Assessing limb dominance and inter-limb asymmetries over multiple angles during change of direction speed tests in basketball players

Oliver Gonzalo-Skok, Tom Dos'Santos, and Chris Bishop

ABSTRACT

The aims of this study were to establish whether directional dominance is displayed during change of direction (COD) tasks across various angles, to determine the angle-variation data for the asymmetry magnitude and direction, and to analyse the relationships in COD performance (completion time and COD deficit) across tasks. Twenty-four young (U-16 to U-20), highly trained male basketball players performed a 10-m linear sprint test and four 10-m COD tests (45º, 90º, 135º and 180º) in left and right directions. COD performance was determined via total times and COD deficit and asymmetry comparisons were made between faster and slower directions and dominant [DL] (i.e., first step leg in lay-up) and non-dominant (NDL) legs. No significant differences ($p>0.05$) were found between DL and NDL for any task excluding 45° COD ($p<0.05$, Effect size [ES]= 0.44-0.78), but significant differences were established between faster and slower sides for all angles ($p<0.05$, ES=0.70-1.28). Levels of the agreement in directional dominance during COD tasks were generally poor to slight (k=-0.14 to 0.14), excluding a fair agreement between COD45 and COD90 (k= 0.34). Correlations between COD total times and COD deficits between angles were moderate to very large (r=0.32 to 0.81) and moderate to large (r=-0.30 to 0.55) respectively. Players displayed superior COD performance in a particular direction across various angles. This directional dominance is not necessarily consistent between angles, thus, highlighting the angle-dependent nature of COD performance. Consequently, practitioners should investigate multiple angles and directions to create a COD angle profile for their athletes.

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

INTRODUCTION

Team sports players must frequently perform change of direction (COD) movements such as running in a zig-zag pattern, side-stepping, crossover cutting, or running back and forth repeatedly (31,40). With this in mind, previous research has shown that basketball players change their movement pattern every 1-2 seconds (23,37), 60% of high-intensity actions are related to changing direction in competitive handball (32), and professional soccer players have been reported to execute up to 726 turns during match play (7). Furthermore, during competitive matches in all team sports, a wide variety of COD angles are performed under varying degrees of intensity. For example, 97% of turns performed during a basketball game are between 0-180° (32), whereas, in soccer, most turns are between 120º to 180º (i.e., 70%) and 90% ≤5.5 m/s entry speed (10). Nevertheless, the repeated appearance of COD actions is highly unpredictable given that players are continuously responding to different stimuli (i.e., ball movement, opponent, teammates, etc.) (26), which frequently results in sudden or unplanned CODs during competition (33). In this regard, to truly assess COD speed, it must be with pre-planned tests. COD speed provides the mechanical foundation for agility, whereby agility movements involve processing information/stimuli (i.e., perceptual cognitive speed) and executing a motor action (i.e., COD speed). Thus, evaluating an athlete's mechanical ability to change direction is highly important in team sports (43). Given the high prevalence of COD actions during competitive team sports, its assessment should be considered a key factor supported by previous research (38). However, the "perfect" COD test or drill seems unlikely to exist due to the unpredictable nature and wide variety of on-field movements performed in sports across a spectrum of angles and approach distances.

Commonly, COD ability is assessed through the metric of 'total time' (alternatively known as completion time) recorded after travelling a specific distance and performing one or several CODs (e.g., 45, 90, 135, and 180º) (35,36). However, evaluating COD ability based on total time only has been questioned and criticised recently. For example, only 31% of the total time during the 505 test is spent changing direction (28), and COD speed assessments are traditionally biased towards athletes with superior linear sprinting abilities and thus a confounding factor (27,28). To overcome this issue, the COD deficit has been proposed to better isolate and identify an athlete's ability to change direction (27,28). This measure provides an impression of the time taken to perform one-directional change compared to a linear sprint of an equivalent distance. The COD deficit has been widely applied during 505 COD assessments, which requires a single 180º COD (27). However, given the fact that athletes are required to perform CODs across a spectrum of angles during match play due to the often unpredictable nature, it is important to evaluate COD deficit (and therefore ability) over a wide variety of angles as the biomechanical demands of COD are angle dependent (12,13). To our best knowledge, there is only one study that has analysed the COD deficit (which refers to the COD component) during several angles (45, 90, 135, and 180º) over a 10-m distance in soccer players (36). However, the authors only showed a between-COD strategy comparison (i.e., side-stepping vs. bypassing) on COD deficit time and they did not actually compare the faster and slower sides (i.e., not truly evaluating inter-limb asymmetries and establish directional dominance). Given the scarce information regarding COD deficit from various angles, further investigations are warranted.

In recent years, there has been a rise in empirical studies investigating inter-limb asymmetries (4,17,18,25,29,30). In this regard, inter-limb asymmetries in strength and power are a practical and valuable tool to detect players at high risk of injury (19), to monitor a successful return to sport after an ACL injury (1) as well as being associated with a reduced jump, speed, and COD performance (6,16). However, previous research has noted that total time might be a poor metric to detect existing side-to-side differences during COD tests (24) and produces substantially lower percentage imbalances which might lead to misinterpretations of an athlete's symmetry in COD ability (3,14). Consequently, there is a suggestion that COD asymmetry should be based on the COD deficit rather than total time (14), and dominance should be based on comparing the faster and slower sides (9). In addition, direction of asymmetry refers to the limb that could be considered as dominant (i.e., directional dominance in the case of COD performance), by virtue of the asymmetry consistently favoring the same side (4). Kappa coefficients determine how consistent asymmetry is in different tests or metrics within the same test. As slight to substantial levels of agreement have been found with respect to asymmetry (5,6), it seems logical to add "direction" as an analysis variable. However, it is currently unclear if athletes display superior COD or turning performance towards one direction consistently across a spectrum of shallow, moderate, and sharp angles and thus, warrant further inspection.

Therefore, the main aims of the current study were: 1) to establish whether directional dominance is displayed during COD tasks across a variety of angles; 2) to determine the angle-variation data for the magnitude and direction of asymmetry; and 3) to analyze the relationships in COD performance (completion time and COD deficit) across various angles. It is an exploratory analysis and it is expected that the results of this research will improve our understanding of COD asymmetries across a spectrum of angles.

