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The Relationship between Kinematic and Kinetic Characteristics of Countermovement Jump and Change of Direction in Elite Female Basketball Players

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Abstract. The countermovement jump (CMJ) is a dynamic strength test used to assess neuromuscular performance in athletes, particularly in sports requiring rapid changes in direction (COD), such as basketball. **Methods:** Twelve professional female basketball players with over 1 year of resistance training and 6 years of specialized training participated. They performed unloaded CMJ (ULCMJ), loaded CMJ (LCMJ), and modified 505 (Mod-505) COD tests sequentially. Pearson's correlation analyzed associations between CMJ and Mod-505 variables. Participants were categorized into fast and slow Mod-505 groups, with differences assessed using t-tests ($p < .05$). **Results:** The fast Mod-505 group showed shorter total times and better performance in entry velocities (EnV1 and EnV2), with no difference in ground contact time. They had higher ULCMJ jump heights, eccentric peak force, mean power, and concentric duration. Negative correlations were found between Mod-505 total time and both ULCMJ and LCMJ jump heights, while positive correlations existed between LCMJ eccentric phase peak power and mean velocity. (r = .58-.83, p = .05). **Conclusion:** The CMJ is a standardized method for assessing lower limb muscle strength and evaluating professional female basketball players' COD performance. Enhancing lower body dynamic strength may improve jumping and COD abilities in this athletic population.

Keywords: Eccentric strength, basketball, vertical jump, multidirectional speed, agility

1 Introduction

The change of direction (COD) ability refers to a predictive technology encompassing an athlete's capacity to accelerate, decelerate, change direction, and re-accelerate swiftly during movement. In team sports arenas, the ability to move swiftly and change direction is a crucial factor for multidirectional athletic activities (Loturco et al., 2022; Martín-Moya & González-Fernández, 2022; Spiteri et al., 2014). For instance, in basketball, rapid changes in direction are frequent, often involving 180 degrees turns in the court (Dos' Santos et al., 2017; Dos'Santos et al., 2021; Spiteri et al., 2015). Elite basketball players execute approximately 50~60 COD movements per game (Spiteri et al., 2014), highlighting the importance of COD ability in basketball performance (Dos' Santos et al., 2017; Spiteri et al., 2015). The modified 505 (mod-505) COD is a frequently employed assessment for evaluating 180 degrees COD performance. Its diagnostic utility can be enhanced by implementing a multiple-timing gate or photoelectric cell system set-up, enabling the subdivision of the test into distinct sub-phases (Condello et al., 2020; Ryan et al., 2022). This COD test is a relatively straightforward assessment method, involving the measurement of the total time required to execute a single 180 degrees change of direction along a 5 meter out-and-back course (Gabbett et al., 2008; Jones & Nimphius, 2018). This test's simplicity and minimal equipment needs have led to its widespread adoption across various sports. However, its limitation lies in solely providing total time data, thus offering restricted diagnostic insight into athletes' entry, execution of 180 degrees turn, enter and exit phases (Dos' Santos et al., 2017; Nimphius et al., 2016; Ryan et al., 2022).

Previous literature has suggested that the Mod-505 COD may be more suitable for assessing the biomechanical performance of basketball players in COD situations (Dos' Santos et al., 2017). Within the basketball court, short-distance linear sprints and multiple COD movements within 5 meters are common indicating shorter overall movement distances (Conte et al., 2015). Basketball players often face scenarios requiring rapid accelerations, decelerations, and abrupt changes in direction within the confined playing area (Scanlan et al., 2014; Sugiyama et al., 2021). Studies indicate that elite basketball athletes transition between movement types every 1~3 seconds during matches (Abdelkrim et al., 2007; Scanlan et al., 2012). Consequently, superior COD performance is considered a crucial physical attribute for basketball players (Spiteri et al., 2014). An athlete's ability to modify their momentum during directional changes relies on sufficient eccentric (braking), isometric (plant phase), and concentric (propulsive) strength to decelerate and accelerate in the new direction swiftly (Dos' Santos et al., 2017; Spiteri et al., 2014; Wyatt et al., 2019). Therefore, COD and agility are context-specific motor skills. Employing a strength assessment replicating the lower body kinematics and muscle actions required during directional changes seems advantageous (Spiteri et al., 2014). Moreover, several studies have indicated a potential correlation between measures of countermovement jump (CMJ) performance, serving as an indicator of lower limb muscle strength, and COD (Jones et al., 2009; Pereira et al., 2018; Salaj & Markovic, 2011; Suarez-Arrones et al., 2020). However, these findings have shown inconsistency.

