



OPEN ACCESS

EDITED BY

Dr. Joel Paul

University of Trinidad and Tobago, Trinidad and Tobago.

Assoc. Prof. Herli Pardilla, Ed.D.

Universitas Muammadiyah Sumatera Utara, Indonesia.

*CORRESPONDENCE

Aldair Jiménez Carrillo
jesusleon.lm@gmail.com

RECEIVED: June 10, 2025

ACCEPTED: September 20, 2025.

PUBLISHED: January 27, 2026.

COPYRIGHT © 2026 (Author)

 Aldair Jiménez Carrillo Jesús Lozada-Medina

This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License.

Peak Height Velocity (PHV) and Its Non-Significant Relationship with Physical Performance in Adolescent Soccer Athletes

Aldair Jiménez Carrillo^{1*}, Jesús Lozada-Medina¹¹Caribbean University Corporation, Colombia.

ABSTRACT

Background & objective: This study aimed to analyze the relationship between conditional capacities (agility, speed, aerobic capacity, and explosive strength) and somatic maturation—expressed as years from PHV—in a cohort of youth male soccer players.**Materials & Methods:** A quantitative, correlational, and cross-sectional design was employed. Seventeen male soccer players aged 14–15 years participated. Somatic maturation was assessed via anthropometric estimation of PHV. Physical performance was evaluated using the Andersen Test (aerobic capacity), 20 m sprint (linear speed), Illinois Agility Test, and horizontal jump (explosive strength). Tests were administered under standardized conditions across three sessions. Data analysis included descriptive statistics, Pearson correlation coefficients, and ANOVA using SPSS software.**Results:** Descriptive findings indicated substantial variability in maturation (mean PHV = -0.89 ± 1.21 years), despite a homogenous chronological age. Correlation analyses revealed no statistically significant associations between PHV and the measured performance variables ($p > .05$). The strongest—but still non-significant—trend appeared between PHV and agility (Illinois test; $r = -0.319$), suggesting that more mature players may demonstrate slightly better change-of-direction ability. Overall, maturation did not directly predict aerobic performance, explosiveness, or speed in this sample.**Conclusions:** Somatic maturation, expressed through PHV, did not significantly relate to physical performance indicators among the adolescent soccer players studied. The considerable variability in maturation reinforces the need for coaches to consider biological age rather than relying solely on chronological age when interpreting performance, prescribing training loads, and making talent selection decisions. These findings highlight the importance of individualized assessment and developmentally informed training in youth soccer contexts.

Keywords

somatic maturation; peak height velocity (PHV); youth soccer performance; biological maturity assessment; physical fitness indicators; agility and speed development.

CITATION APA STYLE 7:

Jiménez Carrillo, A., & Lozada-Medina, J. L. (2026). Peak Height Velocity (PHV) and Its Non-Significant Relationship with Physical Performance in Adolescent Soccer Athletes. *INSPIREE: Indonesian Sport Innovation Review*, 7(01), 01-08. <https://doi.org/10.53905/inspire.v7i01.160>

INTRODUCTION

Global and Theoretical Context

Adolescence is marked by substantial differences in somatic development even among athletes of the same chronological age. In youth soccer, these differences shape training, injury-risk management, and talent identification: age-group systems can reward temporary advantages in stature, lean mass, strength, and speed, potentially obscuring the long-term potential of later maturers (Malina et al., 2004; Towlson et al., 2020). Peak height velocity (PHV) is the point at which an individual's linear growth rate reaches its maximum. Anthropometric maturity-offset equations estimate years before or after predicted PHV; they are practical but measure estimated somatic growth timing, not skeletal, hormonal, neuromuscular, or overall biological maturity directly status (Mirwald et al., 2002).

The Youth Physical Development Model explains why maturation may relate to some performance outcomes but not others. It treats development as an interaction among biological maturation, body size and composition, neuromuscular function, motor skill, and training exposure, rather than as a simple consequence of chronological age or one marker (Lloyd & Oliver,

2012). Around PHV, rapid changes in stature and limb length may challenge coordination, while increases in lean mass can support force production. Sprinting and jumping depend partly on force relative to body mass; change-of-direction performance also requires braking, re-acceleration, and motor control; aerobic field performance is shaped by body size, training, and test characteristics. The theoretical expectation is therefore domain-specific, not a uniform maturational advantage across all fitness tests.

Critical Review of Existing Evidence

Quantitative evidence from youth soccer supports this qualified interpretation. Among 647 players aged 11–18 years, Sellami et al., (2024) found differences in soccer-specific agility and ball-agility metrics among pre-, circa-, and post-PHV groups. Sprinting and lower-limb power were also related to agility, indicating that maturation alone does not explain performance. The large sample provides useful normative evidence, although its broad age span, maturity-group comparisons, and soccer-specific tests differ from continuous PHV correlations with several field tests in a narrow age range.

