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Research article

Chronological age, relative age, pubertal development, and their impact on countermovement jump performance in adolescent football players: An integrative analysis

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A R T I C L E   I N F O

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A B S T R A C T

This paper examined the relationship among countermovement jump (CMJ), football category, chronological age, relative age, and pubertal development status to investigate which parameter could be better associated with jumping performance. We tested 259 young male football players (14.9 ± 1.8 yrs; 169.7 ± 9.8 cm; 60.6 ± 11.3 kg; 20.9 ± 2.6 kg m^{-2}) belonging to elite football academies. One-sample chi-square tests were used to test the uniformity of distributions of the proportions of players in each year quarter (relative age effect, RAE) for the whole sample and stratified for each football age category (U14, U15, U17, and U19). One-way ANOVAs were used to test the associations among a) categories, RAE, and CMJ, and b) the pubertal status category and CMJ. Pearson's correlation assessed the relationship among variables. The birth distribution among the year's quarters significantly differed from the expected proportion of 25 % of participants each quarter ($\chi^2 = 41.74$; $p < 0.001$), highlighting the presence of a relative age effect. Results indicate that age significantly influences CMJ ($F_{(6,231)} = 8.85$, $p < 0.001$, $\eta_p^2 = 0.187$), and a significant interaction effect (age × birth quarter) was found. Coaches, strength and conditioning trainers, and scouts should be aware of physical and biological players' maturation.

1. Introduction

Youth football is a popular sport: in Italy, more than 800,000 participants are engaged in the youth sector [1]. Football is characterized by an alternation of high- and low-intensity exercise periods and other intense actions (e.g., accelerations and decelerations, sprints, jumps, changes of directions, tackles, kicking, dribbling), and the high-intensity periods – despite representing just a small part

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(0.5–3.0 %) of the effective playing time – are determinant for the result of the game and have been reported as a distinguishing factor between top-class and lower level players [2,3]. Compared to adults, the physical performance required for youth football matches differs from youth to youth [4–7]. Youth athletic development is an individual process affected by interdependent factors in constant change (e.g., physical growth, biological maturation, behavioral development, environment) [8].

As in other sports, youth football competitions are arranged into annual age groups, for which 1st January is typically used as the cut-off date [9–11], which implies the observation of different development and maturity among youth athletes. Malina et al. [12] highlighted the term "maturation" for changes in the body's anatomy and functionality toward adult stature, and it can be defined in terms of status, tempo, and timing, which are highly individual. The transition period from childhood to adulthood includes changes in the nervous and endocrine systems and the corresponding anthropometric, physiological, and psychological changes [13–16]. Therefore, youths of the same chronological age can have differences in maturity status. Evidence showed that players born early in the selection year take a physical advantage over their peers born later in the selection year [17].

Several studies [18–23] showed a relationship between biological maturity and advantages in anthropometric and physical fitness variables and a significant difference in categories, subcategories, and playing positions. In this way, Meylan et al. [24] documented that biological maturity status is a predictor of player fitness, performance, and selection in youth football. Non-invasive and predictive methods are used to determine the maturational parameters, which can give coaches and practitioners useful information to administer the training load properly. In this way, Mirwald et al. [25] proposed the estimation of the age of peak height velocity (PHV) as the age at which most athletes undergo their fastest rate of somatic growth, Figueiredo et al. [20] talked of the 'Relative Age Effect' (RAE) as the difference between observed and expected birth date distributions of athletes, Perroni and colleagues [23,26,27] used a self-administered rating scale for pubertal development (PDS) questionnaire to evaluate development and puberty status, and Cumming et al. [28] proposed bio-banding, a strategy to groups athletes relative to the attributes associated with growth or maturation.

While significant research has examined players' biological maturity, physical fitness, and performance, a gap exist in understanding which methods are most closely associated with specific football performance. For instance, a study conducted on thirty-eight 8-12-year-old soccer players in Qatar found a strong relationship between biological maturation (PHV) and jumping performance [29]. Conversely, a recent study found that, despite the presence of a relative age effect and differences in pubertal development, no performance advantages in jumping ability were observed in a sample of 13- and 14-year-old football players, suggesting that the potential effects of age and biological maturation on selected performance variables may not be easily identifiable [30].

Considering that jumping activities and their frequency are correlated with football performance, the aims of this study were: 1) to examine the relationship among countermovement jump (CMJ), category, chronological age, RAE, and pubertal development; 2) to assess which parameter could be better associated with CMJ in young male football players. To our knowledge, little is known about the relationship between the RAE, chronological age, biological maturation, and jumping performance in youth football players.