Previous investigations conducted have demonstrated a moderate to high correlation between CMJ Jump Height (JH) and COD Total Time (TT) (Jones et al., 2009; Pereira et al., 2018). However, COD tests exhibit limited discriminatory ability among higher-skilled groups, as evidenced by the absence of significant differences in completion time observed in ball players (Conte et al., 2015; Spiteri et al., 2015). Moreover, there is a dearth of evidence regarding the impact of velocity and time variables during the 505 tests.The correlation noted between jump performance and COD performance may be predominantly influenced by straight-line sprinting ability rather than the capacity to decelerate and re-accelerate during a COD maneuver (Ascenzi et al., 2020; Vescovi & Mcguigan, 2008). A modified 505 test, partitioned into sub-phases (such as acceleration, deceleration, 180 degrees turn, and reacceleration), could offer valuable insights into the temporal and velocity aspects of directional changes during the test (Ryan et al., 2022). Specifically, it allows for the examination of the time spent and the velocity attained during the transition between directions.

In contemporary sports performance assessment methodologies, field-based evaluations are increasingly favored. Among these, photoelectric systems (OptoJump) have gained traction due to their portability and ability to maintain natural athlete-surface interaction. Additionally, these systems offer content validity, enhancing their utility in sports performance evaluation (Condello et al., 2020; Glatthorn et al., 2011). The study also provided preliminary confirmation of the good-to-excellent reliability of the Optojump instrument for measuring contact time in COD tests (Condello et al., 2020).Numerous studies have posited a close correlation between muscle strength and COD ability (Dos' Santos et al., 2017; Spiteri et al., 2015). The proficient execution of the braking phase during COD maneuvers requires adequate muscle strength to reduce momentum and facilitate the transfer of the body's center of mass, thereby augmenting directional efficiency (Spiteri et al., 2014). Notably, the association between eccentric muscle strength and COD appears particularly prominent (Chaabene et al., 2018; Pereira et al., 2018). For instance, optimal eccentric muscle strength is essential during the braking phase of COD to optimize performance (Jones & Nimphius, 2018). Eccentric muscle strength is underscored in the literature as a pivotal determinant influencing COD performance and can serve as a key performance indicator (Hernández-Davó et al., 2024).

Since athletes are primarily focused on optimizing their performance within the specific requirements of their sport, COD, and agility can be considered as motor skills specific to the context of their sport. Therefore, it would be beneficial to utilize a dynamic strength assessment method that mimics the lower body kinematics and muscle actions necessary for executing directional changes (Bishop, Brashill, et al., 2021b; Spiteri et al., 2014). Spiteri et al (2015) have previously underscored the necessity for female athletes to possess sufficient levels of eccentric, concentric, dynamic, and isometric strength to facilitate rapid changes in direction. This strength capacity allows for enhanced force and impulse generation throughout movement sequences.CMJ are thought to resemble COD due to the shared goal of generating maximal force rapidly, thus optimizing power output. Additionally, the use of the stretch-shortening cycle in fast dynamic exercises such as COD and CMJ is believed to be similar in terms of transitioning muscle contractions from eccentric to concentric states swiftly (Castillo-Rodríguez et al., 2012; Nygaard Falch et al., 2019). Recent studies have established a correlation between CMJ height, and the total time required for COD (Hori et al., 2008; Pereira et al., 2018). However, there has been limited discussion regarding the kinematic and kinetic parameters of both tests, as well as the parameters of CMJ, and improvements in COD performance have shown inconsistent results (Ascenzi et al., 2020; Bishop, Berney, et al., 2021a). Notably, there was no significant correlation observed among athletes (Ascenzi et al., 2020).

The aim of this study is to utilize CMJ measurements to examine the relationship between additional parameters in COD and muscle strength, thereby enhancing understanding of the mechanisms involved in COD. Specifically, this study seeks to investigate the relationship between CMJ eccentric phase kinetic performance and COD biomechanical performance in professional female basketball players. Additionally, it aims to compare differences in COD biomechanical performance between groups with high- and low-level strength.

2 Methods

2.1 Subjects

Twelve professional female basketball players with a minimum of one year of resistance training experience and over six years of specialized training were recruited in the study. The experiment took place during the competitive season, with basketball technical training sessions held five times a week and strength training sessions scheduled one to two times per week, depending on the game schedule. Participants were required to be injury-free at the time of testing and have no history of major lower limb injuries, such as anterior cruciate ligament injuries. Ethics approval was obtained from the university's Human Research Ethics Committee prior to testing, and all participants provided informed consent before participating. Each participant performed the CMJ and Mod-505 COD test in a fixed sequence/random order. Details of the data collection and processing protocols for these tests are outlined in the subsequent sections.

