Enhancement of Change of Direction Performance in Professional Female Soccer Players

David Martínez-Hernández

University of Salford, Manchester, UK

School of Health and Society

Supervisors: Dr Paul Jones, Dr Paul Comfort and Dr Mark Quinn

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ABBREVIATIONS

ACL: Anterior cruciate ligament

AT: Attacker group

BJ: Broad jump

BM: Body mass

BMC: Bloomfield movement classification

BW: Body weight

CG: Control group

CMJ: Countermovement jump

COD: Change of direction

CV: Coefficient of variation

CI: Confidence interval

DG: Defender group

DJ: Drop jump

EPL: English Premier League

FSCS: Flywheel squat concentric strength

FSES: Flywheel squat eccentric strength

GCT: Ground contact time

GPS: Global Positioning System

GRF: Ground reaction force

ICC: Intraclass correlation coefficient

IG: Intervention group

IMTP: Isometric mid-thigh pull

KF: Knee flexor

KE: Knee extensor

M: Matchday

NHES: Nordic hamstring eccentric strength

SD: Standard deviation

SJ: Squat jump

SL: Single leg

SEM: Standard error of measurement

SSC: Stretch shortening cycle

SWC: Smallest worthwhile change

WSL: Women’s Super league

ABSTRACT

The ability to rapidly change direction is believed to be a key physical quality for soccer players and commonly forms part of testing batteries performed by soccer teams. While whole match analysis shows that numerous changes of direction are performed during the game, there is limited research assessing the impact of these on key moments such as goal-scoring actions. Moreover, while numerous researchers have investigated the different methods to enhance change of direction (COD) performance, there is yet no clear evidence of the most effective practice for the improvement of COD ability. This gap in research is particularly concerning in elite female soccer players. Therefore, the understanding of which CODs are more common in key moments of the game and training interventions that can improve this physical ability would be of great interest to practitioners working in soccer.

The primary aims of this thesis are: 1. To identify the movements and combination of them that occur before a goal in male and female professional elite soccer. 2. Determine which of these are considered as COD actions and how often they are involved in goal-scoring situations. 3. Investigate which speed, jump and strength tests correlate with relevant COD tests. 4. Examine the effects of a specific training intervention to improve COD performance in elite soccer players.

The aim of study 1 (Chapter 4) was to analyse the most common movements prior to a goal in the English Premier League (EPL) and Women's Super league (WSL) through video analysis. Linear advancing motion followed by deceleration and turn showed to be the most common movements preceding a goal, with these three movements commonly following a certain cycle. Although players followed similar trends, there were dissimilarities based on their role. Finally, COD actions showed to be highly frequent in goal-scoring situations.

The aim of study 2 (Chapter 5) was to assess within-session reliability of different tests measuring speed, COD, jump [countermovement jump (CMJ), single leg (SL) CMJ, drop jump (DJ), SL DJ and SL broad jump (BJ)] and strength tests [flywheel squat concentric strength (FSCS), flywheel squat eccentric strength (FSES), Nordic hamstring eccentric strength (NHES) and isometric mid-thigh pull (IMTP)] in 11 elite female soccer players (age 26.6 ±4.8 years, height 166 ±6.8 cm, body mass 61.6 ±5.2 kg). Results revealed moderate to excellent intraclass correlation coefficients (ICCs) and low coefficient of variation (CVs) in all tests except for the 5-m split and 505 test to the right (ICC = 0.47 and 0.49, respectively) as well as FSCS (CV = 24.1%) and FSES (CV = 18.8%).

The aim of study 3 (Chapter 6) was to assess whether speed, jump and strength tests had a relation with COD performance in 26 female elite soccer players (age 25.1 ±5.7 years, height 166 ±5.5 cm, body mass 62.8 ±5 kg). Speed showed low to moderate correlations with COD tests (r= 0.14 - 0.49). SL CMJ, CMJ and SL BJ showed moderate to large correlations with 505 COD test (-0.3 to -0.6) and low to moderate correlations with 75-90° COD test (r= -0.15 to -0.49). DJ and SL DJ showed trivial to very large and trivial to large correlations with 505 COD (r= -0.05 to -0.71) and 75-90° COD (r= -0.07 to 0,67), respectively. IMTP and FSES showed large (r= -0.53 to -0.68) and moderate correlations (r= -0.31 to -0.46) with 505 COD test, respectively, while only showing moderate (r= -0.36 to -0.44) and low correlations (r= -0.1 to -0.27) with 75-90° COD test, respectively.

The aim of study 4 (Chapter 7) was to compare two distinct training programs designed for attackers and defenders to improve position-specific COD performance (COD 505 test and COD 75-90°). Elite female soccer players were divided into a control group (CG), a defender group (DG) and an attacker group (AG). Only DG improved pre- to post-test performance on the 505 COD tests. Fast performers in DF and AG showed no improvements in all COD tests, while slow performers in DG showed large to very large improvements in the COD 505 test, with slow performers in AG showing moderate to large improvements in the COD 75-90° test.

Overall, these studies help to provide further insight into the most common COD actions performed in goal-scoring situations and how these vary based on the player's role. In addition, it assists in appropriate test selection and in the development of COD-specific programs (pitch and gym) based on the player's role.

Keywords: change of direction, multidirectional speed, position-specific, elite soccer.

COVID-affected Thesis Statement

The uncertainty surrounding the duration of the pandemic made it challenging to establish clear timelines for data collection. It was difficult to determine whether it would be better to wait for the pandemic to end before starting. Given the uncertainty of the timeframes of COVID-19 to end, I chose to proceed with data collection despite the potential challenges and complications.

COVID-19 impacted data collection in several ways. During reliability, correlation, and experimental studies, all testing equipment had to be sanitized before and after each player's participation, significantly extending the testing time. Additional preventive measures, such as mask-wearing and social distancing, had a smaller impact but still influenced the process.

While for study 2 (Chapter 5) we aimed to recruit a full squad of Women's Super League, seven players were not available for testing due to COVID-19, which highly reduced the total number of players that performed the testing protocol. According to G*Power calculations, the minimum required sample was 26, but the pandemic led to a substantial reduction. This likely affected reliability, as small and homogeneous groups tend to produce lower intraclass correlation coefficients (ICCs) and wider confidence intervals (CIs) (Koo & Li, 2016; Roberts et al., 2001; Borg et al., 2022). Consequently, I relied on the ICC point estimate rather than the more conservative lower-bound CI. With a larger sample size, potentially yielding higher ICCs and narrower CIs, I would have maintained the use of point estimates. A higher sample size and potentially higher reliability scores would have confirmed the consistency of the tests utilised, ensuring that results in the following studies were trustworthy and not influenced by random errors, allowing for accurate interpretation and comparison of scores.

Due to COVID-19 affecting the data collection of study 2 (Chapter 5), I was conscious of not gathering sufficient data for the correlation study (Chapter 6), Therefore, I decided to test players for the whole season and the beginning of the following season, rather than on one occasion in order to gather more data. This affected the number of times we could perform some of the tests, as the equipment utilised was not owned. Therefore, the low sample size in some of the tests could have impacted some of the correlations observed.

If there had not been COVID-19, to start with, the data collection process would have been simpler and less time-consuming. Moreover, I would have been able to test a greater number of players for the reliability study, possibly obtaining higher ICCs and narrower CIs. I would have made the decision of performing the correlation study on one occasion rather than multiple times and would have been able to have a bigger sample size of some of the tests such as the isometric mid-thigh pull.

CHAPTER 1: INTRODUCTION

Introduction

Soccer is the world's most popular sport and a part of the social and cultural fabric of society in many countries (Bangsbo & Iaia, 2013). Although players need technical and tactical skills to succeed (Hoff & Helgerud, 2004), they must also develop a high level of athleticism to be successful (Turner & Stewart, 2014). One of the most important fitness components in soccer is agility (Turner & Stewart, 2014), which is defined as a rapid whole-body movement with a change of velocity or direction in response to a stimulus (Sheppard & Young, 2006). Therefore, according to these authors, agility is formed by change of direction (COD) speed and perceptual and decision-making factors. In this sense, COD could be part of an agility task but also part of a movement where there is no reaction to a stimulus.

COD is an imperative quality in soccer, and so, it is not surprising that different researchers have analysed the number of COD activities during a match (Nedelec et al., 2014: Granero-Gil et al., 2020; Robinson et al., 2011; Baptista et al., 2018; Morgan, et al., 2022; Bloomfield et al., 2007a, Dos'Santos et al., 2022b). The results of these studies differ in the total amount of CODs performed during a match, going from 11.9 hard changes of direction to more than 700 turns and swerves (Nedelec et al., 2014; Bloomfield et al., 2007a). These differences could be related to the different definitions of COD utilised as well as the different methods used for analysis (e.g., video analysis, GPS and gyroscope). When looking at COD actions occurring in key moments of the match, such as goal-scoring actions, a study by Faude et al (2012) showed COD sprint [defined as a very high-intensity run with two distinct and identifiable accelerations in different directions (more than 50° from the initial sprint line)] to be involved in goal-scoring situations with a modest contribution of 8% [95% coefficient intervals (CI) = 5-11%] and 9% (95% CI = 6-12%) for assisting and scoring players respectively, although the definition of these activities could have reduced the frequency. Therefore, even though researchers have investigated the importance of COD actions in a whole game and one study has examined this during key moments (i.e. goal-scoring situations), there is a need for more detailed research in order to understand the implications of this physical action in soccer, more so when COD ability is habitually targeted by practitioners as a physical capacity to enhance through specific training methods

(De Keijzer et al., 2021) and COD and agility tests are frequently assessed in soccer players (Walker & Turner, 2009).

Researchers have conducted a wide range of COD and agility tests, not only to evaluate the physical abilities of soccer players (Walker & Turner, 2009) or for talent identification (Reilly et al., 2000; Mirkov, 2010) but also to assess performance changes following various training protocols. (De Hoyo et al., 2016b; Tous-Fajardo et al., 2016). It is important to note that some of those so-called ‘agility tests’ do not measure agility, as most of these do not include a reaction to a stimulus (Nimphius et al., 2018). Taking into account that these various tests would assess different physical qualities (as these are performed in different manners), factors contributing to possible changes in results can be confusing and/or misinterpreted, and so more research is needed to isolate physical attributes involved in a COD test. Therefore, it is not surprising the lack of consensus in the literature regarding the most important physical qualities underpinning COD speed. In this sense, COD performance is linked to the ability of an athlete to accept force (braking) and produce force (acceleration) within a force-time curve (impulse) (Nimphius et al., 2017). More so, the magnitude of forces produced and the time available to produce these forces can be utilised to recognize the physical requirements to perform the COD (Nimphius et al., 2017). As force is applied during propulsion and braking, concentric, isometric and eccentric strength are important underpinning physical qualities for successful COD performance. Anyhow, the importance of each sub-component of power and strength will be dependent on the type of COD performed. For example, shallow CODs, due to the time available to perform the COD, may rely on and short and long stretch shortening cycle (SSC), while sharp CODs would be more related to strength and slow SSC (Dos’Santos et al., 2018a; Nimphius et al., 2017; McBurnie, & Dos’Santos, 2022). More so, the technique utilised in these COD actions also impacts the success of this action (Dos’Santos et al., 2021a).

Generally, studies show correlations between COD ability and different measures of power or jump (slow and fast SSC) and strength (eccentric, isometric and concentric), but without considering the impact of the ground contact times (GCTs) of the selected CODs with the physical qualities selected. In addition, fast vs slow performers have shown different force characteristics during a COD task, with the faster players demonstrating shorter final ground contacts, lower vertical impact forces, lower horizontal braking forces ratios, and greater horizontal propulsive force (Dos’Santos et al., 2017a).

