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Change of direction speed and deficit over single and multiple changes of direction: Influence of biological age in youth basketball players

Running title: Maturation and change of direction ability in youth basketballers

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Abstract

The study analysed the difference in change of direction (COD) deficit among young male basketball players of different age groups and biological ages and analysed the relationships in COD performance (time and deficit) across single and multiple CODs depending on their biological age. Fifty-four highly-trained male players (U-13 and U-17) were tested on sprinting (25-m) and COD ability over single and multiple CODs through total times and the percentage-based COD deficit (CODD). Results showed that older age groups performed significantly (ES= 0.43-2.32, $p<0.05$) better in linear and COD times, especially those players with post-peak height velocity (PHV) (ES= 0.89-1.90). Controlling for age at PHV, no significant differences were found in any group or inter-limb asymmetries. Moderate relationships were found between CODD in the pool data (*r*= 0.36 to 0.50). All CODD and time relationships in any test (i.e., 180º COD and V-cut) were considerably lower (*r*= -0.27 to 0.32) across individual biological groups. The study highlights the impact of maturation on COD performance, whereas CODD seems to be not affected. Interestingly, the CODD is independent, highlighting this measurement's specific nature. Practitioners should use common distances, angles, and the number of CODs linked to biological status to create a COD profile.

Keywords: multidirectional, team sports, specificity, between-limb differences, linear sprinting

Introduction

In team sports, players are required to make sudden change of direction (COD) movements, which may include running in a zig-zag pattern, side-stepping, crossover cutting, or running back and forth repeatedly (Paul et al., 2016; Taylor et al., 2017). It has been found that basketball players change their movement pattern every 1-2 seconds (Klusemann et al., 2013; Scanlan et al., 2011), 60% of high-intensity actions in competitive handball are related to changing direction (Póvoas et al., 2012), and professional soccer players can execute up to 726 turns during match play (Bloomfield et al., 2007). Various COD angles are performed at varying velocities during competitive matches in all team sports. For instance, most soccer turns range between 120º to 180º, and 90% of turns have an entry speed of ≤ 5.5 m/s (Dos'Santos, Cowling, et al., 2022), while in a basketball game, the entrance velocity would be much less based on the dimensions of the court. Approximately 97% of turns performed are between 0-180º (≤ 45º = 54.6%; 90º = 27.2%; 135º = 7.4%; 180º = 8.3%; > 180º = 2.5%) being the most usual cutting angle during match play about 45º (Robinson & O'Donoghue, 2008). However, due to the continuously changing stimuli in competition, the appearance of COD actions is highly unpredictable (Marković et al., 2007), which frequently results in sudden or unplanned CODs (Reilly et al., 2000). Given the high prevalence of COD actions during competitive team sports, its assessment should be considered a key factor (Sheppard & Young, 2006). Nevertheless, it seems unlikely that a "perfect" COD test or drill exists due to the unpredictable nature and wide variety of on-field movements performed in sports across a spectrum of angles and approach distances.

When evaluating an athlete's COD ability, the metric of 'total time' has been criticized for its bias towards athletes with superior linear sprinting abilities (Nimphius et al., 2013, 2016). As a result, it fails to accurately reflect an athlete's ability to actually change direction. To address this issue, the COD deficit (CODD) has been proposed as a measure to isolate an athlete's ability to change direction (Nimphius et al., 2013, 2016). It shows the time taken to perform a one-directional change compared to a linear sprint of an equivalent distance. While the CODD has been widely applied during single 180º COD assessments (Dos'Santos et al., 2019; Nimphius et al., 2016; Thomas et al., 2018), it seems logical to evaluate the CODD over both single and multiple CODs, given the high unpredictability of COD actions and the fact that many COD movements will occur at smaller angles (Robinson & O'Donoghue, 2008). However, to the authors' knowledge, this has not yet been done and as such, further investigations are essential to gain a better understanding of this critical aspect of athletic performance.

It is interesting to note that while there has been extensive research on the performance of CODD in team sports and inter-limb asymmetries (Dos'Santos et al., 2019; T. Freitas et al., 2018; Loturco et al., 2022), there is a lack of information on age-related differences in young basketball players. As maturation has a direct impact on athletic performance (Radnor et al., 2022), it would be beneficial to compare displacement abilities based on maturation stage for better player selection during talent identification. Additionally, relying solely on total time to detect inter-limb asymmetries during COD tests may lead to misinterpretation of an athlete's symmetry in COD ability (Bishop, Clarke, et al., 2021; Dos'Santos et al., 2019), making CODD a more suitable metric (Dos'Santos et al., 2019). Although research has shown that single CODD inter-limb asymmetries are not affected during the maturation process (Asimakidis et al., 2022), there is still a need to study the influence of biological and chronological ages on CODD over single or multiple CODs, and to differentiate basketball players based on their biological (i.e., based on peak height velocity [PHV]) or chronological age.

Therefore, the main aims of the current study were: 1) to examine whether between-chronological age group (U-13, U-15, and U-17) and biological age (Pre-PHV, Mid-PHV, and Post-PHV) differences exist in CODD across single and multiple CODs in young basketball players; and 2) to analyse the relationships in COD performance (completion time and the percentage-based CODD) across single and multiple CODs depending on their biological age. It is an exploratory analysis, and it is expected that the results of this research will improve our understanding of CODD across different numbers of CODs depending on players' maturation.

