Received: 27 February 2024 | Revised: 5 June 2024 | Accepted: 24 June 2024
DOI: 10.1002/ejsc.12164

Official ECSS Journal Open Access WILEY

ORIGINAL PAPER
Applied Sport Science

Strength characteristics in faster change of direction basketball players: A comparison across cutting angles

Francisco J. Barrera-Domínguez[1] | **Indya del-Cuerpo**[2] | **Antonio Riego-Ruiz**[2] | **Darío Martínez-García**[2] | **Daniel Jerez-Mayorga**[2,3] | **Luís Javier Chirosa-Ríos**[2] | **Jorge Molina-López**[1]

[1]Faculty of Education, Psychology and Sport Sciences, COIDESO, University of Huelva, Huelva, Spain

[2]Faculty of Sports Sciences, Department of Physical Education and Sports, Strength & Conditioning Laboratory, CTS-642 Research Group, University of Granada, Granada, Spain

[3]Faculty of Rehabilitation Sciences, School of Physical Therapy, Exercise and Rehabilitation Sciences Institute, Universidad Andres Bello, Santiago de Chile, Chile

Correspondence
Francisco J. Barrera-Domínguez, Faculty of Education, Psychology and Sport Sciences, COIDESO, University of Huelva, Avd. de las Fuerzas Armadas s/n, Huelva 21007, Spain.
Email: francisco.barrera@ddi.uhu.es

Funding information
Formación del Profesorado Universitario" Programme, run by Spanish Ministry of Universities, Grant/Award Numbers: FPU19/02030, FPU22/01057; Recualificación del Profesorado Universitario. Modalidad Margarita Salas

Abstract

Change of directions (COD) involves multidirectional and complex actions, with performance influenced by multiple factors. As lower limb strength is one of the most determinant of COD performance, the present study aimed to (a) explore the differences in strength outcomes across different lower limb muscle actions between faster and slower basketball players in COD actions at different angles and (b) analyse the relationship between isometric, concentric and eccentric strength outcomes and COD performance at different cutting angles. Twenty-five basketball players (44% female) completed a battery of tests, encompassing isokinetic and isometric squat strength assessments, along with COD tests at 45°, 90° and 180°. Players were categorised as '*low-performance*' and '*high-performance*' groups based on execution time in COD, facilitating a comparison between performance groups. Results indicated that concentric strength showed the greatest differences between performance groups at 45° COD (effect size $\geq$ 0.813; $p \leq 0.034$). Isometric and eccentric strength demonstrated a moderate-to-large relationship with 90° COD performance (Rho $\geq$ 0.394; $p \leq 0.045$), and all muscle actions exhibited a large relationship with 180° COD (Rho $\geq$ 0.445; $p \leq 0.030$). Moreover, the fastest players showed higher levels of concentric strength relative to eccentric strength, regardless of the cutting angle. These findings hold practical applications, suggesting that basketball coaches should train a specific kind of muscle action depending on the individual players' COD demands, focusing on improving the rapid eccentric force application while striving to reduce the eccentric/concentric ratio.

KEYWORDS
acceleration, agility, cutting, deceleration, team sport

Highlights

- Strength is undeniably a key indicator in change of directions (COD) performance. The relationship between strength outcome measures and COD proficiency depends on the cutting angle.
- Cutting angles below 90° emphasise concentric strength, while those above 90° exhibit a stronger reliance on isometric and eccentric strength.
- Rapid eccentric force production strongly correlates with COD performance across all cutting angles. However, the fastest players exhibit higher concentric strength relative to their eccentric strength.

1 | INTRODUCTION

Change of direction (COD) actions, which are vital in basketball, demand precise body control, muscle activation and force production (Spiteri, Newton, Binetti, et al., 2015). This complex and multidirectional skill involves planned deceleration and acceleration in different directions (Nimphius et al., 2016), occurring frequently—over 1000 times per game (Matthew & Delextrat, 2009; Salazar et al., 2020), with 15% of these at maximum intensity (<−3.5 m·s−2) (Svilar et al., 2018). Regardless of a player's position or gender, COD is a crucial physical ability in basketball, providing a physical advantage over opponents, aiding in offencive positioning or enhancing defencive manoeuvers (Power et al., 2022). With the rising intensity of modern basketball (Sugiyama et al., 2021), strength and conditioning coaches must prioritise COD, understanding its physical factors and enhancing athletes' performance in these actions.

Efficient execution of COD relies on distinct types of muscle actions, with athletes needing adequate eccentric strength for initial deceleration, isometric strength during stance and concentric strength for reacceleration in the new direction (Spiteri et al., 2014). Achieving optimal COD at maximum speed involves the crucial interplay of these muscle actions (Castillo-Rodríguez et al., 2012). While prior studies have investigated physical determinants of COD, including eccentric (Jones et al., 2022; Smajla et al., 2022), isometric (Smolarek et al., 2023; Spiteri et al., 2014; Spiteri, Newton, & Nimphius, 2015) and concentric strength (Spiteri et al., 2014; Spiteri, Newton, & Nimphius, 2015), as well as power and reactive strength (Barrera-Domínguez et al., 2020; Castillo-Rodríguez et al., 2012), conflicting conclusions and lack of consensus persist. Divergent findings may stem from variations in sample characteristics, COD assessment protocols employed (i.e., *t*-test vs. 505 test) and muscle strength measurement methods (i.e., isokinetic vs. isoinertial). Notably, the influence of muscle actions on COD likely hinges on the task demands, which are directly affected by cutting angles (Dos'Santos et al., 2018). Thus, the absence of consensus in the scientific literature is justifiable, given the challenge of comparing results across studies using different COD assessment tests.