In Poland, [Konarski et al. \(2024\)](#) assessed 112 male soccer players aged 9–16 years using skeletal age, body size, and tests of strength, sprinting, acceleration, agility, jumping, and intermittent endurance. Among players aged 13–16 years, combined body-size and skeletal-maturity terms accounted for 56.7% of strength variance and 38.7% of speed variance. However, skeletal maturity status alone explained only 0–0.5% of variance in several strength, speed, acceleration, and jump outcomes in this older group. Thus, apparent maturity-related advantages may partly reflect morphology rather than an independent association with maturity status. Participants trained for about 90 minutes on five days each week, a dose that limits direct comparison with studies that do not quantify training exposure.

Evidence also varies by sex and maturity measure. [Gundersen et al., \(2024\)](#) assessed 68 athletes (42 males and 26 females; mean age = 13.9 years) using hand-radiograph bone age, sprinting, standing long jump, a 2,000-m run, and a motor-coordination test. Among males, bone age correlated with 40-m sprint performance ($r = -.556$), standing long jump ($r = .500$), and 2,000-m running performance ($r = -.435$); comparable associations were not detected among females, and bone age was unrelated to coordination in either sex. These moderate associations suggest maturity may coincide with selected performance advantages, but the sex-specific pattern cautions against universal conclusions. Likewise, [Ginés et al., \(2023\)](#) found early-maturing players overrepresented in male elite soccer academies and links between PHV and coaches' current-performance ratings. These findings illuminate selection bias, but academy representation and coach ratings are not direct physiological measures.

Longitudinal evidence provides a complementary perspective. A scoping review of 12 longitudinal studies across youth sports concluded that strength and power are affected around PHV and that training frequency, volume, and sport specificity can modify development ([Retzepis et al., 2025](#)). However, studies differed in sport, follow-up, training exposure, and outcome measure, limiting transfer to every soccer fitness test. Maturity indicators are also not interchangeable. In 124 male academy soccer players with longitudinal growth records, [Monasterio et al. \(2024\)](#) found that common maturity-offset equations misclassified approximately one-third to one-half of players relative to classifications based on individual growth curves. Such prediction error can weaken observed associations when estimated PHV offset is treated as an error-free individual measure.

Differences in age range, competitive level, and statistical approach further explain inconsistent findings. Skeletal age, maturity-group categories, and predicted years from PHV capture related but distinct information; body-size-adjusted models estimate a different association from unadjusted Pearson correlations. Playing position, technical proficiency, and training exposure are not consistently controlled, and cross-sectional

studies cannot establish whether maturation precedes performance change. In small samples, non-significant correlations may reflect imprecision and low power rather than no relationship; effect magnitude and uncertainty therefore matter alongside p values.

Research Gap, Novelty, and International Contribution

Although previous studies link biological maturity with selected speed, strength, power, and agility outcomes in some youth-sport populations, it remains unclear whether anthropometrically estimated years from PHV are associated with aerobic field performance, 20-m sprint time, Illinois Agility Test time, and horizontal-jump distance within the same narrowly defined group of 14–15-year-old male soccer players. Previous studies often use wider age ranges, skeletal-age measures, maturity-group comparisons, or different agility protocols and vary in their control of body size and training-related factors. Examining these four common field-based outcomes concurrently can test whether the direction and magnitude of the maturity association are consistent across performance domains.

The novelty is empirical and context-specific rather than methodological: this study examines four field-test outcomes against continuous, anthropometrically estimated PHV offset in a small convenience cohort tested over three sessions. It introduces no new maturity measure, cannot establish causation, and does not fully control for body size or training history. Its international contribution is a focused replication that can refine application of the Youth Physical Development Model by assessing whether predicted maturity offset explains detectable between-player variation under these conditions. Weak or non-significant associations would not show that maturation is biologically irrelevant; they would indicate that this estimate did not show a statistically detectable linear association with the measured outcomes in this cohort.

Objectives and Hypotheses

The primary objective was to examine the association between predicted maturity offset (years from PHV) and four performance outcomes among male soccer players aged 14–15 years: Andersen Test distance as an indicator of aerobic field performance, 20-m sprint time, Illinois Agility Test time, and horizontal-jump distance. A secondary objective was to compare the direction and magnitude of associations across these domains. We hypothesized that a more positive maturity offset would be associated with greater Andersen Test distance and horizontal-jump distance, and with shorter 20-m sprint and Illinois Agility Test times. These are directional hypotheses about associations, not causal effects. $VO_{2\max}$ calculated from Andersen Test distance is a mathematical transformation of the same test result and should not be treated as an independent outcome.

MATERIALS FOR ANALYSIS

Participants

The sample consisted of 17 male soccer players, aged 14–15 years, with at least one year of training experience. The sampling was non-probabilistic by convenience. Informed consent was given by the researcher and exposed to the players, in accordance with the ethical principles of the Declaration of Helsinki.

Study Organization: Quantitative Analysis

A quantitative, correlational and comparative cross-sectional study was carried out in order to evaluate physical variables related to physical condition and maturation in child soccer players. The

design facilitated the characterization of physical performance according to the maturity level, establishing relationships between the different physical capacities evaluated.

Test and Measurement Procedures

The tests were performed in a period of three consecutive sessions, under normal environmental conditions and based on standardized protocols. Prior to the application of the tests, the players performed a general warm-up for 15 minutes, followed by a specific mobility test.