2.2 Experimental Approach to the Problem

This study utilized a cross-sectional design, involving 12 subjects who underwent evaluation for kinematic mechanical variables during a Mod-505 COD test conducted across three testing sessions. Two different loads were administered: unloaded and loaded. Additionally, the participants performed the CMJ test three times, exerting maximum effort each time, with data collected on eccentric phase kinetic kinematic parameters. This study aims to (a) assess the correlation between CMJ eccentric peak force (PF), peak power (PP), mean power (MP), peak rate of force development (PRFD) and mean rate of force development (MRFD), peak velocity (PV), mean velocity (MV), and eccentric duration (EccDur). And the total time, penultimate ground contact time (PNGCT), final ground contact time (FINGCT), entry velocity 1(EnV1) (0 m to 3.5 m), entry velocity 2 (EnV2) (3.5 m to 5 m), exit velocity 1 (ExV1) (5 m to 3.5 m) and exit velocity 2 (ExV2) (5 m to 0 m) parameters of the Mod-505 COD test using Pearson's product-moment correlation coefficient. (b) Mod-505 total time is utilized to differentiate between high and low-performance groups. Subjects are categorized into groups based on median analysis of the pre-and post-50% Mod-505 total time. A t-test compares differences between the fast and slow Mod-505 total time groups in CMJ Ecc PF, impulse, penultimate (PEN), Final GCT, and EnV.

2.3 Experiment Procedures

Countermovement Jump

A three-axis force plate (9260AA, Kistler, Winterthur, Switzerland) captured the ground reaction force during the CMJ test. Two different loads were utilized for the CMJ test: a no-weight-bearing condition (using a polyvinyl chloride weighing less than 1 kg) unload CMJ (ULCMJ) and a weight-bearing condition (using a 20 kg barbell) load CMJ (LCMJ). Initially, the subjects positioned themselves above the force plate and positioned the load behind their neck. This positioning aimed to minimize hand swing movements, focusing solely on assessing lower limb ability (Kraska et al., 2009). Upon instruction from the tester, the subject swiftly squatted and executed a vertical jump. The depth of the squat was determined by the subject. Throughout the test, subjects were instructed to perform with maximum effort and as quickly as possible. A total of three jumps were completed with maximum effort. The lifting and hooking of the feet were prohibited during the jump to prevent test errors. Adequate rest periods of more than 1 minute were enforced between each jump. The raw data was acquired using BioWare software (2812A) through a data acquisition (DAQ) system analog signal adapter box (5695B, Kistler, Winterthur, Switzerland), and transferred to a computer with a sampling frequency set at 1000 Hz.

Modified-505 change of direction test

The performance of the Mod-505 COD test was measured using the light gate system (Smartspeed, Fusion Sport, Australia) and the Optojump Next System (Microgate, Bolzano, Italy). The light gate system recorded total time, split time, and entry velocity (EnV) during the test, with the positioning of the system adjusted based on previous research (Dos' Santos et al., 2017). Participants initiated preparatory movements with their left and right feet positioned 30 cm forward from the starting

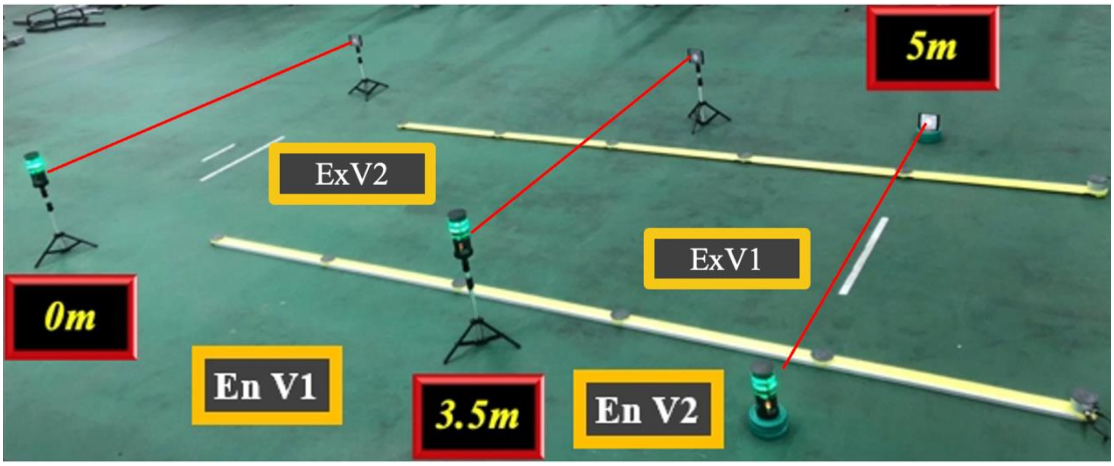

Fig. 1.. Instrument set-up for the modified-505 change of direction test.

point.