2. Materials and methods

2.1. Participants

At the beginning of the Italian competitive football seasons from 2017–18 to 2021–22, in the last week before the first official match (i.e., September to October), we tested 259 Italian young male football players (66 strikers, 81 midfielders, 89 defenders, 23 goalkeepers), who voluntarily participated in the study. They were trained for at least three days and one training match per week for the previous month, and any strenuous activity or training outside of their regular training schedule was done. The sample was made up of players belonging to elite football academies from the "Giovanissimi" (under 14) to "Juniores" (under 19) age categories. A signed consent form was filled out by parents of all football players (<18 years old) before the first day of study and after a verbal and written explanation of the experimental design of the study approved by the Bioethics Committee of the University of Turin (Study Protocol No. 134685) following the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments. In addition, the researcher informed subjects that they could withdraw from the study at any time.

2.2. Procedures

The Football Clubs considered this evaluation a routine exam of their young football players and agreed to the participation of their players in the study. The same experienced investigator examined all subjects to reduce measurement variations, while experimental evaluations were performed in the gym to reduce the influence of weather conditions.

Once participants arrived at the training center, a Self-Administered Rating Scale for Pubertal Development [31,32] was completed in a quiet room to evaluate puberty. Then, each participant was taken to the medical room, where anthropometric measurements were collected. All the players were split into four birth quarters according to their month of birth (Q1: January–March; Q2: April–June; Q3: July–September; Q4: October–December), and then the RAE effect was defined as a higher relative sample size of the first quarter compared with the other birthdate quarters [20].

Before jumping evaluations, the football players performed a standard 15-min warm-up consisting of jogging (40–60 % of individuals' theoretical maximal heart rate, calculated as 220-age and monitored by heart rate devices), strolling locomotion, and 2–3 repetitions of self-administered submaximal jumps.

2.3. Anthropometric evaluation

Using an electronic scale (±0.1 kg) and a stadiometer (±0.1 cm) (Seca 702, Seca GmbH & Co. KG, Hamburg, Germany), body mass and height were measured in light clothes and without shoes. The Body Mass Index (BMI) was calculated by dividing body mass by the squared height ($kg\cdot m^{-2}$).

2.4. Pubertal development

A reliable and valid brief Self-Administered Rating Scale for Pubertal Development [31,32] was used to measure the pubertal development score (PDS) and the Pubertal Status (PS). PDS was derived by summing the responses on a 4-point scale, ranging from 1 (without development) to 4 (development completed), about five different characteristics (body and facial hair growth, skin changes, deepening voice, and growth spurt) associated with pubertal maturation and then dividing by five. The PS was obtained by summing the reported values of body hair growth, facial hair growth, and voice change and classified into five categories: pre-pubertal (a combined score of 3), beginning pubertal (a combined score of 4 or 5), mid-pubertal (a combined score of 6–8), advanced pubertal (a combined score of 9–11), and post-pubertal (a combined score of 12). The internal consistency (Cronbach's α coefficient of 0.89–0.93) and test-retest reliability (intraclass correlation coefficients 0.87) of the questionnaire were previously determined by Perroni et al. [33] and Koopman-Verhoeff et al. [34].

2.5. Countermovement jump

To measure the maximal power of football players' lower extremities, the researcher asked the subjects to perform a countermovement jump (CMJ) test on an optical acquisition system (Optojump, Microgate, Udine, Italy) according to the protocol described by Bosco et al. (1983). The system has been previously reported to show high test-retest stability coefficients (range 0.80–0.98) [35]. From the standing position, subjects have to quickly bend their knees to a 90° angle and, immediately after, perform a maximal vertical thrust (stretch-shortening cycle), avoiding any knee or trunk countermovement. In addition, to avoid any arm-swing effect, subjects had to keep their hands on their hips during the jump. Subjects were instructed to keep the body vertical during the flight phase and land with their knees fully extended. The height of the jump was calculated in real-time by specific software linked to the optical system, which was triggered by the feet of the subject at the instant of taking off and at contact upon landing (10^{-3} s of resolution). Three correct jumps were performed, and the highest was taken for statistical analysis. If football players failed to adhere to the rigorous protocol, the jump was repeated after an additional 1-min rest.

