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ABSTRACT

Change of direction deficit (CODD) offers valuable insights into a player's balance between linear and multidirectional speed. However, there are still no established reference values for CODD. The objectives of this study were to determine CODD thresholds for various change of direction angles in basketball players according to gender and analyse the relationships between CODD and execution time in speed tests. One hundred and thirty basketball players (46% female; age: 23.7±5.29 years; height: 189.1±11.1 cm; body mass: 84.3±15.7 kg) undertook 10-metres linear and change of direction speed test at 45º, 90º and 180º. A k-means cluster analysis was conducted to standardise CODD thresholds and a one-way analysis of variance to identify the differences between clusters. The results revealed angulation-specific CODD thresholds, ranging from 3% to 8%, 17% to 25%, and 43% to 51% for 45º, 90º, and 180º cutting angles, respectively for the pooled sample. Furthermore, differences inter-clusters ($p < 0.05$) were observed for execution time at all cutting angles for both genders. Therefore, strength and conditioning coaches are encouraged to assess CODD as a highly valid variable for evaluating change of direction performance and to use current CODD thresholds to tailor training programs according to each athlete's needs.

KEYWORDS: Multidirectional speed, agility, sprint, assessment, team sport, performance.

1. Introduction

In team sports, high-intensity actions such as jumps, sprints and changes of direction (COD) are influential in the final outcome of a game (Delextrat et al., 2017). Among all these actions, the COD is the most frequently performed during a basketball game regardless of the playing position or gender (Salazar et al., 2020). COD are defined as the ability to decelerate and accelerate in a different direction in a planned manner (Nimphius et al., 2016). Previous research indicates that basketball players perform a COD every 1-3 seconds (Klusemann et al., 2013; Scanlan et al., 2011), and that 15.1% of these actions are performed at maximum intensity (>3.5 $m \cdot s^{-2}$) (Svilar et al., 2018). In addition, basketball players must be able to perform a COD at a wide range of angles (between 0º and 180°) during a game regardless of their playing position (Gonzalo-Skok et al., 2023; Power et al., 2022). In this regard, the cutting angle is one of the most decisive variables in the performance of these actions in order to evade an opponent (Dos'Santos et al., 2018). Therefore, it is strongly recommended to evaluate the athletes through several tests with a single COD at various angles to create a "COD angle profile" of each player (Gonzalo-Skok et al., 2023). Given the high prevalence of COD during team sports competition (Salazar et al., 2020; Young et al., 2022), COD actions should be considered as a key performance indicator for basketball players. Thus, proper assessment and data interpretation of this skill is particularly relevant for strength and conditioning coaches.

COD assessment in team sports has been extensively studied in previous research (Mancha-Triguero et al., 2019; Nimphius et al., 2018; Stojanović et al., 2019) and there are a variety of 48 different tests to analyse the COD performance of basketball players (Sugiyama et al., 2021). Even so, the "Gold-Standard" COD test does not exist and is unlikely to exist due to the unpredictable nature and wide variety of on-court movements performed in basketball across a wide spectrum of angles and approach distances to the cut (Gonzalo-Skok et al., 2023). Given the wide variety of available tests to assess COD and the lack of consensus on the "perfect" COD assessment, many investigations used different COD tests. This may make the results not comparable between studies, as test performance will depend directly on the characteristics of the test such as distance covered, the number of cuts and their angulation (Dos'Santos et al., 2018). This adds a degree of complexity in attempting to advance scientific knowledge about this skill and it was recommended to standardise COD tests (Gonzalo-Skok et al., 2023).