Material and methods

Study design

A cross-sectional mixed research design was employed (within-subject comparative design, associative strategy, agreement). A group of highly trained young male basketball players (U-13 to U-17) were assessed on a 25-m linear sprinting (split times of 5-m, 10-m, and 20-m), a 10-m sprint (i.e., 5 + 5 m) with one 180º COD to either right or left side, and the V-cut test. All participants were familiarized with all testing procedures before starting the experiments. All tests were performed indoors (wooden basketball court) at the same time of the day (18.00-20.00) and under controlled conditions (i.e., temperature ranging between 20 and 24°C with 40-50 %

relative humidity). Players were instructed not to perform strenuous exercise (i.e., no basketball practice, only dynamic mobility was allowed) the day before the test and to consume their last meal at least three hours prior to testing.

Participants

Fifty-four young (U-13 to U-17), highly trained male basketball players (age, 13.8 ± 1.61 years; height, 174.9 ± 16.8 cm; body mass, 60.5 ± 16.9 kg, APHV, 0.62 ± 1.91 years) volunteered to participate in this study. This sample size (n = 54) was selected to detect moderate differences (ES: 0.6) for an ANOVA test at 80% power, with an alpha of 0.05 according to G*power *(version 3.1.9.6)*. Maturity offset was predicted using a non-invasive method appropriate for the age range of the sample, considering anthropometric data (leg length and sitting height), and chronological age (Maturity offset= -9.236 + 0.0002708 x Leg Length and Sitting Height interaction -0.001663 x Age and Leg Length interaction + 0.007216 x Age and Sitting Height interaction + 0.02292 x Body mass by Height ratio) (Mirwald et al., 2002). This measure was previously validated in a male longitudinal study in the range of 8 to 18 years old (R. M. Malina & Kozieł, 2014). Age at peak height velocity (APHV) was calculated by subtracting maturity offset from the chronological age. Data collection occurred during the second month (i.e., November) of the competitive season after a 2-month pre-season period. All players were training in a basketball club for at least seven years and participated on average in approximately 12 hours of combined basketball (6-7 sessions), strength and power (2 sessions), speed, agility, and quickness (1 session) training and two competitive matches per week. At the time of the study, all players were competing at a national level (i.e., Spanish Basketball National League). Furthermore, some players (n=19) were also competing at the international level (i.e., European and World Basketball Championships). Written informed consent was obtained from their parents / guardians before the investigation. The present study was approved by the institutional research ethics committee and conformed to the recommendations of the Declaration of Helsinki.

Procedures

Prior to the speed and COD testing, all players performed a typical pre-game warm-up, including low-intensity jogging (10 minutes), dynamic stretches (lunges, diver, lateral squat) (5 minutes), and moderate to high-intensity activities such as high-knees, butt kicks, cariocas, accelerations, decelerations, linear sprints and changes of direction (5 minutes). Testing was performed in the following order: 10-m linear sprinting, 180º COD, and V-cut test. Players executed two warm-up trials (in each direction during 180º COD tests) at 75% and 90% maximum effort before their maximum effort trials.

Speed tests

Running speed was evaluated by 25-m sprint times with split times at 5-m, 10-m, and 20-m. Time was recorded with photoelectric cells (*Witty*, *Microgate*, *Bolzano*, *Italy*). The front foot was placed 0.5 m before the first timing gate whilst adopting a 2-point staggered stance. Timing gates were placed at 0.75 m height and 1.5 m distance between each other. The 25-m sprint was performed three times, separated by at least 3 min of passive recovery. The best time recorded in the 5-m, 10-m, 20-m, and 25-m (which could have been found in different trials) was used for statistical analysis.

Change of direction tests

180° Change of direction test

A 10-m shuttle-sprint test was performed. The subject sprinted from the start/finish line, crossed the 5-m line with either right or left foot, and turned 180° to sprint back to the start/finish line (Figure 1). The front foot was placed 0.5 m before the first timing gate whilst adopting a 2-point staggered stance. Timing gates were placed at 0.75 m height and 1.5 m distance between each other (*Witty, Microgate, Bolzano, Italy*). Players executed two valid trials with each foot (first, left, and second, right) in alternating order, separated by two minutes, with the fastest retained for calculations. The percentage-based change of direction deficit was calculated using the formula: (COD time – 10 m sprint time)/10 m sprint time (T. T. Freitas et al., 2022).

*****Figure 1 near here*****

V-cut test

In the V-cut test, players performed a 25-m sprint with 4 COD of 45º each 5 m (Figure 2). The front foot was placed 0.5 m before the first timing gate whilst adopting a 2-point staggered stance. Timing gates were placed at 0.75 m height and 1.5 m distance between each other (*Witty, Microgate, Bolzano, Italy*). For the trial to be valid, players had to pass the line, drawing on the floor (i.e., through tape), with one foot completely at every turn. If the trial was considered as failed, a new trial was allowed. Players executed two valid trials. The distance between each pair of cones was 0.7 m. Time of the fastest trial was retained. The percentage-based change of direction deficit was calculated using the formula: (COD time – 25 m sprint time)/25 m sprint time (T. T. Freitas et al., 2022).

*****Figure 2 near here*****

Asymmetry index

To truly investigate inter-limb asymmetries and establish COD dominance, we compared faster and slower sides. The asymmetry index for the 180º COD test performance was calculated as follows: 100/(faster side)*(slower side)*-1+100 (Bishop et al., 2018).