The Optojump Next System recorded ground contact time (GCT) with transmission and reception equipment placed along a 5-meter track. The system detected movement occurrence and calculated GCT when the communication link between the equipment was obstructed. Both the SmartSpeed light gate system and the Optojump Next photoelectric cells system utilized two parallel bars (receiver and transmitter units) installed on both the left and right sides. Participants started with their feet positioned at the front ends on the starting line, accelerated forward for 5 meters, executed a 180 degrees return movement within a designated return area of 5 meters (Gabbett et al., 2008; Hori et al., 2008). The SmartSpeed light gate system comprised a light gate and a reflector, with the distance between the equipment set at 3 meters from the starting point and 3.5 meters from the finishing point. The height of the light gate arrangement aligned with the subject's hip joint height (Dos' Santos et al., 2017; Jones et al., 2017). For subjects positioned at 5 meters, the height was adjusted to ankle height. The Optojump Next System was positioned within the light gate, 1 meter apart, to capture the GCT of subjects performing the Mod-505 COD (Figure 1).

Once the subject observed the green lights on both sides of the light gate at the starting point, they may initiate the test at their discretion. The subject sprinted forward for 5 meters until reaching the return line. To commence the return phase, the returning foot must step beyond the line. If the tester turns back prematurely or pivots with a foot not indicating the return, the score will not be calculated. A successful return entails the foot being positioned behind the line (Dos' Santos et al., 2017), And then performed a Mod-505 COD test both the right and left legs, with a total of two trials completed for each leg. A 2 minute rest period was provided between trials with the fastest trial used for subsequent data analysis.

2.4 Statistical Analyses

This study employed descriptive statistics to present subject characteristics, utilizing mean ± standard deviation (M±SD). Statistical analysis is conducted using SPSS version 20.00, with Pearson's correlation coefficient exploring the relationship between CMJ and mod-505 parameters. The relationship criteria were assessed using the following guidelines as very small ($r < 0.001$), small ($r = 0.1$~0.3), medium ($r = 0.3$~0.5), high ($r = 0.5$-0.7), very high ($r = 0.7$~0.9), nearly perfect ($r = 0.9$), perfect ($r = 1.0$) (Hopkins et al., 2009). Intraclass correlation coefficient (ICC) is utilized to compare reliability between reverse jumps, with ICC > 0.7 indicating high reliability (Koo & Li, 2016). Coefficient of variation (CV) is used to compare test reliability, with CV < 10% indicating high reliability (Turner et al., 2015). Subjects were divided into fast and slow groups based on their Modified-505 total time (Spiteri et al., 2014). Differences between these groups were assessed using a t-test, with effect sizes (ES) evaluated according to thresholds defined by Rhea (2004) such as trivial (≤ 0.19), small (0.20~0.59), moderate (0.60~1.19), large (1.20~1.99), and very large (2.0~4.0). The level of significance was set at 0.05.

Results

3 Results

The results indicated no statistically significant differences in age, height, or weight between the two groups ($p > 0.05$). ES confirming the absence of significant differences in these basic physiological variables between the groups (Table 1).

Table1. Subject's physiological characteristics

Item	Subjects (n = 12)	Fast (n = 6)	Slow (n = 6)	*P*	*ES*
Age (years)	23.1 ± 3.5	23.5 ± 4.6	23.3 ± 2.8	0.94	0.04
Height (cm)	177.2 ± 4.3	177.1 ± 5.7	177.1 ± 2.8	0.99	0.01
Weight (kg)	71.0 ± 6.9	71.9 ± 7.9	70.1 ± 6.4	0.66	0.25
Mod-505COD Total time (sec)	-	2.64 ± 0.01	2.72 ± 0.05	0.01	2.22

The total time for the fast group was significantly superior to that of the slow group. EnV1, indicating entry velocity into the COD scenario, was notably better in the fast group, suggesting they could enter COD situations at a quicker pace. Additionally, En V2 was completed in a shorter time by the fast group. No significant difference was observed between the two groups regarding the ground contact time (GCT) of the last two steps ($p > .05$). However, the fast group exhibited slightly longer final ground contact time (FINGCT) compared to the slow group, with a low effect size. Concerning exit time and velocity performance, which represent re-acceleration ability, the fast group outperformed the slow group, with a high effect size (Table 2).

