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Are coordinative abilities impaired during adolescence in academy soccer?

Ryan J. Hemmings[a,b] and Sean J. Maloney [a]

[a]Faculty of Science and Technology, London Sport Institute, Middlesex University, London, UK; [b]Sports Science Department, Leyton Orient Football Club, Chigwell, UK

ABSTRACT

The current study sought to compare single leg (SL) landing and cutting mechanics within a cohort of youth footballers. A secondary aim was to examine how task complexity modulates the relationship between maturation and performance. Thirty-nine soccer players from an English football academy were categorised as pre-, circa- and post-peak height velocity (PHV). As part of routine club testing, players performed 1) bilateral and SL jumps (countermovement jump (CMJ) and 10/5 rebound jump tests), 2) speed (30-m sprint), and 3) change of direction (COD; 505 test and 45° cut) assessments. Landing (LESS score) and cutting mechanics (CMAS score) were determined during SL CMJ and 45° cuts, respectively. Differences in landing mechanics were not observed between groups. However, large effect sizes indicated that CMAS scores were lower in the post-PHV group versus pre- and circa-PHV groups, indicative of a favourable cutting technique. The circa-PHV group outperformed the pre-PHV group in the 'simpler' bilateral CMJ and linear sprint assessments, but not in the SL CMJ, 10/5 or COD assessments. The observed variability between participants in the circa-PHV period could be interpreted by changes in coordinative abilities. It is possible that athletes may require closer monitoring and possible training modification during this phase.

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KEYWORDS
Adolescent awkwardness; maturation; landing mechanics; cutting mechanics; agility

Introduction

'Adolescent awkwardness' is a term used to signify temporarily impaired sensorimotor function in response to a period of rapid growth (Beunen & Malina, 1988). This period may lead to challenges in motor control and movement efficiency, carrying the potential to impair athletic performance and increase the likelihood of injury in youth athletes (Hill et al., 2023; Quatman-Yates et al., 2012). Investigations in youth soccer have reported increased injury incidence around the period of peak height velocity (PHV) and during periods of accelerated limb growth (Bult et al., 2018; Johnson et al., 2022; van der Sluis A et al., 2014). Further research is required to fully understand the extent and mechanisms of potential motor control deficits during this phase, particularly in relation to athletic performance and injury risk.

Vandendriessche et al. (2012) explored the influence of biological maturation on motor coordination in male youth soccer players aged 15–16 years. They reported earlier maturing players outperformed later-maturing peers in jumping and speed-based tests but observed no differences in soccer dribbling or non-specific *Koordinationstest für Kinder* tasks (e.g., backwards balancing and sideways jumping). However, participants in the investigation were post-PHV, limiting the potential for the identification of impaired coordinative ability circa-PHV. Rommers et al. (2019) examined similar tests in a wider cohort of male U10–U15 soccer players. Maturity effects in jump and speed performances were most pronounced in U14–U15 players, favouring earlier-maturing individuals due to the physical advantages conferred by growth spurts. Conversely, later-maturing players showed an advantage in jumping sideways and balancing backwards, though effect sizes were small. Rommers et al. (2019) hypothesise that these findings may be representative of a period of temporary motor coordinative instability.

Although useful for assessing general motor coordination, the Koordinationstest für Kinder may not adequately reflect more complex, sport-specific skills. Moreover, these assessments do not seek to identify movement 'errors' that could be linked to the increased injury incidence during the circa-PHV period, which has been previously noted (Bult et al., 2018; Johnson et al., 2022; van der Sluis A et al., 2014). The use of subjective 'screening' assessments, such as the FMS and similar tools, is particularly relevant here, as these tools were designed to identify athletes at increased risk of lower-limb injury by assessing dynamic movement patterns (Cook et al., 2006). In academy soccer athletes, Ryan et al. (2018) observed no difference in Functional Movement Screen (FMS) score between pre- (15.5 ± 2.1) and circa-PHV (15.8 ± 2.1) groups, but the scores were higher in the post-PHV group (17.2 ± 1.8). Similar findings were observed by Lloyd et al. (2015) when comparing the U-11, U-13, and U-16 age groups. Whilst these data suggest that subjective movement quality during slow movements (e.g., deep overhead squat, inline lunge, etc.) may not be impaired during the circa-PHV period, Ryan et al. (2018) hypothesised that the plateau in FMS scores was a consequence of improvements in strength and muscle mass that mitigate the negative

CONTACT Sean J. Maloney S.Maloney@mdx.ac.uk Faculty of Science and Technology, London Sport Institute, Middlesex University, StoneX Stadium, Greenlands Lane, London, Hendon NW4 1RL, UK

effects of rapid growth. However, the FMS does not assess the dynamic, sport-specific movements in which athletes typically sustain injuries. The Landing Error Scoring System (LESS) (Padua et al., 2009) and Cutting Movement Assessment Score (CMAS) (Jones et al., 2017) facilitate similar subjective analyses of high-risk movements (jump landing and changing direction) with greater correspondence to athletic performance. Associations between the FMS and LESS are poor ($R^2 = 0.07$) (Tran et al., 2020), necessitating the need for movement quality to be evaluated directly during these types of movement. To the authors' knowledge, the influence of maturation on subjective movement quality during dynamic jump-landing and COD tasks has not been examined.

