as follows: late maturity (SA is more than one year behind CA), on-time maturity (SA is within one year of CA), and early maturity (SA is more than one year ahead of CA).[12,21,22]

Hip adduction and abduction strength

Hip strength was assessed using the ForceFrame strength testing system (Vald Performance, Queensland, Australia), which employs independent load cells to measure isometric force output in Newtons (N).[28] The system demonstrates high test-retest reliability for assessing hip adduction and abduction strength in football players (ICC = 0.92–0.94).[28,29] Following a general warm-up involving dynamic hip mobility exercises, participants were positioned in a crook-lying posture with 45-degree hip flexion and bent knees, resting their knees on pads. For each movement—adduction (knees together) and abduction (knees apart)—they performed three 3-s maximal isometric contractions. Peak values from the left and right limbs were averaged to provide a single value for adduction and abduction strength, as the focus was on overall group differences rather than interlimb strength assessment.

Standing broad jump

The standing broad jump, a validated measure of lower-limb power, was performed twice, with the best score retained for analysis.[30] Participants stood behind the take-off line, feet shoulder-width apart and were instructed to jump forward as far as possible using an arm swing, aiming to "stick the landing." Distance from the line to the back of the heel on landing was measured to the nearest 0.1 cm.

Handgrip strength

Upper-body strength was assessed using a digital handgrip dynamometer (Takei Grip-D, Takei Scientific Instruments Co., Ltd, Niigata, Japan). This test is widely used in sports science for measuring muscular strength and has applications in fitness, sports, rehabilitation, and research.[30] Participants stood in a relaxed posture and gripped the device with their testing hand, applying maximal effort during two trials per hand. The highest value across both hands (in kg, recorded to the nearest 0.1 kg) was averaged and retained for analysis.

Statistical analysis

Descriptive summary statistics, including counts, means, and standard deviations, were calculated to provide an overview of the sample's characteristics and the distribution of key variables. To evaluate potential biases in the distribution of participants, a series of chi-squared ($\chi 2$) tests of independence were conducted.[31] These tests examined the associations between age groups (U12, U14, U16, U18) and birth quarter (Q1, Q2, Q3, Q4), age groups and maturity timing (early, on-time, late), and maturity timing and birth quarter. Cramer's V was used as an effect size measure to assess the strength of the associations within the contingency tables. These tests determined whether the distributions of players across these categories differed significantly.

Players were grouped into CA and SA percentile bands (0–25th, 26th–50th, 51st–75th, 76th–100th) across the full sample to compare physical performance by relative age and maturity. Percentile age group differences were analysed using one-way Welch's ANOVA, a robust method suitable for samples with unequal variances. Effect sizes were reported using omega squared (ω^2) to indicate the practical significance of findings. Where significant differences were found, Games-Howell post-hoc tests were used for pairwise comparisons, which adjust for unequal variances and sample sizes. These comparisons were reported with estimated mean differences, 95% confidence intervals (CIs), and Hedges' g to assess effect magnitude (small = 0–0.2, medium = 0.3–0.5, large > 0.8).

Multiple linear regression models were used to assess the extent to which CA and SA predicted physical performance outcomes: hip adduction and abduction strength, handgrip strength, and broad jump. Each model included estimates, standard errors, 95% CIs, t-values, and p-values for each predictor. Adjusted R-squared values were reported to reflect model fit. Statistical significance was set at $p < 0.05$ for all analyses.

Results

Relative age effect and maturity selection biases

The mean values and standard deviations for CA and SA were 14.1 ± 2.2 years and 13.7 ± 2.2 years, respectively. The mean difference between SA and CA was -0.4 ± 1.1 years, indicating that, on average, the sample was slightly delayed in skeletal maturation. This difference was statistically significant, $T(97) = 3.93$, $p < 0.01$, Hedges' $g = 0.39$ (95% CI [0.19, 0.60]). The distribution of players based on maturity timing was early = 7 (7%), on-time = 64 (65%) and late = 27 (28%) players.

Most participants (62.9%) were born within the first half of the year with a birth quarter distribution of Q1 = 27.6%, Q2 = 35.2%, Q3 = 15.2%, and Q4 = 21.9%, revealing a significant RAE ($\chi2 = 9.43$, $p = 0.02$) when compared to a day corrected uniform distribution[29]; Q1 = 24.7%, Q2 = 24.9%, Q3 = 25.2% and Q4 = 25.2%. Figure 1 illustrates findings from the $\chi2$ tests of independence. The results revealed significant associations between age group and birth quarter ($\chi2 = 26.1$, $p = 0.001$, $V = 0.24$), age group and maturity timing ($\chi2 = 23.9$, $p < 0.001$, $V = 0.31$), while no significant association was observed ($\chi2 = 9.02$, $p = 0.17$, $V = 0.12$) between maturity timing and birth quarter. Overall, 40 of the 105 players (38.1%) were classified as underweight (BMI < 18.5) according to World Health Organization criteria. The prevalence of underweight players was highest in the U12 group (64.3%) and progressively decreased across U14 (50.0%), U16 (22.2%), and U18 (10.0%). When grouped by SA, underweight status was most prevalent in the least skeletally mature group (SA1: 76.9%) and declined steadily with advancing skeletal maturity. Overweight players were rare and observed only in the most skeletally mature groups.

Age group differences in physical performance outcomes

Statistically significant differences in physical performance outcomes ($p < 0.01$) were observed across age groups (U12, U14, U16, U18) with a trend towards greater body size and physical performance in older age groups. The magnitude of these differences varied across the performance outcomes, ranging from medium to large ($\omega^2 = 0.66$ to 0.86). For performance outcomes, handgrip strength demonstrated the largest effect size ($\omega^2 = 0.86$), followed by hip abduction strength and broad jump performance ($\omega^2 = 0.77$ each). Hip adduction strength had the smallest effect size ($\omega^2 = 0.66$). Statistically significant differences in performance outcomes were also observed when players were grouped by CA or SA percentile groups ($p < 0.01$).