Different studies have demonstrated how training strategies aiming to increase force production can impact COD performance, with studies showing improvements in strength and/or power/ jump tests parallel to COD performance enhancement (Pardos-Mainer et al., 2019; González-García et al., 2019; Ramirez-Campillo et al., 2018; Ramírez-Campillo et al., 2016), although other studies have shown enhancement in jump or strength performance with no improvements in COD ability (Millar et al., 2020; Bimson et al., 2017; Pecci et al., 2022), with one study analysing changes in braking and propulsive contact times as well as braking and propulsive forces and impulses (de Hoyo et al., 2016b). Therefore, while numerous researchers have assessed associations between COD ability and different physical qualities, to date, only a limited number of studies have considered how the characteristics of these tests can impact the physical qualities that underpin them (Falch et al., 2021). Moreover, research has not contemplated which COD tests would be more appropriate for soccer players based on the most common COD actions performed in key moments of the game and the characteristics of the player's role (attacker or defender). In addition, researchers generally design training interventions that target single or multiple physical qualities, without considering how the COD/s selected will impact the research findings.

It is also important to acknowledge the differences between males and females, with several key factors impacting player development, performance, and safety. For example, research shows physical differences between male and female soccer players with the 1st showing higher levels of speed, power, strength and endurance (Martín-Moya et al., 2023; Mujika et al., 2009; Brophy et al., 2009). Moreover, genders show a difference in biomechanics (Thomas et al., 2024) and hormonal fluctuations derived from the menstrual cycle in female players (Randell et al., 2021). Irrespective of these physiological differences both male and female soccer players play with the same size and weight of ball, same pitch and goal dimensions for the same game duration, with female players having to adapt to rules and regulations appropriate for men and their physical characteristics, making games much more demanding for women (Pedersen et al., 2019). Due to these differences in strength, biomechanical and hormonal characteristics, genders show differences in the most common injuries sustained (Waldén et al., 2011). Additionally, male and female soccer players differ in psychological characteristics, such as self-confidence and motivation, which are shown to be higher in males (Deaner et al, 2016). Moreover, female athletes are diagnosed with psychological issues more frequently than their male counterparts and seem more vulnerable to challenges in their environment (Schaal et al., 2011).

These differences are even more concerning given the disparities in support, resources, recognition, media representation, and opportunities between male and female elite soccer players, spanning from the academy to the senior level (Fan et al., 2023).

Moreover, while there has been an increased interest in female soccer, most of the research is performed on male players (Kirkendall & Krustrup, 2022). Due to this lack of research, there is a lower level of holistic understanding of female soccer, which could lead practitioners to apply and design programs based on male research.

Aim and Objectives

The aim of this thesis was to inform assessment and training strategies to enhance COD performance of elite female soccer players based on the position-specific COD demands in key moments of matches.

In order to achieve this aim, the thesis had the following objectives:

1. To examine the movements and combination of them that occur before a goal in male and female professional elite soccer, as well as acknowledge differences between genders and roles (attackers and defenders).
2. Identify the movements classified as COD actions and determine their frequency in goal-scoring scenarios.
3. Investigate which speed, jump and strength tests correlate with relevant COD tests.
4. To evaluate the effects of a position-specific training intervention to improve COD performance in elite female soccer players.

Research Questions and Rationale

a) Which are the most common movements performed before a goal in male and female soccer, and at what intensity are these performed? Are there any differences between genders? (Chapter 4)

Different researchers have investigated the frequency of COD or turning activities during matches in male soccer (Baptista et al., 2018; Bloomfield, et al., 2007a; Dos'Santos et al., 2022b; Granero-Gil et al., 2020; Morgan et al., 2022; Nedelec et al., 2014, Dos'Santos et al., 2022b). Anyhow, only one study has analysed the movements occurring before goals, with straight sprint showing to be the most common action and 83% of the involvements showing to involve at least a movement performed at high intensity. (Faude et al., 2012). Nevertheless, it is of interest to determine the movement characteristics of other leagues besides the German National League, such as the English Premier League (EPL). Furthermore, an equivalent analysis has not been conducted within a female professional soccer league. Moreover, there is a necessity for a comprehensive examination encompassing a broader spectrum of movements, intensities, and directions.

b) Are there any differences between roles (attackers and defenders) when looking at the most common actions performed in goal-scoring situations? (Chapter 4)

While the different studies analysing COD and turning actions in a whole match distinguish between different playing positions in soccer (Baptista et al., 2018; Bloomfield, et al., 2007a; Dos'Santos et al., 2022b; Granero-Gil et al., 2020; Morgan et al., 2022; Nedelec et al., 2014), the only study analysing movements in goal-scoring situations analysed only the scoring and assisting player (Faude et al, 2012). Including players with defensive roles would provide insight into their common patterns and highlight the key differences compared to their attacking counterparts.

c) Which are the most common combinations of movements performed during goal-scoring situations and do these involve COD actions? (Chapter 4)

While several studies have analysed how movements are combined, these have been analysed during a whole match (Bloomfield, et al., 2007b; Bloomfield et al., 2007c). In this sense, Bloomfield et al. (2017b), found decelerations to be preceded by sprints on 77% of the occasions while Bloomfield et al. (2007c) found jogging and shuffle frequently preceding and following turns of ≤90°, with turns of >90° usually performed while skipping, stopping, and slowing down. Gaining insights into the typical combination of movements in scenarios leading to goals can significantly augment our comprehension of the significance of these actions and inform effective training methods to enhance performance, as well as the selection of the most applicable physical tests.

d) How frequent are COD actions during goal-scoring situations, and how often are these performed at high intensity (Chapter 4)?

Only one study has specifically analysed COD actions during goal-scoring situations (Faude et al., 2012). Results showed that in 8% and 9% of the involvements for assisting and scoring players, respectively, a COD sprint was performed. Anyhow, the definition and the COD angles utilised could have excluded some of these CODs. Therefore, further analysis is needed to understand the frequency of COD actions at all and at high intensity, which would give us further knowledge of the importance of these actions in soccer.

e) Are the methods utilised for testing COD, speed, jump and strength reliable? (Chapter 5)

While the different tests utilised by researchers to assess reliability of COD, speed, jump and strength have shown to be reliable (Beato et al., 2021a; Stern et al., 2020; Fílter et al., 2020a; Altmann., 2019), guaranteeing consistency of measurements, there is a lack of reliability studies performed in female soccer players (Altmann et al., 2019), especially at an elite level. Moreover, for practitioners to have confidence in the collected data and its subsequent interpretation, it's essential to understand the reliability and variability of the assessment to ascertain genuine performance changes (Hopkins et al., 2000).

f) What are the correlations between COD, speed, jump and strength tests? (Chapter 6)

COD tests are frequently used to assess soccer players as part of testing batteries (Reilly et al., 2000; Walker & Turner, 2009; Risso et al., 2017; Gonçalves et al., 2021). From a training perspective, it is important to understand which physical qualities (i.e., speed, strength, power, etc.) underpin COD performance (Sheppard & Young, 2006) so that adequate training strategies can be implemented. Although many researchers have evaluated the relationships between COD ability and various physical attributes (Sonesson et al., 2021; Loturco et al., 2019b; Emmonds et al., 2019), there is a need to explore how the specific characteristics of COD tests may influence the physical attributes associated with them. Furthermore, while an extensive number of studies have explored correlations between COD tests and physical capabilities in male soccer, limited studies have explored this in the female population (Emmonds et al. 2019).

g) Can a training program tailored for distinct roles (such as attackers and defenders), featuring targeted exercises and drills, lead to enhancements in position-specific COD performance in elite female soccer players? (Chapter 7)

While numerous researchers have implemented training interventions focusing on single or several physical qualities in male and female players (de Hoyo et al., 2016b; Pardos-Mainer et al., 2019; González-García et al., 2019; Ramirez-Camapillo et al., 2018; Mathisen & Pettersen, 2015; Pardos-Mainer et al., 2020), it is questionable whether these are specific to the COD test selected, having an impact on the research findings. In addition, there is a need for more specific COD training interventions based on the movements performed more habitually by players with different roles in key movements of the game.

The following flowchart (Figure 1.1.) provides with a breakdown of the steps followed throughout the thesis.

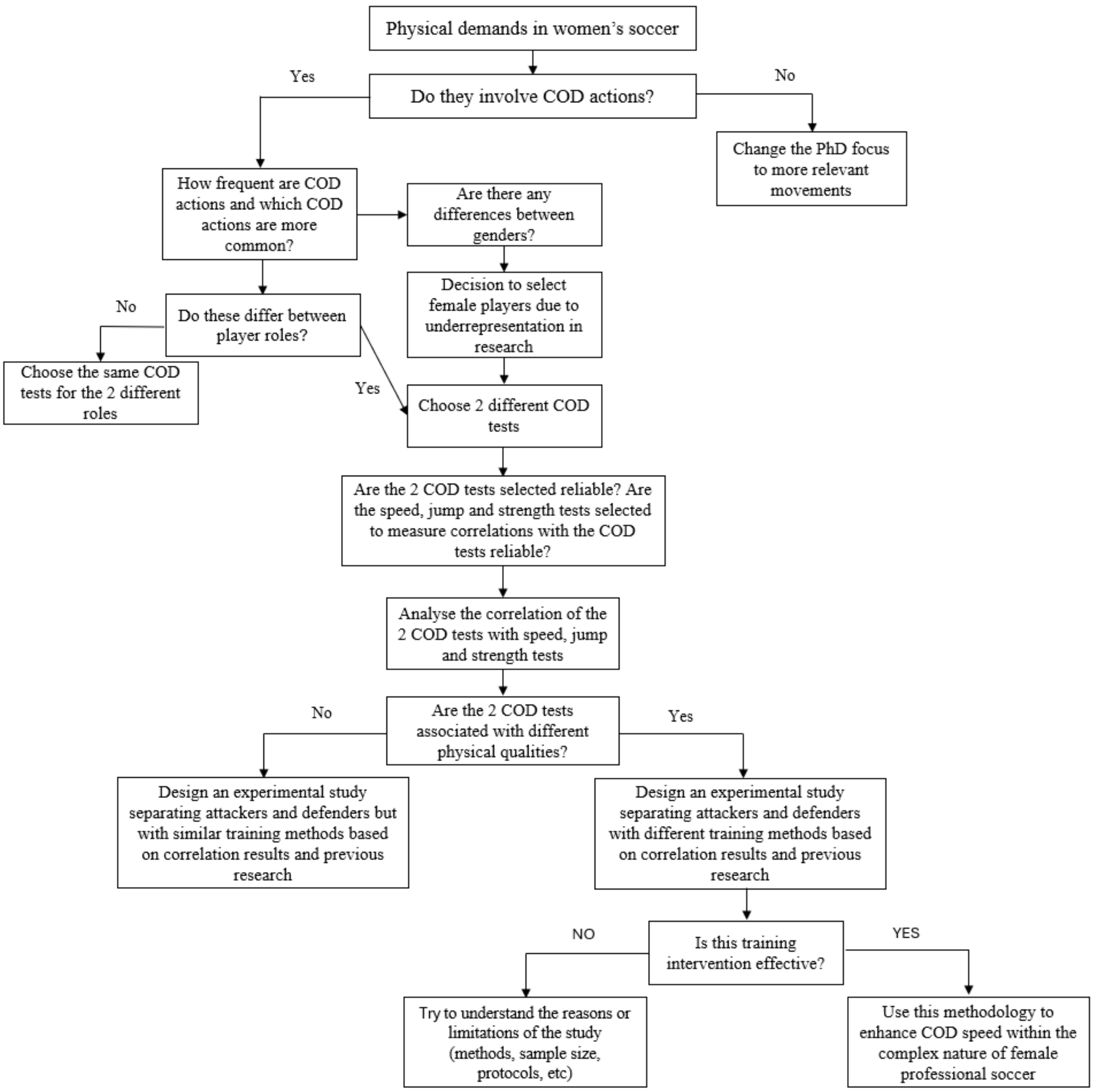


Figure 1.1. Flow chart of the thesis progression

CHAPTER 2: LITERATURE REVIEW

This review begins by examining the definition of change of direction (2.1) and then outlining the physical demands of soccer (2.2). The review continues by analysing the various COD tests used in soccer, highlighting the issues associated with some of them (2.3) and the ability of COD performance to differentiate between levels of performance (2.4.) and gender (2.5.). The review continues by analysing the factors that influence COD performance (2.6.) and finishes by studying the factors influencing COD ability based on the type of COD (2.7.).