Table 2. Comparing the mod-505 variables between the fast and slow groups

Variable	Fast (n = 6)	Slow (n = 6)	*P*	Fast vs. Slow ES	ES magnitude descriptor	Statistical power
Total Time (sec)	2.64 ± 0.01	2.72 ± 0.05	0.01	2.22	Large	0.014
EnV1 (m/s)	4.13 ± 0.09	4.05 ± 0.16	0.31	-0.62	Moderate	0.197
EnV2 (m/s)	5.25 ± 0.44	5.11 ± 0.20	0.48	-0.41	Small	0.726

PNGCT (sec)	0.36 ± 0.01	0.36 ± 0.05	0.73	0.00	Trivial	0.004
FINGCT (sec)	0.38 ± 0.05	0.36 ± 0.03	0.56	-0.49	Small	0.207
ExV1 (m/s)	1.80 ± 0.32	1.91 ± 0.12	0.46	0.44	Small	0.217
ExV2 (m/s)	4.74 ± 0.32	4.34 ± 0.27	0.04	-1.32	Large	0.942

Note. EnV1= entry velocity 1 (0 m-3.5 m), EnV2 = entry velocity 2 (3.5 m-5m), FINGCT = final ground contact time, PNGCT = penultimate ground contact time, ExV1 = Exit Velocity 1 (5m-3.5m), ExV2 = Exit Velocity 2 (3.5m-0m)

In the ULCMJ, the fast group exhibited significantly greater jump heights than the slow group. Notably, during the eccentric phase, parameters including eccentric peak force (EccPF), mean rate of force development (EccMRFD), and eccentric duration (EccDur) were notably higher in the High group ($p < .05$). Additionally, in the concentric phase, variables such as concentric peak force (ConPF), mean power (ConMP), and c oncentric duration (ConDur) were significantly superior in the High group ($p < .05$) (Table 3).

Table 3. Comparing the unloaded countermovement jump variables between the fast and slow groups

CMJ variable	Fast (*n* = 6)	Slow (*n* = 6)	*P*	Fast vs. Slow ES	ES magnitude descriptor	Statistical power
JH (cm)	28.85 ± 2.54	25.94 ± 4.04	0.16	-0.86	Large	0.014
			CMJ Ecc variable			
PF (N)	1643.29 ± 81.95	1469.15 ±136.54	0.02	-3.01	Large	0.567
MRFD ($N.s^{-1}$)	5617.27 ± 496.13	3989.86 ± 1092.58	0.01	-1.92	Large	0.008
EccDur (sec)	0.16 ± 0.01	0.20 ± 0.02	0.02	2.53	Large	0.029
			CMJ Con variable			
PF (N)	1642.75 ± 91.85	1478.99 ±121.47	0.02	-3.01	Large	0.832
MP (W)	1760.92 ± 171.74	1515.37 ± 173.87	0.03	-1.92	Large	0.929
ConDur (sec)	0.28 ± 0.02	0.33 ± 0.02	0.01	0.31	Small	0.926

Note. JH = Jump Height, PF =peak force, MF =mean force, MRFD, mean rate of force development, EccDur = eccentric duration, Ecc =eccentric, Con =concentric

In terms of LCMJ performance, there was no significant difference in jump height between the fast and slow groups ($p > .05$). however, all parameters of the fast group surpassed those of the slow group. specifically, eccentric peak force (EccPF), peak rate of force development (EccPRFD), mean rate of force development (EccMRFD), peak power (EccPP), mean power (EccMP), and eccentric duration (EccDur) exhibited statistically significant differences ($p < .05$) with large effect sizes. during the concentric phase, the fast group exhibited statistically significant differences ($p < .05$) in two parameters: concentric peak force (ConPF) and concentric duration (ConDur) with large effect sizes (table 4).

Table 4. Comparing the loaded countermovement jump variables between the fast and slow groups

CMJ variable	Fast (*n* = 6)	Slow (*n* = 6)	*P*	Fast vs. Slow ES	ES magnitude descriptor	Statistical power
JH (cm)	19.96 ± 2.58	18.61 ± 3.08	0.43	-0.48	Small	0.583
CMJ Ecc variable						
PF (N)	1704.59 ± 128.12	1496.92 ± 93.33	0.01	-1.85	Large	0.550
PRFD ($N.s^{-1}$)	10438.67 ± 1004.99	8407.33 ± 2216.50	0.01	-1.18	Large	0.236
MRFD ($N.s^{-1}$)	3988.89 ± 481.00	2444.15 ± 546.82	0.06	-3.00	Large	0.741
PP (W)	-1371.22 ± 111.50	-1202.96 ± 121.23	0.03	1.44	Large	0.468
MP (W)	-991.56 ± 55.24	-858.82 ± 73.19	0.01	2.05	Large	0.243
EccDur (sec)	0.20 ± 0.01	0.26 ± 0.03	0.01	2.68	Large	0.030
CMJ Con variable						
PF (N)	1700.44 ± 140.28	1536.97 ± 97.79	0.04	-1.35	Large	0.454
ConDur (sec)	0.35 ± 0.03	0.40 ± 0.03	0.02	1.67	Large	0.911