Results from the ANOVAs are presented in Table 1. CA groups were categorized as CA1 (9.4–12.2 years), CA2 (12.2–13.9 years), CA3 (13.9–16.0 years), and CA4 (16.0–18.1 years), while SA groups were categorized as SA1 (8.9–12.1 years), SA2 (12.1–14.4 years), SA3 (14.4–15.8 years), and SA4 (15.8–17.3 years). Effect sizes for group differences ranged from $\omega^2 = 0.65$ to 0.85 for CA and $\omega^2 = 0.68$ to 0.91 for SA, indicating moderate-to-large effects. Handgrip strength had the largest effect size for both CA ($\omega^2 = 0.85$) and SA ($\omega^2 = 0.91$) groupings, while hip adduction strength had the smallest effect size (CA: $\omega^2 = 0.65$; SA: $\omega^2 = 0.68$).

Pairwise comparisons between groups (Table 2) revealed the largest estimated differences between the oldest and youngest groups (CA4 vs CA1 and SA4 vs SA1). The second-largest differences were found between CA3 vs CA1 and SA3 vs SA1. Notably, for consecutive age groups, the largest gains in physical performance were observed between the youngest and second youngest groups (CA2 vs CA1 and SA2 vs SA1) across all characteristics. In the mid-range groups (CA3 vs CA2 and SA3 vs SA2), differences captured by SA groupings were more pronounced than those captured by CA. Estimated differences for SA3 vs SA2 across all physical characteristics were comparable to SA2 vs SA1, whereas for CA3 vs

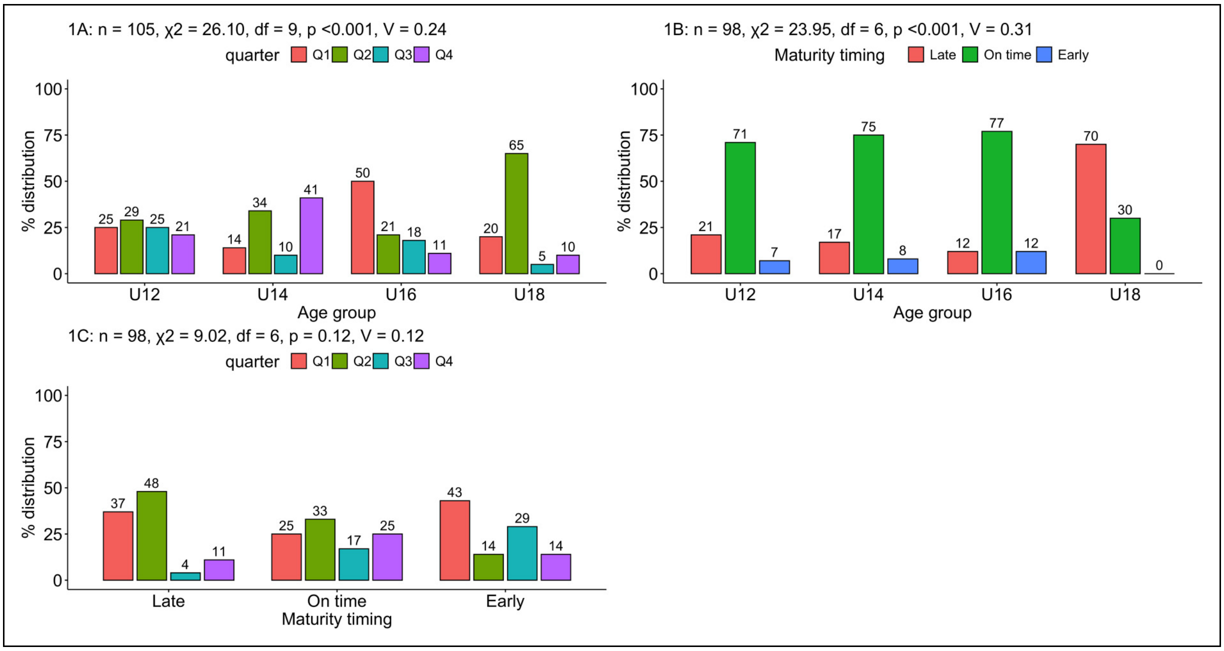

Figure 1. Percentage distribution and associations between age group, birth quarter, and maturity timing.

CA2, differences were reduced, with no significant differences found for hip adduction strength and handgrip strength. For the oldest consecutive groups (CA4 vs CA3 and SA4 vs SA3), no significant differences were observed for hip adduction strength and broad jump performance for CA4 vs CA3, while no significant differences in all four physical performance outcomes were observed for SA4 vs SA3.

Table 3 presents the results from the multiple regression models with SA and CA included as explanatory variables for the physical characteristics. The models demonstrated high explanatory power, particularly for height ($R^2 = 0.95$) and handgrip strength ($R^2 = 0.82$), indicating a strong overall fit. In most cases, SA explained a larger proportion of the variance in outcomes when controlling for CA, while CA contributed minimally when SA was controlled for. Significant associations were found for SA with height ($p < 0.01$), body mass ($p < 0.01$), BMI ($p = 0.01$), hip adduction strength ($p < 0.01$), handgrip strength ($p < 0.01$), and broad jump performance ($p < 0.01$). In contrast, CA was significantly associated only with height ($p < 0.01$) and broad jump ($p = 0.03$), with no other significant effects observed. Variance inflation factors (VIFs) were calculated to assess multicollinearity between SA and CA across all models, yielding values between 4.37 and 4.61. These values remain below the commonly accepted threshold of 5, indicating that although the predictors are moderately correlated, multicollinearity is not at a level that would compromise the regression estimates. Figure 2 displays the relationship between SA and CA with physical performance outcomes across percentile-based groups, illustrating stronger and more consistent associations for SA, particularly in younger athletes.