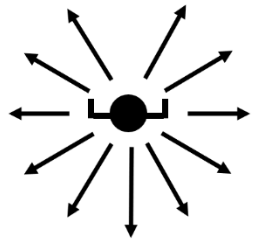
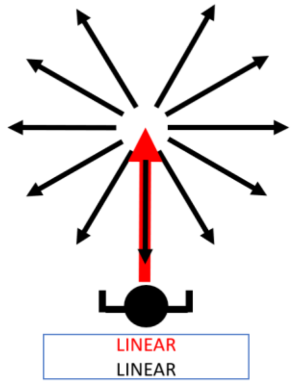
2.1 Change of Direction Definition

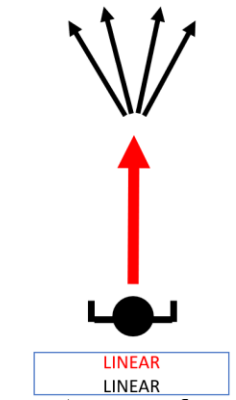
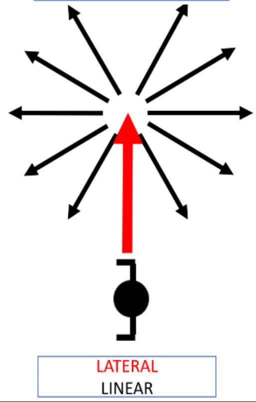
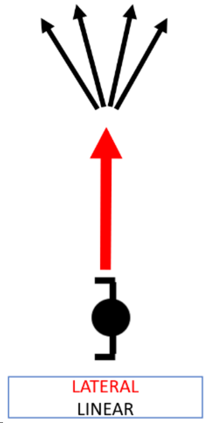
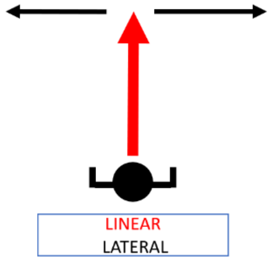
Agility is defined as "*a rapid whole-body movement with change of velocity or direction in response to a stimulus*" (Sheppard & Young, 2006). This definition, which has been widely accepted in the sports science community (Zouhal et al., 2019; Jeffreys, 2011; Krolo et al., 2020) specifies two concepts. First, it includes "change of velocity" which means that agility could include an action where the only movement performed is a deceleration (Young et al., 2015). Second, it includes "in response to a stimulus" which adds in cognitive elements such as visual scanning and decision making (Sheppard & Young, 2006). In this definition, COD could then be included as part of an agility task but also as part of a movement where there is no need to react to a stimulus (Sheppard & Young, 2006). Therefore, COD actions would be performed: 1. When reacting to a certain stimulus, for example, when defending a certain action reacting to an attacker. 2. When performing a COD without reacting to any stimulus, for example, when an attacker performs a cut to change initial direction and gain advantage without the defender making any prior deliberate movement (i.e., the instigator in the situation). As COD is part of agility, COD tests should be differentiated from agility tests, which should include reaction to a stimulus (Sheppard & Young, 2006; Gabbett et al., 2008; Gabbett & Benton 2009; Green et al., 2011). It is important to consider that COD and agility have been shown to be independent capacities and skills (Pojskic et al., 2018; Morral-Yepes et al., 2023), although other studies have shown large correlations (Altman et al., 2021; Krolo et al., 2020).

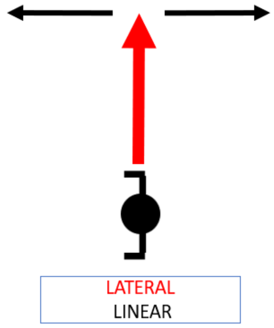
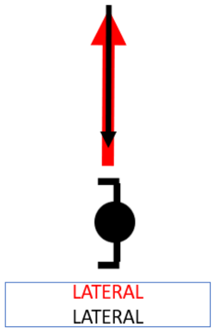
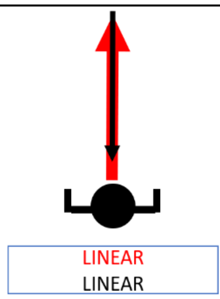
In contrast to agility, COD does not have an established definition accepted by the sports science community. COD speed has been defined as "*the ability to decelerate, reverse or change movement direction and accelerate again*" (Jones, et al., 2009), while COD ability has been defined as "*the ability to change initial direction to a predetermined location and space on a field or court*" (Nimphius, 2014) or more recently "*skills and abilities needed to change movement direction, velocity, or modes*" (DeWeese & Nimphius, 2016). Interestingly, both DeWeese & Nimphius (2016) and Jones et al. (2009) distinguish in their definitions not only a change of initial or movement direction but also the possibility of only decelerating or changing velocity, as it has been previously noted in the agility definition. An example of this is exposed by Young et al. (2015), where this change in velocity could occur in an agility game scenario, for example, when an attacking player decelerates to create space between him or herself and the opponent. While it is true that this deceleration would create a new game situation in terms of time and space, it is also true that this deceleration by itself would not imply that there is a change in the direction that the player was facing or moving towards. Moreover, while in the definition from Nimphius (2014) it can be implied that the athlete/player is advancing in a determined direction prior to changing direction, DeWeese and Nimphius (2016) do not specify if a COD would occur from a static position or advancing in a determined manner. On the other hand, the definition by Jones et al. (2009) implies that a COD could start from a static position. For this thesis, a COD could occur when the player starts from a static position (type 1) and has to move in a different direction and when this advances in a certain direction before manoeuvring into a new direction (type 2). The main difference between performing a COD from a static vs moving approach would be that the first wouldn't involve a deceleration, while the latter is likely to involve a deceleration action, although this will depend on the angle and approaching velocities (Dos'Santos et al., 2018b).

The third type of COD would be a change in the initial path without changing the direction the player is facing. In this type of COD, there would be a combination of linear advancing forwards/backwards (in the sagittal plane) and lateral advancing movements with a deceleration always involved in this type of actions. Finally, the fourth type of COD would involve an arc run or curvilinear type run, which has been defined as a sprint with gradual and continuous COD (Fílter et al., 2020a) and could also be defined as manoeuvrability (Jones and Nimphius, 2018). The different types of COD with the different possible options can be found in Table 2.1. Based on this, individual movements that an action would integrate to then be considered as a COD would be turn, cut, arc run and deceleration, although the latter is delimited by certain factors to consider. While during turn and cut there is a body rotation and a change of initial path direction as well as a change in the direction that the player is facing, which also occurs in an arc run, performing a deceleration wouldn't always imply that the next movement involves a change in direction. Regardless, deceleration would always be the link when, during a COD there is a change in path without the player changing the way they face (Table 2.1., Type 3 CODs). For example, when performing a lateral movement to the left followed by a lateral movement to the right or when performing a lateral movement (e.g., shuffle or crossover) before a linear forward action (e.g., sprinting) as seen in Table 2.1. In these scenarios, the only combination of movements where there is a deceleration, but the action is not considered as a COD is: 1. When there is a linear advancing action + deceleration + linear advancing action in the same direction. 2. When there is a lateral action + deceleration + lateral action in the same direction. Based on this rationale, in this thesis COD is defined as a sudden or gradual change in movement path from a moving or static position.

Table 2.1. COD Actions

Type of COD	Variation	Diagram
Type 1 COD: Turn to new direction from static or semi-static [slow linear or lateral movements (e.g. walking, low-intensity shuffle)] movements type position.	-Turn to new direction	
	-Linear advancing (forward or backward) + deceleration + turn/cut to new direction	

	-Linear advancing (forward or backward) + turn/cut to new direction (usually slow approach and/or low degrees of turn)	
Type 2 COD: turn/cut to new direction from moving position (deceleration included unless slow velocity approach and/or low degrees of turning)	-Lateral + deceleration + turn to new direction	
	-Lateral + turn to new direction (usually slow approach and/or low degrees of turn)	
	-Linear forward/backward + deceleration + lateral advancing motion (or vice versa)	

Type 3 COD: change in path without a change in the direction that player is facing.	-Lateral + deceleration + linear forward/backwards movement	
	-Lateral + deceleration + lateral to opposite direction	
	-Linear + deceleration + Linear (forward to backwards or backwards to forward)	
Type 4 COD: arched run performed to maintain velocity	-Arc run performed with different degrees	

Scale of frequency: + = Low, ++ = Low - medium, +++ = medium, ++++ = medium – high, +++++ = high

2.2. Physical and Physiological Demands in Soccer

Football is an activity that involves both aerobic and anaerobic systems (Osgnach et al., 2009). The average intensity of work is close to the anaerobic threshold, 80-90% of the maximum heart rate (Bangsbo, 1994; Bangsbo et al., 2007; Helgerud et al., 2001), with a study showing that players spend around 50% of the match over the anaerobic threshold (Eniseler, 2005). Match activities have been widely analysed for both males (Bradley et al., 2010; Barros et al., 2007 Burgess et al., 2006; Mallo et al., 2015; Akenhead et al., 2013; Dalen et al., 2016) and females (Vescovi, 2012; Datson et al., 2017; Mara et al., 2017a). Researchers have generally utilised static or linear direction activities such as standing, walking, jogging, running, high-speed running, high-intensity distance, high-speed distance and sprinting (Bradley et al., 2010; Barros et al., 2007 Burgess et al., 2006; Mallo et al., 2015; Gualtieri et al., 2023), with acceleration and deceleration activities also starting to gain interest (Harper et al., 2019). Moreover, lateral movements are also performed during matches, with mean distances ranging between 263-548 m (Rienzi et al., 2000; Da Silva et al., 2007).

Soccer players regularly alternate brief bouts of high-intensity and longer periods of low-intensity exercise (Rampinini et al., 2007) with 150 – 250 intense actions (Mohr et al., 2003) occurring approximately each 70 seconds (Bradley et al., 2009). The results from a systematic review show that males cover 9000-12000 m and females 9600-10400 m, with sprinting actions ranging 117-1100 m and 160-615 m in male and female players, respectively (Taylor et al., 2017). These differences could be related to the different thresholds utilised. In a recent systematic review including 30 studies found that high-speed running, high-intensity distance and high-speed distance entry velocity varies between 12.2 $km \cdot h^{-1}$ and 15.6 $km \cdot h^{-1}$ for females, and between 14.4 $km \cdot h^{-1}$ and 21.1 $km \cdot h^{-1}$ for males, while sprint distance entry velocity is usually set between 19.8 $km \cdot h^{-1}$ and 30 $km \cdot h^{-1}$ for males and between 17.8 $km \cdot h^{-1}$ and 22.5 $km \cdot h^{-1}$ for females (Gualtieri et al., 2023)

2.2.1 Change of Direction in Soccer

Different researchers have analysed COD activities during matches with the total number being different between studies, going from 11.9 hard changes of direction to more than 700 turns and swerves (Nedelec et al., 2014: Granero-Gil et al., 2020; Robinson et al., 2011;

Baptista et al., 2018; Morgan, et al., 2022; Bloomfield et al., 2007a, Dos'Santos et al., 2022b). As seen in Table 2.2 these differences could be related to the definitions of COD utilised as well as the different methods used for analysis (e.g., video analysis, GPS, laser and gyroscope). For example, Nedelec et al. (2014) used "*hard changes in direction while running*" while Morgan, et al. (2022) defined COD actions as "*path change caused by an identifiable plant of a leg that led to the change in path travelled*". On the other hand, some researchers only considered turning actions, again with different definitions (Baptista et al., 2018; Bloomfield et al., 2004; Dos'Santos et al., 2022b). While Baptista et al. (2018) defined turn as *"a continuous and significant rotation of the body in one direction"*, Bloomfield et al. (2004) defined this movement based on the degrees of rotation (e.g. 0°-90°: *"Turn ≤ ¼ circle"*). Therefore, it is not surprising the differences in the number of actions found between studies. Moreover, while physical performance can vary depending on the playing position, competitive standard, gender, match, and contextual and tactical factors (Bradley et al., 2013; Bradley et al., 2014; Bradley & Nassis, 2015), the studies analysing the number of CODs performed generally do not consider these factors, which could have an impact on the frequency of these actions. In this context, studies examining positional differences throughout an entire match have yielded varying conclusions. One study (Morgan et al., 2022) found no significant differences in the estimated change of direction (COD) angle or direction, with most CODs being ≤90°. Similarly, Bloomfield et al. (2007c) reported that most turns were ≤90°, with attackers and defenders executing more COD actions of ≤90° compared to midfielders. However, no significant differences were observed for turns ranging between 90-180°, 180-270°, and 270-360°. A challenge to consider in these type of studies is that they are usually performed throughout a whole match or 15-minute periods. While these studies can assist on the understanding of player's physical match demands and can orientate practitioners in the selection of training drills for performance, injury mitigation or decision-making process during injury rehabilitation, they lack specific context into when these occur or if these are performed in key instances of the game.