METHODS

Experimental approach to the problem

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-16 to U-20) were assessed on a 10-m linear sprinting and a 10-m sprint (i.e., 5 + 5 m) across a variety of COD angles (i.e., 45, 90, 135, and 180º). All participants were familiarized with all testing procedures before starting the experiments. Players performed two testing sessions to analyze the tests' reliability, separated by one week. 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) from 48-h before the test and to consume their last meal at least three hours prior to testing.

Subjects

Twenty-four young (U-16 to U-20), highly trained male basketball players (age, 17.7 ± 1.6 years; height, 189.7 ± 9.2 cm; body mass, 76.8 ± 13.0 kg, %body fat, 12.6 ± 2.5%) volunteered to participate in this study. All players were post-pubertal, and their basketball training experience was 7.3 ± 1.5 years. This sample size (*n* = 24) was selected to detect moderate differences (ES: 0.6) for a paired sample t-test at 80% power and alpha of 0.05 according to G*power *(version 3.1.9.6).* 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* = 9) were also competing at the international level (i.e., European and World Basketball Championships). Written informed consent was obtained from the players and their parents / guardians (i.e., U-18 players) 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, 45º COD, 90º COD, 135º COD, and 180º COD. Players executed two warm-up trials (in each direction during COD tests) at 75% and 90% maximum effort before their maximum effort trials.

Speed tests

Running speed was evaluated by 10-m sprint times (Figure 1). 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 10-m sprint was performed twice, separated by at least 2 min of passive recovery. The best time was used for statistical analysis.

Change of direction tests

45°, 90° and 135° Change of direction test

After performing the linear sprint test, five minutes of passive recovery were provided. A 10-m sprint test was performed as follows: Five meters ahead and a turn of 45°, 90°, or 135° before accelerating to the finish line, and one sprint to the left and a second to the right. They had to sprint around a pole over a width rail of 1.5 m delimited by cones allowing either COD strategies to adopt a lateral foot plant or do a crossover step (Figure 1). If an athlete performed a crossover cut during a left direction, they also did a crossover cut when performing the right at the same angle (and vice versa). The majority of trials analysed involved a lateral foot plant, with only two players performing a crossover cut during a 45º task, most likely due to the angle-velocity trade-off present during changing direction (11,12). A trial was considered valid when the participant performed the test inside the width rail without stepping outside of it. Each test (first, left, and second, right) was repeated twice in alternating order. Total 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. Two minutes of passive recovery were allowed between trials. The best time of every direction in all tests was used for statistical analysis. The COD deficit was calculated using the formula: COD time – 10 m sprint time (27,28).

180° Change of direction test

A 10-m 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 (34). Timing gates were placed at a height of 0.75 m and a distance of 1.5 m between each other (34). 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.

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

Asymmetry index

The dominant (D) leg was defined as the leg used during the first step in a lay-up, whereas that utilized during the second step was the non-dominant (ND) leg. Furthermore, to truly investigate inter-limb asymmetries and establish COD dominance, we also compared faster and slower sides. The asymmetry index for COD performance was calculated as follows: 100/(faster side)*(slower side)*-1+100 (5). To determine the direction of asymmetry, an "IF function" was added to the end of the formula in Microsoft Excel: *IF (left<right, 1, -1) (4).

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 Shapiro-Wilk test and showed COD times as normally distributed variables, whereas inter-limb asymmetries were not. Homoscedasticity was assessed through the Levene's test. Between-session reliability analysis was computed using a 2-way random intraclass correlation coefficient (ICC) with an absolute agreement and 90% confidence intervals and the coefficient of variation (CV). To be deemed a "real" asymmetry, an inter-limb asymmetry index should exceed the CV as suggested by Exell et al. (15). Interpretation of intraclass correlation coefficient values were interpreted in line with Koo and Li (21), where values >0.9 = excellent, >0.75 to 0.9 = good, >0.5 to 0.75 = moderate, and <0.5 = poor; coefficient of variation values was considered as good (<5%), moderate (5-10%) and poor (>10%) (2).

Differences between the two conditions (DL vs. NDL or faster vs. slower) were analyzed using paired t-tests. Friedman's analysis of variance was conducted to determine differences in asymmetry scores between COD angles in total time and COD deficit, with statistical significance set at p<0.05. The magnitude of change was calculated between COD angles, D and NDL, and faster and slower sides using Cohen's d ESs using the formula: (MeanCOD1 – MeanCOD2)/SDpooled, where COD1 and COD2 represent the respective COD angles in question (e.g., COD45, COD90, COD135, COD180). These were interpreted in line with Hopkins et al. (19) where <0.2 = trivial; >0.2–0.6 = small; >0.6–1.2 = moderate; >1.2–2.0 =large; >2.0–4.0 = very large; and >4.0 = near perfect.

Kappa coefficients were calculated to determine the levels of agreement for how consistently an asymmetry favored the same side (direction of asymmetry) when comparing between COD tasks. This method was chosen because the Kappa coefficient describes the proportion of agreement between 2 methods after removing any agreement by chance (8). Kappa values were interpreted in line with suggestions from Viera and Garrett (42), where <0 = poor, 0.01-0.20 = slight, 0.21-0.40 = fair, 0.41-0.60 = moderate, 0.61-0.80 = substantial, and 0.81-0.99 = almost perfect.

Relationships between COD angles were assessed using Pearson's product-moment correlation. According to Hopkins et al. (22), the magnitude of correlation coefficients was considered trivial (r < 0.01), small (r = 0.1 to <0.3), moderate (r = 0.3 to <0.5), large (r = 0.5 to <0.7), very large (r = 0.7 to <0.9), nearly perfect (r = 0.9 to <1) and perfect (r = 1).

RESULTS

Reliability data are presented in Table 1. Relative reliability (ICC) ranged from good to excellent values (ICC= 0.81-0.92; CV = 1.7-2.4) for all linear sprint and COD times. Standard errors of the measurement (SEM) were between 0.024 to 0.048. 10-m linear sprinting performance was 1.80 ± 0.06 s. COD total times and COD deficit data for all angles are presented in Table 2. Trivial to moderate differences (ES= -0.07 to 0.78) were reported between DL and NDL for all COD angles for both total times and COD deficit showing non-significant differences except for COD45 ($p<0.05$). Conversely, with respect to directional dominance, moderate to large and significant differences ($p<0.05$, ES= 0.70 to 1.28) were observed between faster and slower sides for all COD angles.