The analysis of mechanical demands in 180° cutting angles reveals the necessity for athletes to rapidly decelerate at the cut point and then swiftly reaccelerate in the opposite direction. Previous studies emphasise the crucial role of the deceleration phase in COD performance, recognising its instrumental preparation for the final step and the subsequent reacceleration (Dos'Santos et al., 2021a; Dos'Santos et al., 2019). In this phase, athletes experience force peaks reaching up to six times their body mass (Harper et al., 2022), highlighting the significance of eccentric strength in mitigating linear momentum during pre-cutting steps and the braking phase at the final step of the cut (Jones et al., 2017). A strong association between the eccentric strength of knee flexors and extensors and 180° COD performance has been reported (Jones et al., 2017). These sharp cutting actions also extend ground contact time beyond 400 milliseconds during the final step (McBurnie & Dos'Santos, 2022), making isometric strength relevant. Smolarek et al. (2023) discovered significant correlations between peak isometric strength (measured in a mid-thigh pull) and the ability to execute a 180° COD.

In contrast, for shear cuts below 90°, managing the moment of inertia is pivotal, with less emphasis on deceleration (Dos'Santos et al., 2018). Additionally, maintaining high speeds at these wider cutting angles is crucial for higher performance (Hader et al., 2015). While Jones et al. (2022) emphasised the substantial influence of eccentric strength at shear angles ranging from 70° to 90°, Smajla et al. (2022) found only trivial correlations between eccentric strength in an isoinertial flywheel squat and 90° COD performance.

As previously mentioned, distinct muscle actions have been demonstrated to influence COD performance, with all types of muscle actions playing crucial roles in this complex, high-speed action (Spiteri, Newton, Binetti, et al., 2015). Studies assessing full-spectrum strength through dynamic movements show correlations between dynamic strength and COD performance, particularly emphasising the elastic and reactive components of strength at angles of 90° and 180° (Barrera-Domínguez et al., 2020; Castillo-Rodríguez et al., 2012). Strength is undeniably a key indicator in COD performance, yet consensus is lacking on the impact of various strength measures for each muscular action at different cutting angles.

This study sought to achieve two main purposes: (a) to examine the differences in strength measures for different lower limb muscle actions between faster and slower basketball players in COD actions at different angles and (b) to analyse the relationship between isometric, concentric and eccentric strength measures and COD performance at different cutting angles. It was hypothesised that associations between different muscle actions and COD exist, with the strength of these associations varying depending on the specific cutting angle. Faster players engaged in cutting actions at 45° may require greater concentric strength, those at 90° may demand greater eccentric strength, and in the case of cutting actions at 180°, all muscle actions may hold equal importance.

2 | MATERIALS AND METHODS

2.1 | Design

A cross-sectional experimental design was employed to analyse the effect of specific strength characteristics on different cutting angles and to compare different strength characteristics between "fast" and "slow" COD basketball players at each angle. The evaluation session comprised two main components. Firstly, participants performed the modified 505 COD test at 45°, 90° and 180° (Barrera-Domínguez et al., 2023). Subsequently, assessments of isokinetic strength at 0.60 m·s^{-1} were conducted, along with 8-s isometric strength measurements involving knee flexion at 65° and hip flexion at 55°, using functional electromechanical dynamometry (FEMD).

Data collection occurred during the competitive phase of the sports season. The strength assessment was conducted in the (blinded) facility, while the COD tests were executed on the university's basketball court. To familiarise participants with the isokinetic and isometric strength testing procedures using FEMD, a familiarisation session was conducted 1 week before the assessment. All participants completed both the familiarisation and assessment sessions immediately before their basketball training sessions.

2.2 | Participants

A total of 25 basketball players (44% females; age, 23.2 ± 4.69 years; height, 182.5 ± 7.69 cm; body mass, 77.4 ± 11.3 kg), all competing in the (blinded), voluntarily participated in this study. Participants were recruited using convenience sampling and were included if they had been free from lower limb injuries for at least 6 months prior to the assessment, engage in training at least 3 days a week during the season in addition to competitive games and possess a minimum of 10 years of basketball-playing experience.

All participants were informed of potential risks and benefits before the study and provided written consent prior to commencing testing procedures. This study was approved by the (blinded), following the guidelines outlined in the Declaration of Helsinki.

2.3 | Procedures

The familiarisation session lasted 30 min, starting with 5 min of general hip and ankle mobility exercises. Following this, the subjects performed two sets of 30-s bodyweight isometric squats and 10 repetitions of dynamic free squats. Subsequently, familiarisation with FEMD began, involving two sets of 8-s maximum isometric squats. Finally, participants performed two sets of four repetitions (two submaximal and two maximal) of isokinetic squats at a velocity of 0.60 m·s^{-1} with subject-specific ranges of motion (ROM). The ROM depended on the length of the lower limb levers of each subject and was individually adjusted to allow them to perform an isokinetic squat from 0° to 90° of knee flexion.

One week after familiarisation, the main evaluation took place. Before the start of the evaluation sessions, a 15-min warm-up was implemented, starting with general activation, including light intensity jogging, a series of dynamic stretching exercises and several acceleration runs, followed by specific potentiation exercises. Additionally, each player was instructed to ensure adequate hydration and rest, abstain from high-intensity training for 24 h preceding the evaluation and control caffeine and food intake at least 3 h before each assessment.

2.3.1 | Modified 505 COD test at 45°, 90° y 180°

The execution time for speed tests was measured using single-beam timing cells (Chronojump BoscoSystem®, Barcelona, Spain). The timing cells were positioned 2 m apart at a height of 1 m, approximately corresponding to the height of the players' hips. Before the test, each player was positioned 0.5 m behind the first gate in a two-point split stance (i.e., standing with the preferred foot forward and placed exactly 0.5 m behind the starting line). Then, each player accelerated to maximum speed, covering 10 m in all tests, with a turning point at the 5-m mark. At this turning point, each athlete executed turns at angles of 45°, 90° and 180° to reach the second gate in the shortest possible time. The COD tests at 45°, 90° and 180° were performed on both sides, with laterality determined by the leg used during the final step when performing the COD mechanics.