Discussion

The aim of this study was to describe relative age effects and biological maturity status in South African academy football players, and to examine their implications for selection patterns and physical performance outcomes. The observation of a RAE aligns with previous research on South African 13 to 16-year-old rugby union players[32] and 18 to 25-year-old university student-athletes,[5] adding further evidence of its prevalence in South African sport. The overrepresentation of players born in the first half of the selection year is also consistent with studies from football academies in European countries, reinforcing the idea that player selection and participation is influenced by relative age.[2,3,7–9] The RAE was most pronounced in the older age-groups, with 71% of U16 and 75% of U18 players born in Q1 and Q2, compared to 54% among the U12 and 48% among the U14 players. This suggests that the RAE intensified with age in the current sample, contrary to previous studies that reported a slight decrease in the RAE in older age-groups.[4,8]

While in our sample two-year CA bands are used—limiting CA differences within teams to 1.8 to 2 years—the observed SA ranges were significantly broader, spanning from 3.4 to 4.2 years across age groups. This substantial intra-group variation supports previous research showing that players of a similar CA can differ considerably in biological maturity,[5,19] underscoring the limitations of

Table 1. Group differences in physical characteristics by team and percentile based CA and SA age groups.

Variable	n	U12	U14	U16	U18	F_{Welch}	P_{value}	$\omega^2_{effect\ size}$
Height (cm)	99	145.9 ± 7.1	160.4 ± 9.3	170.6 ± 7.7	171.2 ± 6.1	73.02	<0.01	0.80
Body mass (kg)	99	38.6 ± 5.9	49.0 ± 9.2	58.7 ± 7.7	63.9 ± 10.3	55.51	<0.01	0.77
BMI (m/kg^2)	99	18.0 ± 1.6	18.9 ± 2.1	20.1 ± 1.7	21.7 ± 2.7	13.27	<0.01	0.43
CA (years)	105	11.4 ± 0.7	13.3 ± 0.6	15.5 ± 0.6	17.3 ± 0.6	416.77	<0.01	0.96
SA (years)	98	10.9 ± 1.1	13.3 ± 1.3	15.3 ± 1.0	15.8 ± 0.9	111.64	<0.01	0.86
SA - CA (years)	98	−0.4 ± 0.9	0.0 ± 1.1	−0.1 ± 0.9	−1.5 ± 0.9	10.66	<0.01	0.36
Abductors (N)	100	169.8 ± 37.9	248.2 ± 74.6	288.3 ± 46.1	356.3 ± 71.7	55.56	<0.01	0.77
Adductors (N)	100	188.5 ± 47.0	292.0 ± 81.7	317.7 ± 75.2	363.8 ± 98.3	32.64	<0.01	0.66
Handgrip (kg)	98	19.7 ± 3.4	29.8 ± 7.6	35.5 ± 5	40.6 ± 6.2	97.50	<0.01	0.86
Broad jump (cm)	99	157.9 ± 20.3	188.6 ± 26.1	222.3 ± 27.2	228.4 ± 17.6	59.22	<0.01	0.77
CA groups	n	CA1 (9.5–12.2)	CA2 (12.2–13.9)	CA3 (13.9–16.0)	CA4 (16.1–18.1)	F_{Welch}	P_{value}	$\omega^2_{effect\ size}$
Abductors (N)	100	169.0 ± 38.5	238.2 ± 70.3	286.7 ± 55.9	341.7 ± 69.8	49.37	<0.01	0.73
Adductors (N)	100	185.2 ± 47.0	287.9 ± 82.8	308.9 ± 77.9	357.49 ± 89.9	33.30	<0.01	0.65
Handgrip (kg)	98	19.5 ± 3.4	29.3 ± 7.8	34.1 ± 6.3	39.7 ± 5.7	91.47	<0.01	0.85
Broad jump (cm)	99	158.5 ± 21.0	186.7 ± 27.1	213.8 ± 32.7	228.6 ± 16.4	58.54	<0.01	0.77
SA groups	n	SA1 (8.9–12.1)	SA2 (12.1–14.4)	SA3 (14.4–15.8)	SA4 (15.8–17.3)	F_{Welch}	P_{value}	$\omega^2_{effect\ size}$
Abductors (N)	93	165.4 ± 33.5	240.0 ± 54.1	325.3 ± 49.6	337.8 ± 75.7	73.83	<0.01	0.83
Adductors (N)	93	190.8 ± 54.0	280.4 ± 68.0	357.5 ± 75.5	351.4 ± 89.2	34.23	<0.01	0.68
Handgrip (kg)	96	18.9 ± 2.9	28.2 ± 5.8	37.5 ± 4.5	41.0 ± 4.9	162.32	<0.01	0.91
Broad jump (cm)	92	158.8 ± 20.8	194.7 ± 24.6	222.7 ± 22.2	231.0 ± 22.4	52.00	<0.01	0.76

Table 2. Pairwise comparisons of percentile-based groups for CA and SA across physical performance outcomes.