Statistical analyses

All statistical analyses were performed using SPSS (*version 25, IBM, New York, NY, USA*) and Microsoft Excel (*version 2016, Microsoft Corp., Redmond, WA, USA*). Data are presented as mean ± SD. Normality was assessed using the Kolmogorov-Smirnov test and showed all variables as normally distributed variables, with the exception of COD and CODD inter-limb asymmetries. Pearson's correlation coefficients were calculated to establish the relationships between every variable and the percentage-based CODD with right and left legs, and the percentage-based CODD V-cut (within Pre-PHV, Mid-PHV, Post-PHV, and pooled data). The magnitude of the correlation (*r* (95%CI)) between variables was assessed with the following thresholds: ≤0.1=trivial; >0.1–0.3=small; >0.3–0.5=moderate; >0.5–0.7=large; >0.7–0.9=very large; and >0.9–1.0=almost perfect (Hopkins et al., 2009). Furthermore, a one-way ANOVA was conducted to determine between-chronological age group (U-13 vs. U-15 vs. U-17), and between-biological age group (Pre-PHV vs. Mid-PHV vs. Post-PHV) significant differences (p<0.05). Bonferroni's test was developed to establish post-hoc comparisons. Kruskal-Wallis analysis of variance was conducted to determine differences in asymmetry scores between COD in total time and CODD, with statistical significance set at p<0.05. Homoscedasticity was assessed through the Levene's test. Finally, to examine the influence of maturation on between-group differences (p<0.05), an analysis of covariance (ANCOVA) was conducted using APHV as a covariate. The standardized difference or effect size (ES, 95%CI) was calculated using the pooled SD. Threshold values for Cohen d ES statistics were >0.2 (small), >0.6 (moderate), and >1.2 (large) (Hopkins et al., 2009).

Results

Between-chronological age differences (Table 1) showed substantially better performance in the older groups (U-13<U-15<U-17) in 20-m and 25-m linear sprinting (ES:0.43 to 2.01) and COD measured through total times (ES: 0.48 to 2.32). Shorter linear sprinting distances (5-m and 10-m) were significantly (p<0.05) faster in U-17 compared to U-13 and U-15 (ES:1.06 to 1.43). No significant differences (p > 0.05) were found between age groups in the percentage-based CODD. It is interesting to note that a moderate ES (0.65) was reported in the comparison between U-13 and U-15 in the %CODD with the left leg. When APHV was controlled, all significant differences were no apparent (p>0.05) except for 5-m sprint between U-15 and U-17 groups.

***** Insert Table 1 near here*****

Between-biological age differences are shown in Table 2. Significantly lower COD times through both single and several CODs and linear sprinting times (10-m, 20-m, and 25-m) ($p<0.05$) were found in Post-PHV compared to Pre- and Mid-PHV (ES:1.05 to 1.90). No significant differences ($p > 0.05$) were reported between biological age groups in the percentage-based CODD. When APHV was controlled, all significant differences were no apparent ($p>0.05$) except for COD times with either right or left legs between Mid- and Post-PHV groups. No significant differences ($p>0.05$) were found between any group for inter-limb asymmetries in both COD times and CODD (Table 1 and 2).

***** Insert Table 2 near here*****

Correlation coefficients between all variables in the pool data are reported in Table 3. Moderate to large negative relationships (r= -0.42 to -0.56) were reported between linear sprinting and CODD measured through the V-cut test. Negative moderate relationships were found (r = -0.33 to -0.47) between linear sprinting and the CODD measured with the right leg. The V-cut test was very largely to almost perfectly (r = 0.73 to 0.90) related to linear sprinting and COD total times with one COD. All linear sprinting distances were largely to very largely related to COD total time measured with one COD (r=0.66 to 0.89). Moderate relationships (r = 0.36 to 0.50) were found between CODD in the pool data.

*****Table 3 near here*****

Between-maturation group correlations are shown in Table 4. CODD with the right leg was very largely (r = 0.73) related to the CODD V-cut test in the Mid-PHV group. Furthermore, a very large relationship (r = 0.75) was found between CODDD with the right and left legs in the Post-PHV group.

*****Table 4 near here*****

Discussion

The main aims of the current study were to examine whether between-chronological age group (U-13, U-15, and U-17) and biological age (Pre-PHV, Mid-PHV, and Post-PHV) differences exist in the CODD across single and multiple CODs in young basketball players, and to analyse the relationships in COD performance (completion time and CODD) across single and multiple CODs depending on their biological age. The main findings were as follows: 1) chronological and biological ages directly affect COD performance in total time, whereas CODD seems to not be affected, 2) maturation seems to be the key factor to show greater linear and COD performances dividing groups by either chronological or biological age, 3) inter-limb asymmetries measured through COD times and deficit showed no differences irrespective of the maturation status or birth group, 4) as the relationships between COD deficits (single 180º and V-cut) are low in the group data, it suggests to use specific CODD based on the most common basketball player demands (i.e., playing position), and 5) there is a low relationship between CODD and its specific COD total time in both pooled data and each biological group.