Frequently in the scientific literature COD assessments have involved determining the time to complete multiple COD at different angles that simulate sport-specific distances and displacements (Nimphius et al., 2018). However, given the wide range of physical qualities involved in these tests (e.g., linear sprinting ability, anaerobic capacity, and movement specificity for the test), the result of the COD test could be masked by another ability (Nimphius et al., 2016). In particular, 74.8% of the variance in these COD tests is explained by linear sprint speed (Delextrat et al., 2017). This may be because the vast majority of tests currently used to measure COD performance are tests in which more than 70% of the time is spent on linear speed actions and do not isolate the COD action itself (Nimphius et al., 2013, 2016). To avoid this limitation, previous studies have developed the concept of change of direction deficit (CODD). The CODD seeks to most effectively isolate the COD action from the player's linear sprinting ability (Nimphius et al., 2013). Originally, this variable was calculated as the difference between the time in COD and linear speed test (Nimphius et al., 2013), but more recently a percentage change has been advocated to standardise the measurement between the two speed tests (Freitas, Pereira, et al., 2021). In both ways, CODD expresses the amount of time a subject has spent on the COD during the test and indicates the athlete's efficiency in these actions (Freitas, Pereira, et al., 2021; Nimphius et al., 2013, 2016). A lower CODD indicates a great efficiency in changing direction compared to its linear speed, and vice versa, a higher CODD indicates greater reliance on acceleration and linear speed ability but an inefficient COD technique or possess deficiencies in specific muscle strength qualities that results in a worse COD performance (Freitas et al., 2019; Loturco et al., 2022; Pereira et al., 2018). Additionally, previous studies (Freitas, Alcaraz, et al., 2021) have indicated that male athletes showed higher CODD compared to female athletes, suggesting the need to identify different CODD thresholds according to gender.

On the other hand, strength and conditioning coaches should select tests in their assessments that allow them to monitor the evolution of a player, rank the athlete in comparison to others and prescribe an individualised training programme in order to improve performance in the assessed skill (Weakley et al., 2023). In this sense, using time as an outcome variable to measure COD performance may hide other physical qualities required within the test and falls short of providing information for individualising training programmes (Nimphius et al., 2016). In contrast, the use of CODD makes it possible to determine the player's efficiency in COD and to analyse their weaknesses in these actions to improve them. Previous studies showed that faster in linear speed and more powerful athletes tend to exhibit higher CODD (Freitas, Alcaraz, et al., 2021; Loturco et al., 2022; Pereira et al., 2018), this may be linked to the difficulties of handling higher velocities prior to COD (i.e., higher sprint momentum and subsequent braking forces) (Freitas, Alcaraz, et al., 2021; Freitas et al., 2019). Therefore, it was recommended that high CODD athletes should train on COD technique and the ability to handle higher braking forces and, conversely, low CODD athletes should train on acceleration and high speed, whilst still maintain technique and required muscle strength qualities (Freitas, Alcaraz, et al., 2021; Harper et al., 2022; McBurnie et al., 2021). Thus, the current research suggests that athletes may be classified based on CODD as 'Multidirectional Speed Dominant' (MSD; Low CODD), 'Linear Speed Dominant' (LSD; High CODD) or fall in between ('balanced'; Moderate CODD – a trade-off between multidirectional and linear speed dominant). However, to the authors' knowledge there are no previous studies that provide cut-off points for classification of CODD, and this may be useful to individualise COD training.

For the above reasons, the present work aimed to determine the CODD thresholds for different COD angulations in basketball players according to gender. In this regard, it was hypothesised that CODD would increase as the cutting angle increases, so the balanced CODD thresholds should be specific to each COD angulation. Additionally, as a secondary purpose, the relationships between CODD and execution time in speed tests according to gender were analysed.

2. Materials and methods

2.1. Participants

A total of 130 trained basketball players (46% female; age: 23.7±5.29years; height: 189.1±11.1cm; body mass: 84.3±15.7kg) volunteered to participate in this study were included. The sample size was calculated for our primary aim using G*Power software (version 3.1.9.6, Kiel, Germany). To the best of our knowledge, there were no available information on CODD thresholds in basketball players. Therefore, the number of participants to be included in the study was calculated based on the statistical method used to identify the differences between groups (a one factor ANOVA). This calculation was based on a moderate effect size (f) of 0.3, an alpha level of 0.05, and power value of 0.85 (Faul et al., 2007).