Table 1. Summary of Testing Procedures and Measurement Protocols

Test / Procedure	Description	Measurement Output	Horizontal Jump Test	Lower-limb explosive power measured using a standing long jump without run-up. Best distance from three attempts recorded.	Jump distance (cm)
Peak Height Velocity (PHV)	Somatic maturation was estimated by calculating the number of years from the predicted peak height velocity using anthropometric measures: height, weight, sitting height, and chronological age.	Maturity offset (years from PHV)			
20 m Speed Test	Acceleration and linear speed measured through a 20-meter sprint. Each player performed two trials, with the fastest time recorded.	Sprint time (seconds)			
Andersen Test	Aerobic capacity assessed through repeated 15-second run + 15-second rest intervals for 10 minutes. Total distance used to estimate VO_2 max with the formula: $\text{VO}_2 \text{ max} = 18.38 + 0.033 \times \text{distance} - 5.92 \times \text{sex}$.	Total distance (m) and estimated VO_2 max ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)			
Illinois Agility Test	Agility assessed through a standardized course involving accelerations, directional changes, and lateral movements. Two attempts were performed; best time recorded.	Completion time (seconds)			

Statistical Analysis

Data were analyzed by descriptive statistics and Pearson's correlation was applied to explore the relationship between maturation and physical abilities and ANOVA analysis of variance, this was done using SPSS statistical software.

Ethical Considerations

This study was conducted in accordance with the ethical standards of the Declaration of Helsinki and received ethical approval from the Institutional Review Board (IRB) / Ethics Committee of Caribbean University Corporation (Approval No.: CUC/EC/no. 621-2025). Written informed consent was obtained from parents or legal guardians, and verbal assent was obtained from all participants prior to data collection. Participation was voluntary, and all players were informed of their right to withdraw at any time without penalty. All procedures were non-invasive and posed minimal risk, and confidentiality of participant information was ensured through anonymization and secure data handling.

RESULTS

The results of the following work evaluated the relationship between maturation status and performance in different tests in a sample of 17 soccer players.

Table 2. Descriptive statistics for the basic variables of the subjects under study

	Age (years)	Weight (kg)	Height (cm)
N	17	17	17
Missing	0	0	0
Mean	14.4	53.5	168
Median	14.5	52.2	172

Standard Deviation	0.593	8.10	8.13
Minimum	13.3	38.6	148
Maximum	15.1	68.0	177

The sample was composed of 17 soccer players with an average age of 14.4 ± 0.59 years, with an average weight of 53.5 ± 8.10 kg and an average height of 168.0 ± 8.13 cm. Despite the fact that the chronological age was homogeneous, a high dispersion in weight and height could be observed, which translates into disparities in the maturation of the players.

Table 3. Descriptive statistics of the physical fitness tests of the study group

	PHV	Test de Andersen (m)	Salto horizontal (cm)	Vel 20m (seg)	Test Illinois (seg)
Minimum	-2,5	972,0	152,0	371,0	168,0
Maximum	1,8	1220,0	237,0	450,0	1605,0
Median	-,88	1133,8	196,2	398,4	1456,5
Standard Deviation	1,2	57,36	23,5	20,2	333,5

Table 3 shows the descriptive statistics of the variables studied in the sample of 17 players aged 14-15 years, these variables include the PHV and conditional abilities such as aerobic endurance (Andersen test), explosive strength in lower limbs (horizontal jump), linear speed (speed in 20m) and agility (Illinois test). On the side of somatic maturation (PHV) the average value was -0.89 ± 1.21 years, indicating that the players have not yet reached their peak growth rate, the high standard deviation value means an important variability in the maturational level, such variability could have direct implications on the response to the training load and performance. As for the aerobic capacity, by means of the Andersen test, the mean was 1133.88 ± 57.36 m, with a range that had a variation between 972 and 1220m, values that reflect a moderate aerobic level, something estimated in players at those

ages, this capacity is less dependent in relation to maturation and is more influenced by training, which could be the explanation for the lower dispersion. The explosive strength measured by means of the horizontal jump test had a mean value of 196.29 ± 23.51 cm, with test results between 152 and 237 cm, which shows statistical differences in explosive strength that could be attributed to the maturation stage. On the other hand, the 20m speed test showed values of 3.98 ± 0.20 sec, which shows a consistency in the results, this means a homogeneity in the capacity. Finally, the Illinois test had a mean of 14.57 ± 0.33 sec, with a range of 14.56 to 16.80 seconds, a small variability was observed, which could be related to the motor coordination and the efficiency of the neuromuscular system, capacities that evolve with the development of the nervous system.