One of the most important findings was that COD (i.e., total time) was directly affected by age and biology as faster times were found as age (i.e., U-13 > U-15 >U-17) and maturation (i.e., Pre- > Mid- > Post) increased. Previously, similar results have been reported in young basketball players in the V-cut test without dribbling (i.e., greater performance as age increased) (Gonzalo-Skok et al., 2015) or dribbling the ball (i.e., faster times as maturation increased) (Jòdar-Portas et al., 2023). However, if we look at CODD, the current results are different than those previously found in basketball players (Jòdar-Portas et al., 2023). In the present study, the CODD was even greater in the oldest (i.e., U-17) and more mature (i.e., Post-PHV) players than their younger and less mature counterparts. Age and maturation affect linear sprinting and COD times (Lloyd et al., 2016; Lloyd & Oliver, 2012), as also shown in the current study (i.e., faster times in older and more mature players). Even so, it is important to note that such players might have proportionally improved linear sprinting and COD performance. In this regard, it is not reflected within the CODD, and consequently, this may be the reason the CODD was not affected by age and maturation. Furthermore, CODD calculation seems to also be the key factor as its calculation through time or as a percentage shows different results and, thus, as it was previously suggested, CODD should be calculated the percentage-based COD to avoid a misinterpretation (Freitas et al., 2022). Furthermore, in youth soccer players (U-15 to U-19), their CODD time calculated from the Zig-zag test was actually slower as age increased (Loturco et al., 2020), which is different from the results found in the current study. Such differences might be due to several aspects, such as players' categorization (i.e., chronological age vs. biological age) or the sport involved (i.e., soccer vs. basketball). As COD ability mainly depends on anthropometric, technical, physical, and motor capacities (e.g., speed, power, strength, and coordination) (Dos'Santos, McBurnie, et al., 2022), maturation should be taken into consideration to determine if between-player differences are related to either performance per se or the biological situation. Furthermore, despite soccer and basketball being classified as team sports, they have several different movement characteristics, with court size and game time potentially being the most important in this regard. Specifically, basketball is played in a smaller area (28 x 15 vs. 90 x 60 m) and for a reduced duration (40 vs. 90 mins) in comparison to soccer. In addition, basketball players typically perform COD movements every 2 s as well (Ben Abdelkrim et al., 2007), while in soccer every 3 to 5 s (Reilly et al., 2000). Consequently, it may develop different player profiles as a higher volume of high intensity decelerations might appear in basketball. In addition, given the vast majority of cutting tasks in basketball are acute over short distances, resulting in relatively low entrance velocities (i.e., the most common angle is 45º, one COD movement every 2 s), it is suggested that the V-cut test is a useful assessment protocol for basketball players. Thus, it seems logical to consider that maturation affects COD time, and basketball training seems to help develop COD ability without focusing specifically on COD drills.

As chronological age increases, players typically exhibit faster linear sprinting and COD times. However, the most interesting finding was that mid-PHV players actually reported similar or slower times than pre-PHV players. As maturation and growth are interrelated, and they consist of enhancements in neural function, multi-joint coordination, changes in muscle architecture or skeletal growth (R. Malina et al., 2004), some players might be involved in greater rates of change in height (e.g., from 10 to 20 cm in 4 to 6 months) (Mirwald et al., 2002). Therefore, players who are close to or circa PHV might show reductions in motor control or whole-body coordination (Lloyd et al., 2016), commonly termed “adolescent awkwardness” (Quatman-Yates et al., 2012). When it comes to developing talent in basketball, it is important to consider factors beyond just chronological age. The maturation process can have a significant impact on performance, which means that relying solely on age may lead to gross misinterpretations (Lloyd et al., 2016; Lloyd & Oliver, 2012). By focusing on biological age as well as other relevant factors (e.g., technical, tactical, and physical), coaches and talent scouts can ensure that they are identifying the most promising young players for the future.

Although inter-limb asymmetries measured through COD time and deficit decreased over time in biological and chronological groups, no statistically significant differences were reported. Similar results have been recently found in soccer players comparing pre-PHV and post-PHV groups, where no significant between-group differences were evident in inter-limb asymmetries (Asimakidis et al., 2022). Similarly, there were no differences between the three biological age groups in the present study as well. Interestingly, “adolescent awkwardness” might affect linear and COD performance during the growth spurt (i.e., mid-PHV), but the reason these differences are not evident for inter-limb asymmetries is important to understand and comes down to the SD value. Typically, it is not uncommon for the SD to be 50 to 100% of the mean for inter-limb asymmetries (Bishop, Lake, et al., 2021). In our case, the SD was between 74% to 100% of the mean, for tests where asymmetry was computed. Consequently, when looking to determine whether “differences” are significant, this large within-group variation in asymmetry scores, precludes statistical significance from being found. Consequently, an individualized assessment of inter-limb asymmetry is necessary to determine whether the magnitude and direction of imbalance is consistent or fluctuates between groups or test sessions, which has been suggested in previous research (Bishop, Clarke, et al., 2021; Bishop et al., 2018; Bishop, Lake, et al., 2021; Dos'Santos et al., 2019; Gonzalo-Skok et al., 2023).