More consistent relationships are observed between maturation and speed-power performances (Rommers et al., 2019; Vandendriessche et al., 2012). Ryan et al. (2018) observed improvements in jump and sprint performance from pre- to circa-PHV, and from circa- to post-PHV. Similar trajectories have also been reported in more recent investigations (Fernandez-Fernandez et al., 2023; Radnor et al., 2022). Interestingly, both Read et al. (2017) and Radnor et al. (2021) record a stalling of improvement in hopping and sprinting performance, respectively, at the U-13 age group in academy soccer athletes, where the onset of the growth spurt was suggested by anthropomorphic data. Lloyd et al. (2015) reported a similar stalling in performance for the U-13 age group in reactive strength index (RSI) and reactive agility measures. Relationships between maturation and performance may be better elucidated using associative as opposed to group comparisons. For example, maturity offset has been correlated with jump ($r = 0.69$) and reactive agility ($r = 0.58$) performance in academy soccer (Lloyd et al., 2015), and with sprinting ($r = 0.29$–0.33) and jumping ($r = 0.23$–0.34) tests in secondary school boys (Pichardo et al., 2019). Similarly, Moeskops et al. (2021) observed a correlation between predicted adult height (PAH) and take-off velocity during vaulting in young female gymnasts ($r = 0.64$). However, polynomial analyses by Philippaerts et al. (2006) revealed curvilinear relationships, with reductions in 30 m sprint performance observed in youth soccer players approximately 12 months pre-PHV.

To examine the influence of maturation on subjective movement quality during dynamic jump-landing and COD tasks, the current study employed an adapted LESS assessment to examine single-leg landing (Measson et al., 2022) and the CMAS (Jones et al., 2017) to compare movement quality between pre-, circa- and post-PHV groups. Subjective movement assessments were chosen for their practicality in field-based settings, as they have been shown to correlate with quantitative biomechanical analysis (Jones et al., 2017; Padua et al., 2009). These field-based measures provide valuable insights into movement quality and are more feasible for large-scale assessments of youth athletes, making them a suitable alternative to lab-based approaches. It was hypothesised that no difference in LESS or CMAS scores would be observed between pre- and circa-PHV groups, but that scores would be lower (indicative of better movement quality) in the post-PHV group.

In addition, the study attempted to examine how task complexity modulates the relationship between maturation and performance using a variety of performance tests (bilateral and unilateral jumps, bilateral and unilateral rebound jumps, linear sprint and 505-COD assessments) and subsequent ratio metrics (bilateral deficit and COD deficit). It was hypothesised that where the coordinative demands of the task were greater (e.g., SL vs bilateral jumps, or 505 COD versus linear sprints) increases in performance between pre- and circa-PHV groups would be arrested in comparison to more simple tasks.

Methods

Experimental overview

A cross-sectional research design was utilised to help understand the relationship between maturation (determined by %PAH), motor control (evaluated by LESS and CMAS), and athletic performance (across bilateral and unilateral jumps, bilateral and unilateral rebound jumps, linear sprint and 505-COD assessments) in academy soccer athletes. Deficit measures (bilateral deficit and COD deficit) were also determined. All outcome variables were compared between pre-, circa- and post-PHV groups. Moreover, associations between all outcome measures and %PAH were also determined.

Subjects

Thirty-nine players from a category 3 youth football academy in England participated in the study (Table 1). A priori power analyses (G*Power, Version 3.1.97, Heinrich-Heine-Universität, Düsseldorf, Germany) determined the target sample size for each group ($n > 8$) using a statistical power of 0.8, type 1 error probability of 0.05 and an effect size of 0.5 (Fernandez-Fernandez et al., 2023; Radnor et al., 2022; Ryan et al., 2018).

The study utilised participants within the Youth Development Phase (YDP; U12-U16) and Professional Development Phase (PDP; U17). Participants were required to have been at the club for a minimum of four months (range: four months – eight seasons) and completed at least one previous testing battery. Training consisted of three technical training sessions per week within the YDP and five within the PDP. Both phases completed three strength and conditioning sessions (lasting ≥30 min) and participated in at least one competitive fixture each week. Throughout the YPD phase, athletes focus on fundamental movement skills, including single-leg

Table 1. Characteristics of participants within the U14, U15, U16 and U17 squads (overall sample: $n = 39$).

Squad	Age (years)	Body mass (kg)	Height (m)
U14 ($n = 12$)	13.88 ± 0.25	83.43 ± 5.40	1.67 ± 0.12
U15 ($n = 6$)	14.17 ± 0.23	88.27 ± 2.93	1.75 ± 0.05
U16 ($n = 10$)	15.6 ± 0.29	70.40 ± 10.97	1.77 ± 0.08
U17 ($n = 9$)	16.8 ± 0.29	68.32 ± 6.15	1.77 ± 0.06

Figure 1. Overview of the experimental design and order of testing.

landing and change of direction exercises, with an emphasis on strength, power, and movement quality. In the PDP phase, these skills are refined and individualised to prepare for competitive play.

At the time of testing, all participants were free from injury and participating in unconstrained training. Written informed consent for data collection and utilisation was obtained by the football club. Ethical approval for the study was granted by the ethics committee of ***blinded for purpose of peer review*** (REF: 28397).

Procedures

The physical testing (Figure 1) was performed at the football club's training ground as part of the club's routine physical testing battery (performed three times per season). Testing was carried out on grass (where all training was held) at 17:30. All participants were required to have completed at least one previous routine testing battery with the club.