Table 2.2. Frequency of COD actions during a match

Reference	Definition COD activities	Method	Analysis system utilised	Results
Baptista et al. (2018)	Turn: continuous and significant rotation of the body	23 matches from a professional football club	Gyroscope and compass data	32.7 to 42.9 turns

	in one direction			
Bloomfield et al. (2007a)	Turning: 0°-90°: Turn ≤ ¼ circle. 90°-180° Turn > ¼ circle but ≤ ½ circle. 180°-270°: Turn > ½ circle but ≤ ¾ circle. 270°-360°: Turn > ¾ circle but ≤ full circle. >360°: Turn > full circle in one motion. Swerving: to rapidly change direction in one movement without turning the body	Individual players from EPL using 'PlayerCam' (camera focused only on a single player for a 15 min period on six occasions throughout a 90 minute match)	Bloomfield Movement Classification through computerised time-motion video-analysis	~600 turns
Dos Santos et al. (2022b)	Turn: an occurrence where a player completed a deceleration (≤−2 m/s2), an angle change in direction of travel (≥20°), and a subsequent acceleration (≥2 m/s2) within a - 1 second duration	Data from a single EPL soccer team over 18 fixtures during the 2020–2021 season	Sportlight® LiDAR system	7 to 55 turns
Granero-Gil et al. (2020)	COD events and centripetal force generated in	Thirty professional soccer players tracked during the	Inertial measurement devices with 10Hz GPS tracking system	556 to 412 CODs

	each action. COD: skills and abilities needed to change movement direction, velocity or modes	2017–2018 season during friendly matches	technology, four tri-axial accelerometers and three 3D gyroscopes	
Morgan, et al. (2022)	COD: a path change caused by an identifiable plant of a leg that led to the change in path travelled	Twenty-four elite youth soccer players across 10 matches	Time motion analysis using sportcode	305 CODs
Nedelec et al. (2014)	Hard change in direction: hard change in direction while running	10 professional soccer players during four competitive matches	Time motion analysis from video recordings	11.9 hard changes in direction
Robinson et al. (2011)	Path change: a path change is relative to the path previously travelled before the turn or direction change event rather than being related to the aspect faced by the player.	25 players from EPL from at least six 90-minute matches.	Time motion analysis using Prozone®	~75 to 115 path changes
EPL = English Premier League, COD = change of direction				

2.2.2 Change of Direction Actions in Goal-Scoring Situations

One question that arises at this point is: how do these changes in direction impact a game of soccer? This question is partially answered in a study by Faude et al. (2012) who analysed 360 goals of the second leg from the German national league 2007/2008 using multiple replays both live and in slow motion from highlights obtained from public sport programs.

The researchers analysed powerful movements taking place in goal sequences for the scorer and assisting player. The powerful movements were the following: straight sprint, rotation, COD sprint and jump. Results showed that 83% of the goals were preceded by a powerful action. Of these powerful actions COD sprint accounted for 8% (5-11%) and 9% (6-12%) for assistant and scorer respectively. COD sprint was defined as *"a very high-intensity run with two distinct and identifiable accelerations in different directions (more than 50° from the initial sprint line)"*, and so, other movements which could also be considered as COD actions may not have been included. In addition, authors did not define what a very high-intensity run was, which leaves room for interpretation and potential variability in how COD sprints are identified and analysed, possibly affecting the consistency and applicability of the findings. Moreover, rotations, which could also be considered as a COD action, showed to be the second (although with no statistical difference with the third and fourth most common movements) and third (although with no statistical difference with the fourth movement) most frequent actions involved in goal-scoring situations for assistant [8% (5-11%)] and scorer [13% (9-17%)] respectively. This could be considered a modest percentage, although it should be considered that the authors measured rotations only for whole body turns of over 90º. This pioneering study highlights the importance of powerful actions before a goal in scoring and assisting players. Nevertheless, there is a need for a more detailed analysis that includes a wider range of movements, intensities, and directions as well as the inclusion and comparison with female players and the addition of defending roles.

2.3. Change of Direction Testing

COD tests have been incorporated into soccer testing batteries (Walker & Turner, 2009) and used for talent identification, as well as in the development of strength and conditioning programs for soccer teams (Dodd & Newans, 2018).

A recent systematic review found COD tests to generally be reliable, showing intraclass correlation coefficients (ICCs) of more than 0.75 and coefficient of variation (CV) lower than 3.0% for most of the tests (Altmann et al., 2019). A limitation of this study is that researchers didn't report if ICC's were based on point average or the lower bound 95% CI. In soccer players, COD has been assessed through different tests: 180º turns test (Hammami et al., 2017a), 4×5 test with turns (Hammami et al., 2017a), 9-3-6-3-9 m sprint test with 90ª changes of direction and backward and forward running (Hammami et al., 2017a; Sporiš et al., 2010), V-cut test (Tous-Fajardo et al., 2016), Pro Agility test (Risso et al., 2017), Arrowhead test (Rago et al., 2020) Illinois test (Fiorilli et al., 2017; Kutlu et al., 2017; Negra et al., 2017a; Negra et al., 2017b), Y-agility test (planned and reactive) (Fiorilli et al., 2017), T-test (Negra et al., 2017b; Sporiš et al., 2010; Matta et al., 2014; McFarland et al., 2016), modified agility T-test (Los Arcos et al., 2020), 5-0-5 COD test (Emmonds et al., 2016; Chaalali et al., 2017), slalom test (Sporiš et al., 2010), sprint with 90º turns (Sporiš et al., 2010), four line sprint (Rosch et al., 2000; Taskin, 2008), t180 test (Sekulic et al., 2013), 20 yard test (Sekulic et al., 2013), forward-backward running agility test (Sekulic et al., 2013), slalom sprint test (Huijgen et al., 2014), peak shuttle sprint (Huijgen et al., 2014) 5-m shuttle run-sprint (Chaouachi et al., 2012) or recently a curve sprint test (Fílter et al., 2020a). Interestingly, a recent systematic review showed the T-test, 505 COD test and zig-zag test to be the most common tests used to assess COD ability in soccer players (Altmann et al., 2019).

All these tests have differences and similarities based on 1. Approaching distances to the COD (from short to long distances between CODs). 2. Angles of the CODs [from 45º to 270º (Altmann et al., 2019)] 3. The number of changes of direction, ranging from one to 11 (Nimphius et al., 2018). 4. Time to complete the test, from 2 to 19 seconds (Nimphius et al., 2018). Due to the diverse characteristics mentioned above these tests may well examine different factors of COD speed (Svensson & Durst, 2005) as they vary in energy requirements (some of these tests could be mainly measuring anaerobic capacity, Nimphius et al., 2017), number of CODs and force production (Brughelli et al., 2008), and so, it is not surprising that research shows low to high correlations between some of these tests (Sporiš et al., 2010; Kadlubowski, et al., 2019; Cinarli et al., 2018; Freitas et al., 2023). Moreover, due to these different combinations, it is difficult to distinguish the factors contributing to possible changes in test results after interventional studies (i.e., after strength training intervention) (Svensson & Durst 2005), representing a big limitation. Moreover, it would be assumable that the more changes in direction and/or seconds to complete a test, the less information this will provide regarding the kinetic and/or kinematic factors contributing to the completion time.

Consequently, it could be implied that the lesser the duration and movements involved in a COD test, the better one can identify the whys of a certain performance. Anyhow, even when performing tests consisting of a low number of changes of direction and duration, limited information might still be obtained. For example, during the 505 COD test, which consists of one COD of 180º and a completion time that ranges between 2 and 3 seconds (Nimphius et al., 2018), only around 31% of the time is spent changing direction (Nimphius et al., 2013). To isolate the portion of a test where the athlete or player is changing direction in recent years, a new concept named 'COD deficit' has increased popularity. COD deficit is based on the additional time that a directional change requires in comparison with a straight sprint with the same distance, which would possibly provide a more specific measure of COD performance (Nimphius et al., 2016). The most common COD test used for this purpose is the 505 COD test (Nimphius et al., 2016; Freiras et al., 2018; Dos´Santos et al., 2018b), although other formats have also been used. These include the pro-agility COD tests with two 180º turns (Nimphius et al, 2013; Freiras et al., 2018), one 90° turn (Cuthbert et al., 2019), three 90º turns (Freiras et al., 2018) one 45º turn, zig zag test over 20 m (Loturco et al., 2018a) or a combination of 90 and 180º turns (Freiras et al., 2018).

Although COD deficit could represent a step forward towards the isolation of certain parts of a COD, this still does not give precise information on which specific parts of that COD have a 'deficit' (i.e., deceleration, turn) while also not having the same phases of a sprint (Drobnič, 2020).

Another limitation of COD deficit could be that athletes who are faster or have more body mass are exposed to higher "braking demands" during the test (Jones, 2023, Loturco et al., 2018a; Freitas et al., 2023; Freitas et al., 2019b).

To summarize, an ample variety of tests assessing COD ability have been performed in soccer, generally showing to be reliable. Anyhow, these tests may well examine different factors of COD speed as they vary in the COD angles, number of CODs, distance to the COD, total distance, energy requirement, etc. More so, some of these CODs do not necessarily replicate the demands of the sport, and so, more research is needed to understand which tests best replicate these demands.

2.4. Ability of Change of Direction to Differentiate Between Levels of Performance

COD ability has been shown to differentiate between elite and non-elite soccer players of different ages. In young players, COD ability has shown to discriminate between different levels (Höner et al., 2015; Reilly et al., 2000, Trecroci et al., 2019; Rebelo et al., 2013;

Rouissi et al., 2019; Keiner et al., 2021b) although other studies show no differences or conflicting results (Coelho e Silva et al., 2010; Turner, 2016; Haujgen et al., 2012 Risso et al., 2017). As most studies have shown COD tests to discriminate between levels of performance in young players, these have been proposed for their use in talent identification (Höner et al., 2015; Reilly et al., 2000; Unnithan., 2012) although other authors do not recommend its use due to being changeable throughout growth period (Hirose & Seki, 2016).

On the other hand, there is limited research on the differences in COD performance between elite and non-elite senior players. Some studies have shown COD test to discriminate between levels of performance in male players (Kutlu et al., 2017; Kaplan et al., 2009) with a study showing faster times for top level when compared to amateur and local players but not when compared to third division players (Rosch et al., 2000).

When looking at research performed in female players, Lockie et al. (2018a) found higher performance on the 505 COD test and modified T-test for Division 1 vs Division 2 school players, while Turner (2016) found no differences in performance levels between leagues (elite, sub-elite and non-elite) when performing the 505 COD test, but did find better performances for starting vs non-starting players. Moreover, this same study found differences between teams finishing first and second vs mid-table in a non-elite league. On the other hand, Risso et al. (2017) separated starters and non-starters and found no differences in the pro-agility test and 60-yard shuttle test in Division 1 collegiate players.

Therefore, although there is a tendency towards better performance for higher vs lower-level players, the variation of test selection alongside the lack of kinetic and kinematic analysis explaining the differences between groups makes it difficult to draw clear conclusions. It could be theorized that differences in performance would be related to the underpinning physical qualities. For example, Spiteri et al. (2014) found 2 COD tests to be largely correlated with concentric, isometric and eccentric strength. This would make sense as COD performance has been shown to be associated with braking and propulsive forces (Dos'Santos et al., 2017a).