Pooled data showed moderate correlations (*r*=0.36 to 0.50) between CODD measured through 180º COD and V-cut tests. It is worth noting that despite a growing interest in using CODD to isolate COD ability (Dos'Santos et al., 2019; T. Freitas et al., 2018; Gonzalo-Skok et al., 2023; Nimphius et al., 2016; Thomas et al., 2018), no study has, to the authors' knowledge, evaluated the influence of CODD over different numbers of CODs (single vs. multiple). Therefore, direct comparisons are not possible. However, there are two studies which have evaluated the relationship between COD deficits (T. T. Freitas et al., 2021; Gonzalo-Skok et al., 2023). A group of adult rugby sevens male and female players reported almost perfect relationships (*r*=0.90 to 0.95) between different CODD measured through several tests (i.e., L-drill, Pro-agility, and Zig-zag tests) (T. T. Freitas et al., 2021). Such differences might be due to the players' age (adults vs. youth), the court size dimensions (large vs. small area) or the CODD calculation (time vs. percentage-based). Furthermore, a previous study has analysed the relationship between COD deficits of different COD angles (45º, 90º, 135º, and 180º) (Gonzalo-Skok et al., 2023). Similarly, to those results found in the current study, trivial to large correlations (*r*=-0.29 to 0.56) were reported highlighting the specificity of the angle-variation strategy performed. Thus, braking manoeuvres become more critical as the COD angle increases (45º until 180º). The higher velocity maintenance through shorter ground contact times recommends a crossover strategy during COD (Suzuki et al., 2014). At the same time, larger braking occurs over the penultimate foot contact and potentially steps before push-off as directional changes are between 60º and 180º, suggesting either side-stepping or pivoting as effective execution strategies (Suzuki et al., 2014). Consequently, including greater distances covered and the number of CODs executed might increase their impact on CODD relationships and, therefore, use specific player-position assessment to detect strengths and weaknesses.

When analyzing correlations between CODD (i.e., 180º COD test) and the rest of the variables, trivial to moderate relationships (r=-0.47 to 0.44) were found in the pooled sample. Interestingly, all CODD and time relationships in any test (i.e., 180º COD and V-cut) were considerably lower (r= -0.27 to 0.32) except for 180º COD with the right leg and its specific CODD (r = 0.57) in the Pre-PHV group. These results are in line with those found in another study (Lazić et al., 2023), where trivial to small correlations (r =0.05 to 0.23) were found between CODD and COD times of other tests (i.e., Pro-agility and Zig-zag tests) in adolescent basketball players. At the same time, a very large relationship (r=0.75) was reported between the CODD with right and left legs in the Post-PHV group. Hence, basketball might potentiate specific angle skills as they continuously perform CODs (Scanlan et al., 2011) and COD angles are likely to be playing-position dependent. Consequently, training and testing should be playing-position and role-specific-dependent.

It is important to acknowledge some limitations in the present study. Specifically, our results are not necessarily applicable to other team sports due to the unique characteristics of basketball, such as their anthropometry and court size. Second, this study only examined total time and CODD and did not provide insights into actual COD strategy or phase-specific information (e.g., entry and exit velocity, ground contact time during turns, etc.), which could provide a more comprehensive understanding of directional dominance. Third, the age range of our participants (13-17) might be a limiting factor given that older and more mature players would have significantly greater physical parameters than their less mature counterparts. In addition, the complexity of turning-related movements should be considered, depending on the distance covered before changing direction, given the vast combination of possible COD movements. As such, a single COD test only partially addresses the locomotive demands of any team sport. Finally, future studies should examine intra-squad COD abilities based on individual mechanical strategies, anthropometrics, strength, and power outputs, as well as standardizing all assessments of COD ability in basketball.

Conclusions

The current results can help practitioners use specific testing and training methods throughout maturation. When aiming to assess COD ability, we suggest using specific COD tests and their corresponding CODD. Indeed, as locomotive demands are position-dependent, COD ability assessment should also be position-specific. As no between-biological age differences exist, inter-limb asymmetries decrement should be addressed throughout the maturation and growth process to improve physical performance and minimize the injury risk. Finally, maturation status should also be considered during the talent ID process to avoid misinterpretation during the player's profile assessment.

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Table 1. Between-chronological age differences in anthropometric and physical performance (n=54).