All players had their regular basketball training at least three days a week for two hours and played one federated game per week during the season. They played in the Spanish N1 League and had at least 10 years of experience playing basketball. None of the athletes included in the study had suffered an injury in the 6 months prior to the study. All of them were previously informed of the possible risks and benefits of participating in the study and gave their written consent before the start of the test evaluation. This research was approved by the Andalusian Biomedical Research Ethics Committee (reference number: FBD_UHU2020) in accordance with the rules established in the Declaration of Helsinki.

2.2. Study design and procedures

A cross-sectional experimental design was used to calculate the CODD for each athlete and determine CODD thresholds for each COD angulation. Data collection was carried out during the last month of the competitive season. All participants completed the assessment in a single testing session after a familiarisation session with the proposed tests in the previous week. Prior to the speed and COD testing, all players conducted a 15-minute warm-up, including low-intensity movements (high-knees, butt kicks, cario-cas) (5 minutes); dynamic stretches (lunges, diver, lateral squat) (5 minutes); and moder-ate to high-intensity activities such as jumps, accelerations, decelerations, linear sprints and changes of direction (5 minutes). Testing was performed in the following order: 10-m linear sprinting, 45º COD, 90º COD and 180º COD. Players executed two warm-up trials (in each direction during COD tests) at 70% and 90% maximum effort before their maximum effort trials. The testing session took place during regular training schedule, just before the regular basketball training between match day plus 2 and 4. All tests were conducted on the frequent training and competition basketball courts, and the players wore sport clothes and their usual basketball shoes. Moreover, each player was instructed to attend the testing sessions with adequate hydration and rest, and to control their caffeine and food intake at least 3 hours before each evaluation.

Linear speed: 10 metres test

Execution time was recorded with single-beam electronic timing gates (ETG, Chronojump BoscoSystem®, Barcelona, Spain). ETG were placed two metres from each other with a height of one metre (approximately the height of the players' hips). Each player was positioned 0.5 metres behind the first timing gate whilst adopting a 2-point split stance. Then, each player accelerated at maximum linear speed to the second gate 10 metres away (Figure 1). This test was performed three times with a 2-minute rest between trials, and the average of the three attempts was selected for analysis.

Change of direction speed: 505 modified tests at 45º, 90º and 180º

Execution time was recorded with single-beam ETG (Chronojump BoscoSystem®, Barcelona, Spain). ETG were placed two metres from each other with a height of one metre (approximately the height of the players' hips). Each player was positioned 0.5 metres behind the first timing gate whilst adopting a 2-point split stance. Then, each player accelerated at maximum speed five metres ahead and performed a 45° or 90° side-step cut, or 180° turn before accelerating a further five metres to the finish line (Figure 1). The COD performance at 45°, 90° and 180° left and right direction was defined by the leg on which the subjects set on the court when performing the COD. This test was performed three times with a 2-minute rest between attempts, and the average of the three attempts was used for statistical analysis. The CODD for each angulation was calculated as follows (Freitas, Pereira, et al., 2021):

$$CODD\% = \frac{COD\ time - 10\ metres\ tets\ time}{10\ metres\ test\ time}\ x\ 100$$

