

Article

Influence of Maturity Status on the Reliability of the 3-Point Line Curve Sprint Test in Young Basketball Players

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Abstract: This study was designed to evaluate the influence of maturity status in the inter- and intra-session reliability of curvilinear sprinting (CS) and compare the reliability of the half-CS trials with the complete CS trials. Forty-two youth basketball players from an elite academy (13.1 ± 1.7 years; 166.7 ± 16.2 cm; 57.2 ± 17.0 kg) performed two sessions of three CS trials each on both right and left sides with seven days of separation between sessions. The predicted peak height velocity (PHV) was used to establish players' maturity status (pre-PHV, $n = 14$; mid-PHV, $n = 14$; post-PHV = 13). Mid- and post-PHV groups showed a high relative (interclass correlation coefficient [ICC] ≥ 0.75) and absolute (coefficient of variation [CV] $< 5\%$) reliability inter- and intra-session, and pre-PHV showed high relative and absolute reliability in the left trials and in the CS right trial, but moderate (ICC = 0.73) relative reliability in the half-CS right side. Based on these findings, it is recommended that practitioners consider players' maturity status to ensure accurate and reliable assessments of CS performance.



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Keywords: curvilinear sprint; maturity status; peak height velocity; basketball; assessment

1. Introduction

Basketball is a high-intensity, intermittent, court-based team sport characterized by rapid and frequent transitions between offensive and defensive roles [1]. The physical demands of basketball include high-intensity actions such as jumping, sprinting, accelerations, decelerations, and changes of direction (COD), frequently performed under decision-making constraints and during technical–tactical actions such as dribbling, defending, shooting, or blocking [2,3]. Throughout a game, players are required to perform multidirectional high-intensity actions every minute with varying movement patterns, distances, trajectories, frequency, and duration [4]. Notably, these physical demands have increased over time, driven by rule modifications, evolving playing styles, and advancements in the player's physical capabilities [5,6]. Consequently, understanding the speed and movement patterns demands in basketball is crucial for coaches and strength and conditioning coaches to optimize assessment protocols and prescribe targeted sprint-training programs.

Recent scientific literature highlighted the relevance of assessing multidirectional speed performance in basketball players [7]. Previous recommendations for speed assessment in basketball focused on both linear sprint and COD tests [8,9]. However, the

time-motion analyses of elite women's basketball games showed that speed maneuvers include not only linear sprints and COD but also curvilinear sprints (CSs), accounting for approximately 31% of all speed maneuvers [10]. The CS could be defined as the upright running phase of a sprint with the presence of some degree of curvature [11]. The CS presented kinematic and neuromuscular differences in both the inside and outside leg compared to linear sprints (LS) [11–13]. Specifically, the CS is characterized by shorter flight times, reduced step lengths, longer ground contact times, lower velocity, and greater braking impulse to generate the centripetal forces needed for maintaining the bend [14]. In this regard, Baena-Raya et al. [14] analyzed the intra-session reliability and kinematic characteristics of the new CS test using the 3-point line of an official basketball court, reporting high relative and absolute reliability in acceleration, velocity, and sprint time outcomes for young basketball players. However, it is well established that a test's reliability may be influenced by different factors such as biological maturation, speed training experience, or the interval between test–retest measurements [15,16]. Therefore, further research examining the influence of these factors is warranted. Speed testing is widely used for talent identification during the selection process in youth basketball programs [17]. These identification and selection processes often occur during early to mid-adolescence, a pivotal stage of development where athletic performance can be influenced by relative age and biological maturation [18]. Maturation, characterized by structural changes in muscle mass, strength, neuromuscular coordination, androgenic hormone levels, or stretch-shortening cycle effectiveness [19,20], is recognized as one of the strongest predictors of game performance in youth basketball. As such, maturity status should be considered when conducting fitness assessments for youth basketball players. Specifically, previous research has shown that more mature players typically exhibit better linear sprint and COD performance [21]. Moreover, studies have documented a nonlinear development in sprinting during a growth spurt due to changes in anthropometric and muscle architecture optimizing the ability to produce force and increase stride frequency and length [22]. Despite the well-documented influence of maturation on speed performance, its specific effects on CSs remain unexplored. To date, only Filter et al. (2020) have examined the evolution of CS performance across age categories (U-15 to U-20) in youth soccer players [23]. Thus, a deeper understanding of maturity's influences on CS performance could provide relevant insights for optimizing assessment and training prescription in youth basketball players.