				U-13 vs U-15		U-13 vs U-17		U-15 vs U-17	
	U-13 (n=20)	**U-15 (n=23)**	**U-17 (n=11)**	**ES (CI95%)**	**p value**	**ES (CI95%)**	**p value**	**ES (CI95%)**	**p value**
Age (years)	12.2 ± 0.50	14.0 ± 0.57	16.3 ± 0.80	3.28 (2.68; 3.88)	**<0.001**	5.81 (5.00; 6.62)	**<0.001**	3.14 (2.36; 3.93)	**<0.001**
Height (cm)	160.6 ± 12.4	178.6 ± 10.5	193.2 ± 12.5	1.53 (0.92; 2.14)	**<0.001**	2.51 (1.76; 3.27)	**<0.001**	1.21 (0.45; 1.97)	**<0.001**
Body mass (kg)	47.9 ± 11.4	61.6 ± 11.0	81.1 ± 14.8	1.20 (0.59; 1.81)	**<0.001**	2.39 (1.61; 3.18)	**<0.001**	1.42 (0.64; 2.20)	**<0.001**
APHV (years)	-1.16 ± 0.82	0.84 ± 0.86	3.38 ± 1.26	2.32 (1.72; 2.93)	**<0.001**	4.04 (3.24; 4.85)	**<0.001**	2.23 (1.44; 3.02)	**<0.001**
5-m (s)	1.18 ± 0.09	1.18 ± 0.06	1.07 ± 0.10	0.03 (-0.58; 0.65)		1.06 (0.29; 1.84)	**0.003**	1.20 (0.39; 2.00)	**0.002**
10-m (s)	2.04 ± 0.13	2.02 ± 0.11	1.85 ± 0.13	0.23 (-0.38; 0.84)		1.43 (0.68; 2.18)	**<0.001**	1.30 (0.54; 2.06)	**0.002**
20-m (s)	3.60 ± 0.22	3.50 ± 0.21	3.21 ± 0.19	0.43 (-0.17; 1.04)		1.84 (1.11; 2.58)	**<0.001**	1.42 (0.70; 2.13)	**0.001**
25-m (s)	4.37 ± 0.27	4.21 ± 0.27	3.85 ± 0.23	0.56 (-0.05; 1.17)		2.01 (1.27; 2.74)	**<0.001**	1.40 (0.69; 2.11)	**0.001**
180ºCODL (s)	2.99 ± 0.17	2.89 ± 0.19	2.68 ± 2.73	0.59 (-0.01; 1.19)		1.84 (1.09; 2.59)	**<0.001**	1.12 (0.41; 1.84)	**0.007**
180ºCODR (s)	2.97 ± 0.15	2.89 ± 0.16	2.73 ± 0.19	0.48 (-0.13; 1.08)		1.31 (0.53; 2.09)	**0.001**	0.86 (0.10; 1.62)	**0.034**
COD Asy (%)	3.78 ± 3.32	2.93 ± 2.37	2.83 ± 2.60	0.29 (-0.33; 0.90)		0.31 (-0.41; 1.03)		0.04 (-0.71; 0.79)	
%CODDL	46.5 ± 4.31	43.1 ± 5.70	44.7 ± 5.94	0.65 (0.05; 1.25)		0.33 (-0.47; 1.12)		-0.26 (-1.00; 0.48)	
%CODDR	45.5 ± 7.53	43.6 ± 4.95	47.7 ± 9.10	0.30 (-0.32; 0.92)		-0.25(-1.03; 0.53)		-0.53 (-1.35; 0.29)	
CODDAsy (%)	11.1 ± 8.97	9.09 ± 7.06	8.39 ± 6.95	0.24 (-0.37; 0.86)		0.33 (-0.40; 1.05)		0.10 (-0.64; 0.83)	
V-cut (s)	7.80 ± 0.32	7.58 ± 0.48	7.03 ± 0.32	0.53 (-0.07; 1.13)		2.32 (1.56; 3.07)	**<0.001**	1.32 (0.64; 2.00)	**0.001**
%CODD V-cut	79.0 ± 5.77	80.1 ± 5.11	82.8 ± 6.98	-0.20 (-0.81; 0.41)		0.58 (-0.20; 1.35)		-0.43 (-1.21; 0.36)	

APHV: age at peak height velocity; 180ºCODL: 5 + 5 m sprint with one change of direction to the left side; 180ºCODR: 5 + 5 m sprint with one change of direction to the right side; COD Asy: inter-limb asymmetry of 180º change of direction test time; CODDL: change of direction deficit of 180º change of direction to the left; CODDR: change of direction deficit of 180º change of direction to the right; CODDAsy: inter-limb asymmetry of 180º change of direction test deficit; V-cut: 25-m sprint test with 4 x 45º changes of direction; CODD V-cut: change of direction deficit based on the V-cut test; ES: effect size; CI: confidence interval.

Table 2. Between-biological age differences in anthropometric and physical performance (n=54).