Maturation status

Height and sitting height were measured to the nearest 0.01 m using a stadiometer (Seca 711; Seca, Hamburg, Germany). Bodyweight was measured to the nearest 0.1 kg using floor scales (Seca 770, Hanover, MD, USA). PAH was determined using the Khamis Roche method (Khamis & Roche, 1994; Salter et al., 2022). Parental height was self-reported and corrected for overestimation (Parental Height [cm]*0.955) + 2.316) (Khamis & Roche, 1994). Maturity status groupings (Table 2) were then determined based on %PAH using the following thresholds: pre-PHV (<88% PAH), circa-PHV (88–96% PAH), and post-PHV (>96% PAH) (Monasterio et al., 2024; Salter et al., 2022).

Warm-UP

Before each testing session, a dynamic warm-up was completed. This comprised a 'raise' phase (2 × 10-m side shuffle, backpedal, forward skip and carioca), followed by an 'activate and mobilise' phase (2 × 10-m forward lunge with rotation, lateral lunge, hamstring sweep, single-leg RDL with knee drive, and inchworm). Prior to each assessment, submaximal warm-up attempts were prescribed as outlined below.

Jump assessments

Countermovement jump (CMJ) and 10-to-5 repeated jump (10/5) assessments were performed on a dual force platform (ForceDecks FD4000; Vald Performance, Brisbane, Queensland, Australia) sampling at 1000 hZ. Data were collected using the manufacturer provided software. All jump tests were performed with hands on hips. Participants were instructed to stand tall in the centre of the force plates with hands on their hips for a minimum of 3 s before starting each trial. Three submaximal warm-up trials were performed for each test. Thereafter, three maximal trials were performed with 1 min of recovery prescribed between trials. The highest values for each jump were used for the analyses with verbal encouragement provided throughout. The platform was zeroed at the start of each trial. Bilateral assessments were performed first, followed by the single leg (SL) assessments in an alternating manner (left–right–left, etc.).

For the CMJ assessments, procedures were conducted in line with Merrigan et al. (2022). Participants were asked to jump as high as possible with jump height recorded for each trial. One key instruction was added for the SL CMJ assessment as participants were also instructed to stick their landing and 'stay still like a statue' on the same leg.

For the 10/5 assessments, procedures were conducted in line with Southey et al. (2023). Participants performed an initial CMJ followed by 10 rebound jumps for reactivity. Participants were asked to jump as high as possible whilst minimising contact time. The five best RSI scores (flight time divided by ground contact time) from the 10 jumps in each trial were then averaged to determine the reactive strength index (RSI) score for each trial. The bilateral deficit (Howard & Enoka, 1991) was determined for both the CMJ (CMJ-BLD) and 10/5 (10/5-BLD) tests.

Table 2. Characteristics of participants by maturity group classification (overall sample: $n = 39$).

	Pre-PHV ($n = 7$)	Circa-PHV ($n = 20$)	Post-PHV ($n = 11$)
Chronological age (years)	13.29 ± 0.70	14.79 ± 1.06	14.67 ± 1.18
Maturity status (PAH%)	85% ± 3%	93% ± 2%	98% ± 1%
Body mass (kg)	46.99 ± 6.14	66.18 ± 8.58	72.21 ± 6.20
Standing height (m)	1.57 ± 0.07	1.74 ± 0.07	1.81 ± 0.05
Sitting height (m)	0.80 ± 0.04	0.88 ± 0.03	0.90 ± 0.04

Key: PHV = peak height velocity, PAH = predicted adult height.

Table 3. Grading criteria for the single-leg landing error scoring system, adapted from Measson et al. (2022).

Frontal Plane Motion	Sagittal Plane Motion
1. Forward trunk flexion at IC Yes = 0, No = 1	7. Knee valgus at IC Yes = 2, No = 0
2. Knee flexion at IC Yes = 0, No = 1	8. Lateral trunk flexion at IC Yes = 1, No = 0
3. Ankle dorsiflexion at IC Yes = 0, No = 1	9. Knee valgus displacement Yes = 2, No = 0
4. Forward trunk flexion at MKF Yes = 0, No = 1	10. Contralateral pelvic drop at MKF Yes = 1, No = 0
6. Ankle dorsiflexion at MKF Yes = 0, No = 1	12. Overall impression Excellent = 0, Average = 1, Poor = 2

Maximum possible score = 15
Key: IC = Initial contact, MKF = maximal knee flexion

Landing error scoring system

A modified version (Table 3) of the single-leg LESS (Measson et al., 2022) was employed to examine the landing phase of the SL CMJ during the maximal SL CMJ assessment on the dominant limb only. Measson et al. (2022) adapted the original LESS (Padua et al., 2009) derived from a bilateral jump landing to a single-leg hop test to examine unilateral landing competency demonstrating comparable reliability (ICC: 0.87) to the traditional LESS (Hanzlíková & Hébert-Losier, 2020). In the current study, one item was removed from the Measson et al. (2022), 'hop distance covered >64% height' as this was not applicable to the SL CMJ task. The dominant limb was designated as participants' preferred kicking limb. Videos of the SL CMJ were recorded in the frontal (for the first jump) and sagittal plane (for the second jump) using an iPhone 14 plus (60 hz; Cupertino, California, United States) and these were subsequently analysed by the lead author. The phone was positioned on a tripod with the camera at a height of 0.82 m and at a distance of 3 m from the participants.

Speed assessments

Linear sprint and 505 COD tests were performed using a LiDAR timing gate system (Smartspeed Plus; Vald Performance, Brisbane, Queensland, Australia) with pairs of gates set at a height of 0.75-m and width of 1-m. Tests were completed on grass and in participants' own football boots. Following two sub-maximal warm-up trials, three trials were performed for each test with the fastest used for the analyses. Three minutes of recovery were prescribed between each trial.