2.5.1. Statistical analyses

Data are reported as absolute and relative frequencies or mean and standard deviation. For the analyses, U16 and U17 football categories were merged due to the low sample size in some year quarters. One-sample chi-square tests were used to test the uniformity of distributions of the proportions of players in each year quarter (Relative Age Effect) for the whole sample and stratified for each football age category (U14, U15, U17, and U19). One-way ANOVA models were then used to test the associations among a) players' role and CMJ performance (dependent variable), b) football categories, RAE, and CMJ performance (dependent variable), and c) the pubertal status category and CMJ performance (dependent variable). In order to allow comparison among birth quarters of different years (football categories include players born in different years), CMJ data were considered as difference from the mean of the first quarter of each year. Partial eta-squared (η_p^2) was considered as the effect size measure. A correlation matrix (Pearson's r) was computed to assess the relationship among anthropometric variables, chronological age, and pubertal development score. Pearson's r values were considered trivial ($r < 0.10$), small ($0.10 < r < 0.30$), moderate ($0.30 < r < 0.50$), and large ($r > 0.50$) [36]. A forward stepwise multiple linear regression model was used to explore the contribution of each predictor net of the others (p to enter ≤ 0.05; p to remove ≥ 0.10); the adjusted R^2 was considered a measure of the variance explained by the independent variables. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) software (ver. 29 version; IBM Inc., Chicago, IL, USA) at a standard significance level of alpha = 0.05.

3. Results

The sample included 67 players from the U14 category, 76 from the U15, 63 from the U17 (U16 and U17 combined), and 53 from the U19. Based on the pubertal status, participants were classified as 5 pre-pubertal, 54 beginning pubertal, 109 mid-pubertal, 87

Table 1
Participants' characteristics, grouped by football age category (mean ± standard deviation).

Variable	U14	U15	U17	U19	Total
Age (years)	13.1 ± 0.3	14.0 ± 0.2	15.4 ± 0.5	17.9 ± 0.8	14.9 ± 1.8
Height (cm)	160.5 ± 10.7	170.5 ± 6.9	172.9 ± 6.7	176.4 ± 6.4	169.7 ± 9.8
Body mass (kg)	51.1 ± 10.5	60.0 ± 8.7	62.8 ± 8.0	70.7 ± 8.9	60.6 ± 11.3
BMI ($kg\cdot m^{-2}$)	19.7 ± 2.9	20.6 ± 2.3	21.0 ± 1.9	22.7 ± 2.1	20.9 ± 2.6
PDS (a.u.)	2.1 ± 0.6	2.4 ± 0.5	2.7 ± 0.5	3.2 ± 0.5	2.5 ± 0.6

advanced pubertal, and 4 post-pubertal. Participants' characteristics grouped by football age category are reported in Table 1.

Table 2 presents the distribution of the players in the football age categories according to pubertal status (PS).

When looking at the distribution of participants among year's quarters, regardless of birth year, they were distributed as follows: 106 players (40.9 %) were born in the first quarter of the year (January–March), 60 (23.2 %) in the second (April–June), 59 (22.8 %) in the third (July–September), and 34 (13.1 %) in the fourth (October–December). This distribution among year's quarter is significantly different from the expected proportion of 25 % of participants each quarter (one-sample chi-square test: $\chi^2 = 41.74$; $p < 0.001$), highlighting the presence of a relative age effect. Consequently, the same analysis was applied to each football age category to explore if this selection effect was present in all the categories. As a result, the relative age effect recurred in all categories except the U19, in which the distribution of players was not significantly different from the uniform distribution expected (Table 3).

An exploratory one-way ANOVA was conducted to explore the effect of players' role on CMJ performance, but no significant differences were found (p > 0.05). Then, two one-way ANOVA models were used to explore whether age, birth quarter, and pubertal status influenced the countermovement jump performance. In the first model, age and birth quarter were used as independent variables to explore whether a relative age effect existed on CMJ performance and if this could recur at all ages. Results indicate that age significantly influences CMJ performance (main effect, $F_{(6,231)} = 8.85$, $p < 0.001$, $\eta_p^2 = 0.187$), but the birth quarter did not (Table 4).

Nevertheless, a significant interaction effect (age × birth quarter) was found, indicating that an effect of the birth quarter exists, but it is different among ages (interaction effect, $F_{(18,231)} = 2.11$, $p = 0.006$, $\eta_p^2 = 0.141$). This effect is graphically reported in Fig. 1 (the football age category was used instead of the raw age for better readability). It can be appreciated that the RAE effect is exclusively present in the U14 category, while no effect appears to be present in the other categories.