Given this gap in the literature, the current study could enable coaches and sports scientists to implement precise and ecologically valid assessments of key demands of basketball and the needs of the players in different maturational stages. Therefore, the aims of this study were (a) to investigate the inter- and intra-session reliability of the novel curvilinear sprint test in basketball according to the maturity status in youth basketball players and (b) to analyze the reliability of the half-CS test compared with the CS test. Based on the scientific literature [24,25], we hypothesized that (a) younger maturity groups could show less reliability, especially in the performance on the weak side, and (b) less reliability would be shown in the half-CS in comparison to the complete CS due to the different strategies of the players for generating centripetal forces during the sprint.

2. Materials and Methods

2.1. Experimental Approach

This is a cross-sectional experimental design to determine the reliability of the novel 3-point line CS test inter- and intra-session in young basketball players, examining the differences between the different maturity statuses. Before testing sessions, two familiarization sessions were performed to acquaint players with testing protocols. The testing procedures were on the habitual practice courts of the athletes, with 7 days between the

two measurements. The subjects performed a standardized warm-up protocol, which includes jogging, dynamic stretching, and ballistics exercises. To complete the warm-up, players performed 2 progressive CS trials at 60% and 80% of their perceived intensity before the CS test. The athletes performed the 3-point line CS test 3 times on both sides, and they rested for 2 minutes between trials. Participants were instructed to assist the measurements by being free of vigorous activity at least 72 hours previous to the measurements and without food or caffeine intake in the at least 3 previous hours to the testing procedures.

2.2. Subjects

A total of 41 young male basketball players (age range: 10–16 years) participated in this study (166.7 ± 16.2 cm; 57.2 ± 17.0 kg). Players were recruited from an elite young basketball academy affiliated to a Spanish first-division team (ACB). The characteristics of the subjects are presented in Table 1. At the time of this study, all participants met the following inclusion criteria: a minimum of two years of basketball experience, active competition at the regional maximal basketball level within their respective age groups, and a training schedule consisting of three sessions per week along with one competitive game for at least the past two seasons. Players were excluded if they had sustained an injury within the previous three months or had any medical conditions that could hinder their participation in this study (e.g., hypertension, arrhythmia). All the parents or guardians of the participants gave their written consent before this study, and they were informed of the risk and benefits of participation in this study. This study was reviewed and approved by the Ethics Committee of the University of Almería (Ethical Application Ref: UALBIO2019/041). All the procedures were performed in accordance with the Declaration of Helsinki.

Table 1. Characteristics of participants (mean $\pm$ SD).

	N	Age (y)	Height (cm)	Body Mass (kg)	Leg Length (cm)	Maturity Offset (y)
Pre-PHV	14	11.20 $\pm$ 1.10	148.57 $\pm$ 8.08	37.46 $\pm$ 4.08	73.57 $\pm$ 5.02	−2.46 $\pm$ 0.79
Mid-PHV	14	13.16 $\pm$ 0.43	170.89 $\pm$ 9.38	60.55 $\pm$ 8.46	83.61 $\pm$ 5.97	0.02 $\pm$ 0.53
Post-PHV	13	14.99 $\pm$ 0.73	181.73 $\pm$ 7.49	74.92 $\pm$ 7.58	87.23 $\pm$ 8.89	1.99 $\pm$ 0.52

Abbreviations: PHV: peak height velocity.

2.3. Procedures

Maturity Status. Anthropometric measurements were performed before the physical test. Standing height was measured with a fixed stadiometer (Holtain Limited, Crosswell, UK). To measure the sitting height, a fixed-height table was used. The leg length was determined by standing, sitting, and bench height. In order to estimate the biological age and maturity status of the players, a predictive peak height velocity (PHV) equation for boys was used [26] with the given anthropometric data. Players were divided into three maturational groups according to their maturity offset (MO). The MO is the number of years prior to PHV. According to these concepts, players were classified as pre-PHV (<1 years MO), circa-PHV (from −1 to +1 years MO) and post-PHV (>1 years MO) [27].

$$\begin{aligned} \text{Maturity Offset} = & -9.236 + 0.0002708 \times \text{Leg Length and Sitting Height} \\ & \text{Interaction} - 0.001663 \times \text{Age and Leg Length Interaction} + 0.007216 \text{ Age and} \\ & \text{Sitting Height Interaction} + 0.02292 \times \text{Weight by Height Ratio} \end{aligned} \quad (1)$$