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

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

Inter-limb asymmetries for COD total times and COD deficit are presented in Table 3, all of which exceeded the CV and therefore can be treated as "real". Trivial to small ESs (ES= 0.00 to 0.58) were reported for between-angle asymmetries' differences in COD total times without significant differences ($p>0.05$) between them. Conversely, more meaningful ES's (ES= 0.25 to 1.85) were established when comparing COD angles through COD deficit, only showing significant differences ($p<0.05$) between COD45 and the rest of the angles.

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

Kappa coefficients and accompanying descriptors for how consistently asymmetry favored the same limb between COD angles are presented in Table 4. Levels of agreement ranged from poor to slight (k = -0.14 to 0.14), except for the fair agreement between COD45 and COD90. Individual asymmetries scores have also been presented for all COD angles showing positive (i.e., faster D times) or negative (i.e., faster ND times) values (Figure 2). Only three players showed consistency in all COD angles; 13 exhibited in three angles, while 8 in two angles.

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

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

Correlation coefficients between COD angles are reported in Table 5. Moderate to very large relationships (r= 0.32 to 0.81 DL and NDL; 0.38 to 0.89 faster and slower) were reported between all COD angles through total times and 10-m linear sprint (DL and NDL or faster and slower sides analyzed individually) except COD90 and COD180 (r= 0.12) with DL and the correlation between COD45 and COD135 (r= 0.24) with NDL. Trivial to moderate correlations (r= -0.30 to 0.33) were established between all COD angles through COD deficit and 10-m linear sprint with the DL. Linear sprint and COD45 showed trivial to small (r= -0.19 to 0.0) relationships between them and the other angles with the NDL. Conversely, small to large (r= 0.36 to 0.55) correlations were reported between COD90, COD135, and COD180 with the NDL. Similarly, trivial to moderate correlations (r= -0.29 to 0.48) were found between all COD angles (both total time and

COD deficit) and 10-m linear sprint with the faster and slower sides. However, a large relationship (r= 0.56) was established between COD90 and COD135 with the faster side.

*****Table 5 near here*****

DISCUSSION

The main aims of the current study were to examine the influence of COD angles on the magnitude and direction of asymmetry and to analyze the relationships between several COD angles through total times and COD deficit. The main findings were as follows: 1) significantly greater asymmetries were found in COD45 calculated through COD deficit in comparison to all other angles, 2) while inter-limb differences were only significantly found in COD45 total time and COD deficit using D and NDL, significant differences were reported in all angles comparing the faster and slower sides, highlighting directional dominance in our basketball population, 3) not all athletes consistently display faster-turning performance to a specific direction as COD performance is both task and angle-dependent, showing athletes with superior shallow COD performance may not necessarily be faster at sharper COD turns and vice versa, and 4) the relationships between COD angles largely depend on the metric used (more significant correlations with total time compared with the COD deficit).

For the COD deficit, mean asymmetry values for COD45 were much greater (ES = 1.48 to 1.85) than all other angles. As proposed by Dos'Santos et al. (12), this is probably because when cutting at an angle of 45º, velocity maintenance is critical, and athletes do not have to "brake" as hard compared to greater angles (e.g., > 60º). It is important to note that asymmetry has been calculated using the faster side as our reference point (irrespective of D or NDL), noting that this method aligns to fundamental mathematical principles in the way that fractions are computed. This seems especially relevant to mention, given previous literature has highlighted ~9 different ways to compute an asymmetry value (5). From the COD deficit graph (Figure 2), most athletes favor their DL (19/24 bars are above the 0 line – indicating the DL is faster). The key message here is that cutting at 45º appears to be a good measure of detecting inter-limb asymmetry using the COD deficit metric. When comparing to the other angles where (we presume) athletes must use both legs to break much harder (i.e., a failure to sufficiently brake will result in suboptimal COM deflection) (23), though athletes can still display between-limb differences in braking strategies (41), this study was unable to monitor such differences owing to our methodology used. Future research should consider exploring the biomechanical mechanisms which underpin directional dominance.

When comparing the DL and NDL performance, we only found significant differences in COD45 (total time and COD deficit). To our best knowledge, only one study has examined COD deficit across variety of COD angles (36). Their observations contrast with the current study as significant ($p < 0.01$) and small ES values (0.31 to 0.40) were reported between DL and NDL in all COD angles (total times and COD deficit). It is worth noting that significant ($p<0.01$) and moderate to large ES values (0.66 to 1.52) were demonstrated when the faster and slower sides are compared (Table 2). In this regard, we may be cautious with the current results as the calculation of between-limb differences should be based on faster vs. slower sides, not limb dominance (i.e., lay-up). Other reasons why such between-study differences might be 10-m linear sprinting performance (1.92 ± 0.13 vs. 1.80 ± 0.06 s) or COD performance supporting by either players' age (16.1 vs. 17.7 y) or competitive level (sub-elite vs. highly-trained). Another argument may be the dimensions of the playing area. It is possible that as the COD angle increases (45º until 180º), braking manoeuvres become more critical. The higher velocity maintenance through shorter ground contact times recommends a crossover strategy during 45º COD (39). However, substantially larger braking occurs over the penultimate foot contact and potentially steps prior to push-off as directional changes are between 60º to 180º, suggesting either side-stepping or pivoting as effective execution strategies (39). When comparing between-angle the faster and slower side, there is an increment in the absolute and magnitude differences as the angle increases. Push-off strategies during the main execution foot contact might explain the above-mentioned differences. Such previous strategies might be optimized in smaller courts like those used by basketball athletes, as they are continuously braking and compensating those possible inter-limb differences to maintain performance. Thus, the significant differences reported between DL and NDL during COD45 (and no differences in the rest of the angles) might be once again, explained through the angle-variation strategy performed.