For the linear speed test, procedures were performed in line with (Weakley et al., 2023). Pairs of timing gates were positioned at 0-m, 5-m, 10-m and 30-m to permit determination of split times. Participants were instructed to place one foot in line with a cone placed at 0.5-m behind the first timing gate before sprinting as fast as possible.

For the 505 test, procedures were conducted in line with (Nimphius et al., 2016). A single pair of timing gates were positioned on a 10-m line from the participants' starting position. Participants were instructed to sprint as fast as possible to a 15-m line, before turning 180° and sprinting back through the timing gate. The 505 test was performed for both left and right leg turning actions. The COD deficit (COD-D) (Nimphius et al., 2016) was also utilised to further isolate the change of direction ability and calculated using the average of participants' fastest times on left and right limbs, minus their fastest 10-m sprint time.

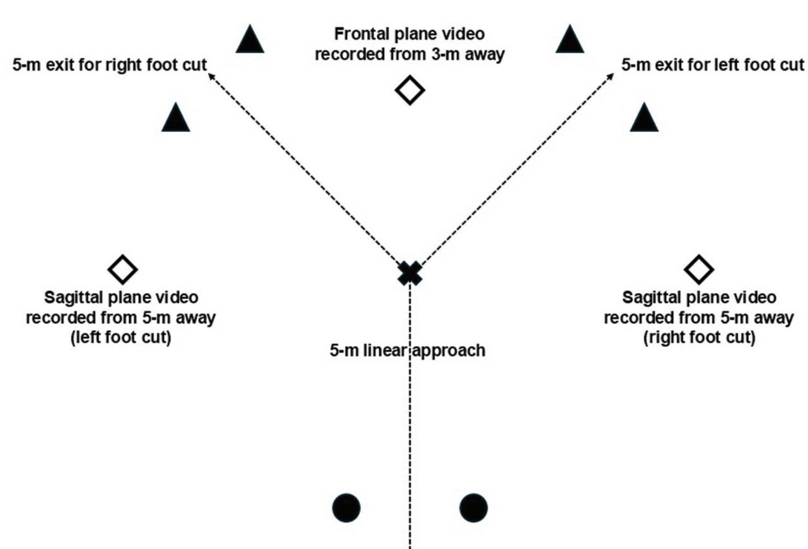

Figure 2. Setup for the 45° change of direction task to examine cutting mechanics.

Cutting Movement Assessment Score

Following the 505 COD assessment and two submaximal warm-up trials, participants then completed three trials of a 45-degree cutting task (Figure 2) during which the CMAS was calculated (Dos'Santos et al., 2021; Jones et al., 2017). As with the LESS, this was only determined for the dominant limb. For right-footed participants, cuts to the left-hand side (i.e., cutting off the right foot) were analysed and vice-versa for left-footed participants. Participants were instructed to run as fast as possible to the cutting mark, before initiating an aggressive cut with the outside foot and accelerating as fast as possible to the exit point. Videos of the 505 test were recorded in the frontal (for the first trial) and sagittal planes (for the second trial) using an iPhone 14 plus (60 hz; Cupertino, California, United States) and these were subsequently analysed by the lead author prior to the determination of PHV status and classification of maturation groupings to minimise potential observed bias.

Statistical analysis

All findings were presented as means ± standard deviation with 95% confidence intervals calculated where appropriate. Results were analysed using SPSS (version 28; IBM, Chicago, USA). To assess the normality of data, a Shapiro–Wilk test was used. Reliability of jump and sprint performances was assessed via the coefficient of variation (CV), standard error of measurement (SEM) and the intraclass correlation coefficient. CV values under 10% were deemed as acceptable for CMJ, reactive jumping, speed and COD assessments in team sport athletes (Bishop et al., 2021; Cormack et al., 2008) and ICC values were interpreted as: poor (<0.5), moderate (0.5–0.75), good (0.75–0.90), or excellent (>0.9) (Koo & Li, 2016).

To determine differences in the variables between maturational status groups (pre-, circa- and post-PHV), a one-way analysis of variance was employed with Tukey HSD tests applied post hoc where applicable. Further, Cohen's d effect sizes (mean difference/pooled standard deviation) were calculated to determine the magnitude of group differences and were interpreted using for the following thresholds: small (d = 0.2), medium (d = 0.5), and large (d = 0.8) (Lakens, 2013), also enabling comparison with previously identified investigations (Lloyd et al., 2015; Ryan et al., 2018). To examine the strength of associations between maturational status (%PAH) and other variables, the Pearson correlation coefficient (*r*) was determined. Correlations were interpreted as: small (≤0.3), moderate (0.31–0.49), large (0.50–0.69, very large (0.70–0.89), and near perfect (≥0.90) (Hopkins, 2006). To further examine the hypothetical premise of impaired coordinative abilities during circa-PHV (e.g., Ryan et al. (2018)) and non-linear development curves (e.g., Philippaerts et al. (2006)), a second-order polynomial was fitted for LESS and CMAS scores. This approach is consistent with the use of second-order polynomials in prior research examining non-linear relationships in performance metrics (Cross et al., 2017).

Results

Data were considered to be normally distributed ($p > 0.05$). ICCs for all tests were excellent (≥0.931). CVs for all tests were deemed acceptable, the majority less than 5% (CMJ: 2.49%, SL CMJ-L: 4.95%, SL CMJ-R: 4.57%, 10/5: 4.39%, 5-m: 2.80%, 10-m: 1.85%, 30-m: 1.03%, 505 COD-L: 1.52%, 505 COD-R: 1.81%). The only values greater than 5% were reported for the SL 10/5 (SL 10/5-L: 6.35%, SL 10/5-R: 6.02%).