In conclusion, while some studies have shown differences between levels of performance, there is a need for more research to understand if these differences are more relevant between levels of performance within the same squad (e.g. starters vs non-starters), within the same league (e.g. based on team ranking) or between leagues (e.g. first vs second division). In addition, there is a need to further understand the reasons underlying these differences in performance, with some of these tests lacking ecological validity. Finally, there is a lack of research performed on female soccer players, especially in senior professional players.

2.5. Differences Between Genders

Male and female show differences in psychological, physiological, biomechanical and physical characteristics (Deaner et al, 2016; Schaal et al., 2011; Randell et al., 2021; Thomas et al., 2024). Males have shown to be faster, more powerful, stronger and have more endurance than females (Martín-Moya et al., 2023; Mujika et al., 2009; Brophy et al., 2009), which would have an impact on the match display, with higher physical outputs for male vs female players (Bradley et al., 2014; Taylor et al., 2017). More so, these differences in physical capacities would have an impact on field tests performed by players such as speed or COD tests (Mujika et al., 2009; Sekulic et al., 2013) and the differences in the ratio of injuries sustained by male vs female (Waldén et al., 2011).

2.5.1. Difference Between Genders on COD Performance

There is a very limited number of studies looking at differences between genders when performing COD tests. To our knowledge, only 2 studies have compared male and female elite players performing a COD task. In this regard, Mujika et al. (2009) found better performances for male vs female elite players in a 15-m COD test at both senior and junior levels (Mujika et al., 2009). More so, Martín-Moya et al (2023) found faster times in male vs female soccer players in the 505 COD test. Other studies have compared differences in performance between male and female soccer players at a youth amateur level (Sonesson, et al., 2021), university level (Dos'Santos et al., 2018b) or college team sport athletes which included soccer players (Sekulic et al., 2013). While Dos'Santos et al. (2018b) found better performances for males vs. females in the 505 COD test, Sekulic et al. (2013) also found faster completion times in five COD tests (T-test, zig-zag test, 20-yard shuttle test agility test with a 180-degree turn and a forward-backwards running agility test). More so, Sonesson et al. (2021) found significant differences between youth amateur male and female players in the 505 COD test and T-test.

These differences in COD test performances between genders could be related to differences in physical attributes. In addition, some of the differences could be related to different techniques utilised by both genders, as males have shown greater knee flexion angles compared to female in COD tasks (45º, 90º, 135º and 180º) (Schreurs et al., 2017), as well as increased knee abduction angles (Thomas et al., 2024). In any case, more research is needed to understand the differences between genders when changing direction. Researchers should not only focus on the differences between genders on isolated tests but should aim to acknowledge the main physical underpinning qualities that explain these differences in COD performance. Additionally, understanding the developmental context of each gender would be valuable in comprehending the development of COD performance and technique. Such differences in training backgrounds, specific sports experience, strength training experience, and exposure and participation in sports within schools and clubs should be gathered to further understand differences between males and females.

2.6. Factors Influencing Change of Direction Performance and Training Strategies

According to Sheppard &Young (2006), COD speed is influenced by: anthropometry, straight sprinting speed, leg muscle qualities and technique. While these factors could certainly have an impact on COD performance, these are very generic attributes, and so, it's important to dissect each of them. More so, it is important to understand if these variables are modifiable and if enhancement of certain physical characteristics can improve COD performance.

2.6.1. Technique

The first factor that could play an important role in COD speed is technique (Sheppard & Young, 2006). While researchers have analysed kinetics and kinematics of type 2 COD actions (Table 2.1.), where there would usually be a turn/cut to a new direction as a transition from a linear direction (Vanrenterghem et al., 2012; Dos'Santos et al., 2018a, Marshall, 2014), it is also important to consider other types of COD actions described in Table 2.1. such as type 1, 3 and 4.

2.6.1.1 Type 1 COD: Turn to New Direction From a Static or Semi-Static Type Position

A very limited number of researchers have analysed the most effective technique when turning from a static position, usually analyzing a 90° or 180° turn before a linear forward sprint (Sato et al, 2021; Hewit et al., 2010; Hewit et al., 2012).

When looking at a 90° turn and sprint, Hewit et al. (2010) theorized that within three different techniques: false start pivot, forward moving side-step and pivoting crossover, the latter was the fastest technique. During this strategy, body weight (BW) is shifted from both legs to the lead leg while the whole body rotates, and the lead leg pivots into external rotation. While the lead leg continues to be in contact with the ground, the trail leg crosses in front of the lead leg and pushes off in the same plane as the sprint. Authors theorized this to be the fastest turning technique, arguing that in this particular technique there is an aggressive arm action and limited forward lean, both being critical for sprinting technique. Anyhow, based on recent research it could be speculated that this technique is not commonly utilised, which would diminish the prior assumption. In this sense, Sato et al. (2021) analysed sprints from elite soccer players from a sideways (90°) and backwards (180°) direction, and found that players utilised in a similar number of occasions a forward and false steps technique [equivalent to false start pivot in Hewit et al. (2010)] and forward step [equivalent to forward moving side step in Hewit et al. (2010)], while in the sprint from backward position, players tend to use the false step technique. Interestingly, in a different study performed on netball players, superior backwards (180°) sprint performance was related to first foot contact being parallel to the new direction, shallow squat in combination with backward-moving centre of mass, head leading the body and arms and legs close to the body through the turn, full extension and large take-off distance during the initial take-off (Hewit et al., 2012). Therefore, the small number of studies that have analysed turns followed by a sprint from a static position show contrasting results, and so, more research is needed.

2..6.5.2. Type 2 CODs. Turn or Cut to a New Direction From a Moving Position

Type 2 COD would refer to a turn or cut to a new direction from a moving position where there is a previous deceleration unless there is a slow velocity approach and/or low turning angles. Indeed, the cutting angle and the speed at which a soccer player approaches a COD have been shown to affect kinetics and kinematics (Havens & Sigward, 2015b; Vanrenterghem et al., 2012; Dos'Santos et al., 2018a). In this sense, Vanrenterghem et al. (2012) found that higher speed in a 45º COD augmented peak horizontal and mediolateral forces while Havens & Sigward (2015b) showed that greater cutting angles (90º vs 45º) augmented propulsive and braking impulse and increased hip and knee flexion.

Recently, attention has been raised to the performance-injury conflict as faster and sharper CODs increase the risk of injury due to greater knee joint loads (Havens & Sigward, 2015b). In this sense, techniques associated with faster cutting performance (faster centre of mass velocities, greater final foot contact braking forces in short GCTs, greater knee flexion moments, smaller knee and hip flexion, greater internal foot progression angles, wider leg plant on final foot contact) are also related with a higher risk of knee injuries [e.g. anterior cruciate ligament (ACL) injury] (Havens & Sigward, 2015b; Dos'Santos et al., 2021b; Sankey et al., 2020), while lateral trunk flexion could negatively impact performance and increase injury risk (Dos'Santos et al., 2021b).

Recently, researchers have implemented strategies which included not only COD training but also movement quality or technique modification (Dos'Santos et al., 2019b; Dos'Santos et al., 2021a; Dos'Santos et al., 2022a) to both enhance COD performance and reduce the risk of injury, showing its potential benefits.

Interestingly, another study performed in amateur/semi-professional multidirectional athletes over six weeks focused on COD technique modification (Dos'Santos et al., 2022a) and found improvements in cutting performance (45° and 90°), with improvements being moderately to very largely related with enhancement in velocity profiles, propulsive forces over shorter GCTs and decreased knee flexion (Dos'Santos et al., 2022a). Although increased velocity profiles, greater propulsive forces over shorter contact times, and reduced knee flexion may enhance performance, the latter could negatively impact the risk of injury due to the high early peak knee abduction moments (Sigurðsson et al., 2021).Special attention should be placed on differences between genders. For instance, techniques utilised may vary during different CODs, as males have shown greater knee flexion angles than females in COD task (45º, 90º, 135º and 180º) (Schreurs et al., 2017). According to the authors, this could be related to a lower speed approach in the terminal steps during sharp CODs and/or the fact that females would have proportionally weaker quadriceps musculature, which would be especially disadvantageous during sharper turns, which demand a high amount of strength in this muscle group.

2.6.1.3. Type 3 CODs. Change in Path Without a Change in the Direction that the Player is Facing

In this type of CODs there is a transition from a lateral to a linear advancing (or vice versa), lateral to lateral or linear to linear (in both cases the players would travel on one direction, decelerate and re-accelerate to the opposite direction). Therefore, it is important to analyse the biomechanics of these transitions. Notably, linear and lateral speed are distinct physical abilities.

To the author's knowledge, the only study analyzing these differences found no correlation between the movements (Malaise, 1969).While there is extensive research on linear acceleration and speed (Marcote-Pequeño et al., 2019; Haugen et al., 2019; Buchheit et al., 2014b), little research has been performed in soccer regarding lateral advancing movements such as shuffle or crossover. Lateral movements are considerable frequent in soccer, with senior players showing mean distances ranging from 263 to 548 m (Rienzi et al 2000; da Silva et al., 2007). It has been previously noticed in tennis that players would perform a lateral shuffle when these have enough time to perform the intended lateral movement, while crossover would be performed when quicker response is required (Roetert & Ellenbecker, 2007). This could also occur in soccer, as during a side shuffle the player would be in a more optimal position to react compared to a crossover, where feet would cross each other, and while this would likely allow more distance to be covered, the player would be in a suboptimal body position to react. In terms of the technique, during side shuffles it is recommended to keep the centre of gravity low and stable, with feet low to the ground, as although feet coming high off the ground may allow covering more ground, when feet are in the air, these cannot be redirected (Jeffreys, 2008). From a kinetic perspective it is important to consider that during side shuffling the magnitude of mediolateral forces and knee adduction and rotation moments during weight acceptance have been shown to determine the remainder of these during the rest of the ground contact (Nigg et al., 2009), and so, the first phase of foot placement could be critical.

When transitioning from this lateral action into either a linear or lateral movement, the player would have to decelerate. Although there is no research concerning kinetics or kinematics of lateral deceleration, some researchers have analysed EMG of lateral exercises where there is a side foot plant, such as the lateral lunge, or lateral step up, showing high activation of glute medius and maximus (Distefano et al., 2009; Simenz et al., 2012), and so, these muscle groups could play a significant role.

When transitioning from a linear action to another linear (forward to backwards or backwards to forward) or from a linear to a lateral movement, there would always be a horizontal deceleration. During this type of deceleration, authors have separated between the ground contact phase or braking force control and the support phase or braking force attenuation (Hewit et al., 2011; Harper et al 2022). Kinematic factors underpinning maximal horizontal deceleration during the contact phase include trunk with erect or posterior lean, decreased centre of mass vertical position and increased centre of mass posterior position with decreased knee valgus. The ankle should be on a dorsiflexed position pre-impact with an increase in plantar flexion on impact, while there should be an increased shin angle. During the support phase, the trunk should be on an erect or posterior position, increased hip and knee flexion, reduced dorsi flexion and decreased forward sway (Hewit et al., 2011; Harper et al 2022).

During high-intensity decelerations, it is important to take into consideration which physical capacities are needed and how the load is distributed between steps. In this sense, the penultimate step has been shown to be important in facilitating faster COD speed as well as reducing injury risk (Dos'Santos et al., 2020; Jones et al., 2016), while a recent study has shown antepenultimate foot contact to play a potentially more pivotal role in assisting deceleration compared to penultimate step contact during a pre-planned 180° COD (Dos'Santos et al., 2021c). This will be highly important to consider, especially when mechanical loading is higher during horizontal deceleration compared to acceleration (Verheul et al., 2021).

2.6.1.4. Type 4 CODs. Arc Run

Arc or curvilinear run has been defined as a sprint with gradual and continuous COD (Fílter et al., 2020a) and has been theorized to be executed preferably to maintain velocity (Nimphius et al., 2018). More so, curved running and linear sprints have been shown to be independent actions (Fílter et al., 2020b), although other studies have found nearly perfect associations (Kobal et al., 2021; Loturco et al., 2020b;), with one study showing that arc runs become less correlated to linear sprint as age increases (Filter-Ruger et al., 2022).