Recently, there has been a suggestion of the importance of determining the direction of asymmetry in an attempt to establish how consistently asymmetry favors the same limb across different tests, metrics, or time points (4). Previous studies have focused on jumping ability through different metrics such as jump height or concentric impulse (4). However, this is the first study that has analyzed the consistency in the direction of asymmetry across various COD angles. Poor to slight levels of agreement indicate that the direction of asymmetry was highly variable. Even though these results demonstrate low consistency, they offer supporting information for the concept of task-specificity during our COD protocols. Further to this, when examining individual cases, 15 out of 24 showed DL consistency on COD45 and COD90. Sharper angles than 90º require more significant reductions in velocity (i.e., braking) (20) as well as greater re-acceleration. The between-angle inconsistency might be reflected as greater magnitude-based differences (faster vs. slower sides) are presented as the COD angle increases. Several reasons might explain such inconsistency, such as technique, eccentric loading, braking force requirements, propulsive forces, or impulse.

COD total time and COD deficit show that completion times increase as the COD angle increased (45 to 90º) and stabilise at 135 to 180º. This result is consistent with the fact that as COD angle increases, the greater the need to decrease the body's momentum (mass × velocity), thus time spent braking. Body momentum requirements are to maintain body balance, adjust stride, and apply sufficient lateral forces to change direction at high speed (21) and increase the time needed to complete the COD test. In addition, although COD speed and linear sprinting seem independent physical qualities (35,38), controversy still exists regarding their influence on each other. Correlational analyses showed moderate to very large relationships between linear sprinting and all COD angles measured through total times with DL and NDL or faster and slower sides, confirming that total times during COD tasks are biased towards athletes with superior linear speed. Interestingly, correlation values substantially decreased (trivial to moderate) when CODs were examined by COD deficit, substantiating the initial work demonstrated by Nimphius et al. (27,28). This fact highlights the importance of using COD deficit as a more isolated measurement to assess COD ability. Using COD total times might misinterpret such ability through the strong influence of linear sprinting. For example, two players with similar COD times and different linear sprinting performances will have different COD deficits. It might provide a foundation for good COD speed and linear performance to explain a "normal" COD deficit, while a good COD speed and poor linear sprinting represent a "good" COD deficit. Thus, correlations should be different based on the metric used and, consequently, to support the use of COD deficit to avoid linear sprinting performance' influences. Finally, the low relationships found between all COD angles suggest that they are independent physical qualities irrespective of covering the same distance (i.e., 10-m) or being considered COD tests.

Some limitations in the present study should be acknowledged. Basketball players have particular characteristics (e.g., anthropometry); thus, our results cannot be directly extrapolated to other sports. Even though we have analyzed various angles, a perfect COD test is unlikely to exist and our results show that multiples angles and directions are needed to better understand COD ability when testing multidirectional athletes. Nonetheless, this study only examined total time and COD deficit, and thus, we did not provide any insights into actual COD strategy (e.g., velocity or ground contact time) or phase specific information (e.g., time spent braking, changing direction and exiting) which can provide more holistic insights into directional dominance. Several critical turning-related movements include a combination of lateral shuffles and slides, backpedalling with pivoting movements or backpedalling with a combination of pivoting and forward sprints. Thus, their complexity should be considered depending on the distances covered prior to changing direction, given the vast combination of possible COD movements. Thus, a COD test only fits part of the team sports locomotive demands.

PRACTICAL APPLICATIONS

Practitioners should use COD deficit for a better representation of COD ability rather than COD total times, which can be influenced mainly through linear sprinting. Basketball athletes are directionally dominant (~0.05 to 0.11s faster to a specific direction) but the favored direction is not necessarily consistent between tasks or directions. Additionally, basketball athletes are not necessarily fast across all angles, thus highlighting that biomechanical demands of COD are angle and task-dependent. As such, practitioners are encouraged to investigate COD ability across both limbs/directions and various angles to create a "COD angle profile" for their athletes. This information can therefore be used to identify strengths and weaknesses to help inform physical preparation and COD specific training.

REFERENCES

1. Ardern, CL, Webster, KE, Taylor, NF, and Feller, JA. Return to the Preinjury Level of Competitive Sport After Anterior Cruciate Ligament Reconstruction Surgery. *Am J Sports Med* 39: 538–543, 2011.
2. Banyard, HG, Nosaka, K, and Haff, GG. Reliability and Validity of the Load–Velocity Relationship to Predict the 1RM Back Squat. *J Strength Cond Res* 31: 1897–1904, 2017.
3. Bishop, C, Clarke, R, Freitas, TT, Arruda, AFS, Guerriero, A, Ramos, MS, et al. Change-of-Direction Deficit vs. Deceleration Deficit: A Comparison of Limb Dominance and Inter-limb Asymmetry between Forwards and Backs in Elite Male Rugby Union Players. *J Sports Sci* 39: 1088–1095, 2021.
4. Bishop, C, Read, P, Chavda, S, Jarvis, P, Brazier, J, Bromley, T, et al. Magnitude or Direction? Seasonal Variation of Interlimb Asymmetry in Elite Academy Soccer Players. *J Strength Cond Res* 36: 1031–1037, 2022.
5. Bishop, C, Read, P, Lake, J, Chavda, S, and Turner, A. Interlimb Asymmetries: Understanding How to Calculate Differences From Bilateral and Unilateral Tests. *Strength Cond J* 40: 1–6, 2018.
6. Bishop, C, Turner, A, and Read, P. Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *J Sports Sci* 36: 1135–1144, 2018.
7. Bloomfield, J, Polman, R, and O´Donoghue, P. Physical Demands of Different Positions in FA Premier League Soccer. *J Sports Sci Med* 6: 63–70, 2007.
8. Cohen, J. A Coefficient of Agreement for Nominal Scales. *Educ Psychol Meas* 20: 37–46, 1960.
9. Dos’Santos, T, Bishop, C, Thomas, C, Comfort, P, and Jones, PA. The effect of limb dominance on change of direction biomechanics: A systematic review of its importance for injury risk. *Physical Therapy in Sport* 37: 179–189, 2019.
10. Dos’Santos, T, Cowling, I, Challoner, M, Barry, T, and Caldbeck, P. What are the significant turning demands of match play of an English Premier League soccer team? *J Sports Sci* 40: 1750–1759, 2022.
11. Dos’Santos, T, McBurnie, A, Thomas, C, Comfort, P, and Jones, PA. Biomechanical Comparison of Cutting Techniques: A Review and Practical Applications. *Strength Cond J* 41: 40–54, 2019.
12. Dos’Santos, T, Thomas, C, Comfort, P, and Jones, PA. The Effect of Angle and Velocity on Change of Direction Biomechanics: An Angle-Velocity Trade-Off. *Sports Medicine* 48: 2235–2253, 2018.
13. Dos’Santos, T, Thomas, C, and Jones, PA. The effect of angle on change of direction biomechanics: Comparison and inter-task relationships. *J Sports Sci* 39: 2618–2631, 2021.
14. Dos’Santos, T, Thomas, C, Jones, PA, and Comfort, P. Assessing Asymmetries in Change of Direction Speed Performance: Application of Change of Direction Deficit. *J Strength Cond Res* 33: 2953–2961, 2019.
15. Exell, TA, Irwin, G, Gittoes, MJR, and Kerwin, DG. Implications of intra-limb variability on asymmetry analyses. *J Sports Sci* 30: 403–409, 2012.
16. Fort-Vanmeerhaeghe, A, Bishop, C, Buscà, B, Aguilera-Castells, J, Vicens-Bordas, J, and Gonzalo-Skok, O. Inter-limb asymmetries are associated with decrements in physical performance in youth elite team sports athletes. *PLoS One* 15: e0229440, 2020.
17. Gonzalo-Skok, O, Moreno-Azze, A, Arjol-Serrano, JL, Tous-Fajardo, J, and Bishop, C. A Comparison of 3 Different Unilateral Strength Training Strategies to