Note. JH = Jump Height, PF =peak force, PRFD, peak rate of force development, MRFD = mean rate of force development, PP = peak power, MP=mean power, EccDur = eccentric duration, Ecc =eccentric, Con =concentric

In this study, correlation analysis between the Mod 505 test and CMJ parameters revealed a significant negative correlation between mod505 COD total time and CMJ jump height, with ULCMJ (r = -0.78, p = 0.01) and LCMJ (r = -0.60, p = 0.05). Mod505 COD total time also showed negative correlations with ULCMJ and LCMJ eccentric phase PF (r = -0.62 to -0.59, p = 0.05), and positive correlations with LCMJ eccentric phase PP (r = 0.78, p = 0.01), MP (r = 0.83, p = 0.01), and MV (r = 0.58, p = 0.05). EnV2 exhibited negative correlations with LCMJ eccentric phase PP (r = -0.71, p = 0.01), MP (r = -0.63, p = 0.05), and MV (r = -0.68, p = 0.05). ExV2 showed positive correlations with ULCMJ and LCMJ eccentric phase JH (r = 0.68 to 0.65, p = 0.05), PF (r = 0.69 to 0.66, p = 0.05), and MRFD (r = 0.75 to 0.80, p = 0.01) (Table5).

The Concentric phase parameter of the CMJ exhibits a significant negative correlation with both Mod505 COD total time and ULCMJ PF (-0.62, p = 0.05). Furthermore, the LCMJ MP demonstrates a high to very high negative correlation (-0.724, p = 0.01; -0.595, p = 0.05), along with PV (-0.765, p = 0.01; -0.625, p = 0.05) and MV (-0.721, p = 0.01; -0.715, p = 0.01).Additionally, ExV2 of Mod505 COD in the Concentric phase parameters of ULCMJ and LCMJ exhibits significant to very high positive correlations with PF (0.613, p = 0.05; 0.589, p = 0.05), PP (0.698, p = 0.05; 0.622, p = 0.05), MP (0.709, p = 0.05; 0.697, p = 0.05), PV (0.844, p = 0.05; 0.760, p = 0.05), and MV (0.674, p = 0.05; 0.675, p = 0.05) (Table 6).

Table 5. The correlation between the modified 505 test and the unloaded and loaded countermovement jump eccentric variables.

			ULCMJ				
	JH	PF	MRFD	PRFD	PP	MP	MV
Total Time	-0.786**	-0.621*	-0.813**	-0.662*	-	-	-
EnV2	0.208	0.166	0.290	0.364	-	-	-
ExV2	0.685*	0.690*	0.757**	0.427	-	-	-
			LCMJ				
Total Time	-0.609*	-0.590*	-0.806**	-0.655*	0.762**	0.830**	0.586*
EnV2	-0.054	0.052	0.173	0.460	-0.715**	-0.631*	-0.689*
ExV2	0.655*	0.666*	0.807**	0.382	-0.217	-0.388	-0.069

Note. **. The correlation is significant at the .01 level, *.The correlation is significant at the .05 level, EnV1= entry velocity 1 (0 m-3.5 m), EnV2 = entry velocity 2 (3.5 m-5m),ExV2 = Exit Velocity 2 (3.5m-0m),JH = Jump Height, PF = peak force, PRFD, peak rate of force development, MRFD = mean rate of force development, PP = peak power, MP = mean power, MV = mean velocity, ULCMJ = unload countermovement Jump, LCMJ = load countermovement Jump.

Table 6. The correlation between the modified 505 test and the unloaded and loaded countermovement jump concentric variables.

			ULCMJ			
	IMP	PF	PP	MP	PV	MV
TT	-0.510	-0.627*	-0.537	-0.724**	-0.765**	-0.721**
ExV2	0.613*	0.698*	0.709**	0.844**	0.674*	0.605*
			LCMJ			
TT	-0.445	-0.511	-0.487	-0.595*	-0.625*	-0.715**
ExV2	0.589*	0.622*	0.697*	0.760**	0.675*	0.722**

Note. **. The correlation is significant at the .01 level, *. The correlation is significant at the .05 level, ExV2 = Exit Velocity 2 (3.5m-0m), IMP= impulse, PF = peak force, PP = peak power, MP = mean power, PV = peak velocity, MV = mean velocity, ULCMJ = unload countermovement jump, LCMJ = load countermovement jump.