In the second ANOVA model, pubertal status was used as an independent variable to explore whether pubertal development influenced CMJ performance. Results indicate a significant effect of pubertal development on CMJ (pre-pubertal: 24.4 ± 2.9 cm; beginning-pubertal: 26.4 ± 5.6 cm; mid-pubertal: 28.7 ± 5.8 cm; advanced-pubertal: 31.5 ± 5.6 cm; post-pubertal: 35.4 ± 2.0 cm; main effect: $F_{(4,254)} = 9.244$; $p < 0.001$; $\eta_p^2 = 0.127$).

Finally, Pearson's correlations were computed to investigate the relationship between anthropometric variables, chronological age, pubertal development score, and CMJ jump performance (Fig. 2).

Age and physical growth (i.e., anthropometric measures and pubertal development) showed – as expected – high correlation values, ranging from $r = 0.52$ and $r = 0.78$ (large Cohen's effect size; $p < 0.001$ for all). Consequently, a forward stepwise multiple linear regression was performed to explore the contribution of each predictor net of the others. All the predictive variables (chronological age, height, body mass, and PDS) entered into the model; the overall fit was statistically significant ($F_{(4,254)} = 20.805$; $p < 0.001$). The model explained 24.7 % of the variance in CMJ performance, with an adjusted R^2 of 0.235. Age ($t = 2.53$; $\beta = 0.186$; $p = 0.012$), height ($t = 4.77$; $\beta = 0.425$; $p < 0.001$), and PDS ($t = 2.42$; $\beta = 0.175$; $p = 0.016$) showed a positive association with CMJ performance, while body mass showed a negative association ($t = -2.37$; $\beta = -0.244$; $p = 0.009$).

4. Discussion

This study aimed to explore the relationship between chronological age, relative (biological) age, pubertal development, and CMJ performance in young male football players in an attempt to understand which parameter would be better associated with jumping performance. The main findings of our study are a) both chronological age and pubertal development have a significant impact on CMJ performance, b) a players' selection bias (RAE) exists, although the influence of birth quarter on performance is limited on the younger categories, c) anthropometric variables should be taken into account when analyzing jumping performances, as they explain a good portion of jumping variability.

It is well known that the range of variability between individuals of the same chronological age in somatic and biological growth is large, and it has been demonstrated that differences in growth and physical development between those born at the beginning and end of the year can lead to significant variations in performance [37–39]. Perroni et al. [27] have highlighted the importance of assessing the development and the pubertal status in youth football categories. Compared to that article, football players' PDS value in this study was slightly higher for U14 and U15 (2.3 ± 0.6 vs. 1.9 ± 0.5) but similar for U17 (2.7 ± 0.5 vs. 2.7 ± 0.4) and U17 and older (3.2 ± 0.5 vs. 3.2 ± 0.6). When considering the distribution among the pubertal status categories, comparing them with those reported by Perroni et al. [40], similar distributions were reported for Giovanissimi (U14 and U15) and Allievi (U17) categories, while in the Juniores (U19) category, a wider distribution across the pubertal categories was reported in this study; the players in Perroni and colleagues' study were mostly in the Advanced Pubertal (82 %) and Post Pubertal (18 %) categories.

The power (which heavily depends on maximal strength) of lower limbs has been previously indicated as a key parameter in football, as it allows players to maximally perform critical football skills such as sprinting, jumping, changing direction, or accelerating

Table 2
Distribution of the players according to the PS (n (column %)).

Pubertal Status	U14	U15	U17	U19	Total
Pre-pubertal	4 (6.0 %)	0 (0.0 %)	1 (1.6 %)	0 (0.0 %)	5 (1.9 %)
Beginning-pubertal	29 (43.3 %)	17 (22.4 %)	7 (11.1 %)	1 (1.9 %)	54 (20.8 %)
Mid-pubertal	26 (38.8 %)	37 (48.7 %)	33 (52.4 %)	13 (24.5 %)	109 (42.1 %)
Advanced-pubertal	8 (11.9 %)	22 (28.9 %)	22 (34.9 %)	35 (66.0 %)	87 (33.6 %)
Post-pubertal	0 (0.0 %)	0 (0.0 %)	0 (0.0 %)	4 (7.5 %)	4 (1.5 %)

Table 3
Distribution of participants among year's quarters (n_{obs} (%) [n_{exp}]).