Group mean data are presented in Table 4 and associated effect sizes in Table 5. Whilst no between-group differences were observed for LESS (Figure 3), large effect sizes indicated that CMAS scores (Figure 4) were lower in the post-PHV group versus the pre- (d = 0.85 [95%CI: −0.17 to 1.79]) and circa-PHV (d = 0.83 [95% CI: 0.04 to 1.57]) groups. For the CMJ, large effect sizes (Table 5) indicated the BLD was lower for circa-PHV versus both pre- (d = 0.88 [95%CI: −0.04 to 1.74]) and post-PHV (d =

Table 4. Group mean (± standard deviation) data and association with the percentage of predicted adult height for each of the variables.

Variable	Pre-PHV (*n* = 7)	Circa-PHV (*n* = 20)	Post-PHV (*n* = 11)	Correlation with PAH (*r* =)
Movement quality				
LESS (out of 15)	4.86 ± 0.83	6.05 ± 2.08	5.18 ± 2.52	0.03
CMAS (out of 16)	5.71 ± 1.67	5.67 ± 1.86	4.27 ± 1.71#	−0.19
Jump performance				
CMJ (cm)	26.16 ± 4.43	34.20 ± 4.96*	33.66 ± 4.60*	0.52††
SL CMJ-L (cm)	16.11 ± 2.31	17.60 ± 3.69	19.25 ± 2.25*	0.33†
SL CMJ-R (cm)	15.56 ± 1.06	17.94 ± 3.48	18.42 ± 1.76*	0.36†
10/5 (FT:CT)	1.23 ± 0.08	1.34 ± 0.41	1.49 ± 0.44	0.25
SL 10/5-L (FT:CT)	0.50 ± 0.14	0.47 ± 0.25	0.56 ± 0.29	0.03
SL 10/5-R (FT:CT)	0.45 ± 0.09	0.54 ± 0.24	0.48 ± 0.13	−0.01
Speed performance				
5-m sprint (s)	1.25 ± 0.10	1.12 ± 0.10*	1.09 ± 0.05*	−0.47††
10-m sprint (s)	2.06 ± 0.12	1.85 ± 0.10*	1.83 ± 0.07*	−0.54††
30-m sprint (s)	5.03 ± 0.24	4.43 ± 0.20*	4.40 ± 0.22*	−0.66††
505 COD-L (s)	2.24 ± 0.06	2.27 ± 0.20	2.27 ± 0.15	0.10
505 COD-R (s)	2.25 ± 0.09	2.29 ± 0.16	2.25 ± 0.09	0.07
Deficit indices				
CMJ BLD (%)	17.28 ± 12.53	1.30 ± 19.60*	10.80 ± 8.18#	−0.16
10/5 BLD (%)	−33.01 ± 21.72	−49.42 ± 26.87	−53.16 ± 52.52	−0.29
COD deficit (s)	0.19 ± 0.07	0.43 ± 0.18*	0.43 ± 0.11*	0.48††

Key: PHV = peak height velocity, LESS = Landing Error Scoring System; CMAS = Cutting Movement Assessment Score, CMJ = countermovement jump; SLCMJ = left single leg countermovement jump; FT:CT = flight time to contact time ratio; COD = change of direction.
* indicates significant between-group difference from pre-PHV, # indicates significant difference from circa-PHV (both $p \le 0.05$).
Significant correlations indicated by † ($p \le 0.05$) and †† ($p \le 0.01$).

0.85 [95% CI: 0.06 to 1.59]). No differences were observed for the BLD in 10/5. The COD-D was larger for both circa- (d = 1.47 [95% CI: 0.48 to 2.36]) and post-PHV (d = 2.46 [95% CI: 1.13 to 3.57]) versus pre-PHV.

Effects of the group were observed for the bilateral CMJ and all linear sprint distances (Table 4). The circa- and post-PHV groups outperformed the pre-PHV groups (with large effect sizes [d > 1.40]), but no further group differences were observed. No group differences were observed for the SL CMJ, 10/5, SL 10/5 and COD assessments. However, large effect sizes [d > 1.37] demonstrated that the post-PHV group outperformed the pre-PHV group in the SL CMJ.

Correlations (Table 4) for %PAH were reported with linear speed (moderate-large), CMJ (large) and SL CMJ (moderate) performances. COD-D was also moderately correlated with % PAH. Second-order polynomial regression did not reveal significant relationships for LESS (R^2 = 0.089, p = 0.188; Figure 3) or CMAS (R^2 = 0.110, p = 0.123; Figure 4).

Discussion

The aim of the current study was to compare movement quality between pre-, circa- and post-PHV groups using the LESS and

Table 5. Overall effect of group and between-group effect sizes for each of the variables.