Table 4. Pearson Correlation Matrix Between PHV and Physical Performance Variables

Variables	PHV	Andersen (m)	VO_2 max ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	Illinois Agility (s)	20 m Speed (s)	Horizontal Jump (cm)
PHV	—	—	—	—	—	—
Andersen (m)	$r = -0.017$ $p = 0.950$ $df = 15$	—	—	—	—	—
VO_2 max	$r = -0.017$ $p = 0.950$ $df = 15$	$r = 1.000^{***}$ $p < 0.001$ $df = 15$	—	—	—	—
Illinois Agility (s)	$r = -0.319$ $p = 0.213$ $df = 15$	$r = -0.053$ $p = 0.839$ $df = 15$	$r = -0.053$ $p = 0.839$ $df = 15$	—	—	—

Peak Height Velocity (PHV) and Its Non-Significant Relationship with Physical Performance in Adolescent Soccer Athletes

20 m Speed (s)	$r = -0.107$ $p = 0.682$ $df = 15$	$r = 0.001$ $p = 0.996$ $df = 15$	$r = 0.001$ $p = 0.996$ $df = 15$	$r = 0.582^*$ $p = 0.014$ $df = 15$	—	—
Horizontal Jump (cm)	$r = 0.132$ $p = 0.613$ $df = 15$	$r = 0.049$ $p = 0.853$ $df = 15$	$r = 0.049$ $p = 0.853$ $df = 15$	$r = 0.002$ $p = 0.994$ $df = 15$	$r = 0.106$ $p = 0.687$ $df = 15$	—

Notes: r = Pearson correlation coefficient; df = degrees of freedom; $^*p < .05$ = significant correlation; perfect correlation due to derived VO_2 max formula from Andersen test.

The analysis of bivariate correlations did not show statistical relationships between PHV and the rest of the physical variables evaluated, which suggests that maturation evaluated by means of time relative to peak growth velocity was not a direct indicator of conditional performance in the sample evaluated ($p > .05$). The most relevant association was between the PHV and the agility test ($r = -0.319$, $p = 0.213$), which indicates a negative and moderate tendency, although not significant, it could indicate that the more

mature players obtain better changes of direction.

Among the variables analyzed the correlations between the PHV and the physical tests are presented the Pearson coefficient (R), degrees of freedom (gl) and statistical values (p -value) the variables are analyzed with main results, the PHV states a low correlation with Andersen ($R = 0.017$) (P -value = 0.950) with the VO_2 MAX ($R = 0.017$) (p -value = 0.950) with horizontal jump ($R = 0.132$) (p -value = 0.613).

DISCUSSION

Principal Findings

This study examined whether somatic maturation, expressed as years from predicted Peak Height Velocity (PHV), was associated with aerobic capacity, linear speed, agility, and lower-limb explosive performance in adolescent male soccer players. The principal finding was that PHV was not significantly associated with any of the physical performance indicators assessed. The observed relationships with the Andersen test, 20-m sprint, and horizontal jump were small, whereas the association with Illinois agility was moderate in magnitude but did not reach statistical significance. Thus, the working hypothesis that greater maturational advancement would be systematically associated with superior physical performance was not supported in this sample.

Importantly, the absence of statistical significance should not be interpreted as evidence that biological maturation has no practical relevance to youth performance. Statistical significance and practical importance address different questions. With only 17 participants, the study had limited capacity to detect small or moderate associations. Consequently, the non-significant correlations should be interpreted as evidence that a clear linear relationship was not demonstrated in this particular cohort, rather than as definitive evidence of no maturational influence. This distinction is particularly important because maturation is a multidimensional developmental process involving changes in body size, muscle mass, neuromuscular function, coordination, and hormonal status (Malina et al., 2004; Lloyd & Oliver, 2012).

The finding therefore contributes to international knowledge by suggesting that the relationship between maturation and performance may be domain-specific and context-dependent, rather than uniformly expressed across all physical capacities. This interpretation is consistent with evidence indicating that maturation can be associated with selected performance characteristics while explaining relatively little variation in other outcomes (Konarski et al., 2024; Retzepis et al., 2025). In the present cohort, chronological age alone did not adequately describe the heterogeneity of biological development, but variation in maturation also did not translate into a statistically detectable advantage across the complete physical test battery.

Comparison with International Evidence

The present findings both agree and disagree with previous international research, highlighting the importance of population characteristics and methodological differences when interpreting maturity-performance relationships. Research from Norway, for example, reported significant associations between skeletal maturity and 40-m sprint, standing long jump, and 2,000-m running

performance among adolescent male athletes, although comparable associations were not observed among females (Gundersen et al., 2024). That study used skeletal age assessed through hand radiography, whereas the present investigation estimated maturity through anthropometric prediction of years from PHV. The different maturity indicators may partly explain the contrasting findings because skeletal age and predicted maturity offset are related but not interchangeable constructs.

Similarly, Konarski et al. (2024), using soccer players aged 9–16 years, reported that body size and skeletal maturity contributed to differences in strength and motor performance. Their broader age range included both younger and older developmental stages than the present 14–15-year-old cohort. Consequently, the physiological expression of maturation may have been more heterogeneous in their sample. In addition, their analysis explicitly considered body size and skeletal maturity, whereas the present study primarily examined bivariate relationships between PHV and physical performance. Differences in analytical strategy and control of body-size-related variation can therefore produce different estimates of the apparent contribution of maturation.