– Please, insert here Figure 1 –

2.3. Statistical Analyses

Means ± standard deviations (SD) were used to describe variables. The assumption of normality of the data was verified using the Shapiro-Wilk test. Homoscedasticity was determined with the Levene test. A two-way random, absolute agreement intraclass correlation coefficient (ICC) determined the relative test-retest reliability of measures. Relative reliability was deemed as excellent when ICC >0.9 (Koo & Li, 2016). Absolute reliability of test measures was computed using the coefficient of variation (CV) and the typical error of measurement (TEM). CV was calculated as: (SD/average)*100; and values ≤5% were deemed acceptable as a criterion for intraday reliability (Atkinson & Nevill, 1998). TEM was calculated as: SD*√(1-ICC); and was deemed acceptable if the TEM value was less than 10% the mean cumulative test-retest scores (Fox et al., 2014). Student's *t*-test for independent samples was used to assess the influence of gender on tests. Cohen's d was computed, with thresholds for qualitative descriptors set at < 0.20 "trivial", 0.20 – 0.50 "small", 0.50 – 0.80 "moderate", and > 0.80 ‘‘large’’ (Cohen, 1988). A Pearson product-moment test with 95% confidence intervals (CI) was performed to determine the correlations (r) between the performance in the different linear speed and COD tests with CODD. The magnitude of Pearson's correlation was interpreted as trivial (<0.1), small (0.1–0.3), moderate (0.3–0.5), large (0.5–0.7), very large (0.7–0.9), and almost perfect (0.9–1.0) (Hopkins et al., 2009). Coefficient of determination (R^2 x 100) was also calculated and interpreted as trivial (< 0.04), small (0.04 – 0.25), moderate (0.25 – 0.64), and strong effect (> 0.64) (Hopkins et al., 2009). Then, a k-means cluster analysis was used to establish cut-off CODD scores based on COD execution time and rank athletes according to their CODD for each cutting angle. A non-hierarchical k-means cluster analysis was used for each angulation (Hartigan & Wong, 1979), obtaining the final cluster solution and including a total of 3 clusters for each angulation. Finally, a one factor ANOVA was used to identify the differences between clusters, and the effect size (ES) were determined using the partial eta-square. ES was considered trivial (<0.01), small (0.01–0.06), moderate (0.06–0.14), large (>0.14) (Lenhard & Lenhard, 2016). Additionally, the Bonferroni post-hoc for multiple comparisons was performed to identify cluster significant changes. Statistical significance was set at $p < 0.05$. All statistical analysis was performed using IBM SPSS Statistics for Macintosh, Version 25.0 (Armonk, NY: IBM Corp.).

3. Results

Table 1 presents the mean performance of the linear speed and COD tests analysed differentiating between genders, alongside the ICC, CV, and TEM for each variable. Male players showed a better performance for all speed variables analysed (ES ≥1.03; p <0.01), except for CODD90º and CODD180º.

– Please, insert here Table 1 –

Table 2 depicts the relationships between CODD at several angulations with linear speed and COD execution time, indicating the correlation coefficients between these variables for the pooled sample and differentiating between genders. The correlations between the CODD and execution time in the COD tests were demonstrated to be angle-specific, with the most significant correlations observed when comparing CODD and execution time in the COD at the same angles. Significant large correlations and moderate coefficient of determination were observed at 45º (r =0.48 [CI 95% =0.34–0.61]; R^2 =23.3%), 90º (r =0.55 [CI 95% =0.42–0.66]; R^2 =29.8%), and 180º (r =0.52 [CI 95%

=0.39–0.64]; R^2 =27.4%) for the pooled sample. Furthermore, the relationships between CODD and execution time were significantly higher and steadier in the female gender.

– Please, insert here Table 2 –

The results of the k-means cluster analysis were shown in Table 3, setting the CODD thresholds for each cut-off angle in the pooled sample and differentiating between genders to classify the athletes into MSD, Balanced or LSD. This analysis showed that CODD thresholds are different and specific for each COD angle, the cut-off points were higher for sharper angles. Moreover, the cut-off points showed to be different between genders mainly at CODD45°.

– Please, insert here Table 3 –

Table 4 shows comparative analysis between clusters on linear speed and angulation-specific COD performance differentiating between genders. The analysis showed moderate to large significant inter-groups differences (ES ≥0.08; p <0.05) for all COD angulations regardless of gender. However, linear speed performance showed no significant inter-group differences at CODD90º cluster for males and CODD180º cluster for females. A post-hoc Bonferroni analysis revealed differences in both genders between LSD group and the other clusters (p <0.05) in the execution time of COD, being the players of this group the ones who obtained the highest execution time in COD tests regardless of the cutting angle. In contrast, it was the MSD group that showed differences with the other clusters (p <0.05) in the execution time of linear speed, being this group the ones that showed the lowest performance in linear speed test. The balanced group showed the best trade-off between linear speed and COD performance.