2.4. The 3-Point Line Curve Sprint Test

The procedures of the assessments were following the indications of Baena-Raya et al. [14], which have shown high absolute and relative reliability (ICC from 0.90 to 0.95, CV from 1.2 to 4.9 in ACC_{ma} , ACC_{avg} , Vel_{max} and Vel_{av}). We used the arc of the 3-point line (regulation basketball court according to the International Basketball Federation) to measure the CS performance, which has the following characteristics: 6.75 m of radius, 10.58° of amplitude, and 18.7 m of total distance (Figure 1). The time of the test was recorded using photocells (Microgate, Bolzano, Italy). A total of 3 pairs of photocells were placed to measure the beginning, half, and total (0—9.35—18.7 m) time of the curvilinear sprint. Players started the trials from a split start position with their preferred foot at 0.5 m behind the starting photocell. To prevent any countermovement at the beginning of the sprint, an experienced reviewer surveyed the trials.



Figure 1. The 3-point line curve sprint test.

2.5. Statistical Analyses

Descriptive analyses are presented as mean $\pm$ standard deviation (SD). The normality of data distribution was checked using the Shapiro–Wilk test. As the data met the normality assumption, parametric tests were conducted. All statistical analyses have been conducted using the statistical software R version 4.2.3. Specifically, the reliability analyses were performed using the R package “SimplyAgree” [28]. The intra-session and inter-session reliability were explored using the following coefficients: 2-way fixed effects interclass correlation coefficient (ICC3,1), standard error of measurement (SEM), and coefficient of variation (CV). The thresholds for interpreting ICC results were: 0.20–0.49 low, 0.50–0.74 moderate, 0.75–0.89 high, 0.90–0.98 very high, and ≥ 0.99 extremely high [29]. A CV of $\leq 10\%$ was considered small [30,31]. The average reliability of each measure was interpreted as acceptable for an ICC ≥ 0.75 and a CV $\leq 10\%$, moderate when ICC < 0.75 or CV $> 10\%$, and unacceptable/poor when ICC < 0.75 and CV $> 10\%$ [32]. A *t*-test for related samples was used to explore the differences between sessions 1 and 2. In this analysis, the effect sizes and confidence intervals (95% CIs) were calculated using Cohen’s *d*. Based on Hopkins et al. [29], Cohen’s *d* is interpreted as trivial ($d < 0.2$), small ($0.2 \leq d < 0.6$), moderate ($0.6 \leq d < 1.2$), large ($1.2 \leq d < 2.0$), and very large (≥ 2.0). In addition, a repeated measures analysis of variance (ANOVA) was applied to compare the same-day (intra-session) CS performance for both sides. For repeated measured ANOVA, the partial eta squared (η^2) was used. The statistical significance was set at $p < 0.05$ for all statistical analyses.

3. Results

3.1. Inter-Session Reliability

Table 2 shows the absolute and relative reliability of the 3-point line CS test among different maturity statuses between sessions. Specifically, the CS test performed to both right and left sides showed high relative and absolute reliability ($ICC \geq 0.75$ and a $CV \leq 10\%$) for all groups, excluding the half-CS trials to the right side in the pre-PHV group, in which reliability was moderate ($ICC < 0.75$ or $CV > 10\%$).

Table 2. Inter-session reliability for 3-point line curve sprint test performance according to the maturity status in youth basketball players.