2.3.2 | Isometric and isokinetic strength

Isokinetic and isometric strength were assessed during the squat exercise using a FEMD (Myoquality, Spain) (del-Cuerpo et al., 2023; Morenas-Aguilar et al., 2023; Rodriguez-Perea et al., 2021) with high precision, featuring a three-mm displacement accuracy, a load detection sensitivity of 100 g and a sampling frequency of 1000 Hz. The FEMD system comprises a rope connected to the machine body, passing through a floor-mounted pulley located just in front of the machine. To isolate lower limb strength, the player stood with one foot on each side of the pulley, ensuring that the application of force against the rope remained completely vertical (Figure 1). The player then hooked the rope to a waist harness. In the correct position, players applied force to the rope, and a load cell detected the tension on the rope to measure lower limb strength.

Isometric strength assessment involved conducting two sets of 8-s isometric squats with the knee flexed at 65° and the hip at 55°, replicating the joint angles experienced during COD (Dos'Santos et al., 2021b). The rope length was individually adjusted for each

FIGURE 1 Isokinetic and isometric squat set-up. Initial (left) and final (right) position.

player to achieve the specified squat position. Players were instructed to exert maximum and steady force quickly.

For isokinetic strength, participants completed two sets of four maximal repetitions of isokinetic squats at a velocity of 0.60 m·s^{-1}. The FEMD system precisely controlled angular velocity using a 2000 W electric motor (Martinez-Garcia et al., 2020). The squat movement ranged from a standing position to a knee flexion of 90° (Figure 1), encompassing the angles experienced by the lower limbs during COD actions (Dos'Santos et al., 2021b). Rope length and distance covered were individually adjusted for each player. Players were instructed to resist the "pull" of the rope as much as possible during the eccentric phase and to exert maximal force during the concentric phase.

A five-minute rest period was maintained between each set using the FEMD system. Mean strength values for each type of muscular action were used to calculate eccentric/isometric (E/I), eccentric/concentric (E/C) and isometric/concentric (I/C) strength ratios. A sampling period of 20 milliseconds was used to analyse the peak rate of force development (pRFD), given its demonstrated reliability in prior studies (Haff et al., 2015).

2.4 | Statistical analyses

Means ± standard deviations (SD) were used for variable descriptions. The relative and absolute reliabilities of the tests were evaluated using the intraclass correlation coefficient (ICC; ICC > 0.9 was considered strong) and the coefficient of variation (CV; CV < 10% was established as an intraday reliability criterion). A median cut-off score was established for the execution time of each COD angulation, thus dividing participants according to their performance in each COD test. High Performance (HP) included participants with a performance above the 50th percentile in each COD test. Low Performance (LP) consisted of players with a performance below the 50th percentile in each COD test. Normality and homogeneity of data were assessed using Shapiro–Wilk and Levene's tests, respectively. Given non-compliance with assumptions, the Mann–Whitney *U*-test was used to analyse the influence of the strength variables across the different COD performance groups. Cohen's *d* was calculated for effect size (ES) interpretation. Thresholds for qualitative descriptors of Cohen's *d* were set at < 0.20 'trivial', 0.20–0.50 'small', 0.50–0.80 'moderate' and >0.80 'large' (Cohen, 1988). Spearman's correlation coefficient assessed relationships between the different strength variables and COD, with the following thresholds indicating magnitude: <0.10 'trivial', 0.10–0.30 'small', 0.30–0.50 'moderate', 0.50–0.70 'large', 0.70–0.90 'very large' and >0.9 'almost perfect' (Hopkins et al., 2009). The alpha level was set at $p < 0.05$. All statistical analyses were conducted using IBM SPSS Statistics for Macintosh (V25.0, IBM Corporation).

3 | RESULTS

Table 1 presents the mean ± SD values for the assessed strength and COD variables, along with the ICC and CV for each variable. The test reliability, both in relative and absolute terms, was confirmed (ICC ≥ 0.905; CV ≤ 7.94).

Table 2 displays a comparison between LP and HP groups for different turning angles with each strength variable. The HP group showed the highest levels of strength for all muscle actions. Concentric strength characteristics showed the largest significant differences between performance groups (ES ≥ 0.813; $p \le 0.034$) for a shear angle at 45°. At a cutting angle of 90°, the only variable demonstrating significant and substantial differences between

TABLE 1 Descriptive analysis (mean ± SD) of the performance variables analysed.

Variables	Mean ± SD	Minimal–Maximal	ICC	CV (%)
Isometric strength				
Mean force (kg)	175.5 ± 43.3	106.4–265.8	0.969	7.94
Peak force (kg)	203.3 ± 48.4	125.1–296.0	0.940	7.17
Impulse (N·s)	14,032.2 ± 3338.9	8498.1–21,238.5	0.981	4.35
Peak RFD (N/s)	9899.3 ± 6175.3	2992.9–26,935.9	0.973	3.75
Concentric strength at 0.6 $m{\cdot}s^{-1}$				
Mean force (kg)	67.4 ± 32.3	21.0–129.2	0.976	7.77
Peak force (kg)	134.5 ± 50.8	52.0–236.5	0.977	7.55
Peak RFD (N/s)	6941.5 ± 3044.3	1678.9–12,451.0	0.957	7.61
Eccentric strength at 0.6 $m{\cdot}s^{-1}$				
Mean force (kg)	165.1 ± 57.7	74.3–269.1	0.982	4.24
Peak force (kg)	246.8 ± 74.2	142.7–381.1	0.986	6.88
Peak RFD (N/s)	12,300.8 ± 3725.2	6514.4–19,987.1	0.919	7.49
Change of direction tests				
COD 45° L (s)	2.01 ± 0.16	1.63–2.51	0.941	2.38
COD 45° R (s)	2.01 ± 0.15	1.57–2.44	0.983	1.45
COD 90° L (s)	2.32 ± 0.18	1.94–2.83	0.935	2.55
COD 90° R (s)	2.32 ± 0.19	1.96–3.08	0.905	3.50
COD 180° L (s)	2.81 ± 0.21	2.54–3.44	0.955	2.25
COD 180° R (s)	2.81 ± 0.22	2.39–3.28	0.956	1.59