	Pre-PHV (n=15)	Mid-PHV (n=19)	Post-PHV (n=20)	Pre- vs. Mid-		Pre- vs. Post-		Mid- vs. Post-	
				ES (CI95%)	p value	ES (CI95%)	p value	ES (CI95%)	p value
Age (years)	12.1 ± 0.50	13.5 ± 0.66	15.5 ± 1.13	2.31 (1.63; 2.99)	**<0.001**	3.77 (3.12; 4.42)	**<0.001**	2.11 (1.48; 2.75)	**<0.001**
Height (cm)	154.9 ± 6.51	174.5 ± 7.69	190.3 ± 11.7	2.67 (1.98; 3.35)	**<0.001**	3.64 (2.99; 4.29)	**<0.001**	1.55 (0.92; 2.19)	**<0.001**
Body mass (kg)	43.3 ± 8.03	58.0 ± 8.03	75.9 ± 14.1	1.71 (1.00; 2.41)	**<0.001**	2.78 (2.12; 3.43)	**<0.001**	1.52 (0.89; 2.16)	**<0.001**
APHV (years)	-1.53 ± 0.51	0.21 ± 0.52	2.62 ± 1.3	3.29 (2.60; 3.98)	**<0.001**	4.08 (3.43; 4.73)	**<0.001**	2.36 (1.73; 3.00)	**<0.001**
5-m (s)	1.16 ± 0.06	1.20 ± 0.09	1.12 ± 0.10	-0.51 (-1.18; 0.17)		0.55 (-0.11; 1.21)		0.90 (0.26; 1.53)	**0.01**
10-m (s)	2.02 ± 0.09	2.07 ± 0.15	1.90 ± 0.12	-0.40 (-1.07; 0.27)		1.14 (0.48; 1.81)	**0.02**	1.29 (0.65; 1.93)	**<0.001**
20-m (s)	3.55 ± 0.13	3.62 ± 0.27	3.30 ± 0.20	-0.31 (-0.97; 0.36)		1.46 (0.80; 2.12)	**0.03**	1.37 (0.73; 2.01)	**<0.001**
25-m (s)	4.31 ± 0.17	4.36 ± 0.33	3.95 ± 0.24	-0.17 (-0.84; 0.49)		1.67 (1.01; 2.33)	**<0.001**	1.42 (0.78; 2.05)	**<0.001**
180ºCODL (s)	2.96 ± 0.11	2.99 ± 0.21	2.72 ± 0.15	-0.19 (-0.86; 0.47)		1.68 (1.02; 2.34)	**<0.001**	1.45 (0.81; 2.09)	**<0.001**
180ºCODR (s)	2.96 ± 0.13	2.96 ± 0.19	2.77 ± 0.16	-0.08 (-0.75; 0.60)		1.31 (0.64; 1.97)	**0.003**	1.05 (0.41; 1.69)	**0.002**
COD Asy (%)	3.74 ± 3.47	3.30 ± 2.77	2.77 ± 2.25	-0.15 (-0.86; 0.56)		0.32 (-0.38; 1.02)		0.17 (-0.48; 0.81)	
%CODDL	46.1 ± 4.47	44.7 ± 5.36	43.4 ± 5.88	0.34 (-0.34; 1.02)		0.57 (-0.10; 1.24)		0.24 (-0.40; 0.87)	
%CODDR	46.9 ± 7.41	42.9 ± 5.75	45.9 ± 7.46	0.59 (-0.12; 1.29)		0.14 (-0.54; 0.82)		-0.44 (-1.07; 0.20)	
CODDAsy (%)	10.7 ± 8.93	10.2 ± 8.37	8.49 ± 6.28	0.12 (-0.59; 0.82)		0.30 (-0.40; 0.99)		0.16 (-0.49; 0.81)	
V-cut (s)	7.78 ± 0.27	7.78 ± 0.48	7.17 ± 0.35	-0.02 (-0.69; 0.65)		1.90 (1.23; 2.56)	**<0.001**	1.45 (0.81; 2.09)	**<0.001**
%CODD V-cut	80.6 ± 4.46	78.6 ± 5.94	81.5 ± 6.48	0.37 (-0.30; 1.05)		-0.15 (-0.81; 0.51)		-0.45 (-1.09; 0.19)	

APHV: age at peak height velocity; 180ºCODL: 5 + 5 m sprint with one change of direction to the left side; 180ºCODR: 5 + 5 m sprint with one change of direction to the right side; COD Asy: inter-limb asymmetry of 180º change of direction test time; CODDL: change of direction deficit of 180º change of direction to the left; CODDR: change of direction deficit of 180º change of direction to the right; CODDAsy: inter-limb asymmetry of 180º change of direction test deficit; V-cut: 25-m sprint test with 4 x 45º changes of direction; CODD V-cut: change of direction deficit based on the V-cut test; ES: effect size; CI: confidence interval.

Table 3. Relationships (95% confidence intervals) between linear sprinting (5-m, 10-m, 20-m, and 25-m), change of direction (COD) times, and the percentage change of direction deficit (%CODD) in single and multiple changes of direction tests in the pool data (n=54).

	10-m	20-m	25-m	180ºCODL	180ºCODR	COD Asy	%CODDL	%CODDR	CODDAsy	V-cut	%CODD V-cut
5-m	**0.92 (0.86; 0.95)**	**0.86 (0.76; 0.91)**	**0.83 (0.72; 0.89)**	**0.77 (0.63; 0.86)**	**0.66 (0.48; 0.79)**	-0.02 (-0.29; 0.25)	-0.23 (-0.46; 0.04)	**-0.47 (-0.65; -0.23)**	0.04 (-0.23; 0.30)	**0.73 (0.57; 0.83)**	**-0.42 (-0.61; -0.17)**
10-m	---	**0.97 (0.95; 0.98)**	**0.96 (0.93; 0.97)**	**0.86 (0.77; 0.92)**	**0.76 (0.62; 0.85)**	-0.00 (-0.27; 0.26)	-0.22 (-0.46; 0.04)	**-0.45 (-0.64; -0.21)**	0.05 (-0.22; 0.32)	**0.88 (0.79; 0.93)**	**-0.47 (-0.65; -0.24)**
20-m	---	---	**0.99 (0.99; 0.99)**	**0.88 (0.80; 0.93)**	**0.79 (0.66; 0.87)**	0.05 (-0.21; 0.32)	-0.15 (-0.39; 0.12)	**-0.36 (-0.56; -0.10)**	0.11 (-0.16; 0.37)	**0.89 (0.83; 0.94)**	**-0.54 (-0.70; -0.32)**
25-m	---	---	---	**0.89 (0.81; 0.93)**	**0.79 (0.66; 0.87)**	0.07 (-0.20; 0.33)	-0.12 (-0.37; 0.15)	**-0.33 (-0.54; -0.07)**	0.12 (-0.15; 0.37)	**0.90 (0.83; 0.94)**	**-0.56 (-0.71; -0.34)**
180ºCODL	---	---	---	---	**0.78 (0.65; 0.87)**	0.12 (-0.15; 0.38)	**0.32 (0.06; 0.54)**	-0.21 (-0.45; 0.05)	0.15 (-0.12; 0.40)	**0.87 (0.79; 0.92)**	**-0.27 (-0.49; -0.00)**
180ºCODR	---	---	---	---	---	0.26 (-0.04; 0.49)	0.08 (-0.18; 0.34)	0.23 (-0.03; 0.47)	0.26 (-0.01; 0.49)	**0.87 (0.79; 0.92)**	-0.14 (-0.39; 0.13)
COD Asy	---	---	---	---	---	---	**0.27 (0.00; 0.49)**	**0.37 (0.12; 0.58)**	**0.99 (0.98; 0.99)**	0.09 (-0.17; 0.35)	0.09 (-0.17; 0.35)
%CODDL	---	---	---	---	---	---	---	**0.44 (0.21; 0.63)**	0.21 (-0.05; 0.45)	0.06 (-0.21; 0.32)	**0.36 (0.11; 0.57)**
%CODDR	---	---	---	---	---	---	---	---	**0.27 (0.00; 0.49)**	-0.11 (-0.36; 0.16)	**0.50 (0.27; 0.68)**
CODDAsy	---	---	---	---	---	---	---	---	---	0.12 (-0.15; 0.37)	0.03 (-0.24; 0.29)
V-cut	---	---	---	---	---	---	---	---	---	---	-0.10 (-0.36; 0.16)