Maturity Status	Variables	Session 1 (Mean $\pm$ SD)	Session 2 (Mean $\pm$ SD)	<i>p</i> -Value	ES (95% CI)	SEM	CV (%)	ICC (95% CI)	Reliability Score
Pre-PHV	Half-CSRS (s)	2.04 $\pm$ 0.09	2.00 $\pm$ 0.09	0.04	0.61 (0.03 to 1.17)	0.05	2.31	0.73 (0.43–0.87)	Moderate
	CSRS (s)	3.71 $\pm$ 0.16	3.67 $\pm$ 0.14	0.15	0.41 (−0.14 to 0.95)	0.07	1.79	0.81 (0.57–0.92)	High
	Half-CSLS (s)	2.01 $\pm$ 0.12	2.01 $\pm$ 0.10	0.81	0.07 (−0.46 to 0.59)	0.03	1.37	0.94 (0.84–0.97)	Very High
	CSLS (s)	3.69 $\pm$ 0.17	3.69 $\pm$ 0.12	0.99	0.01 (−0.53 to 0.52)	0.06	1.61	0.83 (0.62–0.93)	High
Mid-PHV	Half-CSRS (s)	1.94 $\pm$ 0.10	1.94 $\pm$ 0.10	0.77	0.08 (−0.45 to 0.60)	0.03	1.72	0.90 (0.76–0.96)	Very High
	CSRS (s)	3.51 $\pm$ 0.20	3.50 $\pm$ 0.17	0.88	0.04 (−0.48 to 0.56)	0.06	1.66	0.90 (0.76–0.96)	Very High
	Half-CSLS (s)	1.92 $\pm$ 0.10	1.90 $\pm$ 0.11	0.44	0.21 (−0.32 to 0.74)	0.05	2.55	0.80 (0.54–0.92)	High
	CSLS (s)	3.49 $\pm$ 0.18	3.47 $\pm$ 0.17	0.42	0.22 (−0.31 to 0.75)	0.05	1.50	0.91 (0.78–0.96)	Very High
Post-PHV	Half-CSRS (s)	1.74 $\pm$ 0.07	1.79 $\pm$ 0.08	0.02	−1.1 (−1.79 to −0.39)	0.03	1.78	0.84 (0.61–0.94)	High
	CSRS (s)	3.18 $\pm$ 0.14	3.23 $\pm$ 0.14	0.05	−0.94 (−1.59 to −0.27)	0.04	1.16	0.93 (0.82–0.97)	Very High
	Half-CSLS (s)	1.73 $\pm$ 0.09	1.77 $\pm$ 0.09	0.04	−0.65 (−1.24 to −0.04)	0.04	2.03	0.83 (0.60–0.93)	High
	CSLS (s)	3.18 $\pm$ 0.16	3.22 $\pm$ 0.14	0.05	−0.60 (−1.19 to 0.00)	0.05	1.49	0.90 (0.75–0.96)	Very High

Abbreviations: CSRS: curve sprint test right side; CSLS: curve sprint test left side; PHV: peak height velocity; ES: effect size; CI: 95% confidence intervals; SEM: standard error of measurement; ICC: intraclass correlation coefficient; CV: coefficient of variation. Reliability score classification: Acceptable: $ICC \geq 0.75$ and a $CV \leq 10\%$; Moderate: $ICC < 0.75$ or $CV > 10\%$; Unacceptable/poor: $ICC < 0.75$ and $CV > 10\%$.

Table 3 shows the absolute and relative reliability of the CS test of the first trial, best of three trials, average of two trials, and average of the three trials performed in the first session for the different maturity groups. Mid- and post-PHV groups showed high reliability scores in first, best, and the average of 2 and 3 trials for the right and left sides (ICC from 0.78 to 0.95). The pre-PHV group displayed low ($ICC = 0.18$) and moderate ($ICC = 0.73; 0.69; 0.65$) reliability for the half-CSRS first trial, best trial, average of 2 trials, and the CSRS first trial, respectively. CS performance to the left side showed a high reliability score in the pre-PHV group (ICC ranged from 0.79 to 0.98).

Table 3. Inter-session reliability for 3-point line curve sprint test performance according to the number of trials and maturity status in youth basketball players.