Curved compared to linear sprints have shown different body mechanics (Brice et al., 2008). In this sense, Brice et al. (2008) identified greater ankle, knee and hip flexion of the inside leg, with the latter possibly involving alteration of its orientation to perform the curved motion. Furthermore, Smith et al. (2006) identified that the outside leg contributes most in a curved running movement pattern, with this leg providing greater propulsion and impulse forces, and so, concluding that performance enhancement should focus on the outside limb. On the other hand, a different study showed that the inside leg had longer foot contact times when compared to linear sprint, with authors suggesting that this leg could play a determinant role in limiting maximum speed during arched runs (Fílter et al., 2020b). Interestingly, this same study also measured EMG of different lower limb muscles (gluteus medius, biceps femoris long head, semitendinosus, adductor), and found that the outside leg required higher activation of external rotator muscles (gluteus medius and biceps femoris long head), compared to inside leg, while inside leg showed higher activation of internal rotation muscles (semitendinosus and adductor) compared to outside leg. Therefore, while arched run shows some relationships with linear sprint, the inside and outside leg display different kinetic and kinematic characteristics.

2.6.2. Anthropometric Measures

When looking at anthropometric measures, the athlete's body mass (BM) (lean BM and body fat) could impact COD performance in soccer players. Los Arcos et al. (2020) found correlations between BM and two COD tests (modified T-test and free agility T-test) when pooled in elite academy and senior professional male players. On the other hand, when looking at the number of COD actions in a match, Morgan et al. (2022) found no correlations between the frequency of CODs and BM, while Granero-Gil et al. (2020) found a lower number of CODs in heavier players. One measure that could have a negative impact on COD performance is body fat, as increased inertia would require higher force production when decelerating and/or turning and reaccelerating into a new direction (Enoka, 2002). Therefore, it's not surprising that different studies have shown body fat to be related to decreased COD performance (Zanini et al., 2020; Negra et al., 2022; França et al., 2022). e

Limited research has analysed the impact of lean BM on COD performance. The only study, to the author's knowledge, analysing the associations between lean BM and COD was implemented by Valente-dos-Santos et al. (2014). This study, consisting of a 4-year longitudinal study in young players playing at national league level, found that an increase in 1 kg of fat-free mass was related to a 5% improvement in COD performance. While more research is needed in this area, this study gives us an idea of the potential influence that lean mass, especially contractile lean mass, has on COD ability.

Another anthropometric measure that could have an impact on COD performance in soccer players is body height. According to Samaras (2007) smaller players can rotate faster than taller players due to rotational inertia being proportional to height. Interestingly, a novel study analyzing typical path changes from 25 players in at least six 90-minute games from the English Premier League (EPL) found that shorter lighter players were likely to perform more path changes than taller players (Robinson et al., 2011). In the same line, Granero-Gil et al. (2020) found lower number of CODs in taller players, while Morgan et al. (2022) found no relationships. When looking at the relation of height with COD tests, Los Arcos et al. (2020) found correlations between height and two COD tests (modified T-test and free agility T-test) when pooled. More so, Chaouachi et al. (2012), showed height to be associated with COD speed in elite soccer players, suggesting that players with a lower centre of mass could apply horizontal forces more effectively compared to taller players.

2.6.3. Linear Sprint Speed

Tests used for the measurement of COD ability include some kind of linear acceleration or reacceleration and so it would be reasonable to assume that straight sprint speed would correlate with COD tests. Anyway, while some studies have shown associations between COD tests and straight sprint speed in elite young male soccer players (Erikoglu & Arslan, 2016; Köklü et al., 2015, Vescovi & Mcguigan, 2008; Sonesson et al, 2021, Kadlubowsk et al., 2021), non-elite male soccer players (Mathisen, 2014), female young soccer players (Mathisen & Pettersen, 2015: Sonesson et al, 2021), male and female semi-professional players (Los Arcos et al., 2017; Zhang et al., 2022), senior male elite/professional soccer players (Loturco, et al., 2019a; Sariati et al., 2020) and female senior professional players (Emmonds et al., 2019), other studies have shown little or no relations in elite young male soccer players (Rouissi et al., 2017), male professional or elite soccer players (Chaouachi et al., 2012; Freitas et al., 2020; Braz, et al., 2017; Papla, et al. 2020) or senior amateur soccer players (Little & Williams, 2005). In the same line, where non-elite soccer players were analysed as part of a group of team sport athletes some studies have shown relationships between COD tests and straight-line sprint tests (Jones et al., 2009; Mackala et al., 2020; Dos'Santos et al. 2018b) with one study showing poor associations (Pauole et al., 2000). Interestingly, other studies show conflicting results in male young amateur (Ates, 2018), young elite (Sporiš et al., 2011; Popowczak et al., 2019; Freitas et al., 2023), senior amateur (Kapidžić et al.,2011) semi-professional (Cinarli et al., 2018; Los Arcos et al., 2017) and in team sport players with sample including non-professional soccer players (Suarez-Arrones et al., 2020). Various authors have explained the absence of correlations between speed and COD tests by suggesting that they are distinct motor qualities or represent different abilities (Suarez-Arrones et al., 2020; Kapidžić et al., 2011; Popowczak et al., 2019). Meanwhile, one study identified the T-test as the most suitable for measuring COD speed, as it demonstrated the lowest correlation with linear running compared to the Illinois test, pro-agility test, and 505 COD test.

The lack of agreement could be related, as mentioned previously, to the diverse COD tests utilised as well as the different sprint distances tested. Interestingly, a study conducted on individuals engaged in activities involving sprinting and/or CODs found that straight-line sprinting showed a strong correlation with the same test incorporating 2 × 20º CODs. However, the correlation decreased as the number and sharpness of CODs increased (Young et al., 2001).. This would support findings from Freitas et al. (2023), who found a 17-m sprint to be related to 'smoother' multidirectional tasks such as curvilinear sprint and zig-zag test, but not with sharper COD manoeuvres (i.e., 505 COD test). In any case, all COD tests would have some type of linear activity, and so, this could arguably have an influence on COD performance.

2.6.3.1 Sprint Training for the Improvement of COD Performance

When analysing straight-line sprinting studies in soccer, it is worth noting the sport itself involves sprinting [117-1100 m and 160-615 m in male and female players during a match, respectively (Taylor et al., 2017)], with an average sprint distance of 17 m (Bangsbo, 1994) and so, caution should be taken when relating improvements in COD after sprint training in soccer players.

Novel studies have investigated the influence of sprint training on the enhancement of COD performance, showing improvements in young male amateur and elite soccer players (Marzouk et al., 2021; Pavillon et al., 2021) while a study performed in elite young players found no improvements (de Hoyo et al., 2016a). In this sense, de Hoyo et al. (2016a) analysed different physical qualities of elite U-19 players before and after eight weeks of resisted sprints with 12.5% of each player´s BM and found no improvements in the zig-zag test, while the only improvements in straight line sprint were found in 30–50 m split. On the other hand, Marzouk et al. (2021) found improvements in T-test after 10 weeks of sprint training in elite young soccer players, with no difference between one or two sessions/week while Pavillon et al. (2021) found improvements in the 10-m slalom test in young amateur male soccer players after 30 weeks of training. This slalom test would have a high emphasis on sprinting as it consisted of a total of 20m of sprinting and less emphasis on COD ability, with four subtle changes in direction.

While these studies showed improvements in COD ability, it is important to take into account that the specificity of training could play a key part in these type of experimental studies. In this sense, it would be logical that if a COD test involves some type of linear running, after a sprinting intervention, the phase of the test that involves sprinting could improve. Anyhow, while sprint training might assist COD performance during these tests, Young et al. (2001) found different results in team sport players. In this study, subjects performed a straight-line speed test (30 m) and six COD tests with two to five CODs before and after six weeks of training of either straight-line sprints (20 – 40 m) or straight-line sprints (20 – 40 m) with three to five CODs of 100º. While the group performing straight-line sprint training significantly improved in the 30-m speed test, limited improvements were seen in COD tests. On the other hand, subjects involved in the COD training improved COD performance but not straight-line sprint. The authors attributed these results to the specificity of the training intervention and concluded that straight-line sprints and sprints with CODs do not transfer to each other. In this sense, subjects in the straight-line sprint group could have been unable to cope with the greater momentum derived from higher speeds during the deceleration phase.

2.6.4. Leg Muscle Qualities

The model of agility presented by Sheppard and Young (2006), showed leg muscle qualities subdivided into reactive strength, concentric strength and power and left-right muscle imbalances, which provides a rather superficial overview of the potential muscle strength qualities that are likely important in COD across different angles and approach velocities. COD performance is associated with an athlete's ability to absorb force (braking) and generate force (acceleration) within a force-time curve (impulse) (Nimphius et al., 2017). Additionally, understanding the magnitude of forces produced and the time available to generate these forces can help identify the physical demands required for effective COD (Nimphius et al., 2017). Since force is applied during both propulsion and braking, concentric, isometric, and eccentric strength are crucial physical qualities for achieving successful COD performance. In this sense, depending on the selected COD, short and/or long SSC could also play an important part in COD performance (Dos'Santos et al., 2018a; Nimphius et al., 2017; McBurnie, & Dos'Santos, 2022). Finally, the orientation of the force applied such as vertical or horizontal vectors could also have an impact (Ramírez-Campillo, et al., 2015; Tous-Fajardo et al., 2016).

2.6.4.1 Reactive Strength

Reactive strength is been defined as the ability to change from an eccentric to a concentric contraction (Young, 1995) and is calculated by dividing jump height by contact time (Lloyd et al., 2009; Falch et al., 2021), although other researchers have used drop jump (DJ) height (Castillo-Rodríguez et al., 2012), a series of 5 forward jumps with alternated limb contacts (Chaouachi et al., 2012; Chaouachi et al., 2009) and consecutive vertical rebounds (Salaj, & Markovic, 2011). Anyhow, there is limited and inconsistent research assessing the relations between reactive strength and COD performance in soccer players, with studies using diverse protocols and subjects. Different studies have shown drop jump scores (DJ height and reactivity index) to be unable to predict COD performance in team sport athletes (including soccer players), elite male and female soccer players, male and female amateur young players (Jones et al., 2009; Chaouachi et al., 2012; Northeast et al., 2019; Sonesson et al., 2021; Emmonds et al.,2019), while other studies have shown small to moderate correlations (Falch et al., 2021; Castillo-Rodríguez et al., 2012; Kapidžić et al., 2011) in young non-elite female handball and soccer players and amateur soccer players.

Interestingly, this inconsistency is found in other research where team sports subjects were recruited, with several studies showing significant correlations (Young et al., 2002; Chaouachi et al., 2009; Lockie et al., 2014)) and others showing low or no associations (Barnes et al., 2007; Salaj, & Markovic, 2011; Lockie et al., 2014). This inconsistency in the associations between COD and reactive strength could be based on the different reactive tests and COD tests utilised and the diversity of participants utilised in the studies. In this sense, reactive strength would share similarities with CODs with shallow turns due to the similar GCTs (Dos'Santos et al., 2018a). Additionally, previous research has indicated very poor relative reliability of the actual drop height in a DJ test (Costley et al., 2017). One study estimated that the actual drop height differed by 28.6–37.4% from the box height when sports students performed DJs from boxes 0.20–0.50 m high (Geraldo et al., 2019), and so, these limitations should be considered when drawing any conclusions.