Abbreviations: COD, change of direction; CV, coefficient of variation.; ICC, intraclass correlation coefficient; L, left; R, right; RFD, rate of force development; SD, standard deviation.

groups was eccentric pRFD (ES = 0.882; $p = 0.035$). The sharpest COD at 180° revealed the greatest significant differences between groups for all isometric (ES ≥ 1.080; $p \leq 0.015$), concentric (ES ≥ 1.03; $p \leq 0.010$) and eccentric (ES ≥ 0.697; $p \leq 0.050$) strength outcome measures.

The correlation analysis between different strength outcome measures of each muscle action and COD tests is presented in Figure 2. Mean force (MF) and impulse in the isometric squat exhibited moderate negative correlations that were statistically significant with 90° (Rho ≥ 0.394; $p \leq 0.048$) and 180° (Rho ≥ 0.445; $p \leq 0.030$) cutting angles. The MF of the concentric phase of the isokinetic squat demonstrated a substantial negative correlation with 45° (Rho ≥ 0.460; $p \leq 0.022$) and 180° (Rho ≥ 0.551; $p \leq 0.005$) cutting angles. In relation to eccentric strength, it was fast force application, specifically pRFD, that displayed significant negative correlations with all COD angles (Rho ≥ 0.469; $p \leq 0.019$).

Table 3 displays the comparison between LP and HP groups for different turning angles in terms of each strength ratio. Significant large differences were identified in the E/C and I/C ratios (ES ≥ 0.834; $p \leq 0.035$) between performance groups, with the HP group showing the lowest values at a 45° cutting angle. Additionally, the I/C ratio also showed significant large differences between performance groups (ES = 0.994; $p = 0.030$) during the 180° COD test, indicating that those fastest at this cutting angulation resulted in the lowest I/C ratio.

4 | DISCUSSION

The purpose of the present study was to examine differences in strength outcome measures of lower limb muscle actions between faster and slower basketball players in COD actions at different angles. Additionally, the study aimed to analyse the relationship between isometric, concentric and eccentric strength outcome measures and COD performance at different cutting angles. The findings shed light on how the disparities in performance groups for each strength outcome measure were directly influenced by the cutting angle. Specifically, concentric strength measures displayed the most differences at a 45° angle, fast eccentric strength emerged as pivotal for cuts at 90° and all muscle actions showed significant differences at 180° COD. Noteworthy findings of this research included the robust relationship between the pRFD and all COD angulations, the significant relationship between concentric strength and COD at 45° and 180° and the moderate relationship between isometric strength and COD at 90° and 180°. Finally, the strength ratios underscored the importance of possessing high concentric strength levels

TABLE 2 Comparison (mean ± SD) of the different strength characteristics between *low performance* and *high performance* groups classified by each change of the direction test.

	COD 45°		**COD 90°**		**COD 180°**		***p value* (ES)**		
	LP (*n* = 12)	**HP (*n* = 13)**	**LP (*n* = 12)**	**HP (*n* = 13)**	**LP (*n* = 12)**	**HP (*n* = 13)**	**45°**	**90°**	**180°**
Isometric strength									
MF (kg)	166.6 ± 37.3	182.7 ± 46.4	167.0 ± 35.7	182.4 ± 47.5	149.5 ± 23.3	197.2 ± 43.1	*0.277* (0.503)	*0.424* (0.372)	***0.002*** (1.574)
PF (kg)	196.7 ± 43.8	206.8 ± 51.4	194.7 ± 39.5	208.5 ± 53.7	177.0 ± 32.2	223.5 ± 48.5	*0.733* (0.203)	*0.691* (0.193)	***0.015*** (1.080)
Impulse (N·s)	13,312.7 ± 2976.8	14,683.7 ± 3388.1	13,345.9 ± 2855.5	14,655.6 ± 3485.7	12,050.5 ± 1733.3	15,751.8 ± 3239.0	*0.331* (0.440)	*0.424* (0.355)	***0.002*** (1.495)
RFDp (N/s)	8794.4 ± 6741.3	10,834.1 ± 5757.9	10,277.8 ± 5546.3	9578.9 ± 6871.2	7583.5 ± 3772.4	11,858.7 ± 7221.9	*0.246* (0.328)	*0.562* (0.111)	*0.132* (0.723)
Concentric strength at 0.6 m·s^{-1}									
MF (kg)	52.6 ± 31.3	81.0 ± 27.6	65.3 ± 38.9	69.3 ± 26.2	49.8 ± 26.7	83.6 ± 29.0	***0.014*** (0.892)	*0.574* (0.116)	***0.002*** (1.299)
PF (kg)	112.3 ± 48.6	155.0 ± 45.1	137.0 ± 60.8	132.2 ± 42.0	110.5 ± 45.5	156.7 ± 46.5	***0.030*** (0.813)	*0.852* (0.007)	***0.010*** (1.032)
RFDp (N/s)	5935.6 ± 2913.7	7869.8 ± 2967.7	6584.7 ± 3328.9	7270.8 ± 2851.7	5858.4 ± 3251.9	7941.2 ± 2566.2	***0.034*** (0.865)	*0.807* (0.222)	*0.221* (0.715)
Eccentric strength at 0.6 m·s^{-1}									
MF (kg)	159.4 ± 64.5	170.3 ± 52.6	147.5 ± 62.1	181.3 ± 50.2	133.3 ± 58.7	185.3 ± 50.8	*0.503* (0.205)	*0.137* (0.569)	***0.049*** (0.775)
PF (kg)	235.2 ± 86.7	257.4 ± 62.1	222.8 ± 69.9	268.9 ± 73.6	202.3 ± 77.2	269.4 ± 66.3	0.347 (0.265)	*0.137* (0.535)	***0.050*** (0.697)
RFDp (N/s)	10,890.8 ± 3261.1	13,606.8 ± 2900.8	10,707.6 ± 2698.8	13,775.9 ± 3920.4	10,214.4 ± 2616.4	14,231.2 ± 2708.1	***0.035*** (0.882)	***0.016*** (1.027)	***0.001*** (1.507)