Physical characteristics	Comparison group	CA p-value	CA estimated diff (95% CI)	CA hedges' g	SA p-value	SA estimated diff (95% CI)	SA hedges' g
Hip abduction (N)	2 vs 1	<0.001	102.7 (52.4, 152.9)	−1.49	<0.001	89.6 (42.3, 136.9)	−1.45
	3 vs 2	0.79	21.0 (−39.5, 81.5)	−0.26	<0.001	77.1 (21.9, 132.3)	−1.05
	4 vs 3	0.19	48.6 (−15.3, 112.5)	−0.57	1.00	−6.1 (−74.7, 62.5)	0.07
	3 vs 1	<0.001	123.7 (74.0, 173.3)	−1.9	<0.001	166.7 (117.4, 215.9)	−2.51
	4 vs 2	0.03	69.6 (5.2, 134.1)	−0.79	0.04	71.0 (3.7, 138.3)	−0.89
	4 vs 1	<0.001	172.3 (117.7, 226.9)	−2.37	<0.001	160.6 (97.6, 223.5)	−2.23
Hip adduction (N)	2 vs 1	<0.001	69.2 (26.9, 111.6)	−1.2	<0.001	74.6 (39.5, 109.7)	−1.66
	3 vs 2	0.04	48.4 (0.8, 96.1)	−0.75	<0.001	85.3 (45.2, 125.4)	−1.62
	4 vs 3	0.02	55.1 (7.0, 103.1)	−0.86	0.92	12.5 (−142.0, 66.9)	−0.20
	3 vs 1	<0.001	117.6 (80.8, 154.5)	−2.42	<0.001	159.9 (128.1, 191.7)	−3.73
	4 vs 2	<0.001	103.5 (51.3, 155.6)	−1.46	<0.001	97.8 (41.7, 153.9)	−1.48
	4 vs 1	<0.001	172.7 (129.9, 215.6)	−3.02	<0.001	172.4 (121.0, 223.7)	−3.07
Broad jump (cm)	2 vs 1	<0.001	9.7 (4.9, 14.6)	−1.65	<0.001	9.3 (6.0, 12.7)	−2.00
	3 vs 2	0.11	4.8 (−0.8, 10.4)	−0.68	<0.001	9.3 (5.5, 13.3)	−1.76
	4 vs 3	<0.01	5.6 (1.1, 10.1)	−0.92	0.10	3.4 (−0.5, 7.3)	−0.72
	3 vs 1	<0.001	14.6 (10.7, 18.4)	−2.85	<0.001	18.6 (15.8, 21.5)	−4.95
	4 vs 2	<0.001	10.4 (5.0, 15.8)	−1.52	<0.001	12.7 (8.5, 17.0)	−2.31
	4 vs 1	<0.001	20.2 (16.1, 23.7)	−4.24	<0.001	22.1 (18.6, 25.5)	−5.66
Handgrip (kg)	2 vs 1	<0.001	28.2 (10.0, 46.5)	−1.14	<0.001	35.9 (18.5, 53.2)	−1.55
	3 vs 2	0.01	27.1 (4.3, 49.9)	−0.89	<0.001	28.0 (9.9, 46.0)	−1.18
	4 vs 3	0.21	14.8 (−5.3, 34.9)	−0.56	0.62	8.3 (−10.1, 26.7)	−0.36
	3 vs 1	<0.001	55.3 (34.0, 76.6)	−1.98	<0.001	63.8 (47.5, 80.2)	−2.93
	4 vs 2	<0.001	41.9 (25.2, 58.6)	−1.83	<0.001	36.2 (17.0, 55.5)	−1.50
	4 vs 1	<0.001	70.1 (55.7, 84.5)	−3.67	<0.001	72.1 (54.4, 89.9)	−3.30

CA = chronological age; SA = skeletal age; *95% CI = 95% confidence intervals.*

Table 3. Multiple regression analysis of CA and SA as predictors of physical performance outcomes.

Outcome	R^2 adjusted	Predictor	Standard error	T_{value}	P_{value}	Estimate (95% CI)
Height (cm)	0.95	(Intercept)	1.85	46.44	<0.01	85.8 (82.2, 89.5)
		SA	0.27	25.15	<0.01	6.8 (6.3, 7.4)
		CA	0.26	−4.91	<0.01	−1.3 (−1.8, −0.8)
Body mass (kg)	0.82	(Intercept)	3.52	−5.32	<0.01	−18.7 (−25.7, −11.8)
		SA	0.52	10.39	<0.01	5.4 (4.4, 6.4)
		CA	0.50	−0.47	0.64	−0.2 (−1.2, 0.8)
BMI (m/kg^2)	0.38	(Intercept)	1.24	8.22	<0.01	10.2 (7.8, 12.6)
		SA	0.18	2.64	0.01	0.5 (0.1, 0.8)
		CA	0.18	1.09	0.28	0.2 (−0.2, 0.5)
Hip abduction (N)	0.66	(Intercept)	34.12	−5.39	<0.01	−183.9 (−251.4, −116.4)
		SA	5.05	4.71	<0.01	23.8 (13.8, 33.8)
		CA	4.95	1.72	0.09	8.5 (−1.3, 18.3)
Hip adduction (N)	0.53	(Intercept)	45.14	−3.27	<0.01	−147.4 (−236.5, −58.3)
		SA	6.69	4.46	<0.01	29.8 (16.6, 43.0)
		CA	6.55	0.32	0.75	2.1 (−10.9, 15.1)
Handgrip (kg)	0.82	(Intercept)	2.73	−8.53	<0.01	−23.3 (−28.7, −17.9)
		SA	0.41	8.54	<0.01	3.5 (2.7, 4.3)
		CA	0.40	1.06	0.29	0.4 (−0.4, 1.2)
Broad jump (cm)	0.67	(Intercept)	14.04	1.01	0.32	14.2 (−13.5, 41.8)
		SA	2.04	4.39	<0.01	9.0 (4.9, 13.0)
		CA	2.00	2.22	0.03	4.4 (0.5, 8.4)

SA = skeletal age; CA = chronological age; 95% CI = 95% confidence intervals.

grouping athletes solely by CA.[1–2,5] In this sample, a statistically significant delay in SA relative to CA was observed, indicating a general trend toward later biological maturation. The relative underrepresentation of early-maturing players in this sample contrasts with patterns reported in many European, North American, and South American academy systems, where early-maturing players are often overrepresented.[17,19] Notably, among the U18 players in this study, 70% were late maturing and none were early maturing. Additionally, a high proportion (85%) of late-maturing players were born in the first half of the year (Q1 or Q2), suggesting that relative age may offer a compensatory selection advantage. This could allow late-maturing but relatively older players to remain in development systems longer or be reintegrated as they catch up biologically. In this context, RAE—rather than early maturation—may play a role in supporting continued participation and selection.