2.6.4.1.1 Training Reactive Strength (Fast Stretch-Shortening Cycle)

For the examination of different training interventions aiming to improve COD performance through reactive strength, studies implementing exclusively fast SSC activities (< 0.25 s) (i.e., DJs, hurdle jumps, etc.) are investigated. Several researchers have examined the effects of reactive strength training on COD performance, with the majority of these interventions being performed in young soccer players (Ramírez-Campillo et al., 2014; Ramírez-Campillo et al., 2018a; Ramírez-Campillo et al., 2019; Thomas et al., 2009; Hammami et al., 2016). Most of these studies showed that training reactive strength can elicit significant improvements in COD performance (Ramírez-Campillo et al. 2014; Ramírez-Campillo et al., 2018a; Ramírez-Campillo et al., 2019; Thomas et al., 2009), while only 1 study showed no improvements (Hammami et al., 2016). Interestingly, in this study, participants did improve in two out of three tests that assessed repeated COD ability. According to the authors, the lack of improvements in COD performance in this study could be due to two reasons: players being in a good initial condition and the tests selected (sprint with 180° turns, a 9-3-6-3-9 m test and a 4×5 m sprint test with turns).

Interestingly, while reactive strength shows inconsistent correlations with COD performance, training interventions which included exclusively reactive strength drills have shown to be effective for improving COD performance in soccer players. These could be related to the lack of homogeneity of studies assessing correlations between COD tests and reactive strength. On the other hand, experimental studies evaluating improvements of COD after reactive strength training were mainly performed on young soccer players of varied performance levels, with Illinois test being performed in the majority of studies. This particular test has shown to be a concern when assessing COD performance, as due to its long duration is suggested to have metabolic limitations (Vescovi & Mcguigan, 2008). As reactive strength shares similarities with CODs with shallow turns due to the similar GCTs (Dos'Santos et al., 2018a), future studies should investigate if a training protocol performing reactive strength before and after a COD test with shallow turns enhances performance in that specific test.

2.6.4.2 Concentric Strength and Power/ Jump

2.6.4.2.1 Vertical Power/ Jump: Slow Stretch Shortening Cycle

SSC power/ jump movements of more than > 0.25 s are known as slow SSC [i.e., countermovement jump (CMJ)]. Due to the high number of studies (20 studies) assessing correlations between vertical power and/or jump height with slow SSC component, a table has been added to highlight the methods and associations found in these studies (Table 2.3.).

It is worth highlighting that the majority of the studies show moderate to high correlations between CMJ and the COD tests performed (r= -0.40 to -0.79) (Castillo-Rodríguez et al., 2012; Jones et al., 2009; Lockie et al., 2014; Vescovi & Mcguigan, 2008; Falch et al., 2020a; Falch et al., 2021; Emmonds et al., 2019; Thomas et al., 2018; Los Arcos et al., 2017; Yanci et al., 2014; Köklü et al., 2015; Sonesson et al., 2021; McFarland et al., 2016; Freitas et al., 2020) although other studies show conflicting results or small associations in amateur young male and female players, elite junior and elite male and female players [Ates, 2018: r= 0.09 to -0.49; Kobal et al., 2021: r=0.21 to 0.56; Falch et al., 2021: r=-0.22 to -0.28; Northeast et al., 2019: r=0.09 to 0.38)]. Interestingly, the highest correlations were found in the study by McFarland et al. (2016), who utilised power output from a CMJ divided by total BM. This along with the study from Northeast et al. (2019) are the only studies taking into consideration the players' body mass. Anyhow, while McFarland et al. (2016) found the highest correlations within the studies analysed, Northeast et al. (2019) did not find any correlations between relative peak power and the COD test utilised (Y-shaped test).

Within all the studies analysed in Table 2.3. only four studies analysed power along with jump height. While McFarland et al. (2016) and Northeast et al. (2019) utilised jump height along power and power to weight ratio, Loturco et al., (2019b) utilised peak power as well as peak force (alongside jump height). Finally, Emmonds et al. (2019) utilised both jump height and rate of force development (slope of the vertical force curve between peak force and take-off). Nevertheless, this study did not present results on the correlations between these measures and the COD 505 test. However, it did report that an increase of one standard deviation (SD) in CMJ height led to a decrease of -3.317 SD in the 505 COD test. These could be related to the similarities in ground reaction forces between the sharp CODs and slow SSC.

The link between CMJ and 505 COD test was also investigated in a recent study by Falch et al. (2020a), who analysed relationships in muscle activity and performance between different CMJs (bilateral and unilateral) and a modified 505 COD test which consisted of two COD test (10 m + 180º COD + 10 m and 5 m + 180º COD + 5 m) in male soccer players from second to sixth national league level. Researchers found muscle activity in the COD test and in CMJ to be only differentiated by greater peak muscle activity in biceps femoris, semitendinosus and adductor longus in the COD.

It is important to acknowledge the limitations in the abovementioned cross-sectional studies. Firstly, the predominant test employed was the T-test, which, as previously discussed in the thesis, encompasses a broad spectrum of movements and transitions, along with an extended total duration. . Consequently, there exists a multitude of factors that could potentially impact observed associations. Moreover, there is a lack of research conducted on elite soccer players, particularly female athletes, with only three studies (Loturco et al., 2019b; Kobal et al., 2020; Emmonds et al., 2019). Thus, further investigation is warranted.

2.6.4.2.2 . Vertical Power/ Jump Training: Slow SSC

There is very limited research looking at the improvement of COD through a training programme based exclusively on vertical CMJs in soccer. Although CMJ has been used in training protocols to acknowledge potential improvement in COD ability, researchers have commonly accompanied this with other plyometric drills, and so, conclusions raised on its transfer or not to COD ability in these studies should be avoided.

The only study, to the author's knowledge, to utilise slow SSC training found significant improvements in the 505 COD tests after six weeks of a CMJ training intervention in young male semi-professional players (Thomas et al., 2009). Anyhow, researchers didn't specify the exercises performed by participants other than mentioning that all movements started with a countermovement. Therefore, while there is consistent evidence on the associations between vertical CMJ and COD ability, more research is needed to understand the effects of training interventions which include CMJ on the enhancement of COD ability in soccer players.

Table 2.3. Power and jump (slow SSC) associations with COD performance

Reference	Participants characteristics	Training status	Test utilised and apparatus	Calculation method	COD Test utilised	Correlations	Significance
Ates (2018)	Eighty-one soccer U-16, U-17, U-18 and U-18 (17.7 ±1.16 years)	Local and school teams with at least 3 years of experience	CMJ SmartJump (Jumpmeter)	Cm	T-test (s)	U-16: r=-0.46 U-17: r= 0.09 U-18: r=-0.30 U-19: r=-0.41*	*p<0.05
Braz et al. (2017)	Twenty-five male soccer players (age: 28.1 ±1 years; height: 181 ±12 cm body mass: 78.2 ±6.8 kg;)	Professional soccer player with at least six years of systematized training	CMJ Ergo Jump (contact platform)	Cm	Acyclic Sprint (20m + 180° turn +20m) Zig-zag test	Acyclic Sprint: r=-0.53* Zig-zag test: r=-0.54*	*p<0.01
Castillo-Rodríguez et al. (2012)	Forty-five soccer players (age: 20.11 ±3.68 years; body mass: 73.41 ±8.43 kg)	Amateur soccer players training 3 days/ week	CMJ Left leg CMJ Right leg CMJ Ergo Jump (contact platform)	Cm	COD 180˚ (5m + 180˚+ 5m) COD 90° (5m + 90˚+ 5m)	COD 180˚ and CMJ: r=-0.595** COD 180˚ and left leg CMJ: r=-0.214 COD 180˚ and	*p<0.05 **p<0.01

						right leg CMJ: r=0.471** COD 90° left and CMJ: r=-0.568** COD 90° left and left CMJ: r=-0.392* COD 90° left and right CMJ: r=-0.642** COD 90° right and CMJ: r=-0.385** COD 90° right and left CMJ: r=-0.249 COD 90° right and right CMJ:	

						r=0.487**	
Emmonds et al. (2019)	Ten female soccer players (age: 25.4 ±7.0 years; height: 167.2 ±5.3 cm; body mass: 62.6 ±5.1 kg)	Elite female players training 4-5 times per week and 1-2 gym-based strength sessions.	CMJ Force platform	Cm N/s	505 COD test	No information given on correlations between CMJ scores and 505 COD test. One SD increase in CMJ height resulted in a reduction of -3.317 SD in 505 COD test	
Falch et al. (2021)	Twenty-three male football players (age: 22.5 ±2.6 years; height:	Second to sixth division of the Norwegian national	Unilateral CMJ Forcé plate	M	20m 45˚ 20m 180˚	20m 45˚: r=-0.28 20m 180˚ (s): r=-0.22	p>0.05

	181.3 ±6.3 cm; body mass: 79.9 ±8.6 kg)	league. Soccer training minimum of two times a week.					
Freitas et al. (2020)	Twenty-nine under-20 soccer players (age: 19.2±0.6 years; height: 176.1 ±7.3 cm; body mass: 72.1 ±6.9 kg)	No information on the player's training status	CMJ Contact platform	Cm	Zig-zag test Curved sprint test good side and curved sprint weak side	Zig-zag test: r= 0.37 Curved sprint test good side r=0.51* Curved sprint test weak side r=0.51*	*p<0.05
Jones et al. (2009)	Thirty-eight university students (age: 21.5 ±3.8 years; height, 1.77 ±0.07 m; body mass: 77.5 ±13.9 kg)	College team sport athletes that included soccer players	CMJ, Jump mat	Cm	505 COD test	505 COD test: r=-0.498*	*p<0.01
Kobal et al. (2020)	Seventeen female soccer players	Elite female soccer players	CMJ Contact platform	Cm	Zig-zag test Curvilinear test	Zig-zag test: r=0.21	*p<0.05

	(age: 25.6 ±3.7 years; height: 165.7 ±5.6 cm; body mass: 60.7 ±5.6 kg)				good side, Curvilinear test weak side	Curvilinear test good side: r=0.56* Curvilinear test weak side: r=0.53*	
Köklü et al. (2015)	Fifteen soccer male players (age: 16.0 ±0.8 years; height 168.4 ±4.7 cm; body mass: 62.6 ±7.7 kg)	Elite academy players, with six years of experience and training 4 days/ week	CMJ Force platform	Cm	Zig-zag test	Zig-zag test: r=−0.769*	*p<0.01
Lockie et al. (2014)	Thirty male recreational team-sport athletes (age: 22.60 ±3.86 years; height: 1.80 ±0.07 m; body mass = 79.03 ±12.26 kg)	Recreational team-sport athletes that included soccer players	Left leg CMJ Right leg CMJ Vertec apparatus	Cm	505 COD test T-test	505 COD left leg test and left leg CMJ: r=-0.238 505 COD left leg test and right leg CMJ: r=-0.062	*p<0.01

						505 COD right leg test and left leg CMJ: r=-0.238 505 COD right leg test and right leg CMJ: r=-0.224 T-test left and left leg CMJ: r=-0.202 T-test left leg test and right leg CMJ: r=-0.380 T-test right and left leg CMJ: r=-0.232 T-test right and	

						right leg CMJ: r=-0380*	
Los Arcos et al. (2017)	Forty-two male soccer players (age: 23.2 ±2.4 years; body mass: 76.6 ±8.2 kg; height: 179.6 ±5.8 cm)	Players competing in the Spanish 2nd B and 3rd division championships who trained 3-5 days/ week	CMJ CMJAs Optical measurement system	Cm	505 COD test T-test 20 yard test	505 COD test and CMJ: r=0.44** 505 COD test and CMJAs; r=0.49** T-test and CMJ: r=0.49** T-test and CMJAs: r=0.55** 20 yard test and CMJ: r=0.47** 20 yard test	*p<0.05 **p<0.01

						and CMJAs: r=0.44**	
Los Arcos et al. (2020)	One hundred and eighteen male soccer players (age: 16.5 ±3.0 years; height: 179.3 ±6.7 cm, body mass: 72.8 kg ±6.0)	Player belonged to seven different age categories: senior-professional (the second team of the club that competed in the Spanish Second Division B), junior (Under-19 and Under-17), cadets (Under-16 and Under-15) and child category (Under-14 and Under-13)	CMJ CMJAs Optical measurement system	Cm	Modified T-test Modified T-test free	Modified T-test and CMJ: r=0.703 Modified T-test and CMJAs: r=0.696* Modified T-test free and CMJ: r=0.698* Modified T-test free and CMJAs: r=0.721*	*p<0.001