Evidence from soccer-specific research also demonstrates that maturation does not operate independently of the performance domain. Sellami et al. (2024), studying soccer players aged 11–18 years, examined maturation in relation to specific agility performance and its fitness predictors. Their findings emphasize that sprinting, jumping, anthropometric characteristics, and maturation can jointly contribute to performance profiles. The present study similarly observed that agility showed the largest PHV association among the evaluated tests, although the relationship was not statistically significant. The convergence is therefore more apparent at the conceptual level than at the level of statistical significance: both studies suggest that agility should not be interpreted through maturation alone.

Research involving elite under-16 footballers has also demonstrated maturational effects on physical capacities and anabolic hormones (Eskandarifard et al., 2021). The contrast with the current findings may partly reflect differences in competitive level, training exposure, sample composition, and physiological characteristics. Elite players are exposed to systematic training and selection processes that may increase homogeneity in technical and physical characteristics while simultaneously producing different developmental profiles from recreational or regional youth players. Training exposure may also modify the expression of maturation-related differences, making the observed relationship dependent on both biological development and accumulated training stimulus.

The absence of a significant relationship between PHV and aerobic performance is nevertheless compatible with evidence indicating that aerobic development in youth athletes is influenced by training, body composition, and scaling considerations rather than maturation alone (Armstrong & Welsman, 2020; Tingelstad et al., 2023). Likewise, the absence of a significant PHV relationship with horizontal jumping performance is compatible with the broader literature suggesting that strength and power development follow complex developmental trajectories and are not determined exclusively by maturation status (Granacher et al., 2011; Radnor et al., 2017; Retzepis et al., 2025).

The differences between studies may therefore arise from several interacting factors: population and age range, competitive level, maturity assessment method, physical-performance tests, training exposure, body-size adjustment, study design, and statistical modelling. Duration and training dose are especially relevant when comparing cross-sectional studies with longitudinal or intervention research. The present study was cross-sectional and therefore could not determine whether changes in PHV preceded changes in performance. It also did not quantify training volume, intensity, or accumulated training history sufficiently to separate maturational effects from training adaptations. These distinctions caution against interpreting apparently inconsistent international findings as contradictory evidence; instead, they may reflect different developmental and methodological contexts.

Theoretical, Methodological, and Practical Implications

Theoretically, the findings support a multifactorial interpretation of youth physical performance. The Youth Physical Development framework emphasizes that strength, speed, power, and coordination develop through interactions among biological maturation, neuromuscular development, training, and individual characteristics rather than through a single developmental mechanism (Lloyd & Oliver, 2012). The current results extend this perspective by demonstrating that even when maturation varies substantially within a relatively narrow chronological age range, PHV may not independently explain performance variation across multiple field-based tests.

The findings also refine the interpretation of PHV as a practical monitoring tool. PHV remains useful for describing biological development and identifying maturity-related differences, but the present results suggest that it should not be treated as a stand-alone predictor of performance. This is consistent with recommendations emphasizing individualized consideration of maturation, training load, injury risk, and performance development in youth soccer (Towson et al., 2020; Helsen et al., 2021). Maturity information may therefore be most useful when integrated with anthropometry, training history, technical ability, physical testing, and longitudinal growth monitoring.

Methodologically, the study demonstrates the value of assessing several performance domains rather than relying on a single physical outcome. However, the findings also expose the limitations of simple bivariate correlations for understanding a complex developmental process. Future analyses should incorporate multivariable models that account for chronological age, body size, training exposure, playing position, and potentially nutritional or socioeconomic factors. Such approaches could determine whether PHV contributes unique explanatory information after other relevant predictors are considered.

A particularly important practical implication concerns talent identification. The findings do not support using PHV alone to classify adolescent players according to physical potential. Previous work has shown that advanced maturation can create selection advantages in youth soccer, while these advantages may

vary according to playing position and developmental context (Sweeney et al., 2022, 2023). Therefore, maturity-informed assessment should complement rather than replace technical, tactical, psychological, and physical evaluation. Maturity-matched approaches such as bio-banding may also help reduce the influence of temporary size and maturity differences during player development (Towson et al., 2020; Helsen et al., 2021).

Strengths and Limitations

Several strengths should be considered when interpreting these findings. First, the study evaluated several important physical-performance domains—agility, linear speed, aerobic capacity, and explosive strength—using standardized field-based procedures. Second, testing was conducted across three consecutive sessions under standardized conditions, with warm-up procedures and repeated trials for selected tests. Third, the study explicitly quantified biological maturation rather than relying exclusively on chronological age. Finally, there were no reported missing observations in the principal descriptive variables, which reduces uncertainty arising from incomplete datasets.

Nevertheless, the limitations substantially constrain interpretation. The most important limitation is the very small convenience sample ($n = 17$). Such a sample limits statistical power, increases uncertainty around correlation estimates, and reduces transferability to other adolescent soccer populations. A non-significant result may therefore represent either a genuinely weak relationship or insufficient precision to detect an existing association. The cross-sectional design is another major limitation because it captures maturation and performance at one point in time and cannot establish temporal or causal relationships. Longitudinal follow-up would be necessary to determine whether changes in maturity status precede changes in physical performance.