Variable	ANOVA (p =)	Pre- vs. circa-PHV (d = [95% CI])	Pre- vs. post-PHV (d = [95% CI])	Circa- vs. post-PHV (d = [95% CI])
Movement quality				
LESS	0.348	0.64 [−0.25 to 1.50]	0.16 [−0.80 to 1.10]	0.53 [−0.23 to 1.27]
CMAS	0.119	0.03 [−0.84 to 0.89]	0.85 [−0.17 to 1.79]	0.83 [0.04 to 1.57]
Jump performance				
CMJ	**0.002**	**1.66 [0.65 to 2.58]***	**1.66 [0.50 to 2.65]***	0.12 [−0.62 to 0.85]
SL CMJ-L	0.140	0.44 [−0.45 to 1.29]	1.38 [0.27 to 2.25]	0.72 [−0.06 to 1.46]
SL CMJ-R	0.108	0.77 [−0.13 to 1.63]	1.87 [0.67 to 2.89]	0.36 [−0.39 to 1.09]
10/5	0.379	0.31 [−0.56 to 1.17]	0.75 [−0.26 to 1.69]	0.56 [−0.20 to 1.29]
SL 10/5-L	0.681	0.13 [−0.56 to 0.99]	0.22 [−0.74 to 1.16]	0.41 [−0.34 to 1.15]
SL 10/5-R	0.548	0.38 [−0.50 to 1.24]	0.18 [−0.78 to 1.12]	0.45 [−0.31 to 1.18]
Speed performance				
5-m sprint	**0.002**	**1.40 [0.42 to 2.29]***	**2.16 [0.89 to 3.21]***	0.29 [−0.45 to 1.03]
10-m sprint	**<0.001**	**1.96 [0.91 to 2.90]***	**2.45 [1.12 to 3.55]***	0.15 [−0.59 to 0.88]
30-m sprint	**<0.001**	**2.84 [1.62 to 3.89]***	**2.78 [1.36 to 3.93]***	0.14 [−0.60 to 0.87]
505 COD-L	0.932	0.15 [−0.71 to 1.01]	0.21 [−0.75 to 1.15]	0.02 [−0.71 to 0.76]
505 COD-R	0.733	0.24 [−0.63 to 1.10]	0.01 [−0.94 to 0.96]	0.39 [−0.37 to 1.12]
Deficit indices				
CMJ BLD	0.065	0.88 [−0.04 to 1.74]	0.65 [−0.35 to 1.58]	0.85 [0.06 to 1.59]
10/5 BLD	0.523	0.35 [−0.52 to 1.21]	0.46 [−0.52 to 1.40]	0.11 [−0.63 to 0.84]
COD deficit	**0.003**	**1.47 [0.48 to 2.36]***	**2.46 [1.13 to 3.57]***	0.03 [−0.71 to 0.76]

Key: PHV = peak height velocity, CMJ = countermovement jump; SLCMJ = left single leg countermovement jump; FT:CT = flight time to contact time ratio; COD = change of direction, LESS = Landing Error Scoring System; CMAS = Cutting Movement Assessment Score.
* indicates significant between-group difference from pre-PHV, # indicates significant difference from circa-PHV (both $p \le 0.05$).
Significant correlations indicated by † ($p \le 0.05$) and †† ($p \le 0.01$).

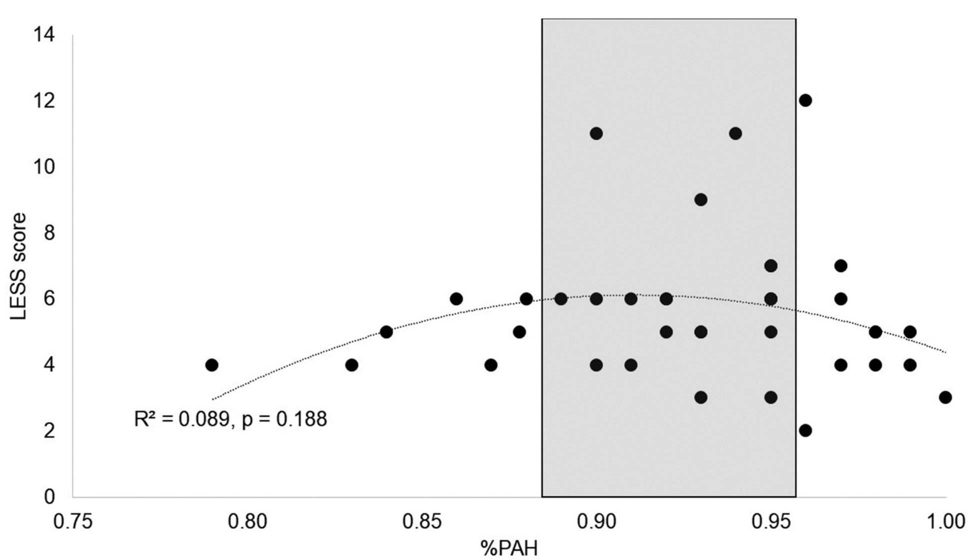

Figure 3. Individual LESS scores versus percentage of predicted adult height. The shaded area represents the circa-PHV period. R^2 value is reported for second-order polynomial fit of the data.