Maturity Status	Variables	First Trial	Best Trial	Avg. of 2 Trials	Avg. of 3 Trials
Pre-PHV					
Half-CSRS (s)	ICC (95% CI)	0.18 (−0.28–0.58)	0.73 (0.43–0.89)	0.69 (0.36–0.87)	0.80 (0.56–0.92)
	CV	3.70	2.31	2.21	1.81
	Reliability Score	Low	Moderate	Moderate	High
CSRS (s)	ICC (95% CI)	0.65 (0.30–0.85)	0.81 (0.57–0.92)	0.81 (0.57–0.92)	0.88 (0.71–0.95)
	CV	2.18	1.79	1.65	1.36
	Reliability Score	Moderate	High	High	High
Half-CSLS (s)	ICC (95% CI)	0.93 (0.82–0.97)	0.94 (0.84–0.97)	0.97 (0.93–0.99)	0.98 (0.94–0.99)
	CV	1.31	1.37	0.82	0.77
	Reliability Score	Very High	Very High	Very High	Very High
CSLS (s)	ICC (95% CI)	0.79 (0.53–0.91)	0.83 (0.62–0.93)	0.87 (0.71–0.95)	0.91 (0.79–0.97)
	CV	1.81	1.61	1.36	1.12
	Reliability Score	High	High	High	Very High
Mid-PHV					
Half-CSRS (s)	ICC (95% CI)	0.88 (0.72–0.95)	0.90 (0.76–0.96)	0.95 (0.87–0.98)	0.94 (0.84–0.97)
	CV	2.04	1.72	1.27	1.39
	Reliability Score	High	Very High	Very High	Very High
CSRS (s)	ICC (95% CI)	0.91 (0.80–0.97)	0.90 (0.76–0.96)	0.93 (0.82–0.97)	0.93 (0.83–0.97)
	CV	1.57	1.66	1.43	1.35
	Reliability Score	Very High	Very High	Very High	Very High
Half-CSLS (s)	ICC (95% CI)	0.84 (0.62–0.93)	0.80 (0.55–0.92)	0.79 (0.54–0.91)	0.81 (0.59–0.92)
	CV	2.37	2.55	2.45	2.32
	Reliability Score	High	High	High	High
CSLS (s)	ICC (95% CI)	0.94 (0.85–0.98)	0.91 (0.78–0.96)	0.91 (0.79–0.96)	0.92 (0.82–0.97)
	CV	1.25	1.5	1.45	1.34
	Reliability Score	Very High	Very High	Very High	Very High
Post-PHV					
Half-CSRS (s)	ICC (95% CI)	0.81 (0.57–0.93)	0.84 (0.61–0.94)	0.91 (0.77–0.96)	0.85 (0.65–0.94)
	CV	2.14	1.78	1.54	1.96
	Reliability Score	High	High	Very High	High
CSRS (s)	ICC (95% CI)	0.79 (0.52–0.92)	0.93 (0.82–0.97)	0.88 (0.71–0.95)	0.92 (0.79–0.97)
	CV	2.01	1.16	1.55	1.34
	Reliability Score	High	Very High	High	Very High
Half-CSLS (s)	ICC (95% CI)	0.78 (0.52–0.90)	0.82 (0.60–0.92)	0.92 (0.81–0.97)	0.92 (0.81–0.97)
	CV	1.98	1.95	1.35	1.37
	Reliability Score	High	High	Very High	Very High
CSLS (s)	ICC (95% CI)	0.83 (0.61–0.93)	0.82 (0.59–0.93)	0.91 (0.77–0.97)	0.93 (0.82–0.98)
	CV	1.62	1.64	1.33	1.18
	Reliability Score	High	High	Very High	Very High

Abbreviations: CSRS: curve sprint test right side; CSLS: curve sprint test left side; PHV: peak height velocity; ES: effect size; CI: 95% confidence intervals; SEM: standard error of measurement; ICC: intraclass correlation coefficient; CV: coefficient of variation. Reliability score classification: Acceptable: ICC $\geq$ 0.75 and a CV $\leq$ 10%; Moderate: ICC < 0.75 or CV > 10%; Unacceptable/poor: ICC < 0.75 and CV > 10%.

3.2. Intra-Session Reliability

Intra-session reliability is presented in Table 4. The pre-PHV group exhibited a moderate reliability score in the half-CSRS (ICC = 0.65) and a high reliability score in the CSRS and both outcomes to the left (ICC from 0.80 to 0.85). The mid-PHV group presented a high reliability score (ICC from 0.85 to 0.93; CV from 1.18 to 2.45). The post-PHV group demonstrated moderate reliability scores for the half-CS to right and left sides (ICC = 0.73; 0.64, respectively) and a high reliability score in the CS performance for both sides.

Table 4. Intra-session reliability for 3-point line curve sprint test performance according to the maturity status in youth basketball players.