Measurement considerations are also important. PHV was estimated using anthropometric measures and predicted maturity offset rather than direct skeletal-age assessment. Prediction-based maturity estimates are practical and non-invasive, but they contain estimation uncertainty and should not be interpreted as equivalent to direct biological markers (Mirwald et al., 2002; Towson et al., 2020). In addition, the physical tests were field-based and therefore provide ecologically useful outcomes but may not capture detailed biomechanical, neuromuscular, or physiological mechanisms.

Potential confounding was another limitation. The analysis did not appear to adjust simultaneously for body mass, stature, body composition, training history, playing position, technical proficiency, or previous exposure to structured training. These variables may influence both maturation and performance. Furthermore, the sample consisted exclusively of male players aged approximately 14–15 years, restricting transferability to female athletes, younger children, older adolescents, and different competitive levels.

The study also involved multiple performance outcomes and several correlation tests. No correction for multiplicity was reported. Consequently, individual p -values should be interpreted cautiously, particularly in a small sample. The reported perfect correlation between Andersen distance and estimated VO_2max also requires special caution because VO_2max was mathematically derived from Andersen-test distance; it therefore does not represent an independent empirical association.

Blinding of testers was not reported, and there was no follow-up period. Although the performance tests were standardized, lack of information regarding tester blinding means that observer-related bias cannot be completely excluded. These limitations do

not invalidate the findings, but they support a conservative interpretation: the study provides evidence concerning this specific cohort and measurement approach rather than definitive evidence that PHV is unrelated to youth soccer performance.

Future Research

Future research should move from small cross-sectional samples toward multicentre, longitudinal, and adequately powered designs. Studies should recruit larger cohorts of male and female players from different competitive levels and geographical regions, including Europe, Latin America, Asia, Africa, and the Middle East, to determine whether the maturity-performance relationship is context-specific. Repeated measurements over at least 12–24 months would allow researchers to examine trajectories before, during, and after PHV rather than treating maturation as a single cross-sectional value.

Future studies should also compare complementary maturity indicators, including predicted maturity offset, skeletal age, and longitudinal growth velocity, while explicitly modelling uncertainty in maturity estimation. Performance assessment should combine sprinting, change-of-direction ability, jumping, aerobic capacity, technical performance, and sport-specific match outcomes. Potential mediators and moderators—including body composition, training exposure, playing position, sex, biological maturity status,

and technical proficiency—should be examined using multivariable and longitudinal models.

Replication should use harmonized testing protocols and preregistered analytical plans, including explicit approaches to multiplicity and missing data. Larger datasets would also permit nonlinear models and interaction analyses to determine whether the influence of maturation differs before, around, and after PHV. Implementation studies should subsequently evaluate whether maturity-informed training and bio-banding approaches improve player development, reduce inappropriate training-load allocation, or alter talent-selection patterns. Finally, cost-effectiveness analyses are warranted to determine whether routine maturity monitoring provides sufficient practical benefit relative to its financial, personnel, and logistical requirements.

Overall, the present study contributes to the international literature by showing that PHV should not be interpreted as a universal or stand-alone determinant of physical performance in adolescent soccer. Instead, maturation appears best understood as one component within a broader developmental system in which biological, morphological, neuromuscular, technical, training, and contextual factors interact. This interpretation is consistent with the increasingly multifactorial approach advocated in contemporary youth athlete development research (Towilson et al., 2020; Sweeney et al., 2023; Retzepis et al., 2025).

CONCLUSION

This study examined the relationship between somatic maturation, expressed as years from predicted Peak Height Velocity (PHV), and physical performance among adolescent male soccer players. The findings showed that PHV was not significantly associated with aerobic capacity, linear speed, agility, or lower-limb explosive performance in the study cohort. Accordingly, the hypothesis that greater maturational advancement would be consistently associated with better physical performance was not supported. The findings indicate that PHV should not be interpreted as a stand-alone indicator of physical performance during early-to-mid adolescence, as performance is likely influenced by the interaction of biological, neuromuscular, morphological, technical, and training-related factors.

From an international perspective, these findings contribute to the growing evidence that the maturity-performance relationship in youth soccer is context-dependent rather than uniform across physical domains and populations. The results support the use of maturity-informed assessment while cautioning against relying exclusively on chronological age or PHV when evaluating adolescent players, prescribing training, or informing talent-development decisions. However, given the small convenience sample and cross-sectional design, the findings should not be generalized to all youth soccer populations. Larger, longitudinal, and more diverse studies are required to determine how changes in biological maturation interact with physical performance across different developmental stages and sporting contexts.

DECLARATIONS

Ethical Approval

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki and received ethical approval from the Institutional Review Board (IRB) / Ethics Committee of Caribbean University Corporation (Approval No. CUC/EC/no. 621-2025).

Consent for Publication

Not applicable. The manuscript does not contain identifiable individual information, photographs, or other personally identifiable data that would require consent for publication.

Author Contributions (CRediT)

Aldair Jiménez Carrillo: Conceptualization, Study Design and Writing Original Draft Preparation.

Jesús Lozada-Medina: Study Design, Data Collection, Statistical Analysis, Writing – Original Draft Preparation

Funding

The authors received no specific funding for this research. The study was conducted without financial support from governmental,

commercial, or non-profit funding agencies.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to applicable ethical, privacy, and institutional restrictions.