Year's quarter	U14	U15	U17	U19	Total
January–March	25 (37.3 %) [16.8]	37 (48.7 %) [19]	29 (46.0 %) [15.8]	15 (28.3 %) [13.3]	106 (40.9 %) [64.8]
April–June	12 (17.9 %) [16.8]	17 (22.4 %) [19]	17 (27.0 %) [15.8]	14 (26.4 %) [13.3]	60 (23.2 %) [64.8]
July–September	20 (29.9 %) [16.8]	15 (19.7 %) [19]	9 (14.3 %) [15.8]	15 (28.3 %) [13.3]	59 (22.8 %) [64.8]
October–December	10 (14.9 %) [16.8]	7 (9.2 %) [19]	8 (12.7 %) [15.8]	9 (17.0 %) [13.3]	34 (13.1 %) [64.8]
Chi-square	8.76	25.68	17.95	1.87	41.74
p-value	0.033	<0.001	<0.001	0.600	<0.001

Table 4
Countermovement jump performance (cm) grouped by soccer category, age, and year's quarter (mean ± standard deviation).

Category/Age	N	Jan–Mar	Apr–Jun	Jul–Sep	Oct–Dec	Total
U14	67	28.5 ± 5.1	25.9 ± 6.1	26.8 ± 7.7	22.2 ± 6.2	26.6 ± 6.5
13 years old	62	28.1 ± 5.5	25.9 ± 6.1	26.4 ± 7.7	22.2 ± 6.2	26.2 ± 6.7
U15	76	28.7 ± 4.6	28.9 ± 4.7	28.1 ± 4.4	29.5 ± 4.9	28.7 ± 4.5
14 years old	80	28.7 ± 4.4	28.9 ± 4.7	28.8 ± 3.8	29.5 ± 4.9	28.8 ± 4.3
U17	63	28.9 ± 5.5	29.6 ± 4.6	28.8 ± 6.4	30.5 ± 3.6	29.3 ± 5.1
15 years old	40	27.7 ± 5.5	27.8 ± 3.8	30.5 ± 6.3	31.7 ± 3.7	28.7 ± 5.2
16 years old	24	31.8 ± 4.3	31.3 ± 4.8	23.2 ± 2.8	28.4 ± 2.8	30.5 ± 4.7
U19	53	29.0 ± 4.8	35.0 ± 5.6	33.4 ± 5.3	36.1 ± 7.5	33.0 ± 6.1
17 years old	21	25.9 ± 4.3	36.0 ± 7.6	36.0 ± 5.7	37.9 ± 9.8	33.1 ± 8.2
18 years old	19	31.4 ± 3.5	35.6 ± 6.2	31.1 ± 5.3	34.1 ± 3.4	32.8 ± 4.9
19 years old	13	32.2 ± 4.3	34.1 ± 5.0	32.9 ± 1.7	32.5 ± 0.0	33.3 ± 3.8