One possible explanation for the distinct selection pattern observed in this study may lie in broader population-level developmental trends.[22,23,33] Previous research has shown that African boys are, on average, nearly one year delayed in skeletal maturity compared to their European peers.[22,23] Longitudinal data from the Birth to Twenty cohort in Johannesburg, South Africa, further showed that black boys matured later by an average of seven months compared to white boys, although the rate of maturation was similar between groups.[31] This may explain the observed bias toward delayed maturation and provides support for the concurrent validity of the SA estimation method used in this study.[13,23] Although the method was based on generalised equations not developed specifically for this population, it still produced findings consistent with established maturation patterns.[13,14,22,23] Given these population-level trends, players who appear biologically delayed by international standards may, in fact, be relatively mature within their local peer group, highlighting the importance of considering local context when interpreting selection patterns.[22,23] Nevertheless, interpretations should be made cautiously, given the small and non-representative sample. Furthermore, the greatest delay in SA was observed in the older age groups, suggesting that the observed selection pattern may be context-sensitive—whether deliberate or emergent—and could reflect an environment that prioritizes long-term potential over early physical dominance. Taken together, these insights highlight the importance of using locally relevant maturity assessments and investigating selection strategies more directly to better understand how relative age, biological maturity, and contextual factors interact in shaping developmental pathways in South African football.

Physical characteristics comparisons by age

Differences in body size observed across age groups align with expected adolescent growth trajectories.[6,12,16] Players showed a progressive increase in height and weight across age groups, reflecting the natural physical development that occurs during puberty.[16] The multiple regression

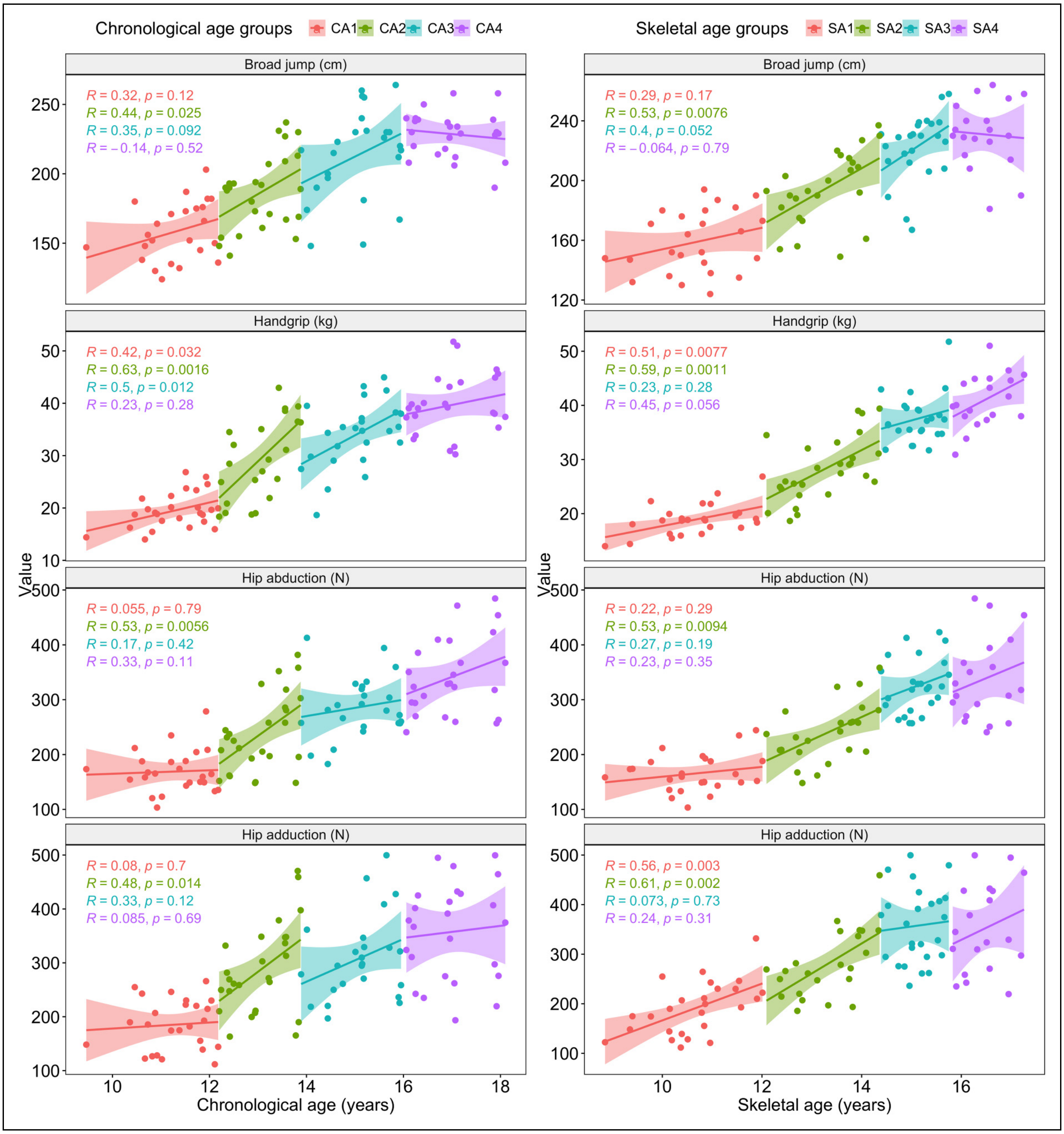

Figure 2. Relationships between CA and SA, and physical performance in percentile-based age groups.