Acknowledgements

The authors would like to thank the players who participated in the tryouts, as well as their parents and the coaches of the club, for their participation and support in this study.

Generative AI Disclosure

The authors declare that no generative artificial intelligence (AI) tools were used to generate, analyze, or interpret the research data, or to make scientific decisions in this study. Any use of AI-assisted tools, if applicable, was limited to language editing and/or improving the clarity and readability of the manuscript, with all final content reviewed and approved by the authors.

REFERENCES

- Aixa-Requena, S., Gil-Galve, A., Legaz-Arrese, A., Hernández-González, V., & Masià, J. R. (2025). Influence of Biological Maturation on the Career Trajectory of Football Players: Does It Predict Elite Success? *Journal of Functional Morphology and Kinesiology*, 10(2), 153. <https://doi.org/10.3390/jfkm10020153>
- Antoničević, S., Stanković, D., Antoničević, M., Bujan, S., Manić, M., Veličković, P., Živković, M., & Đorđević, S. (2023). Differences in Motor Abilities among Basketball Players in Relation to Biological Maturity. *Sport Mont*, 21(2), 79. <https://doi.org/10.26773/smj.230712>
- Armstrong, N., & Welsman, J. (2020). The Development of Aerobic and Anaerobic Fitness with Reference to Youth Athletes. *Journal of Science in Sport and Exercise*, 2(4), 275. <https://doi.org/10.1007/s42978-020-00070-5>
- Campa, F., & Greco, G. (2022). *Growth, Somatic Maturation and Their Impact on Physical Health and Sports Performance*. <https://doi.org/10.3390/books978-3-0365-3086-4>
- Eskandarifard, E., Silva, R., Nobari, H., Clemente, F. M., Pérez-Gómez, J., & Figueiredo, A. J. (2021). Maturation effect on physical capacities and anabolic hormones in under-16 elite footballers: a cross-sectional study. *Sport Sciences for Health*, 18(2), 297. <https://doi.org/10.1007/s11332-021-00806-y>
- Ginés, H. J., Huertas, F., García-Calvo, T., Ponce-Bordón, J. C., Figueiredo, A. J., & Ballester, R. (2023). Age and Maturation Matter in Youth Elite Soccer, but Depending on Competitive Level and Gender. *International Journal of Environmental Research and Public Health*, 20(3), 2015. <https://doi.org/10.3390/ijerph20032015>
- Gonaus, C., Müller, E., Stöggel, T., & Birkbauer, J. (2023). Determining the effect of one decade on fitness of elite Austrian youth soccer players using propensity score matching. *Frontiers in Sports and Active Living*, 5, 1186199. <https://doi.org/10.3389/fspor.2023.1186199>
- Granacher, U., Muehlbauer, T., Maestrini, L., Zahner, L., & Gollhofer, A. (2011). Can Balance Training Promote Balance and Strength in Prepubertal Children? *The Journal of Strength and Conditioning Research*, 25(6), 1759. <https://doi.org/10.1519/jsc.0b013e3181da7886>
- 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. <https://doi.org/10.3389/fspor.2024.1435497>
- Helsen, W., Thomis, M., Starkes, J. L., Vrijens, S., Ooms, G., MacMaster, C., & Towson, C. (2021). Leveling the Playing Field: A New Proposed Method to Address Relative Age- and Maturity-Related Bias in Soccer. *Frontiers in Sports and Active Living*, 3. <https://doi.org/10.3389/fspor.2021.635379>
- Kalčíková, P., & Přidalová, M. (2023). The Influence of Somatic Maturity on Anthropometrics and Body Composition in Youth Soccer Players. *Children*, 10(11), 1732. <https://doi.org/10.3390/children10111732>
- Konarski, J. M., Skrzypczak, M., Freitas, D., & Malina, R. M. (2024). Influence of body size and skeletal maturity status on strength and motor performances of soccer players 9–16 years. *Scientific Reports*, 14(1), 4768. <https://doi.org/10.1038/s41598-024-55042-4>
- Kuswari, M., Gifari, N., & Himarwan, A. (2021). Effects of Aerobic Endurance Training vs HIIT on Energy Intake, Macronutrient Intake, and VO2Max Level on Fitness Centre Participants. *INSPIREE Indonesian Sport Innovation Review*, 2(3), 186. <https://doi.org/10.53905/inspiree.v2i3.48>
- Lloyd, R. S., & Oliver, J. L. (2012). The Youth Physical Development Model. *Strength & Conditioning Journal*, 34(3), 61. <https://doi.org/10.1519/ssc.0b013e31825760ea>
- Lloyd, R. S., Read, P., Oliver, J. L., Meyers, R. W., Nimphius, S., & Jeffreys, I. (2013). Considerations for the Development of Agility During Childhood and Adolescence. *Strength and Conditioning Journal*, 35(3), 2. <https://doi.org/10.1519/ssc.0b013e31827ab08c>
- Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, Maturation, and Physical Activity*. *Human Kinetics eBooks*. <https://doi.org/10.5040/9781492596837>