180ºCODL: 5 + 5 m sprint with one change of direction to the left side; 180ºCODR: 5 + 5 m sprint with one change of direction to the right side; COD Asy: inter-limb asymmetry of 180º change of direction test time; %CODDL: percentage change of direction deficit of 180º change of direction to the left; %CODDR: percentage change of direction deficit of 180º change of direction to the right; CODDAsy: inter-limb asymmetry of 180º change of direction test deficit; V-cut: 25-m sprint test with 4 x 45º changes of direction; %CODD V-cut: percentage change of direction deficit based on the V-cut test. Bold correlations denote $p<0.05$.

Table 4. Relationships (95% confidence intervals) between change of direction (COD) times and the percentage change of direction deficit (CODD) in single and multiple changes of direction tests across biological age groups categories (pre-, mid-, and post-peak height velocity).

		CODDR	**CODD V-cut**	**180ºCODL**	**180ºCODR**	**CODasy**	**CODDasy**	**V-cut**
	CODDL	0.11 (-0.43; 0.58)	0.47 (-0.06; 0.79)	0.25 (-0.30; 0.67)	-0.36 (-0.74; 0.18)	**0.42 (-0.12; 0.77)**	0.44 (-0.08; 0.78)	-0.27 (-0.68; 0.28)
Pre-PHV	**CODDR**	---	0.34 (-0.21; 0.72)	**-0.52 (-0.81; -0.01)**	**0.57 (0.09; 0.84)**	**0.67 (0.24; 0.88)**	**0.60 (0.13; 0.85)**	-0.25 (-0.67; 0.29)
	CODD V-cut	---	---	0.03 (-0.49; 0.53)	0.08 (-0.44; 0.57)	0.47 (-0.06; 0.79)	0.49 (-0.02; 0.80)	0.20 (-0.34; 0.65)
	CODDL	0.37 (-0.10; 0.80)	0.21 (-0.27; 0.61)	0.32 (-0.16; 0.67)	0.00 (-0.45; 0.45)	0.16 (-0.31; 0.58)	0.13 (-0.34; 0.55)	-0.02 (-0.47; 0.44)
Mid-PHV	**CODDR**	---	**0.73 (0.41; 0.88)**	-0.22 (-0.61; 0.26)	0.17 (-0.31; 0.58)	-0.12 (-0.46; 0.44)	-0.05 (-0.49; 0.41)	0.00 (-0.45; 0.45)
	CODD V-cut	---	---	-0.39 (-0.72; 0.07)	-0.10 (-0.53; 0.37)	-0.20 (-0.60; 0.28)	-0.25 (-0.63; 0.23)	-0.14 (-0.55; 0.33)
	CODDL	**0.75 (0.46; 0.89)**	0.34 (-0.12; 0.68)	0.26 (-0.21; 0.63)	0.19 (-0.28; 0.58)	0.15 (-0.31; 0.56)	0.02 (-0.42; 0.46)	-0.09 (-0.51; 0.36)
Post-PHV	**CODDR**	---	**0.52 (0.10; 0.78)**	0.03 (-0.42; 0.46)	0.37 (-0.08; 0.69)	**0.50 (0.07; 0.77)**	0.37 (-0.08; 0.69)	-0.08 (-0.51; 0.37)
	CODD V-cut	---	---	-0.27 (-0.64; 0.19)	-0.05 (-0.48; 0.39)	0.07 (-0.44; 0.45)	-0.11 (-0.53; 0.34)	0.00 (-0.44; 0.44)

PHV: peak height velocity; 180ºCODL: 5 + 5 m sprint with one change of direction to the left side; 180ºCODR: 5 + 5 m sprint with one change of direction to the right side; COD Asy: inter-limb asymmetry of 180º change of direction test time; %CODDL: percentage change of direction deficit of 180º change of direction to the left; %CODDR: percentage change of direction deficit of 180º change of direction to the right; CODDAsy: inter-limb asymmetry of 180º change of direction test deficit; V-cut: 25-m sprint test with 4 x 45º changes of direction; %CODD V-cut: percentage change of direction deficit based on the V-cut test.