analysis further emphasises the dominant role of SA as a predictor of growth, with SA emerging as a significant predictor of height, body mass, and BMI, even when controlling for CA. The negative association observed between CA and height suggests that players with younger SA tend to be shorter than their peers with similar CA. Notably, CA showed no significant relationship with body mass or BMI when controlling for SA, underscoring the limitations of relying solely on CA for assessing physical growth. These findings highlight the value of SA in assessing and supporting growth and development in youth football players.[11,12]

The high prevalence of underweight players observed in this cohort raises important considerations regarding the role of nutrition in growth, biological maturation, and physical development.[22–24] When viewed alongside the overall trend toward delayed skeletal maturation, this finding suggests that undernutrition may be influencing growth and biological development.[16,22,24] Nutritional deficits, often linked to broader socioeconomic challenges, have been shown to delay maturation, limit growth potential, and impair physical performance during adolescence.[16,22,24] Evidence indicates that nutritional status influences not only the timing of pubertal onset but also its progression and duration, with undernourished boys typically entering puberty later than their normal- or overweight peers.[24] In this sample, the high prevalence of underweight players observed alongside delayed skeletal maturation suggests that nutritional factors may be contributing to observed maturational differences. However, as nutritional intake and socioeconomic status were not directly assessed, these findings should be interpreted cautiously and cannot be used to infer causality. Rather, they highlight the potential role of environmental factors that may exacerbate biological delays in growth and maturation despite comparable training exposure.[16,22–24] Development programmes should integrate nutritional support and education alongside technical and physical training, ensuring players have the resources needed to support healthy growth and optimise athletic development. Periodic monitoring of dietary habits and body composition may help inform more individualised and effective development strategies.[22]

This study also examined physical performance characteristics—specifically hip abduction and adduction strength, handgrip strength, and broad jump—across percentile-based groupings of CA and SA. Performance generally improved with increasing age, and SA showed a stronger and more consistent association with physical outcomes than CA. Older players, in both CA and SA groupings, recorded greater strength and power, with the oldest age groups recording the highest average values. These findings reflect established patterns of adolescent development, where physical capacities such as strength and explosiveness increase progressively through adolescence.[6,17] While these gains in performance are often attributed to natural growth processes, the role of structured and age-appropriate training remains essential in supporting athletic development throughout this period.[11,25]

Notably, no significant differences were found between the two oldest SA groups (SA3: 14.4–15.8 years and SA4: 15.8–17.3 years) across all four physical performance measures. This suggests a plateau in performance once a certain level of skeletal maturity is reached. These findings align with research describing the staggered and nonlinear nature of developmental growth, where performance gains slow after key maturation milestones.[20] CA, on the other hand, showed less consistent patterns. Significant differences between CA3 (13.9–16.0 years) and CA4 (16.0–18.1 years) were observed only in hip adduction and broad jump, indicating a more variable and outcome-specific influence of CA on physical performance. Multiple regression analysis further clarified these relationships: SA was a significant predictor for all performance outcomes, even after controlling for CA, highlighting its central role in physical development. Conversely, CA was only significantly associated with broad jump performance when SA was controlled for, reflecting a more limited and outcome-specific influence.

Practical implications

These findings underscore the importance of considering both CA and SA in the selection and development of youth football players. While biological maturity has a stronger influence on physical performance, it should not be the sole basis for training or selection decisions. The plateau observed among skeletally mature players suggests that early physical advantages—often linked to advanced maturity—may taper off over time.[20] This supports the idea that physical maturity does not guarantee long-term athletic success.[2,6] As biological differences diminish, other attributes such as psychological, technical, and tactical skills become increasingly important.[10,21] Therefore, a holistic approach to player development is essential—one that recognises individual variability in both relative age and maturity. This presents a compelling case for integrating psychological, nutritional, technical, and tactical training and assessment as early as possible in youth development programmes. Collectively, these findings also highlight the importance of paying closer attention to nutrition within youth development environments.[24] Closer collaboration with nutrition professionals may help support healthier growth conditions by addressing potentially modifiable environmental factors that could influence growth and maturation, without attempting to alter the natural, genetically driven timing of biological development.

The concept of bio-banding, whereby players are grouped based on biological maturity rather than CA, offers a promising strategy for managing physical disparities between players at different stages of maturation.[34–36] Implementing bio-banding within South African academies could help ensure equitable opportunities for all players, particularly late-maturing individuals who may otherwise be disadvantaged in traditional CA-based grouping systems. This approach has been adopted by national development teams and professional football academies as a practical method for promoting equity and optimising individual development.[34–36] Although still relatively new, emerging research indicates that bio-banding can yield distinct benefits for both early- and late-maturing players.[34–36] For early maturing players, competing with peers of similar physical maturity but greater experience can reduce reliance on physical dominance and foster development in the technical and tactical domains.[35,36] For late maturers, bio-banding creates more balanced competitive environments where they are less likely to be physically overshadowed, offering them greater opportunity to demonstrate ability, take on leadership roles, and build confidence.[33,35] This may be especially beneficial during the younger age phases, where the influence of biological maturity on physical performance is most pronounced.[16,18,20]

Moreover, research suggests that pre-PHV players participating in bio-banded small-sided games (SSGs) may develop valuable psychological attributes—such as resilience and adaptability—through more equitable competition.[34] Integrating bio-banding into selected training components, such as SSGs, enables practitioners to address maturity-related imbalances while maintaining the broader team framework, supporting a more comprehensive model of player development.[21,35,36] In practical terms, however, the implementation of formal maturity assessments required for bio-banding may be constrained in some academy settings by resource limitations, cost considerations, and access to appropriate technical expertise. In such contexts, collaborative partnerships between academies and research institutions may offer a feasible approach to supporting accurate and sustainable maturity assessment practices. Further research is warranted to better understand the potential benefits and limitations of bio-banding and the mechanisms through which it may influence player development and performance. Taken together, these findings highlight how monitoring and supporting players across all maturational stages can help academies balance immediate performance considerations with long-term development potential.[34,36]