Note: Bold indicates significant differences between groups $p < 0.05$.

Abbreviations: COD, change of direction; HP, high performance group; LP, low performance group; MF, mean force; PF, peak force; RFDp, rate of force development peak.

compared to other muscular actions for achieving superior performance across various COD angulations.

These findings align with prior research, consistently indicating a strong relationship between isometric (Smolarek et al., 2023; Spiteri et al., 2014; Spiteri, Newton, & Nimphius, 2015), concentric (Spiteri et al., 2014, 2015) and eccentric (Jones et al., 2022; Smajla et al., 2022) strength measures and COD performance. However, these studies only examined the relationship between strength variables at a single cutting angle or within manoeuvrability tests that involved various cutting actions across multiple angles (Nimphius et al., 2018). Consequently, they could not provide a detailed analysis of the effect of each strength outcome measure on various COD angulations.

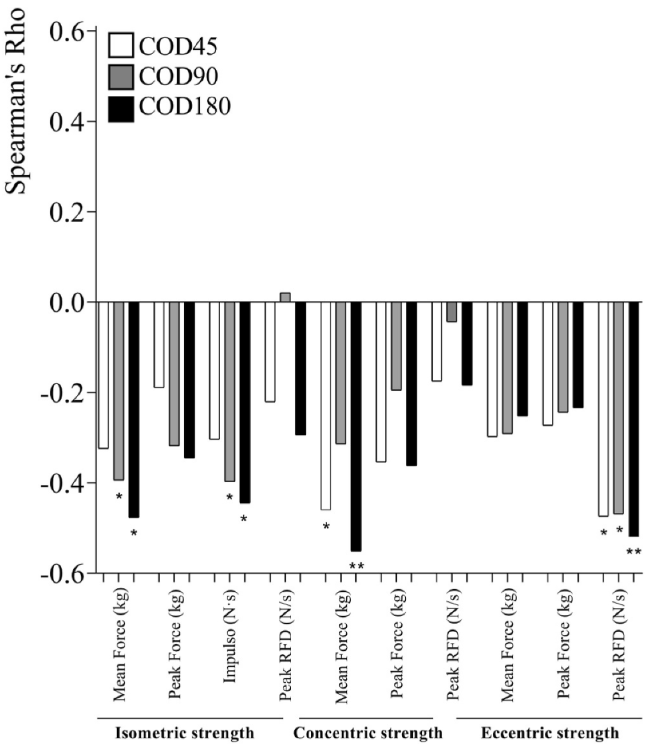

FIGURE 2 Spearman's Rho correlations between different strength outcome measures of each muscle action and change of direction tests. COD, Change of Direction time at 45° (COD45), 90° (COD90) and 180° (COD180) turn; RFD, Rate of Force Development. An asterisk (*) indicates $p < 0.05$; two asterisks (**) indicate $p < 0.001$.

The present study reinforces the existing literature's assertion that strength is an indispensable component for successful COD performance (Barrera-Domínguez et al., 2020; Young et al., 2002). Furthermore, it sheds light on the specific strength characteristics of each cutting angle. In this regard, for wide cutting angles of 45°, the concentric strength outcome measures had the greatest influence on COD performance. This could be explained by the emphasis on velocity in these shear angles (Bourgeois et al., 2017). Achieving optimal performance at 45° COD requires a primary focus on maintaining high speeds (Hader et al., 2015), characterised by ground contact times of less than 150 milliseconds and minimal braking forces (McBurnie & Dos'Santos, 2022). Thus, it makes sense that concentric strength is of great relevance in 45° COD.

Nevertheless, when performing COD with sharper cutting angles, the strength requirements undergo significant changes, and other strength outcome measures become increasingly influential on COD performance. Prior research has indicated that the mechanical characteristics of 90° and 180° cuts result in longer ground contact times in the final step, ranging from 250 to 500 milliseconds (McBurnie & Dos'Santos, 2022). The findings from the present study showed a strong relationship between isometric strength and COD performance at sharp angles. This relationship can be attributed to the need for the lower limbs to maintain isometrically longer reaction forces in the final step while the rest of the body undergoes reorganisation and redirection towards a new direction of displacement (Dos'Santos et al., 2021a).

In addition, it is known that 180° COD actions emphasise force-oriented characteristics (Bourgeois et al., 2017), demanding substantial braking and reacceleration forces for higher performance. The current results align with previous literature and show that the sharpest angles of 180° COD are the most force-demanding, with all assessed strength outcome measures serving as determinants in 180° COD. Finally, it is worth noting that among all the strength outcome measures obtained, eccentric pRFD showed the strongest relationship with COD and was the sole variable that exerted a significant impact on all cutting angles. COD actions are executed at maximal intensities and speeds with high external load demands, as demonstrated in recent studies that have recorded values of knee joint

TABLE 3 Comparison (mean ± SD) of the different strength ratios between *low performance* and *high performance* groups classified by each change of the direction test.