– Please, insert here Table 4 –

4. Discussion

This is the first study that aims to determine the CODD thresholds for different COD angulations in basketball players according to gender. Additionally, the relationship between the execution time to perform the linear sprint and COD tests, and the CODD for each angulation were analysed for the pooled sample and differentiating between genders. The K-mean cluster analysis undertaken revealed the CODD thresholds. Furthermore, it was observed that these thresholds are angulation specific. These findings hold the potential to empower strength and conditioning coaches to effectively identify their athletes' strengths and weaknesses in COD actions based on the specific cutting angle. Subsequently, coaches can design individualized training programmes tailored to each athlete's CODD. Another noteworthy finding in this research is the great relationship between CODD variables and COD execution time for each cutting angle. This corroborates the conclusions of prior studies (Freitas, Pereira, et al., 2021; Gonzalo-Skok & Bishop, 2023; Nimphius et al., 2013, 2016), and supports the validity of CODD as a performance measure for COD actions. This variable precisely reflects the physical quality to be measured, the COD, while mitigating the influence of other physical qualities that might otherwise impact test results.

Although a strong relationship between the performance of linear speed and COD actions has traditionally been observed in basketball players (Michael et al., 2021), this relationship disappeared when CODD is used as a measure of COD performance (Nimphius et al., 2013, 2016). This may be explained by the fact that CODD exactly measures the time an athlete dedicates to the COD action itself during the test, thereby reducing the impact of other physical capabilities on the test outcome. In line with these previous studies, our study results corroborate the absence of a significant relationship between linear sprint performance and COD actions in basketball players, so that both physical skills should be considered entirely distinct (Young et al., 2015). It is relevant to take into account that the number and angle of cuts, and the distance covered in both speed tests included in the CODD equation could condition the final result (Gonzalo-Skok & Bishop, 2023). On the other hand, it is worth noting that our study identifies a moderate to high positive relationship between CODD and execution time in the COD tests, a finding consistent with prior research (Lazić et al., 2022; Nimphius et al., 2013, 2016). These results underscore the validity of employing CODD as a COD performance metric independent of linear velocity. In practice, if an athlete enhances their linear velocity without concurrent improvement in COD performance, the time taken in a COD test might decrease (indicating better COD ability), yet the CODD would not show improvement, or it could even increase. Therefore, CODD emerges as more sensitive to detect changes in COD performance and is recommended as a minimum requirement for evaluating COD ability.

A priority for coaches when evaluating their athletes is to accurately identify their athletes' strengths and weaknesses (Weakley et al., 2023). In this regard, the use of CODD offers more than a specific measure of COD actions; it provides additional advantages. CODD serves as a variable that aids in identifying the optimal and individual balance between linear speed and COD performance for athletes seeking to enhance their linear and multidirectional speed (Nimphius et al., 2013, 2016). However, since the concept of CODD is relatively new and performance in COD actions are complex and depends on the cutting angle (Dos'Santos et al., 2018), reference values for CODD in various angulations have not been established so far. The present study has disclosed that players exhibiting CODD within the approximate ranges of 3-8%, 17-25%, and 43-51% for angulations of 45º, 90º, and 180º, respectively, manifest a balanced CODD (Table 3). This balance provides the best trade-off between linear speed and COD performance. Conversely, players falling below this range in any of the mentioned angulations would be categorized as MSD players (i.e., they have a high COD ability, but have a low linear performance). On the other hand, athletes exceeding this CODD range for each angulation would be classified as LSD players (i.e., they have a high linear speed performance, but are inefficient in COD actions). Although previous studies have shown differences between genders for CODD (Freitas, Alcaraz, et al., 2021), no significant differences were found between genders for CODD in the current research, except for the CODD45°. Therefore, CODD thresholds might be slightly different according to gender as shown in Table 3.