- Maturana, F. M., Fontana, F. Y., Pogliaghi, S., Passfield, L., & Murias, J. M. (2017). Critical power: How different protocols and models affect its determination. *Journal of Science and Medicine in Sport*, 21(7), 742. <https://doi.org/10.1016/j.jsams.2017.11.015>
- Mirwald, R. L., Baxter-Jones, A., Bailey, D. A., & Beunen, G. (2002). An assessment of maturity from anthropometric measurements. *Medicine & Science in Sports & Exercise*, 34(4), 689. <https://doi.org/10.1097/00005768-200204000-00020>
- Mujika, I., Txabarri, R. G. de, Maldonado-Martin, S., & Pyne, D. B. (2012). Warm-Up Intensity and Duration's Effect on Traditional Rowing Time-Trial Performance. *International Journal of Sports Physiology and Performance*, 7(2), 186. <https://doi.org/10.1123/ijsp.7.2.186>
- Monasterio, X., Cumming, S. P., Larruskain, J., Johnson, D. M., Gil, S. M., Bidaurreaga-Letona, I., Lekue, J. A., Diaz-Beitia, G., Santisteban, J. M., & Williams, S. (2024). The combined effects of growth and maturity status on injury risk in an elite football academy. *Biology of Sport*, 41(1), 235–244. <https://doi.org/10.5114/biolSport.2024.129472>
- Pichardo, A. W., Oliver, J. L., Harrison, C., Maulder, P. S., Lloyd, R. S., & Kandoi, R. (2019). The Influence of Maturity Offset, Strength, and Movement Competency on Motor Skill Performance in Adolescent Males. *Sports*, 7(7), 168. <https://doi.org/10.3390/sports7070168>
- Radnor, J. M., Oliver, J. L., Waugh, C., Myer, G. D., Moore, I. S., & Lloyd, R. S. (2017). The Influence of Growth and Maturation on Stretch-Shortening Cycle Function in Youth. *Sports Medicine*, 48(1), 57. <https://doi.org/10.1007/s40279-017-0785-0>
- Reis, M. A. M. dos, & Almeida, M. B. de. (2020). The role of somatic maturation in the tactical effectiveness, efficiency and variability of young soccer players. *International Journal of Performance Analysis in Sport*, 20(2), 305. <https://doi.org/10.1080/24748668.2020.1743165>
- Retzepis, N.-O., Avloniti, A., Kokkoti, C., Stampoulis, T., Balampanos, D., Gkachtsou, A., Aggelakis, P., Kellaraki, D., Protopapa, M., Pantazis, D., Emmanouilidou, M., Zaras, N., Draganidis, D., Smilios, I., Kambas, A., Fatouros, I. G., Michalopoulou, M., & Chatziniolaou, A. (2025). The Effect of Peak Height Velocity on Strength and Power Development of Young Athletes: A Scoping Review. *Journal of Functional Morphology and Kinesiology*, 10(2), 168. Multidisciplinary Digital Publishing Institute. <https://doi.org/10.3390/jfkm10020168>
- Sellami, M. H., 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). <https://doi.org/10.1186/s13102-024-00855-z>
- Sweeney, L., Cummin, S., MacNamara, Á., & Horan, D. (2022). The selection advantages associated with advanced biological maturation vary according to playing position in national-level youth soccer. *Biology of Sport*, 40(3), 715. <https://doi.org/10.5114/biolSport.2023.119983>
- Sweeney, L., Taylor, J., & MacNamara, Á. (2023). Push and Pull Factors: Contextualising Biological Maturation and Relative Age in Talent Development Systems [Review of *Push and Pull Factors: Contextualising Biological Maturation and Relative Age in Talent Development Systems*]. *Children*, 10(1), 130. Multidisciplinary Digital Publishing Institute. <https://doi.org/10.3390/children10010130>
- Tavakoly, R. (2025). *International Journal of Sports Medicine*. *International Journal of Sports Medicine*. <https://doi.org/10.1055/s-00000028>
- Thieschäfer, L., & Büsch, D. (2022). Development and trainability of agility in youth: A systematic scoping review. *Frontiers in Sports and Active Living*, 4. <https://doi.org/10.3389/fspor.2022.952779>
- Tingelstad, L. M., Raastad, T., Till, K., & Luteberget, L. S. (2023). The development of physical characteristics in adolescent team sport athletes: A systematic review [Review of *The development of physical characteristics in adolescent team sport athletes: A systematic review*]. *PLoS ONE*, 18(12). Public Library of Science. <https://doi.org/10.1371/journal.pone.0296181>
- Towson, C., Salter, J., Ade, J., Enright, K., Harper, L. D., Page, R., & Malone, J. J. (2020). Maturity-associated considerations for training load, injury risk, and physical performance in youth soccer: One size does not fit all [Review of *Maturity-associated considerations for*



training load, injury risk, and physical performance in youth soccer: One size does not fit all]. *Journal of Sport and Health Science/Journal of Sport and Health Science*, 10(4), 403. Elsevier BV. <https://doi.org/10.1016/j.jshs.2020.09.003>