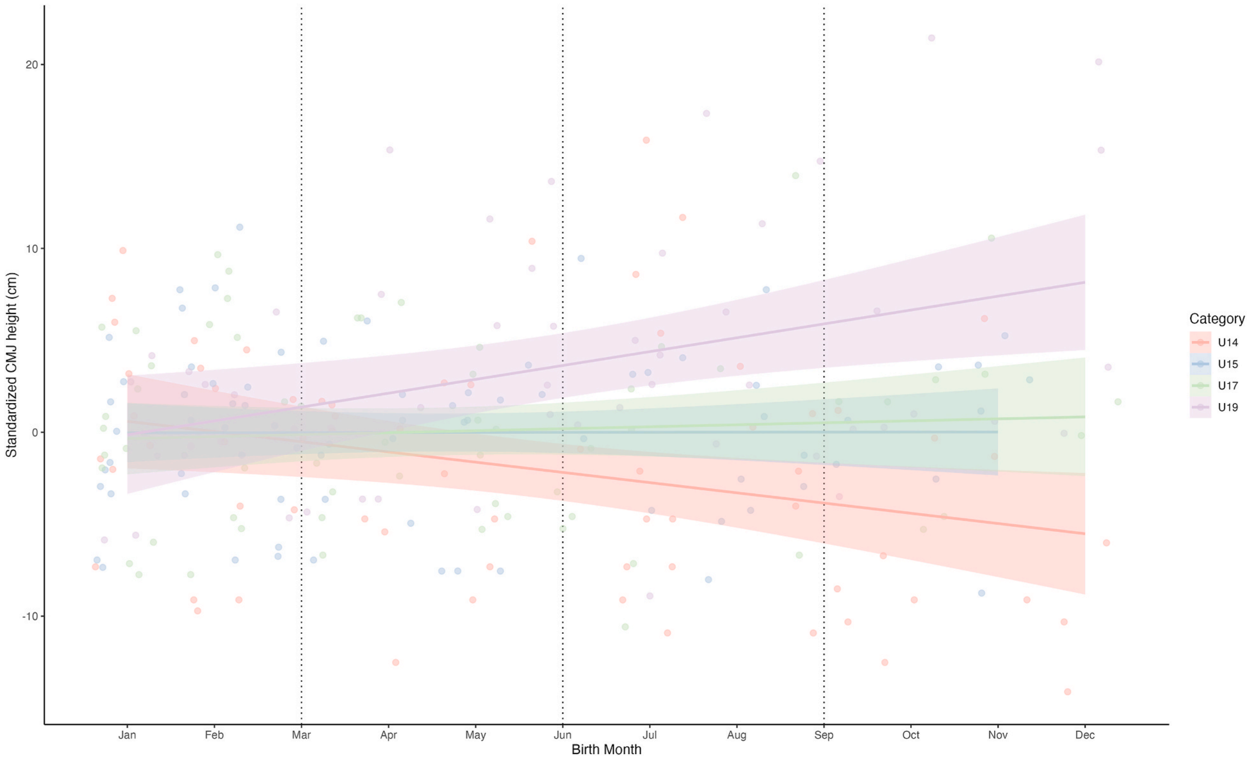

Fig. 1. Jitter plot of the Relative Age Effect on the different football age categories. On the x-axis, the birth month (vertical dotted lines divide the year's quarter) is reported, while on the y-axis, the CMJ height after standardization on the mean of the first quarter is reported to allow comparison between different birth years. The colors of the points and regression lines represent different categories.

[41,42]. In the attempt to evaluate lower limbs' power, the countermovement jump test is frequently used in the literature, as it has been shown that jumping height is strongly associated with maximal strength [42] and power [43]. Several studies employed this test in the youth categories: for example, the CMJ values of our football players were lower than previously reported by Malina et al. [22] in

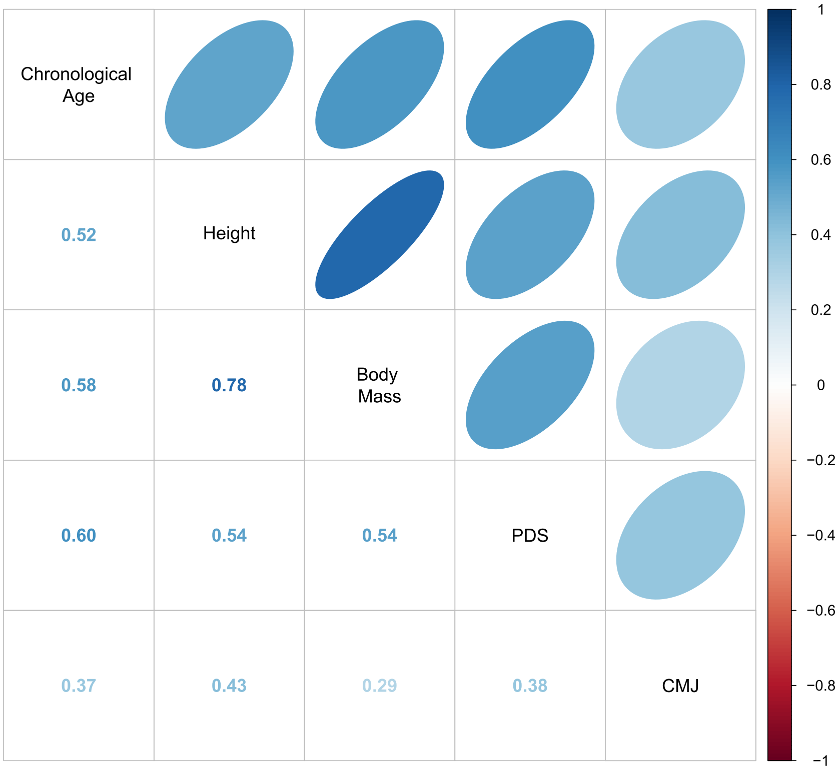

Fig. 2. Correlation plot (Pearson's r) among chronological age, anthropometric variables, pubertal development score (PDS), and countermovement jump (CMJ) performance.