	COD 45°		COD 90°		COD 180°		*p value* (ES)		
	LP (n = 12)	HP (n = 13)	LP (n = 12)	HP (n = 13)	LP (n = 12)	HP (n = 13)	45°	90°	180°
Strength ratios									
E/I	1.04 ± 0.49	0.97 ± 0.38	0.92 ± 0.38	1.07 ± 0.47	1.06 ± 0.52	0.96 ± 0.34	*0.910* (0.162)	*0.361* (0.350)	*0.820* (0.214)
E/C	3.53 ± 1.37	2.45 ± 1.20	2.91 ± 1.58	3.02 ± 1.22	3.53 ± 1.58	2.44 ± 0.94	***0.035*** (0.834)	*0.650* (0.078)	*0.087* (0.743)
I/C	4.15 ± 2.04	2.59 ± 0.86	3.60 ± 2.03	3.06 ± 1.35	3.95 ± 1.81	2.76 ± 1.41	***0.026*** (1.026)	*0.649* (0.317)	***0.030*** (0.994)

Note: Bold indicates significant differences between groups $p < 0.05$.

Abbreviations: C, concentric; COD, change of direction; E, eccentric; ES, effect size; HP, high performance group; I, isometric; LP, low performance group.

angular velocities ranging from 469 to 493°/s during the deceleration phase before COD (Nedergaard et al., 2014). These elevated knee joint angular velocities underscore the paramount importance of rapid eccentric force production capacity and pre-activation of the knee extensors to facilitate early pRFD occurrence within the first 40 milliseconds of stance (data not shown).

Previous studies have highlighted the crucial role of eccentric muscle action in COD performance (Jones et al., 2017, 2022; Smajla et al., 2022), primarily due to substantial peaks in eccentric strength during braking actions. These peaks, reaching 168% higher than propulsive forces (Harper et al., 2022), emphasise the importance of eccentric strength. However, existing research often isolated eccentric muscle action without considering its interplay with other muscle actions or the specific COD tests performed. Our comprehensive study examined various strength outcome measures and scrutinised strength ratios across all muscle actions. Surprisingly, the swiftest players in COD exhibited higher concentric strength relative to eccentric and isometric strength, reflected in lower E/C and I/C ratios. This trend was evident in both sharper (180°) and shear (45°) cuts. These underscore the importance of possessing high concentric strength levels compared to other muscular actions for achieving superior performance in various COD angles. Although the capacity to rapidly apply eccentric strength during maximum deceleration at the COD is crucial (Harper et al., 2022), players demonstrating rapid eccentric force production with minimal disparities between eccentric and concentric strength excel across cutting angles. This highlights the multifaceted nature of COD performance, emphasising the importance of strength ratios for a more comprehensive assessment.

To the best of our knowledge, this study represents the first comprehensive analysis of the impact of different muscle actions assessed with FEMD on different cutting angles in basketball players. Even though the findings provide valuable insights into COD performance, it is essential to acknowledge several limitations inherent in our study. Firstly, all squats evaluated were performed bilaterally, while actual COD actions in basketball involve bilateral asymmetric or unilateral actions. Unilateral squat assessment with FEMD may be more specific and better simulate COD execution, which might lead to greater correlations, but may also show worse ICC and CV values. Secondly, the sample size is relatively small, which may restrict the generalisability of the findings to a larger population. Furthermore, it is important to note that due to the cross-sectional nature of our study, we cannot establish a cause-and-effect relationship. Nonetheless, it is worth mentioning that Barrera-Domínguez et al. (2023) reported improvements in COD performance at different angles in basketball players after an 8-week of individualised training program designed to enhance all strength outcome measures in the squat. This further reinforces the present research findings, adding valuable insights to the existing literature regarding the impact of diverse strength measures on COD. These insights may prove beneficial for coaches in devising more effective training programmes to enhance their athletes' COD performance.

5 | CONCLUSION

In conclusion, strength emerges as a pivotal factor influencing COD performance, and this study sheds light on intriguing discoveries in this domain. The results unequivocally demonstrated that the relationship between strength outcome measures and COD proficiency depends on the cutting angle. Specifically, cutting angles below 90° emphasise concentric strength, while those above 90° exhibit a stronger reliance on isometric and eccentric strength. Furthermore, rapid eccentric force production strongly correlates with COD performance across all cutting angles. However, the fastest players exhibit higher concentric strength relative to their eccentric strength. These findings are crucial for coaches seeking to improve their players' COD performance. Coaches should analyse the individual COD requirements, considering angle variations, and design tailored training programmes that focus on augmenting rapid eccentric force while aiming to reduce the E/C ratio. This strategic approach could optimise basketball players' COD abilities.

ACKNOWLEDGEMENTS

The authors are particularly grateful to all the athletes who voluntarily participated in the present study. The authors are also grateful for the support of the 'Network of Sports Functional Dynamometry' (09/UPB/23). This paper is part of the first author's doctoral thesis carried out in the Doctoral Program of the University of Huelva (Spain), thanks to the support and funding of the 'Formación del Profesorado Universitario' Program (FPU22/01057), run by Spanish Ministry of Universities. This program supports and funds the predoctoral researchers F.J.B.-D. (FPU22/01057) and I.d.-C. (FPU19/02030). Postdoctoral researchers D.J.-M. and D.M.-G., have a contract through the program 'Recualificación del Profesorado Universitario. Modalidad Margarita Salas', Universidad de Granada/Ministerio de Uni-versidades y Fondos Next Generation of the European Union. Funding for open access charge: Universidad de Huelva/CBUA.

CONFLICT OF INTEREST STATEMENT

The authors declare that they do not have any conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, F.J.B.-D., upon reasonable request.

PATIENT CONSENT STATEMENT

Informed consent was obtained from all participants included in the study.