Enhance Jumping Performance and Decrease Interlimb Asymmetries in Soccer Players. *Int J Sports Physiol Perform* 14: 1256–1264, 2019.

18. Gonzalo-Skok, O, Tous-Fajardo, J, Suarez-Arrones, L, Arjol-Serrano, JL, Casajús, JA, and Mendez-Villanueva, A. Single-Leg Power Output and Between-Limbs Imbalances in Team-Sport Players: Unilateral Versus Bilateral Combined Resistance Training. *Int J Sports Physiol Perform* 12: 106–114, 2017.
19. Gustavsson, A, Neeter, C, Thomeé, P, Grävare Silbernagel, K, Augustsson, J, Thomeé, R, et al. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. *Knee Surgery, Sports Traumatology, Arthroscopy* 14: 778–788, 2006.
20. Hader, K, Palazzi, D, and Buchheit, M. Change of direction speed in soccer: how much braking is enough? *Kinesiology* 47: 67–74, 2015.
21. Hewit, JK, Cronin, JB, and Hume, PA. Kinematic Factors Affecting Fast and Slow Straight and Change-of-Direction Acceleration Times. *J Strength Cond Res* 27: 69–75, 2013.
22. HOPKINS, WG, MARSHALL, SW, BATTERHAM, AM, and HANIN, J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Med Sci Sports Exerc* 41: 3–12, 2009.
23. Klusemann, MJ, Pyne, DB, Hopkins, WG, and Drinkwater, EJ. Activity Profiles and Demands of Seasonal and Tournament Basketball Competition. *Int J Sports Physiol Perform* 8: 623–629, 2013.
24. Madruga-Parera, M, Bishop, C, Beato, M, Fort-Vanmeerhaeghe, A, Gonzalo-Skok, O, and Romero-Rodríguez, D. Relationship Between Interlimb Asymmetries and Speed and Change of Direction Speed in Youth Handball Players. *J Strength Cond Res* 35: 3482–3490, 2021.
25. Madruga-Parera, M, Bishop, C, Fort-Vanmeerhaeghe, A, Beato, M, Gonzalo-Skok, O, and Romero-Rodríguez, D. Effects of 8 Weeks of Isoinertial vs. Cable-Resistance Training on Motor Skills Performance and Interlimb Asymmetries. *J Strength Cond Res* 36: 1200–1208, 2022.
26. Marković, G, Sekulić, D, and Marković, M. Is agility related to strength qualities?--Analysis in latent space. *Coll Antropol* 31: 787–93, 2007.
27. Nimphius, S, Callaghan, SJ, Spiteri, T, and Lockie, RG. Change of Direction Deficit: A More Isolated Measure of Change of Direction Performance Than Total 505 Time. *J Strength Cond Res* 30: 3024–3032, 2016.
28. Nimphius, S, Geib, G, Spiteri, T, and Carlisle, D. “Change of direction deficit” measurement in Division I American football players. *Journal of Australian Strength and Conditioning* 21: 115–117, 2013.
29. Pardos-Mainer, E, Casajús, JA, Bishop, C, and Gonzalo-Skok, O. Effects of Combined Strength and Power Training on Physical Performance and Interlimb Asymmetries in Adolescent Female Soccer Players. *Int J Sports Physiol Perform* 15: 1147–1155, 2020.
30. Pardos-Mainer, E, Casajús, JA, and Gonzalo-Skok, O. Adolescent female soccer players’ soccer-specific warm-up effects on performance and inter-limb asymmetries. *Biol Sport* 36: 199–207, 2019.
31. Paul, DJ, Gabbett, TJ, and Nassis, GP. Agility in Team Sports: Testing, Training and Factors Affecting Performance. *Sports Medicine* 46: 421–442, 2016.
32. Póvoas, SCA, Seabra, AFT, Ascensão, AAMR, Magalhães, J, Soares, JMC, and Rebelo, ANC. Physical and Physiological Demands of Elite Team Handball. *J Strength Cond Res* 26: 3365–3375, 2012.