Maturity Status	Variables	CS 1 (Mean $\pm$ SD)	CS 2 (Mean $\pm$ SD)	CS 3 (Mean $\pm$ SD)	<i>p</i> -Value	ES	SEM	CV (%)	ICC (95% CI)	Reliability Score
Pre-PHV	Half-CSRS (s)	2.08 $\pm$ 0.07	2.07 $\pm$ 0.10	2.05 $\pm$ 0.09	0.26	0.025	0.05	2.53	0.65 (0.41–0.83)	Moderate
	CSRS (s)	3.81 $\pm$ 0.14	3.79 $\pm$ 0.17	3.73 $\pm$ 0.17	0.01	0.038	0.06	1.63	0.85 (0.71–0.93)	High
	Half-CSLS (s)	2.01 $\pm$ 0.11	2.04 $\pm$ 0.11	2.04 $\pm$ 0.12	0.78	0.003	0.05	2.48	0.80 (0.62–0.91)	High
	CSLS (s)	3.75 $\pm$ 0.16	3.74 $\pm$ 0.17	3.74 $\pm$ 0.17	0.96	0.963	0.08	2.01	0.80 (0.63–0.91)	High
Mid-PHV	Half-CSRS (s)	1.99 $\pm$ 0.14	1.96 $\pm$ 0.13	1.97 $\pm$ 0.13	0.37	0.008	0.05	2.45	0.85 (0.71–0.93)	High
	CSRS (s)	3.59 $\pm$ 0.20	3.53 $\pm$ 0.21	3.55 $\pm$ 0.21	0.07	0.014	0.06	1.75	0.91 (0.82–0.96)	Very High
	Half-CSLS (s)	1.94 $\pm$ 0.11	1.93 $\pm$ 0.11	1.94 $\pm$ 0.11	0.43	0.005	0.03	1.18	0.89 (0.79–0.95)	High
	CSLS (s)	3.53 $\pm$ 0.17	3.52 $\pm$ 0.17	3.52 $\pm$ 0.19	0.80	0.800	0.05	1.36	0.93 (0.85–0.97)	Very High
Post-PHV	Half-CSRS (s)	1.79 $\pm$ 0.10	1.76 $\pm$ 0.09	1.79 $\pm$ 0.11	0.33	0.017	0.05	2.93	0.73 (0.51–0.88)	Moderate
	CSRS (s)	3.25 $\pm$ 0.16	3.21 $\pm$ 0.15	3.22 $\pm$ 0.15	0.30	0.011	0.06	1.87	0.85 (0.70–0.93)	High
	Half-CSLS (s)	1.77 $\pm$ 0.08	1.79 $\pm$ 0.13	1.76 $\pm$ 0.11	0.59	0.011	0.06	3.63	0.64 (0.39–0.83)	Moderate
	CSLS (s)	3.24 $\pm$ 0.13	3.25 $\pm$ 0.19	3.21 $\pm$ 0.16	0.31	0.308	0.07	2.28	0.79 (0.61–0.91)	High

Abbreviations: CSRS: curve sprint test right side; CSLS: curve sprint test left side; PHV: peak height velocity; ES: effect size; CI: 95% confidence intervals; SEM: standard error of measurement; ICC: intraclass correlation coefficient; CV: coefficient of variation. Reliability score classification: Acceptable: ICC $\geq$ 0.75 and a CV $\leq$ 10%; Moderate: ICC < 0.75 or CV > 10%; Unacceptable/poor: ICC < 0.75 and CV > 10%.

4. Discussion

This study examined both inter- and intra-session reliability of the 3-point line curve sprint test according to the maturity status in youth basketball players. The main findings of this study revealed variability in both relative and absolute reliability across maturity groups. Specifically, the mid-PHV and post-PHV groups demonstrated very high and high reliability, respectively, in CS trials, whereas lower reliability was observed for half-CS trials in both maturity groups. Additionally, pre-PHV basketball players displayed high reliability for CS trials but only moderate reliability for half-CS trials on the weak side. Finally, the pre-PHV group requires at least three trials to achieve high reliability, whereas mid- and post-PHV groups can attain high or very high relative and absolute reliability with just one trial. In terms of intersession reliability, all maturity groups demonstrate high

to very high scores, except for the weak side of half-CS trials in the pre-PHV group, which shows moderate reliability. These results highlight the influence of maturity status on the reliability of CS performance in youth basketball players.