ORCID

Francisco J. Barrera-Domínguez https://orcid.org/0000-0002-5387-1788
Indya del-Cuerpo https://orcid.org/0000-0002-2949-7896
Antonio Riego-Ruiz https://orcid.org/0009-0006-3593-2555

Darío Martínez-García https://orcid.org/0000-0003-0077-6813
Daniel Jerez-Mayorga https://orcid.org/0000-0002-6878-8004
Luís Javier Chirosa-Ríos https://orcid.org/0000-0002-1008-176X
Jorge Molina-López https://orcid.org/0000-0003-2516-5226

REFERENCES

Barrera-Domínguez, F. J., B. J. Almagro, E. Sáez de Villarreal, and J. Molina-López. 2023. "Effect of Individualised Strength and Plyometric Training on the Physical Performance of Basketball Players." *European Journal of Sport Science* 23(12): 1–10. https://doi.org/10.1080/17461391.2023.2238690.

Barrera-Domínguez, F. J., B. J. Almagro, I. Tornero-Quiñones, J. Sáez-Padilla, Á. Sierra-Robles, and J. Molina-López. 2020. "Decisive Factors for a Greater Performance in the Change of Direction and its Angulation in Male Basketball Players." *International Journal of Environmental Research and Public Health* 17(18): 6598. https://doi.org/10.3390/ijerph17186598.

Bourgeois, F., M. McGuigan, N. Gill, and G. Gamble. 2017. "Physical Characteristics and Performance in Change of Direction Tasks: A Brief Review and Training Considerations." *Journal of Australia Strength* 25: 104–17.

Castillo-Rodríguez, A., J. C. Fernández-García, J. L. Chinchilla-Minguet, and E. Á. Carnero. 2012. "Relationship between Muscular Strength and Sprints with Changes of Direction." *The Journal of Strength & Conditioning Research* 26(3): 725–32. https://doi.org/10.1519/JSC.0b013e31822602db.

Cohen, J. 1988. *Statistical Power Analysis for the Behavioural Sciences* 2nd ed. Routledge. https://doi.org/10.4324/9780203771587.

del-Cuerpo, I., D. Jerez-Mayorga, P. Delgado-Floody, M. D. Morenas-Aguilar, and L. J. Chirosa-Ríos. 2023. "Test–Retest Reliability of the Functional Electromechanical Dynamometer for Squat Exercise." *International Journal of Environmental Research and Public Health* 20(2): 1289. https://doi.org/10.3390/IJERPH20021289.

Dos'Santos, T., C. Thomas, P. Comfort, and P. A. Jones. 2018. "The Effect of Angle and Velocity on Change of Direction Biomechanics: An Angle-Velocity Trade-Off." *Sports Medicine* 48(10): 2235–53. https://doi.org/10.1007/s40279-018-0968-3.

Dos'Santos, T., C. Thomas, P. Comfort, and P. A. Jones. 2019. "Role of the Penultimate Foot Contact during Change of Direction." *Strength and Conditioning Journal* 41(1): 87–104. https://doi.org/10.1519/SSC.0000000000000395.

Dos'Santos, T., C. Thomas, and P. A. Jones. 2021a. "How Early Should You Brake during a 180° Turn? A Kinetic Comparison of the Antepenultimate, Penultimate, and Final Foot Contacts during a 505 Change of Direction Speed Test." *Journal of Sports Sciences* 39(4): 395–405. https://doi.org/10.1080/02640414.2020.1823130.

Dos'Santos, T., C. Thomas, and P. A. Jones. 2021b. "The Effect of Angle on Change of Direction Biomechanics: Comparison and Inter-task Relationships." *Journal of Sports Sciences* 39(22): 2618–31. https://doi.org/10.1080/02640414.2021.1948258.

Hader, K., D. Palazzi, and M. Buchheit. 2015. "Change of Direction Speed in Soccer: How Much Braking Is Enough?" *CHANGE OF DIRECTION SPEED IN SOCCER: Kinesiology* 47: 67–74.

Haff, G. G., R. P. Ruben, J. Lider, C. Twine, and P. Cormie. 2015. "A Comparison of Methods for Determining the Rate of Force Development during Isometric Midthigh Clean Pulls." *The Journal of Strength & Conditioning Research* 29(2): 386–95. https://doi.org/10.1519/JSC.0000000000000705.

Harper, D. J., A. J. McBurnie, T. D. Santos, O. Eriksrud, M. Evans, D. D. Cohen, D. Rhodes, C. Carling, and J. Kiely. 2022. "Biomechanical and Neuromuscular Performance Requirements of Horizontal Deceleration: A Review with Implications for Random Intermittent Multi-Directional Sports." *Sports Medicine* 52(10): 2321–54. https://doi.org/10.1007/S40279-022-01693-0.

Hopkins, W. G., S. W. Marshall, A. M. Batterham, and J. Hanin. 2009. "Progressive Statistics for Studies in Sports Medicine and Exercise Science." *Medicine & Science in Sports & Exercise* 41(1): 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278.

Jones, P. A., T. Dos'Santos, J. J. McMahon, and P. Graham-Smith. 2022. "Contribution of Eccentric Strength to Cutting Performance in Female Soccer Players." *The Journal of Strength & Conditioning Research* 36(2): 525–33. https://doi.org/10.1519/JSC.0000000000003433.

Jones, P. A., C. Thomas, T. Dos'santos, J. J. McMahon, and P. Graham-Smith. 2017. "The Role of Eccentric Strength in 180◦ Turns in Female Soccer Players." *Sports* 5(2): 42. https://doi.org/10.3390/SPORTS5020042.

Martinez-Garcia, D., A. Rodriguez-Perea, P. Barboza, D. Ulloa-Díaz, D. Jerez-Mayorga, I. Chirosa, and L. J. C. Ríos. 2020. "Reliability of a Standing Isokinetic Shoulder Rotators Strength Test Using a Functional Electromechanical Dynamometer: Effects of Velocity." *PeerJ* 8: e9951. https://doi.org/10.7717/PEERJ.9951/FIG-5.