33. Reilly, T, Bangsbo, J, and Franks, A. Anthropometric and physiological predispositions for elite soccer. *J Sports Sci* 18: 669–683, 2000.
34. Robert Lockie. Sprint testing. In: Performance Assessment in Strength and Conditioning.Routledge, 2018. pp. 117–139
35. Rouissi, M, Chtara, M, Owen, A, Burnett, A, and Chamari, K. Change of direction ability in young elite soccer players: determining factors vary with angle variation. *J Sports Med Phys Fitness* 57, 2017.
36. Rouissi, M, Chtara, M, Owen, A, Chaalali, A, Chaouachi, A, Gabbett, T, et al. Effect of leg dominance on change of direction ability amongst young elite soccer players. *J Sports Sci* 34: 542–548, 2016.
37. Scanlan, A, Dascombe, B, and Reaburn, P. A comparison of the activity demands of elite and sub-elite Australian men's basketball competition. *J Sports Sci* 29: 1153–1160, 2011.
38. Sheppard, JM and Young, WB. Agility literature review: Classifications, training and testing. *J Sports Sci* 24: 919–932, 2006.
39. Suzuki, Y, Ae, M, Takenaka, S, and Fujii, N. Comparison of support leg kinetics between side-step and cross-step cutting techniques. *Sports Biomech* 13: 144–153, 2014.
40. Taylor, JB, Wright, AA, Dischiavi, SL, Townsend, MA, and Marmon, AR. Activity Demands During Multi-Directional Team Sports: A Systematic Review. *Sports Medicine* 47: 2533–2551, 2017.
41. Thomas, C, Dos'santos, T, Cuthbert, M, Fields, C, and Jones, PA. The effect of limb preference on braking strategy and knee joint mechanics during pivoting in female soccer players. *Science and Medicine in Football* 4: 30–36, 2020.
42. Viera, AJ and Garrett, JM. Understanding interobserver agreement: the kappa statistic. *Fam Med* 37: 360–3, 2005.
43. Young, W, Dos'Santos, T, Harper, D, Jefferys, I, and Talpey, S. Agility in Invasion Sports: Position Stand of the IUSCA. *International Journal of Strength and Conditioning* 2, 2022.

Figure Legends

Figure 1. Schematic illustration of 10-m linear sprinting and COD tests.

Figure 2. Individual asymmetry data for 45, 90, 135 and 180° COD angles. N.B: bars above 0 indicate faster times on the dominant leg and bars below 0 indicate faster times on the non-dominant leg.

Figure 1.

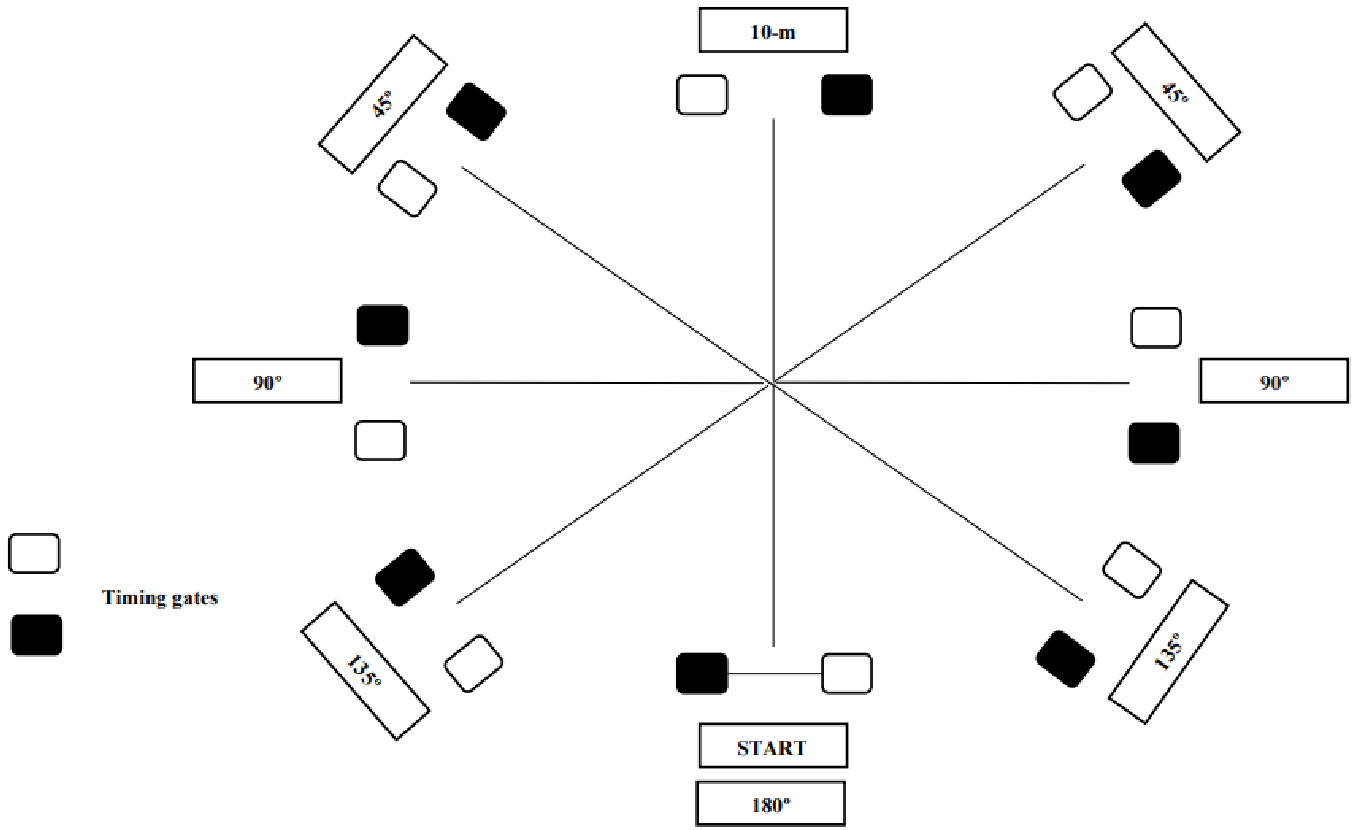
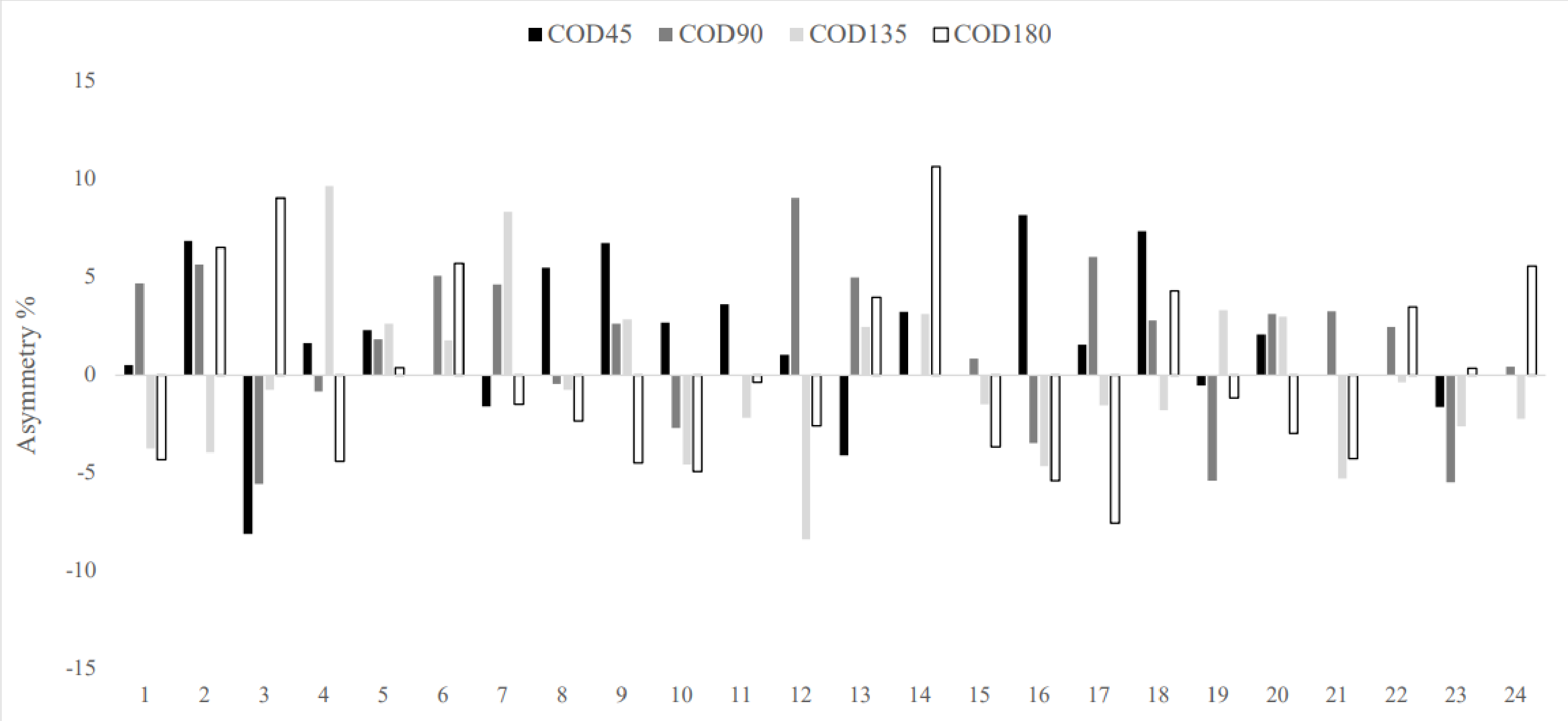