To date, evidence on curvilinear sprinting and the reliability of CS tests considering maturation is scarce. In the current study, the CS test demonstrated higher absolute (CV range from 1.55 to 2.55) and relative reliability (CV range from 0.80 to 0.91) for the mid-PHV group. These findings align with previous studies that evaluated speed, agility, and jump test protocols in similar age groups [15,16,33]. This contrasts with the common characterization of mid-PHV players as being in the "motor clumsiness" phase, during which rapid growth in the trunk and limbs is thought to compromise motor coordination and stretch-shortening cycle efficiency [34–36]. In the post-PHV maturational stage, youth basketball players presented high reliability in CS trials (ICC from 0.79 to 0.85 and CV from 1.87 to 2.28) but only moderate reliability in half-CS trials (ICC from 0.64 to 0.73 and CV from 2.93 to 3.63). Maturity seems to play a critical role in enhancing the ability to manage centripetal forces during CS, as post-PHV athletes demonstrate increased stability in sprint-related factors such as motor coordination, ground contact time, stride length, and stride frequency [37,38]. Importantly, pre-PHV players reported moderate reliability scores on the weak side of the half-CS test (ICC = 0.65 and CV = 2.53). The lower reliability in this group likely reflects the developmental stage of motor skills, as these athletes are still refining fundamental movement patterns, leading to greater variability in complex tasks [39]. Accordingly, previous studies have reported higher variability in countermovement jump performance (CMJ) [25] or maximal isometric force tasks [24] in pre-PHV athletes compared to their older counterparts. Altogether, these results highlight the need to consider the maturity status when interpreting CS performance data in youth basketball players.

Selecting appropriate tests and developing efficient protocols to maximize valuable information within the time constraints of strength and conditioning coaches is essential to optimize training practices [40]. In this regard, our findings indicated that averaging three trials resulted in the highest reliability across all maturational groups (ICC from 0.80 to 0.98 and CV from 0.77 to 2.34) in youth basketball players. However, considering the time constraints encountered by coaches, a single trial would be sufficient to achieve high to very high reliability in the mid- and post-PHV groups (ICC from 0.78 to 0.94 and CV from 1.25 to 2.37). Conversely, the pre-PHV basketball players showed difficulties in consistently repeating movement patterns [39], suggesting the need for additional familiarization sessions or a greater number of repetitions (i.e., at least three trials) to ensure both absolute and relative reliability data during CS performance measurements. Additionally, this study also analyzed the feasibility of simplifying the testing procedures to the first half of the curve (i.e., 9.35 m) in comparison with the CS test with a total of 18.7 m to optimize testing time and reduce neuromuscular fatigue. Regarding this, our findings showed general lower reliability in half-CS trials (ICC from 0.64 to 0.89 and CV from 1.18 to 3.63) in contrast with complete CS trials (ICC from 0.79 to 0.93 and CV from 1.36 to 2.28). It is worth highlighting that mid- and post-PHV demonstrated similar reliability to both sides performing half- and complete CSs, while pre-PHV exhibited less reliability performing half-CS to the weak side (ICC = 0.65 and CV = 2.53). This approach suggests that young basketball players likely require more distance to generate sufficient centripetal forces during curvilinear sprinting, given the kinematic and neuromuscular demands of the CS [12,13,19].

This study has several limitations that must be acknowledged. First, the sample size was small, so further research is needed with larger cohorts of youth basketball players to corroborate or contrast our current findings. Second, the maturity offset was estimated using anthropometric measures and a non-invasive method [26]. While this approach offers a more affordable and simple assessment compared to the expensive and time-consuming

reference standard methods, such as radiographs or magnetic resonance imaging of the wrist and hand bones, it is subject to measurement errors, especially when applied to samples that differ from the original reference, which could limit the accuracy of the maturity assessment [41]. Finally, considering the specific playing position could provide a more detailed understanding of curvilinear sprinting.

5. Conclusions

The present findings indicate that mid-PHV players demonstrated very high reliability in CS trials, while pre-PHV and post-PHV groups exhibited high reliability scores. However, half-CS trials showed lower reliability than complete CS trials, particularly on the weak side in the pre-PHV group. Regarding inter-session reliability, all three maturational groups displayed high to very high reliability, except for the weak side of half-CS trials in the pre-PHV group. Additionally, mid- and post-PHV players require only one trial to achieve high reliability, while pre-PHV players need a minimum of three trials. These findings provide preliminary theoretical insights for conditioning coaches to assess CS performance in youth basketball players based on their maturity status.

6. Practical Applications

Our results provide young basketball players' coaches tools to measure CS performance, taking into account the maturity status of the players. From a practical perspective, coaches can easily evaluate with a regulated basketball court. Considering the neuromuscular and anthropometric differences among maturational process, coaches should consider biological age to assess CS performance properly. Pre-PHV would need further familiarization with the test, and they need to perform it at least three times to show reliability data, whilst mid- and post-PHV just require one trial to get high reliability data. From the perspective of performance, as the CS is a crucial action that must be optimized to enhance basketball player effectiveness, our results will encourage more future studies to determine the potential impact of the CS in young basketball players and particular training initiatives on its development.

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