Matthew, D., and A. Delextrat. 2009. "Heart Rate, Blood Lactate Concentration, and Time-Motion Analysis of Female Basketball Players during Competition." *Journal of Sports Sciences* 27(8): 813–21. https://doi.org/10.1080/02640410902926420.

McBurnie, A. J., and T. Dos'Santos. 2022. "Multidirectional Speed in Youth Soccer Players: Theoretical Underpinnings." *Strength and Conditioning Journal* 44(1): 15–33. https://doi.org/10.1519/SSC.0000000000000658.

Morenas-Aguilar, M. D., L. J. Chirosa Rios, A. Rodriguez-Perea, J. A. Vázquez Diz, I. J. Chirosa Rios, J. F. Vera Vera, L. Ruiz-Orellana, and D. Jerez-Mayorga. 2023. "Test-Retest Reliability of 3 Specific Strength Tests in Professional Handball Players." *Journal of Sport Rehabilitation* 33(1): 53–62. https://doi.org/10.1123/JSR.2022-0267.

Nedergaard, N. J., U. Kersting, and M. Lake. 2014. "Using Accelerometry to Quantify Deceleration during a High-Intensity Soccer Turning Manoeuvre." *Journal of Sports Sciences* 32(20): 1897–905. https://doi.org/10.1080/02640414.2014.965190.

Nimphius, S., S. J. Callaghan, N. E. Bezodis, and R. G. Lockie. 2018. "Change of Direction and Agility Tests: Challenging Our Current Measures of Performance." *Strength and Conditioning Journal* 40(1): 26–38. https://doi.org/10.1519/SSC.0000000000000309.

Nimphius, S., S. J. Callaghan, T. Spiteri, and R. G. Lockie. 2016. "Change of Direction Deficit: A More Isolated Measure of Change of Direction Performance Than Total 505 Time." *The Journal of Strength & Conditioning Research* 30(11): 3024–32. https://doi.org/10.1519/JSC.0000000000001421.

Power, C. J., J. L. Fox, V. J. Dalbo, and A. T. Scanlan. 2022. "External and Internal Load Variables Encountered during Training and Games in Female Basketball Players According to Playing Level and Playing Position: A Systematic Review." *Sports Medicine - Open* 8(1): 107. https://doi.org/10.1186/S40798-022-00498-9.

Rodriguez-Perea, Á., D. Jerez-Mayorga, A. García-Ramos, D. Martínez-García, and L. J. Chirosa Ríos. 2021. "Reliability and Concurrent Validity of a Functional Electromechanical Dynamometer Device for the Assessment of Movement Velocity." *Proceedings of the Institution of Mechanical Engineers - Part P: Journal of Sports Engineering and Technology* 235(3): 176–81. https://doi.org/10.1177/1754337120984883.

Salazar, H., J. Castellano, and L. Svilar. 2020. "Differences in External Load Variables between Playing Positions in Elite Basketball Match-Play." *Journal of Human Kinetics* 75(1): 257–66. https://doi.org/10.2478/HUKIN-2020-0054.

Smajla, D., Ž. Kozinc, and N. Šarabon. 2022. "Associations between Lower Limb Eccentric Muscle Capability and Change of Direction Speed in Basketball and Tennis Players." *PeerJ* 10: e13439. https://doi.org/10.7717/PEERJ.13439.

Smolarek, T., G. G. Haff, W. C. K. Poon, T. Nagatani, O. R. Barley, and S. N. Guppy. 2023. "Dynamic and Isometric Force-Time Curve Characteristics Influencing Change of Direction Performance of

State-Level Netball Players." *The Journal of Strength & Conditioning Research* 37(12): 2397–404. https://doi.org/10.1519/JSC.0000000000004616.

Spiteri, T., R. U. Newton, M. Binetti, N. H. Hart, J. M. Sheppard, and S. Nimphius. 2015a. "Mechanical Determinants of Faster Change of Direction and Agility Performance in Female Basketball Athletes." *The Journal of Strength & Conditioning Research* 29(8): 2205–14. https://doi.org/10.1519/JSC.0000000000000876.

Spiteri, T., R. U. Newton, and S. Nimphius. 2015b. "Neuromuscular Strategies Contributing to Faster Multidirectional Agility Performance." *Journal of Electromyography and Kinesiology* 25(4): 629–36. https://doi.org/10.1016/J.JELEKIN.2015.04.009.

Spiteri, T., S. Nimphius, N. H. Hart, C. Specos, J. M. Sheppard, and R. U. Newton. 2014. "Contribution of Strength Characteristics to Change of Direction and Agility Performance in Female Basketball Athletes." *The Journal of Strength & Conditioning Research* 28(9): 2415–23. https://doi.org/10.1519/JSC.0000000000000547.

Sugiyama, T., S. Maeo, T. Kurihara, H. Kanehisa, and T. Isaka. 2021. "Change of Direction Speed Tests in Basketball Players: A Brief Review of Test Varieties and Recent Trends." *Frontiers in Sports and Active Living | Www.Frontiersin.Org* 1: 645350. https://doi.org/10.3389/fspor.2021.645350.

Svilar, L., J. Castellano, and I. Jukic. 2018. "Load Monitoring System in Top-Level Basketball Team: Relationship between External and Internal Training Load." *Kinesiology* 50(1): 25–33. https://doi.org/10.26582/K.50.1.4.

Young, W. B., R. James, and I. Montgomery. 2002. "Is Muscle Power Related to Running Speed with Changes of Direction?" *The Journal of Sports Medicine and Physical Fitness* 42(3): 282–8. http://www.ncbi.nlm.nih.gov/pubmed/12094116.