Methodological considerations

This study offers valuable insights into relative age, maturation, and physical performance in adolescent football players from South Africa; however, several methodological and practical considerations should be addressed to inform future research and player development strategies. First, the cross-sectional design limits the ability to track the individual longitudinal progression of physical and biological development in players over time. Future research should consider longitudinal designs to observe changes for example, pre-season to the end of the season or as the individual transitions into older age groups. Second, the relatively small sample size, drawn from a single geographical area, restricts the generalisability of the findings, despite spanning multiple age groups. It limited more detailed comparisons between late-, on-time-, and early-maturing players, as well as analysis of birth quarter effects within each age group due to low subgroup numbers. Expanding the sample by including data from more clubs and geographical regions could provide a better understanding of these patterns, potential selection biases, and their relationship with physical performance. Future studies could address this by incorporating larger player registries for instance, all adolescent football players in the Western Cape region and/or other geographical regions within South Africa.

Whereas BMI data offered a basic understanding of body mass status relative to height, the absence of detailed nutritional and body composition data limited the capacity to fully assess the role of nutrition in maturation and performance.[16,22,24] Future studies should explore the impact of nutritional status more closely, given its likely influence on growth, development, and athletic performance. Finally, environmental factors such as training history, training methods, socio-economic status, and access to resources were not examined in this study but may significantly affect physical development and performance.[2,6,12] Accounting for these contextual influences in future research would support a more holistic understanding of youth football player development.

Conclusion

This study is the first to examine the impact of both CA and SA on specific physical performance outcomes in a selective sample of South African football players in the Western Cape. A RAE was observed, with an overrepresentation of players born earlier in the selection year. In contrast to previous literature, a novel selection bias emerged, with late- and on-time-maturing players overrepresented compared to early maturing players. These findings suggest that, in this context, relative age—rather than early maturation—may offer a compensatory advantage in selection and participation.

The results highlight the limitations of using CA alone to group players, as it does not account for substantial variation in biological maturity. SA consistently showed stronger associations with body size and physical performance outcomes than CA, particularly in younger age groups. However, these advantages appeared to plateau in older groups. We also observed a notable proportion of players categorised as underweight, which may contribute to delayed maturation, underscoring the importance of integrating nutritional monitoring and support within development programmes. It should be noted, however, that nutritional status was not directly assessed in this study; therefore, interpretations regarding its potential role in growth and maturation remain speculative and warrant confirmation through future research incorporating direct nutritional and socioeconomic measures. In addition, this study provides valuable baseline data for future research and interventions aimed at improving talent identification and development strategies in South African youth football. Integrating both CA and SA assessments into player evaluation processes can improve the fairness and effectiveness of youth talent selection and development.

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Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki and received ethical approval from the Health Research Ethics Committee of Stellenbosch University (Ethics Reference No: S23/10/250; Project ID: 29296) on 18 December 2024. Ethical clearance was granted to conduct a secondary analysis of de-identified data extracted from a pre-existing, adolescent athlete database with ethical approval. As the data were already de-identified and no direct contact with participants occurred, a waiver of informed consent for this specific study was requested and approved by the ethics committee.

Consent to participate

Written informed parental/guardian consent and child assent were originally obtained as part of the broader South African Adolescent Athlete Database project. These consents included approval for the use of data collected both before (optional) and after the signing of the consent form, as well as permission to use anonymised data in future research. For this study, no new consent was required, as approval for secondary use of de-identified data was covered under the original database consent and supplemented by an approved waiver of consent.

Consent for publication

Consent for publication of de-identified data was obtained from parents or legal guardians as part of the database enrolment process. No identifying information or images are included in this manuscript. All data used in this study were fully de-identified prior to access and analysis.

Author contributions

EW and WD designed and led the management of the South African Adolescent Athlete Database from which the current dataset was extracted. EW and SD undertook data collection. SD: Conceptualization, methodology, formal analysis, data curation, writing – original draft, visualization, project administration. HG, SC, WD, EW: Supervision, methodology, validation, writing – review, interpretation, and editing. All authors have read and approved the final manuscript.

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Data availability

De-identified data were provided in Excel format by the custodians of the South African Adolescent Athlete Database. All statistical analyses, tables, and figures were performed in RStudio (version 2024.09.0). The dataset and analysis code are available from the corresponding author upon reasonable request, limited to participants who consented to sharing of data for this purpo

Supplemental material

Supplemental material for this article is available online.