Notably, the classification based on CODD presented significant differences inter-groups in COD performance across different angulations in both genders (Table 4). Regardless of cutting angle and gender, athletes with a high CODD (i.e., LSD players) achieved a better performance in linear speed and showed a lower performance in COD. Additionally, females showed lower CODD at the different cutting angles as they were considerably less in the LSD group (n =27) than in MSD (n =53) and Balanced (n =101) (which is not the case for the males with 61, 60 and 89 for LSD, MSD, and Balanced, respectively). While no prior evidence exists for comparing CODD cut-off points, our finding was aligned with previous studies (Freitas, Alcaraz, et al., 2021) in which rugby sevens male athletes, who were faster and more powerful in linear speed compared to females, exhibited reduced efficiency in COD actions and the highest CODD, irrespective of the cutting angle. This was attributed to male athletes having to manage higher cutting approach speeds, sprint momentum, and braking forces (Freitas, Alcaraz, et al., 2021). The present research, alongside the CODD thresholds, provided novel results with respect to previous studies since it analysed the behaviour of linear speed and COD according to each CODD threshold proposed for both genders. In this regard, the results revealed that the MSD athletes were the fastest in COD, but their performance was the lowest in linear speed. Furthermore, it was the balanced group who showed the best trade-off between linear speed and COD performance across all cutting angles in both genders. Hence, since both linear and multidirectional speed is an essential physical ability in basketball, strength and conditioning coaches would be advised to take these CODD thresholds into account to improve the speed profile and performance in their players whether male or female.

Despite the interesting and novel findings found in the present study, some limitations should be considered when interpreting the results. Firstly, our sample exclusively comprised non-professional basketball players, which implies that the standardised values in this study can serve as a reference but should be applied cautiously when extrapolated to different competitive levels or sports. Secondly, the use of k-means cluster analysis to compute CODD thresholds represents a novel approach, and as far as our knowledge extends, this study marks the initial endeavour to standardize CODD values for the purpose of athlete classification. Moreover, other covariates could not be analysed in the cluster analysis due to the sample size. Therefore, it is recommended that similar studies be conducted in the future with larger samples, to analyse the influence of anthropometric variables or playing position and to pool more information around this very interesting COD measurement tool and thus be able to get the most out of it. Lastly, the cross-sectional design provided a single time-point measurement for capturing player performance, so it was not possible to analyse the fluctuations of this variable over time. In this context, it would be advisable to conduct intervention studies to see how this variable may change after individualised training programmes.

5. Conclusions

Briefly, strength and conditioning coaches should understand that basketball is becoming more and more physically demanding, a greater number of linear and multidirectional actions occur at maximum intensity and these actions may determine the final outcome of the game (Salazar et al., 2020). Thus, coaches must place a strong emphasis on achieving balanced development of linear speed and COD capabilities. For this purpose, it is recommended to use the CODD as standardised measurement tool, offering insights into a player's efficiency in COD and shedding light on the trade-off between linear speed and COD for each individual athlete. Interestingly, the current research analysed and established normative data for CODD, providing sport scientists and coaches with invaluable information to craft more effective training programmes tailored to the specific needs and attributes of each athlete. Therefore, the measurement of CODD as the most valid variable for assessing COD performance and endorse the use of the cut-off thresholds unveiled in this study is strongly recommended. CODD provides extensive information on the relationship between linear speed and COD for each athlete, identifying individual strengths and weaknesses in this skill. Furthermore, the CODD thresholds found allow to classify basketball players, to share and compare standardised data with other samples, to improve the management and performance monitoring of each player and, most importantly, to propose training programmes targeting the individual weaknesses and needs of the athlete.

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Declaration of interest statement

The authors declare no conflict of interest.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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