Figure 2.



COD45
COD90
COD135
COD180
15
10
5
0
-5
-10
-15
Asymmetry %
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Table 1. Reliability data for linear sprinting and COD tests with dominant (DL) and non-dominant (NDL) legs (n=24).

		ICC (95% CI)	SEM	CV%
10-m (s)		0.86 (0.75; 0.97)	0.024	2.1
COD45 (s)	DL	0.84 (0.72; 0.96)	0.028	1.7
	NDL	0.84 (0.72; 0.96)	0.036	2.1
COD90 (s)	DL	0.82 (0.69; 0.95)	0.043	2.4
	NDL	0.81 (0.67; 0.95)	0.048	2.3
COD135 (s)	DL	0.88 (0.79; 0.97)	0.032	2.4
	NDL	0.89 (0.81; 0.97)	0.036	2.2
COD180 (s)	DL	0.91 (0.84; 0.98)	0.036	1.8
	NDL	0.92 (0.86; 0.98)	0.031	1.7

Note. COD: change of direction; ICC: intra-class correlation coefficient; SEM: standard error of measurement; CV: coefficient of variation; COD45, COD90, COD135 and COD180: 5 + 5 m sprint test with a 45º, 90º, 135º or 180º change of direction.

Table 2. Change of direction total times and change of direction deficit times with both dominant and non-dominant legs and faster and slower sides.

		DL	NDL	ES	CI (95%)	p value
COD (s)	COD45	1.86 ± 0.07	1.89 ± 0.09	0.44	0.08 to 0.81	0.01*
	COD90	2.29 ± 0.10	2.32 ± 0.11	0.29	-0.11 to 0.66	0.08
	COD135	2.69 ± 0.09	2.69 ± 0.11	-0.07	-0.60 to 0.45	0.39
	COD180	2.64 ± 0.12	2.64 ± 0.11	0.00	-0.45 to 0.45	0.49
CODD (s)	COD45	0.06 ± 0.04	0.10 ± 0.06	0.78	0.13 to 1.42	0.01*
	COD90	0.49 ± 0.09	0.52 ± 0.09	0.31	-0.13 to 0.75	0.08
	COD135	0.90 ± 0.09	0.89 ± 0.10	-0.08	-0.62 to 0.46	0.39
	COD180	0.85 ± 0.10	0.85 ± 0.09	0.00	-0.55 to 0.55	0.49

		Faster	Slower	ES	CI (95%)	p value
COD (s)	COD45	1.85 ± 0.07	1.90 ± 0.09	0.70	0.41 to 1.01	<0.001*
	COD90	2.26 ± 0.09	2.34 ± 0.10	0.86	0.60 to 1.11	<0.001*
	COD135	2.64 ± 0.09	2.74 ± 0.09	1.06	0.73 to 1.40	<0.001*
	COD180	2.59 ± 0.11	2.70 ± 0.09	0.97	0.72 to 1.23	<0.001*
CODD (s)	COD45	0.05 ± 0.03	0.11 ± 0.06	0.97	0.65 to 1.29	<0.001*
	COD90	0.46 ± 0.08	0.55 ± 0.08	1.00	0.71 to 1.30	<0.001*
	COD135	0.85 ± 0.08	0.94 ± 0.08	1.17	0.80 to 1.54	<0.001*
	COD180	0.79 ± 0.08	0.90 ± 0.06	1.28	0.95 to 1.61	<0.001*

Note. COD: change of direction; CODD: change of direction deficit; DL: dominant leg; NDL: non-dominant leg; ES: effect size; CI (95%): effect size confidence interval at 95%; COD45, COD90, COD135 and COD180: 5 + 5 m sprint test with a 45º, 90º, 135º or 180º change of direction. *Significant differences ($p<0.05$) between dominant and non-dominant leg or faster and slower side.