4 Discussion

This investigation explored the relationship between CMJ and COD parameters among professional women's basketball players. The findings suggest a significant correlation between COD ability and CMJ performance, particularly those involving the SSC, which mirrors muscle action during directional changes. These insights provide valuable guidance for practitioners in evaluating the athletic performance of female basketball players and designing targeted strength and conditioning training programs.

The CMJ unloading phase initiates the countermovement, generating negative kinetic energy. Variations in the unloading strategy may impact downward kinetic energy, influencing the demand for eccentric force production and elastic energy storage. Athletes with greater eccentric force production capacity may have more braking strategies available, potentially affecting choices in competition (Barker et al., 2018).

Previous investigations conducted have demonstrated a moderate to high correlation between CMJ Jump Height (JH) and COD Total Time (TT) (Jones et al., 2009; Pereira et al., 2018).This finding is consistent with the results of the present study, wherein significant correlations were observed between CMJ JH and COD TT, with coefficients of ($p < 0.05$) of $r = -.78$ for ULCMJ and ($p < 0.05$) of $r = -.60$ for LCMJ, indicating a robust relationship between vertical jump performance and agility in female basketball players. Another study also assessed 505 COD total time, which exhibited no correlation with performance in any of the countermovement jumps. The correlation noted between jump performance and COD performance may be predominantly influenced by straight-line sprinting ability rather than the capacity to decelerate and re-accelerate during a COD maneuver (Ascenzi et al., 2020; Vescovi & Mcguigan, 2008).

Further exploration of the CMJ unveiled significant correlations among PV, 505-agility time, and the total time taken to complete the 505 COD test ($r > -0.57$, $p \leq 0.03$) (Ascenzi et al., 2020). However, this study lacked a comprehensive kinematic analysis of the COD, focusing solely on the correlation between the total time of COD and CMJ parameters. There exists a gap in further analyzing the kinematics of the COD maneuver and the concentric and eccentric parameters of the CMJ. The significance of lower body force production has been underscored in both COD and the CMJ (Bishop, Brashill, et al., 2021a; Hori et al., 2008; Marshall et al., 2014; Nygaard Falch et al., 2020). The eccentric phase of the CMJ was identified as the most indicative measure of eccentric strength ability (Smajla et al., 2022). Muscle activation patterns observed suggest similarities in the required force production by the lower limb muscles when comparing the COD step with CMJ (Jones & Nimphius, 2018; Nygaard Falch et al., 2020; Spiteri et al., 2014). Furthermore, research findings revealed a high correlation with the CMJ ($r = 0.6$) when employing a similar sprint with a 180° turn to assess COD performance (Castillo-Rodríguez et al., 2012). This may be attributed to a shared dependency on peak muscle activities (Nygaard Falch et al., 2020). Therefore, to enhance COD performance, it is essential to focus on various aspects of maximal eccentric strength and execute eccentric-concentric actions with velocity and agility.

Spiteri et al. (2014) established significant correlations between diverse muscle strength attributes and COD proficiency, with eccentric force parameters exhibiting the strongest association. Prior investigations consistently underscore the pivotal role of eccentric force in the braking phase of COD, accentuating its capacity to augment braking prowess, curtail momentum, and thereby enhance overall movement efficacy. Delaney et al. (2015) scrutinized the interplay between the LCMJ and the braking phase of COD. Their findings elucidated that LCMJ effectively replicates the braking phase of COD. Furthermore, heightened braking proficiency during COD fosters more streamlined directional shifts and seamless transitions to subsequent movements. Moreover, research on LCMJ has delineated correlations between eccentric phase parameters observed during 180 degrees COD and Total Time (Delaney et al., 2015; Hori et al., 2008; Spiteri et al., 2014).

The significance of lower body force production has been underscored in both COD and the CMJ (Bishop, Brashill, et al., 2021b; Hori et al., 2008; Marshall et al., 2014; Nygaard Falch et al., 2020). Muscle activation patterns observed suggest similarities in the required force production by the lower limb muscles when comparing the COD step with CMJ (Jones & Nimphius, 2018; Nygaard Falch et al., 2020; Spiteri et al., 2014). Furthermore, research findings revealed a high correlation with the CMJ (r = 0.6) when employing a similar sprint with a 180° turn to assess COD performance (Castillo-Rodríguez et al., 2012). This may be attributed to a shared dependency on peak muscle activities (Nygaard Falch et al., 2020).