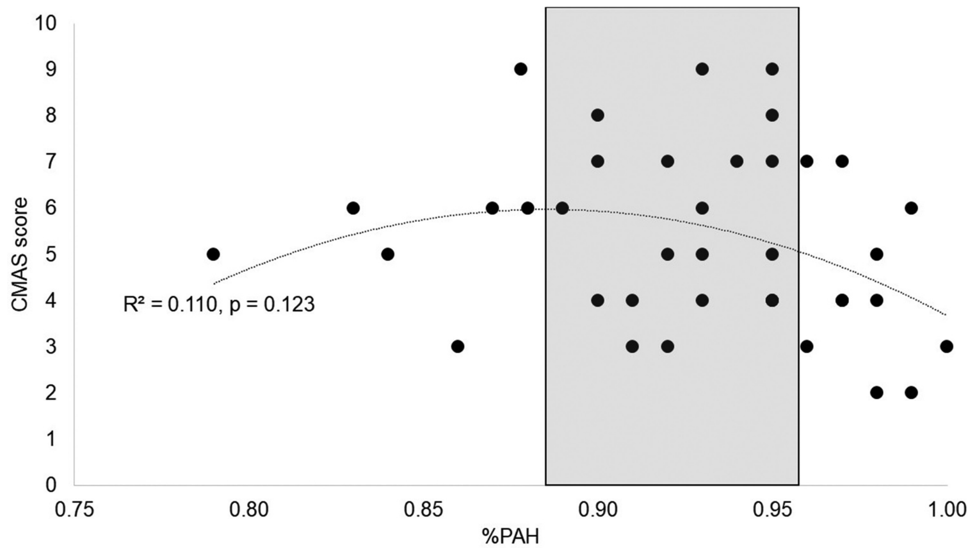

Figure 4. Individual CMAS scores versus percentage of predicted adult height. The shaded area represents the circa-PHV period. R^2 value is reported for second-order polynomial fit of the data.

CMAS grading criteria. It was hypothesised that no difference in LESS or CMAS scores would be observed between pre- and circa-PHV groups, but that scores would be lower (indicative of better movement quality) in the post-PHV group. This finding was observed for CMAS, but not for LESS, and therefore the hypothesis is partially accepted. Although CMAS findings align with this expectation, polynomial regression did not reveal significant relationships for either test to support an 'inverted-U' relationship indicative of a period of impaired movement quality often theorised during circa-PHV. The study also aimed to determine how task complexity modulates the relationship between maturation and performance. It was hypothesised that where the coordinative demands of the task were greater, increases in performance between pre- and circa-PHV groups would be arrested in comparison to more simple tasks. As between-group differences were reported for the bilateral CMJ and linear sprints, but not for the SL CMJ, 10/5 or COD assessments, this hypothesis is also accepted.

Previous investigations by Lloyd et al. (2015) and Ryan et al. (2018) evaluated FMS performances across different age and maturation groups, respectively. Both studies observed no difference in score between U-11 or pre-PHV group when compared to the U-13 or circa-PHV groups, but a higher score (indicative of greater movement quality) for the U16 or post-PHV groups. This same trend is evident for the CMAS in the current study. No difference was observed between the pre- and circa-PHV groups, but a large effect size demonstrated superior scores for the post-PHV group (vs. pre-PHV: d = 0.85 [95%CI: −0.17 to 1.79]), vs. circa-PHV: d = 0.83 [95% CI: 0.04 to 1.57]). Whilst this was not replicated in the LESS, it is possible to parse a slightly different development trajectory. Moderate effect sizes show an impairment in landing mechanics from pre- to circa-PHV (d = 0.64 [95% CI: −0.25 to 1.50]) and a subsequent recovery from circa- to post-PHV (d = 0.53 [95%CI: −0.23 to 1.27]). This could provide some degree of support for impaired coordinative ability during adolescence. However, mean differences were approximately ± one error in the test, and smaller than the standard deviations observed for circa- and post-PHV groups (~two errors). Such differences are, therefore, not likely to be practically meaningful on a group level and may simply prove an artefact of the small sample size, particularly in the pre-PHV group ($n = 7$) which did not a priori sample size estimations (≥8 participants per group). Small sample sizes and the resulting variability likely inflated effect sizes and widened confidence intervals, as evidenced by the variability observed in CMAS scores. While this limits generalisability, the findings align with prior research trends and still highlight potential developmental shifts that merit further exploration with larger cohorts.

Maturation was correlated with CMJ ($r = 0.52$), SL CMJ ($r = 0.33$ to 0.36) and linear sprint ($r = −0.47$ to 0.66) performance in the current study, as has been observed in other investigations (Lloyd et al., 2015; Pichardo et al., 2019). Prior comparisons between maturity- and age-based groups are also indicative of the linear development of bilateral jumping and linear sprinting performance (Fernandez-Fernandez et al., 2023; Lloyd et al., 2015; Ryan et al., 2018) and are replicated once again in this data set. Thus, the current study does not support the idea of stalled development for these metrics (Philippaerts et al., 2006; Radnor et al., 2021). However, the physical advantage of the circa-PHV group over the pre-PHV group (demonstrated in 'simple' bilateral jumping and linear sprinting) did not appear to transfer to improved performances in more complex jump or speed assessments. The circa-PHV group significantly outperformed the pre-PHV group in the bilateral CMJ (d = 1.66 [95% CI: 0.65 to 2.58]), but these differences were not replicated in the SL CMJ (d = 0.44–0.77; $p \leq 0.14$). Thus, for BLD in the CMJ, a large reduction (d = 0.88 [95% CI: −0.04 to 1.74]) was observed between pre- and circa-PHV groups. Whilst this does not replicate the reduction in hop performance observed by Read et al. (2017) in youth soccer players at the

U-13 age group, it is again possible to explain this finding in light of an impaired coordinative ability during adolescence. However, Fernandez-Fernandez et al. (2023), observed similar trajectories of CMJ and SL CMJ improvement in a mixed-sex cohort of youth tennis players, although the more frequent COD demands of tennis are likely to provide a more potent unilateral stimulus compared to soccer.