Table 3. Mean inter-limb asymmetry for change of direction total times and change of direction deficit and between-angles effect size.

	CODAsy	*CODDAsy*	*COD asymmetry (ES)*			*CODD asymmetry (ES)*		
			COD45	*COD90*	*COD135*	*CODD45*	*CODD90*	*CODD135*
COD45	2.66 ± 2.54	43.0 ± 29.3	---	---	---	---	---	---
COD90	3.39 ± 2.32	14.5 ± 9.3	-0.30	---	---	1.48#	---	---
COD135	3.39 ± 2.44	9.75 ± 6.59	-0.29	0.00	---	1.85#	0.60	---
COD180	4.16 ± 2.61	12.4 ± 7.8	-0.58	-0.31	-0.30	1.65#	0.25	-0.37

Note. CODAsy: change of direction total time asymmetry; CODDAsy: change of direction deficit asymmetry; ES: effect size; COD45, COD90, COD135 and COD180: asymmetry calculated from 5 + 5 m sprint test with a 45º, 90º, 135º or 180º change of direction performed with dominant and non-dominant leg or faster and slower side. #Significant differences ($p<0.05$) in comparison to COD45.

Table 4. Kappa coefficients and accompanying descriptors for levels of agreement describing how consistently asymmetry favored the same side across angles.

	COD45	COD90	COD135	COD180
COD45	---	---	---	---
COD90	0.34 (Fair)	---	---	---
COD135	-0.16 (Poor)	0.05 (Slight)	---	---
COD180	-0.14 (Poor)	0.14 (Slight)	0.04 (Slight)	---

COD45, COD90, COD135 and COD180: 5 + 5 m sprint test with a 45º, 90º, 135º or 180º change of direction performed with dominant and non-dominant leg.

Table 5. Relationships (95% confidence intervals) between angles on change of direction total (COD) times and change of direction deficit (CODD) times with both dominant and non-dominant legs and faster and slower sides.

		DL					NDL				
		10-m	COD45	COD90	COD135	COD180	10-m	COD45	COD90	COD135	COD180
COD	10-m	---	0.81 (0.61, 0.91)**	0.49 (0.11, 0.75)**	0.39 (-0.01, 0.69)	0.58 (0.23, 0.80)**	---	0.74 (0.49, 0.88)**	0.55 (0.20, 0.78)**	0.47 (0.08, 0.73)**	0.58 (0.24, 0.80)**
	COD45	---	---	0.35 (-0.06, 0.66)	0.42 (0.03, 0.71)*	0.34 (-0.08, 0.65)	---	---	0.39 (-0.10, 0.69)	0.24 (-0.18, 0.59)	0.37 (-0.04, 0.67)
	COD90	---	---	---	0.32 (-0.09, 0.64)	0.12 (-0.29, 0.50)	---	---	---	0.60 (0.26, 0.81)**	0.70 (0.41, 0.86)**
	COD135	---	---	---	---	0.51 (0.13, 0.76)*	---	---	---	---	0.53 (0.17, 0.77)**
CODD	10-m	---	-0.16 (-0.53, 0.26)	-0.16 (-0.53, 0.26)	-0.30 (-0.63, 0.11)	0.07 (-0.34, 0.46)	---	0.06 (-0.35, 0.45)	-0.03 (-0.43, 0.38)	-0.13 (-0.51, 0.29)	0.00 (-0.40, 0.40)
	COD45	---	---	-0.06 (-0.45, 0.35)	0.23 (-0.19, 0.58)	-0.29 (-0.62, 0.13)	---	---	-0.03 (-0.43, 0.37)	-0.19 (-0.55, 0.23)	-0.12 (-0.49, 0.38)
	COD90	---	---	---	0.20 (-0.22, 0.56)	-0.24 (-0.59, 0.18)	---	---	---	0.47 (0.08, 0.73)*	0.55 (0.19, 0.78)**
	COD135	---	---	---	---	0.33 (-0.08, 0.65)	---	---	---	---	0.36 (-0.05, 0.67)

		Faster					Slower				
		10-m	COD45	COD90	COD135	COD180	10-m	COD45	COD90	COD135	COD180
COD	10-m	---	0.89 (0.76, 0.95)**	0.54 (0.18, 0.78)**	0.48 (0.10, 0.74)*	0.66 (0.34, 0.84)**	---	0.72 (0.45, 0.87)**	0.59 (0.24, 0.80)**	0.50 (0.12, 0.75)*	0.70 (0.41, 0.86)**
	COD45	---	---	0.38 (-0.03, 0.68)	0.38 (-0.02, 0.68)	0.50 (0.12, 0.75)*	---	---	0.39 (-0.01, 0.69)	0.39 (-0.02, 0.68)	0.54 (0.17, 0.77)**
	COD90	---	---	---	0.66 (0.35, 0.84)**	0.50 (0.11, 0.75)*	---	---	---	0.63 (0.31, 0.83)**	0.58 (0.24, 0.80)**
	COD135	---	---	---	---	0.61 (0.27, 0.81)**	---	---	---	---	0.65 (0.33, 0.83)**
CODD	10-m	---	-0.04 (-0.44, 0.37)	-0.18 (-0.55, 0.24)	-0.29 (-0.62, 0.13)	0.11 (-0.31, 0.49)		-0.03 (-0.43, 0.38)	-0.03 (-0.43, 0.38)	-0.21 (-0.57, 0.21)	-0.04 (-0.43, 0.37)
	COD45	---	---	-0.26 (-0.60, 0.16)	-0.10 (-0.48, 0.31)	-0.25 (-0.59, 0.17)			-0.05 (-0.44, 0.36)	0.05 (-0.36, 0.45)	0.07 (-0.34, 0.46)
	COD90	---	---	---	0.56 (0.20, 0.79)**	0.20 (-0.22, 0.56)				0.48 (0.10, 0.74)*	0.30 (-0.11, 0.63)
	COD135	---	---	---	---	0.39 (-0.02, 0.68)					0.48 (0.09, 0.74)*

Note. Results are shown as correlation coefficient (confidence interval 95%); COD: change of direction; CODD: change of direction deficit; DL: dominant leg; NDL: non-dominant leg; COD45, COD90, COD135 and COD180: 5 + 5 m sprint test with a 45º, 90º, 135º or 180º change of direction. *p<0.05; **p<0.01.