U14 elite Portuguese football players (26.6 vs. 29.3 cm, respectively) and Sporis et al. [44] in 14–15 aged Croatian football players (28.8 vs. 45.47 cm, respectively).

Recent studies explored the associations between jumping performance and biological maturation. For example, Hermassi and colleagues [29] recently reported a significant correlation between maturation (measured as PHV) and CMJ in a sample of 8 to 12-year-old soccer players. Perroni et al. [27] showed a large ($r = 0.63$) correlation between CMJ and PDS in a sample of youth football players (13 ± 3 years). However, the same research group did not report a significant association between PDS and CMJ ($r = 0.12$) in a sample of over one hundred players (13.5 ± 1.4 years) [45], nor in another sample of sixty-one players (13.5 ± 0.6 years) [30]. Interestingly, in the latter paper, CMJ was not associated with PDS when "jump height" was considered as the outcome measure, but it moderately was ($r = 0.37$) when CMJ "work" (product of force × distance) was considered; this point suggests that anthropometric characteristics should be considered when analyzing jumping performance, as they could represent confounding factors in the analyses. This latter point is in agreement with the present study: indeed, a moderate correlation was reported between PDS and CMJ ($r = 0.38$), partially replicating Perroni et al. [27] results, but when PDS was added in a multiple regression model along with other variables, it showed a standardized beta of 0.175, indicating that age, physical growth, and pubertal development are strictly related, so their contribution to performance should be considered net of the others. The concept that anthropometric variables should be considered when analyzing jumping performances – as they explain a good portion of jumping variability – is not really new. Indeed, some previous evidence reported that muscle power output increases with body size, and the maximal jump height could be a measure of muscle power output normalized for body size [46]. Although it has been suggested that performance of rapid movements (such as jumping height) could be relatively independent of body size in adults, muscle power is regulated by biological maturation as a function of sex hormones that rise with the progression of puberty, and as biological maturation advances, body mass increases, favoring the predominance of lean body mass and promoting the development of muscle strength [29]. Accordingly, Jones et al. [47] examined the effect of body size on CMJ kinetics in 7–11 years old children and concluded that body size must be accounted for to enable accurate conclusions to be drawn independent of growth, as body size significantly influenced the CMJ kinetics. This was also recently confirmed by other recent studies, which reported that different anthropometric characteristics in youth soccer players were key predictors of change of direction [48] and small-sided games [49] performances.

The relative age effect (RAE) has been well-documented in football for the past two decades [11,17,50,51], and it is considered the strongest predictor for player selection at the foundation level [52]. Several studies [53,54] highlighted that athletes born earlier in the year have an advantage over those born later in the same year when they encounter a similar task or exercise, and they have more opportunities to be selected by an elite soccer academy. As an example, practical advantages have been identified in the physical performances of youth football players born in Q1 (January–April) versus Q4 (September-December) [55,56]. The overall RAE for all soccer players included in this study showed that players born at the beginning of the year (Q1) were consistently over-represented (Table 3), and it was in line with the RAE of players reported in several elite soccer leagues [51,57–59]. Castillo et al. [60] showed that in the U14 and U16 age categories, players born early in the year were over-represented compared to players born late in the year. However, birth distribution was not associated with the likelihood of a player being selected or promoted. Despite a common RAE, the proportions of players in each birth quarter might differ among studies and samples. For example, in our study, we had a lower proportion of players in Q1 and Q2 (and higher in Q3 and Q4) compared to the data reported by Gotze and Hoppe [61] from the German male soccer team, but higher proportions in Q1 and Q2 (and lower in Q3 and Q4) compared to the U17 category in Figueiredo et al. [62], which analyzed the Portuguese National team. Previous studies [57,63–65] highlighted that the prevalence of RAE in sports gradually diminishes at older age categories, as confirmed by our results in which the RAE is no longer present in the U19 category, although other research reported that an RAE exists in over 44,000 Olympic athletes [66].