Current understanding suggests that centrifugal force plays a significant role in the braking phase of COD, impacting Total Time and Ground Contact Time (GCT) during COD maneuvers. Despite numerous studies investigating the relationship between COD and biomechanical performance, the specific biomechanical mechanisms underlying braking performance during COD remain unclear (Dos' Santos et al., 2019; Marshall et al., 2014).

Previous research on ground reaction force production during COD movements has emphasized the importance of braking capacity (eccentric strength) for accelerating out of directional changes (Wisløff et al., 2004). Enhanced force application is imperative for braking, aiding in the reduction of an athlete's momentum (Brughelli et al., 2008; Martín-Moya & González-Fernández, 2022), When encountering pronounced directional alterations, athletes must decelerate rapidly, requiring increased engagement of eccentric muscles. This phenomenon, involving deceleration at velocities exceeding multiples of body weight, may explain the significant correlations (r = -0.39 to -0.85) observed between power in the LCMJ and performance time in the 505 COD test (Hori et al., 2008; Nimphius et al., 2010). Comparing the performances of loaded and unloaded CMJ variations can offer valuable training insights into the efficiency of a player's ability. This comparison may be particularly crucial considering the involvement of the SSC in various basketball-related activities, such as sprinting, jumping, and COD (Delaney et al., 2015; Hori et al., 2008).

The rapid 180° directional change, as demonstrated in the Modified 505 COD test, simulates a backdoor cut in basketball and reflects the demands on athletes to position themselves relative to their opponents (Spiteri et al., 2015). The findings of Spiteri et al. (2015) are supported by faster athletes in the 505 COD test exhibiting notably higher braking and propulsive forces compared to slower athletes, despite having shorter contact times. This trend is consistent with the results of this study.Increasing force application during the braking phase of COD movements has been demonstrated to enhance exit velocity (Spiteri et al., 2013; Spiteri et al., 2015) due to improved storage and utilization of elastic energy as muscles lengthen under eccentric loading (Dos' Santos et al., 2017; Spiteri et al., 2013; Spiteri et al., 2015). Although this study did not observe a significant difference in entry velocity between faster and slower athletes, noteworthy disparities were noted in exit velocity 3.5m-0m (ExV2). (Fast: 4.74 ± 0.32 m/s, Slow: 4.34 ± 0.27 m/s) ($p < .05$, ES = -1. 32), The proposal posits that although the transition from the eccentric phase is protracted and slower, the conversion from eccentric to concentric force may directly result from the athletes' eccentric strength capacity to absorb and generate force during this phase. Consequently, this promotes an increase in subsequent sprint velocity (Baena-Raya et al., 2022; Jones & Nimphius, 2018; Spiteri et al., 2015).

In this investigation, female basketball players in the high-performance cohort demonstrated significantly greater strength, power, and force production rates during the eccentric phase of both ULCMJ and LCMJ compared to their counterparts in the low-performance group. This underscores the capacity of the eccentric phase to generate heightened force output within a condensed timeframe, thereby enhancing overall eccentric phase power output. Moreover, a higher force production rate indicates the ability to generate maximum force within a brief period. In situations involving changes in direction, deceleration necessitates increased strength and consequently leads to greater power generation during the deceleration action within a short timeframe (Nygaard Falch et al., 2019; Smajla et al., 2022).Additionally, the concentric phase, crucial for re-acceleration during directional shifts, also contributes to heightened power production within a short duration. Hence, the development of strength and power attributes is paramount for executing forceful propulsive movements, such as sprinting.The correlation between CMJ performance and COD is influenced by both the concentric execution of the jump and the subsequent linear sprint velocity achieved after completing the directional change maneuver. Further biomechanical validation is essential for understanding COD, as it involves distinct eccentric and centripetal displacement of the center of gravity and primarily consists of lateral steering actions rather than solely vertical muscle contraction modes typical of CMJ.

5 Conclusion

In conclusion, this study has established a foundational understanding of the relationship between jump eccentric velocity, COD velocity, and timing in female basketball players. The incorporation of eccentric training methods into strength and conditioning programs is recommended to enhance performance in movements requiring rapid directional changes. Furthermore, future research should focus on longitudinal studies to monitor the progression of strength attributes over time and investigate injury prevention strategies aimed at improving eccentric strength and power. Such efforts will optimize the athletic performance of female basketball players, highlighting the critical role of eccentric training in their development.

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