References

1. Cobley S, Baker J, Wattie N, et al. Annual age-grouping and athlete development. *Sports Med* 2009; 39: 235–256.
2. Wattie N, Schorer J and Baker J. The relative age effect in sport: a developmental systems model. *Sports Med* 2015; 45: 83–94.
3. Patel R, Nevill A, Cloak R, et al. Relative age, maturation, anthropometry and physical performance characteristics of players within an elite youth football academy. *Int J Sports Sci Coach* 2019; 14: 714–725.
4. Jackson RC and Comber G. Hill on a mountaintop: a longitudinal and cross-sectional analysis of the relative age effect in competitive youth football. *J Sports Sci* 2020; 38: 1352–1358.
5. Dube SR and Grobbelaar HW. Prevalence of the relative age effect among high-performance, university student-athletes, versus an age-matched student cohort. *S Afr J Sports Med* 2022; 34: 1–6.
6. Patel R, Nevill A, Smith T, et al. The influence of birth quartile, maturation, anthropometry and physical performances on player retention: observations from an elite football academy. *Int J Sports Sci Coach* 2020; 15: 121–134.
7. Sweeney L and Lundberg TR. Relative age and biological maturity-related selection biases in male youth soccer across different competitive levels within a national association. *Sci Med Footb* 2024; 23: 1–99.
8. Hill M, Scott S, Malina RM, et al. Relative age and maturation selection biases in academy football. *J Sports Sci* 2019; 38: 1359–1367.
9. Sweeney L, Cumming SP, MacNamara Á, et al. A tale of two selection biases: the independent effects of relative age and biological maturity on player selection in the football association of Ireland's national talent pathway. *Int J Sports Sci Coach* 2023; 18: 1992–2003.
10. Towlson C, MacMaster C, Parr J, et al. One of these things is not like the other: time to differentiate between relative age and biological maturity selection biases in soccer? *Sci Med Footb* 2021; 6: 273–276.
11. Lloyd RS, Oliver JL, Faigenbaum AD, et al. Chronological age vs. Biological maturation. *J Strength Cond Res* 2014; 28: 1454–1464.
12. Malina RM, Rogol AD, Cumming SP, et al. Biological maturation of youth athletes: assessment and implications. *Br J Sports Med* 2015; 49: 852–859.

13. Ruf L, Cumming S, Härtel S, et al. Construct validity of age at predicted adult height and BAUS skeletal age to assess biological maturity in academy soccer. *Ann Hum Biol* 2021; 48: 101–109.
14. Rachmiel M, Naugolni L, Mazor-Aronovitch K, et al. Bone age assessments by quantitative ultrasound (SonicBone) and hand X-ray based methods are comparable. *Isr Med Assoc J* 2017; 19: 533–538.
15. Johnson A. Monitoring the immature athlete. *Sports Med J* 2015; 4: 114–118.
16. Beunen GP, Rogol AD and Malina RM. Indicators of biological maturation and secular changes in biological maturation. *Food Nutr Bull* 2006; 27: S244–S256.
17. Marinho JLC, Martins AO, Rey E, et al. Influence of biological maturation on speed, jump, and endurance in high-level youth soccer players. *Rev Bras Ciênc Esporte* 2020; 42: 1–5.
18. Meylan C, Cronin J, Oliver J, et al. Talent identification in soccer: the role of maturity status on physical, physiological and technical characteristics. *Int J Sports Sci Coach* 2010; 5: 571–592.
19. Johnson A, Farooq A and Whiteley R. Skeletal maturation status is more strongly associated with academy selection than birth quarter. *Sci Med Footb* 2017; 1: 157–163.
20. Towlson C, Cobley S, Parkin G, et al. When does the influence of maturation on anthropometric and physical fitness characteristics increase and subside? *Scand J Med Sci Sports* 2018; 28: 1946–1955.
21. Cumming SP, Searle C, Hemsley JK, et al. Biological maturation, relative age and self-regulation in male professional academy soccer players: a test of the underdog hypothesis. *Psychol Sport Exerc* 2018; 39: 147–153.
22. Hawley NL, Rousham EK, Johnson W, et al. Determinants of relative skeletal maturity in South African children. *Bone* 2012; 50: 259–264.
23. Jones LL, Griffiths PL, Norris SA, et al. Age at menarche and the evidence for a positive secular trend in urban South Africa. *Am J Hum Biol* 2009; 21: 130–132.
24. Norris SA, Frongillo EA, Black MM, et al. Nutrition in adolescent growth and development. *Lancet* 2022; 39: 172–184.
25. SASCOC. *South African Sport for Life Long-Term Participant Development 'Forging sport excellence and an active lifestyle through Long-Term Participant Development'*. Johannesburg: Resource paper V3, 2011.
26. Vandenbroucke JP, von Elm E, Altman DG, et al. Strengthening the reporting of observational studies in epidemiology (STROBE): explanation and elaboration. *Int J Surg* 2014; 12: 1500–1524.
27. Stewart A, Marfell-Jones M, Olds T, et al. *International Standards for Anthropometric Assessment*. Potchefstroom: International Society for the Advancement of Kinanthropometry, 2011.
28. O' Connor C, McIntyre M, Delahunt E, et al. Reliability and validity of common hip adduction strength measures: the ForceFrame strength testing system versus the sphygmomanometer. *Phys Ther Sport* 2023; 59: 162–167.
29. Desmyttere G, Gaudet S and Begon M. Test-retest reliability of a hip strength assessment system in varsity soccer players. *Phys Ther Sport* 2019; 37: 138–143.
30. Dugdale JH, Arthur CA, Sanders D, et al. Reliability and validity of field-based fitness tests in youth soccer players. *Eur J Sport Sci* 2019; 19: 745–756.
31. Delorme N and Champely S. Relative age effect and chi-squared statistics. *Int Rev Sociol Sport* 2015; 50: 740–746.
32. Grobler TD, Shaw BS and Coopoo Y. Relative age effect (RAE) in male school-aged rugby union players from Gauteng, South Africa. *Afr J Phys Act Health Sci* 2016; 22: 626–634.
33. Cole TJ, Rousham EK, Hawley NL, et al. Ethnic and sex differences in skeletal maturation among the birth to twenty cohort in South Africa. *Arch Dis Child* 2015; 100: 138–143.
34. Cumming SP, Lloyd RS, Oliver JL, et al. Bio-banding in sport: applications to competition, talent identification, and strength and conditioning of youth athletes. *Strength Cond J* 2017; 39: 34–47.
35. MacMaster C, Portas M, Parkin G, et al. The effect of bio-banding on the anthropometric, physical fitness and functional movement characteristics of academy soccer players. *PLoS One* 2021; 16: 1–16.
36. Towlson C, Macmaster C, Gonçalves B, et al. The effect of bio-banding on physical and psychological indicators of talent identification in academy soccer players. *Sci Med Footb* 2020; 5: 280–292.