Lloyd et al. (2015) demonstrated associations for maturation (using maturity offset) with rebound jump RSI and reactive agility performance but did not observe differences between U-11 and U-13 age groups. These findings are partially replicated in the current study. No differences between pre- and circa-PHV groups were observed for any of the 10/5 assessments ($d \le 0.38$) or either COD direction ($d \le 0.24$), but associations with %PAH reported were not reported for either measure. Whereas Lloyd et al. (2015) report superior RSI and agility performances for the U-16 group versus U-13, the current study reports no difference between circa- and post-PHV groups for RSI ($d \le 0.56$) or COD ($d \le 0.39$). Once more, group comparisons by Fernandez-Fernandez et al. (2023) show a different trajectory; the authors observed faster 505 COD performances for circa- versus pre-PHV, but no difference between circa- and post-PHV. In concordance with Fernandez-Fernandez et al. (2023), the current study does report an increase in COD deficit from pre- to circa-PHV followed be a subsequent plateau. This trend likely reflects increased sprint momentum during circa-PHV, which may compromise COD ability due to greater braking and re-acceleration demands and heightened neuromuscular control requirements (Fernandes et al., 2021). These findings suggest the importance of targeted training to address braking efficiency and COD mechanics during key growth periods.

Despite the results observed in the current study, it would not be appropriate to conclude that this is clear evidence of 'adolescent awkwardness' for two important reasons. First, it is likely that these results were affected by a handful of individuals with high LESS scores, an effect further magnified by the small sample size. The presence, or not, of adolescent awkwardness is acknowledged to have a high degree of variability between individuals (Beunen & Malina, 1988). Nonetheless, by focusing on effect sizes and movement quality indicators rather than null-hypothesis significance alone, this study aims to offer applied insights despite inherent constraints commonly faced in youth athlete monitoring. Second, these data report a single timepoint. Longitudinal analyses are key to elucidate the true nature of the phenomenon as the timing and tempo of physical maturation will also vary greatly between individuals (Beunen & Malina, 1988). The current study employed a classification of 88–96% PAH for the circa-PHV group. This is recognised as a conservative bandwidth for grouping – in comparison to a less conservative classification of 88–93% PAH (Monasterio et al., 2024; Salter et al., 2022). It is possible that different classifications for participant groups would yield different findings. Further, integrating accurate measurements of growth rate would consolidate identification of individuals with a greater likelihood of experiencing adolescent awkwardness (Johnson et al., 2022). More sophisticated analyses should also seek to account for interactions between chronological, biological, and training ages. Accounting for training age may help differentiate natural developmental trends from adaptations driven by training exposure, thereby refining interpretations of movement quality across maturation stages.

Experimental limitations of the current study must also be considered. LESS and CMAS scores were only evaluated for the participant's preferred kicking limb, a decision influenced by time constraints and the practical demands of a field-based study. While this approach limits the evaluation of potential inter-limb coordinative differences, previous reviews highlight the task-specific nature of limb dominance (Virgile & Bishop, 2021) and a recent meta-analysis has demonstrated greater injury incidence on the dominant limb in soccer players (DeLang et al., 2020). This suggests that focusing on a single limb may still capture sport-relevant movement patterns. Nonetheless, future investigations are encouraged to adopt a more comprehensive analysis of both limbs where time and resources allow. A further limitation relates to both LESS and CMAS assessments, where video analysis was conducted separately from the frontal and sagittal planes, as two cameras were not available to simultaneously record each trial from both perspectives. While this approach may introduce the possibility of between-trial differences – such as variations in kinematic strategies observed between planes – standardising this procedure across all groups helped mitigate inconsistencies and maintain uniformity in data collection. Participants could not be blinded to the perspective of recording but were cued before and during each trial to perform each trial with maximal intent. CMAS scores were examined exclusively during a 45° cutting task with minimal decelerative demand. It is recognised that sharper COD angles increase knee adduction moment and are more likely to result in 'higher risk' kinematics (Dos'Santos et al., 2018). Assessing CMAS scores across a range of COD angles, including those with greater decelerative demands, might yield further insights into how coordinative abilities are affected during more challenging manoeuvres. Overall, the study's design decisions – from test selection to maturity grouping and statistical emphasis – were made to enhance ecological validity and provide coaches with actionable insights into movement quality around the PHV period.

Practical applications

The current study provides some indirect support for the existence of impaired coordinative abilities or 'adolescent awkwardness' during the circa-PHV period. However, this is likely a highly individual phenomenon and requires longitudinal data to properly examine. The observed increase in speed and power from the pre- to circa-PHV period, aligned also with increased body mass, causes the immature musculoskeletal system to experience a substantial increase in relative loading. If coordinative abilities are also impaired during this period – and 'higher risk' movement kinematics are demonstrated – this may place athletes at an increased likelihood of injury. Coaches and practitioners would be advised to prioritise movement quality at all developmental stages, but it is possible that athletes close to and during the circa-PHV periods may require closer monitoring and possible training modification. It would be wise to monitor anthropometric data (e.g., height), training load (e.g., external GPS and internal heart rate data) and subjective movement quality (e.g., the coaches' eye) more closely during this period. If signs of adolescent awkwardness are perceived, it would appear prudent to suggest biasing training towards refining technical performance during higher-risk activities such as single-leg landing and cutting.

In support of these recommendations, it is important to highlight that both the data collection procedures and statistical analyses used in this study were chosen with applied, field-based settings in mind. The use of practical, low-cost assessments (e.g., CMAS, LESS, RSI, and COD tests) mirrors tools readily available to practitioners in academy and school-based environments. Maturity groupings were based on %PAH, a method that balances accessibility with acceptable accuracy, while effect size thresholds were prioritised in analysis to enhance the applied interpretability of group differences. These design choices reflect the constraints and realities of working in youth sport settings and aim to support practitioners in identifying, monitoring, and responding to potential risk periods like the circa-PHV window with greater confidence.

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ORCID

Sean J. Maloney http://orcid.org/0000-0002-6637-5310

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