When comparing the jumping performances between birth quartiles, the results obtained in this study are comparable with those of previous studies. For example, Deprez et al. [55], which investigated the presence of RAE on anaerobic parameters in elite Belgian youth soccer players, reported that despite RAE being found in all categories (U13 to U17), the jumping performances were not different among birth quarters, in none of the categories. Similarly, Fernández-Jávega et al. [67] reported that RAE was present in a sample of U14 and U16 goalkeepers, but jumping performances were not affected by relative age, suggesting that biological maturation should be considered in the talent identification process. Pena-Gonzalez et al. [68] explored the relative age-related differences between different competitive levels in young football players, reporting that although the proportion of players born in the first half of the year was higher than their counterparts born in the second half, jumping performances did not differ. In addition, Bezuglov et al. [69] investigated the RAE on jumping, sprinting and soccer-specific technical skills of over 670 young male soccer players in Russia, and although early-born players were more mature than late-born players, no statistically significant differences in any performance measure were found. Similarly, Toselli et al. [70] explored the influence of relative age on physical performance in 162 young soccer players from the U12 to U15 age categories of elite and non-elite teams, reporting a significant effect of RAE on CMJ only in the U13 category. Coherently, in our study, we found that an RAE is present in all categories (except U19), but an effect of the birth quarter on CMJ height was found only in U14. The fact that an RAE exists although the influence of birth quarter on jumping performance is limited in the younger categories is particularly important because it shows that, although no performance RAE-related appears to be present after the U14 category, the selection of the players is 'biased' also in U15 and U17 categories. This might be explained by the fact that this selection bias in the younger categories ('justified' somehow by performance differences) is also maintained in the upper categories when performance differences are no longer present and might take years (up to the U19 category) to be corrected.

This study presents some limitations: a) it is focused on male competitions only, and considering the evolution of female football organizations, further studies are needed to investigate the phenomenon of relative age effect in female football players as well. This would provide a more comprehensive understanding of the impact of RAE across genders in the sport; b) it had a retrospective design, and future longitudinal studies could be helpful to ascertain whether athletes labeled as talented during their youth actually go on to reach a high level in their professional careers or if their careers unfold differently than expected.

In conclusion, the novel findings of our study suggested that chronological age and pubertal development have a significant impact on CMJ performance, although anthropometric variables should be taken into account when analyzing jumping performances in the youth categories. Furthermore, a relative age effect exists, although the influence of birth quarters on performance is limited in the younger categories. Given that football performance is influenced by technical, physical, and physiological factors, many predictors of talent have to be considered by coaches and directors of football academies. Youth coaches, strength and conditioning coaches, and scouts should be aware of physical and biological maturation. A talent selection strategy centered only on physical performance parameters could lead to underestimating talented youth players who are competent in other performance factors. Furthermore, predicting future talent during adolescence is difficult because talent can change or disappear completely if not adequately developed [71]. Thus, football players may be physically underprepared to meet the demands of high training loads. Training to improve the physical qualities required by the intermittent nature of football (aerobic and anaerobic energy pathways, strength, speed, and flexibility) in youth football players is a complex and longitudinal process that has to take into account changes in training load administration in relation to the stage of development, and their potential windows of opportunity, of the young athlete.

These results can help the Football Federations and youth football academies develop new football rules and appropriate training programs aimed at improving the adequate fitness, technical level, and well-being of youth football players at different developmental stages. As suggested, players who are advanced in biological maturity are generally better performers than their late-maturing peers, and our findings suggest that training programs should be planned based on biological age to ensure an adequate progression of load to meet the physiological characteristics of the young players.

The implications of these findings extend beyond the jumping performance and the soccer context. Indeed, this methodological framework – which considers relative age, pubertal development and specific performance parameters – can be applied to other sports disciplines, genders, and categories. The practical ease of our approach, which used the birth date to assess RAE and a simple questionnaire to determine pubertal development, makes it a valuable reference for coaches and researchers aiming to replicate or reinterpret our findings in different contexts.

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Data availability statement

The data associated with this study have not been deposited into a publicly available repository but are available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Stefano Amatori: Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Antonio Pintus:** Writing – review & editing, Methodology. **Lorenzo Corsi:** Writing – review & editing, Methodology. **Roberto Bensi:** Writing – review & editing, Methodology. **Laura Zanini:** Writing – review & editing, Methodology. **Vanessa Rocco:** Writing – review & editing, Methodology. **Laura Guidetti:** Writing – review & editing, Supervision. **Carlo Baldari:** Writing – review & editing, Supervision. **Marco B.L. Rocchi:** Writing – review & editing, Supervision, Formal analysis. **Davide Sisti:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation. **Fabrizio Perroni:** Writing – original draft, Supervision, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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