Loturco et al. (2019b)	Sixteen female soccer players (age: 23.0 ±3.8 years; body mass: 60.2 ±7.3 kg; height: 165.1 ±5.5 cm)	Elite female soccer players	CMJ CMJ dominant leg CMJ non-dominant leg Force platform	Cm PP PF	Zig-zag test	Zig-zag test and CMJ height; r=0.63* Zig-zag test and CMJ PF; r=-0.39 Zig-zag test and CMJ PP; r=0.64* Zig-zag test and dominant CMJ height; r=0.44 Zig-zag test and dominant leg CMJ PF; r=-0.47 Zig-zag test and dominant leg CMJ PP;	*p<0.05

						r=0.40 Zig-zag test and non-dominant CMJ height; r=0.41 Zig-zag test and non-dominant leg CMJ PF; r=-0.45 Zig-zag test and non-dominant leg CMJ PP; r=0.37	
Loturco et al. (2020b)	Twenty-eight under-20 soccer players (age: 18.5 ±0.5 years; height:	No information on player's training status	CMJ Contact platform	Cm	Curved sprint test good side and curved sprint weak side	Curved sprint test good side: r= 0.57* Curved sprint	*p<0.05

	175.7 ±8.5 cm; body mass: 70.3 ±7.4 kg)					test good side: r=-61*	
McFarland et al. (2016)	Thirty-six soccer players. Males (n: 20; height: of 67.71 ±3.50 cm; body mass: 75.80 ±7.73 kg). Females (n: 16; height: 64.21 ±2.68 cm; body mass: 62.37 ±7.07 kg)	NCAA Division II soccer players	CMJ, Jump mat	Cm PAPw P:W	Pro-agility test T-test	Male Pro-agility test and CMJ (cm): r=-0.30 Pro-agility test and CMJ (PAPw); r=0.03 Pro-agility test and CMJ (P:W); r=-0.45* T-test and CMJ (cm); r=-0.16 T-test and CMJ (PAPw); r=0.02	*p<0.05

						T-test and CMJ (P:W); r=-0.25 Female Pro-agility test and CMJ (cm): r=-0.58 Pro-agility test and CMJ (PAPw): r=-0.50* Pro-agility test and CMJ (P:W); r=-0.60* T-test and CMJ (cm); r=-0.76* T-test and CMJ (PAPw); r=-0.46	

						T-test and CMJ (P:W): r=-0.79*	
Northeast et al. (2019)	Twenty-six male soccer players (age: 25 ±4 years; body mass: 76.3 ±8.6 kg; height: 179 ±8 cm)	Elite players playing in the EPL	CMJ Force platform	Cm PP RPP	Y-shaped test left Y-shaped test right	Y-shaped test left and CMJ (cm): r=-0.117 Y-shaped test right and CMJ (cm): r=-0.348 Y-shaped test left and CMJ (PP): r=0.136 Y-shaped test right and CMJ (PP): r=-0.108 Y-shaped test left and CMJ (RPP): r=0.094	p<0.05

						Y-shaped test right and CMJ (RPP): r=-0.388	
Sonesson et al. (2021)	One-hundred and fifteen football players. Boys (n: 66; age:14 ±0.6 years; height; 167 ±9 cm; body mass = 56 ±11 kg) and female players (n: 49; age:14 ±0.8 years; height:164 ±9 cm; body mass: 55 ±9 kg).	Eight youth teams were tested. All teams had scheduled football training at least two days/ week, with player having around seven and a half years of experience playing football.	CMJ Contact mat	Cm	505 COD test T-test	505 COD test: r=-0.601* T-test; r=-0.658	*p<0.01
Thomas et al. (2018)	Fifteen male (n = 56) and female (n = 59) team-sport athletes. Soccer	Team-sport athletes that included soccer players.	Left leg CMJ Right leg CMJ Force platform	Cm	505 COD test Modified 505 COD test	505 COD test and left leg CMJ: r=-0.69* 505 COD test	*p<0.01

	players: n: 15; age: 20.6 ±0.6 years; height; 168.0 ±7.2 cm; body mass: 56.2 ±6.3 kg.					and right leg CMJ: r=-0.53* 505 modified COD test and left leg CMJ: r=0.65* 505 modified COD test and right leg CMJ: r=-0.60*	
Vescovi & Mcguigan (2008)	Female high school soccer players (n: 83; age: 15.1 ±years: 1.63 ±0.07 m; body mass; 54.6 ±7.9 kg), college soccer players (NCAA	High school soccer player with around nine years of experience, college soccer (NCAA Division I) with around 13	CMJ Contact mat	Cm	Illinois test Pro-agility test	Illinois test and high school soccer players: r=-0.477** Pro-agility test and high school soccer players: r=-	*p<0.006 **p<0.0001

	Division I) (n: 51; age: 19.9 ±0.9 years; body mass: 64.8 ±5.9 kg) and college lacrosse (NCAA Division I) female athletes (n: 79, age; 19.7 ±1.1 years; body mass: 64.7 ±7.91kg)	years of experience and college lacrosse with around seven years of experience.				0.358* Illinois test and college soccer players: r=-0.551** Pro-agility test and college soccer players: r=-0.613** Illinois test and college lacrosse players: r=-0.698** Pro-agility test and college lacrosse players: r=-0.571**	

Yanci et al. (2014)	Thirty-nine male soccer players (age: 22.9 ±2.8 years; height: 179.9 ±6.01 cm; body mass: 77.0 ±8.3 kg)	Players competed in third division of the Spanish Soccer League. Players had around fifteen years of experience.	CMJ CMJAs Optical measurement system	Cm	505 COD test T-test 20 yard test	505 COD test and CMJ: r=0.60** 505 COD test and CMJAs; r=0.62** T-test and CMJ: r=-0.34 T-test and CMJAs: r=-0.41* 20 yard test and CMJ: r=0.47* 20 yard test and CMJAs: r=0.45*	*p<0.05 **p<0.01
COD = change of direction, CMJAs: Arm swing CMJ, PAPw = peak anaerobic power in watts; P:W = power to weight ratio., PP = peak power, PF = peak force, N/s = Newtons divided by seconds, RPP = relative pe							

ak power, SSC = stretch shortening cycle

2.6.4.3.1 Loaded and Unloaded Power/ Jump without countermovement

The ability of a player to generate vertical power performed without countermovement on unloaded [squat jump (SJ)] or loaded (squat jump with barbell) conditions could also be related to the ability to perform fast CODs. Freitas et al. (2019a) showed that male elite soccer and rugby players with higher peak power scores on a jump squat outperformed players with lower scores in the zig-zag test. In addition, SJ without additional load has shown moderate to large correlations with different COD tests in semi-professional and professional players(Braz et al., 2017; Los Arcos et al., 2017), young male players (França et al., 2022; Koklu et al., 2015), amateur female players (McFarland et al., 2016) and U-20 male soccer players (Loturco et al., 2020b). Furthermore, loaded SJ has also shown associations with COD tests in U-20s (Loturco et al., 2017b) and male senior professional players (Loturco et al., 2018b). On the other hand, other studies found small to moderate (Yanci et al., 2014) or small correlations (Papla et al., 2020) between concentric power and COD ability on semi-professional and elite male soccer players, respectively.

Therefore, the results of most of these studies show certain correlations between COD tests and vertical jump height without countermovement or vertical concentric power, and so, it could be considered an important physical quality related to COD performance. In this sense, Emmonds et al. (2019) attributed associations to the similar time available to produce force during these movements. Again, this could depend on the angles of the CODs, possibly with higher associations with sharper CODs (≥ 135°) (Dos'Santos et al., 2018a). Anyhow, caution is needed when interpreting these results due to the different methods utilised to assess correlations with COD ability (e.g. vertical jump height and power measures with different % of 1RM max). Therefore, more research is needed to understand which measurements show higher associations with COD performance.

2.6.4.3.2 Training Loaded and Unloaded Vertical Power/ Jump Without Countermovement

To the author's knowledge, there are only four experimental studies performed in soccer players where either loaded or unloaded SJ was used as an exercise in isolation to measure improvements in COD performance.

Interestingly, the methodologies utilised in these studies differ, with Sammoud et al. (2022) utilising loads from 40 to 60% of 1RM, Loturco, et al. (2016) utilising optimum load power, Loturco et al. (2020a) using loads 20% higher or lower than optimum load and

Coratella et al. (2018) having participants perform either weighted SJ or BM SJ. In any case, while participants characteristics differed (elite U-20, recreational and young amateur soccer players) most studies found improvements in the different tests utilised (zig-zag test, T-test). However, Coratella et al. (2018) only found improvements in the weighted JS group. Researchers should be cautious when drawing further conclusions, as the methodologies utilised in the four studies analysed differ. Moreover, only one study included SJ without added weight, and so, future research should identify if this training method is beneficial for COD performance enhancement. More so, landing from the loaded or unloaded squat jumps would have an eccentric component, and so, it could be argued that improvements in COD performance could occur due to the eccentric component rather than from the concentric phase performed. In this sense, both Cortella et al. (2018b) and Loturco et al. (2020a) found higher improvements in the experimental groups that utilised higher loads. Finally, zig-zag test was the most common test utilised (3 studies out of 4). This is formed of several CODs (usually four: two to each side), and so, it could be argued that a different test with shorter duration or a smaller number of CODs would be more relevant, as mentioned previously in this thesis.

2.6.4.4.1 Horizontal Jump

Due to the multidirectional nature of CODs, the ability of a player to apply force horizontally could also partly explain a player's capability to change direction during certain tests. Moreover, it is important to clarify that tests evaluating horizontal jumps measure the ability to generate force horizontally. Additionally, the player can only produce an impulse that they are able to absorb during the landing phase.

In other to understand the relationships between horizontal jump and COD performance, studies have utilised different strategies (Lockie et al., 2016; Yanci et al., 2014; Falch et al., 2020b; Chaouachi et al., 2012; Lockie et al., 2014; Rouissi et al., 2017; Popowczak et al., 2019; Kobal et al., 2016; Rouissi et al., 2017). Some studies utilised a SL horizontal jump, others a DL horizontal jump, while some incorporated SL or DL horizontal jumps but performed continuously (e.g. triple single maximal horizontal jumps), which would require different physical qualities. For example, SL horizontal jump would be considered a test that requires slow SSC, while during repeated horizontal jumps, the first jump would be considered slow SSC while the rest of the jumps could be considered fast SSC. In any case, most studies found moderate to large correlations with the diverse COD tests performed (505

COD test, modified T-test, 20-yard test, zig-zag test, etc.). It is worth noting that most studies were performed on college or recreational athletes that included soccer players or young male soccer players, and so, caution is necessary when interpreting these findings. More so, the large variations of jump and COD tests utilised, along with the contrasting results, make it difficult to draw further conclusions. Therefore, more research is needed to understand how the different types of horizontal jumps can impact COD performance.

2.6.4.4.2 Training using Horizontal Jumps

To the author's knowledge, only two studies in the scientific literature have isolated horizontal jump training with measures of COD pre- and post-intervention in soccer. Yanci, et al. (2016) found no improvements in the T-test in semi-professional male soccer players. In this study, players were divided into two groups, both performing varied horizontal jumps but with one group performing double the volume compared to the second group (180 vs 360 foot contacts). Interestingly, enhancement in horizontal jump performance didn't transfer to improved COD performance. This could be related to the characteristics of the COD test utilised, as the T-test would involve a straight line sprint, followed by a deceleration in the sagittal plane (this could resemble horizontal jumps), followed by lateral shuffle and backwards running. In addition, Ramírez-Campillo et al. (2015) found no improvements in the zig-zag test after six weeks of horizontal jump training in young male soccer players. Despite these two studies finding no beneficial effects, considering the high number of studies that have found meaningful correlations between horizontal jump and COD ability, future research should examine whether improvements in horizontal jump have potential benefits on COD performance.

2.6.4.5.1 Lateral Jumps

Within the limited research examining the association between COD and lateral jumps only four studies included participants involved in soccer practice (McCormick et al., 2014; Lockie et al., 2014; Falch et al., 2021; Falch et al., 2020a), with studies finding small to very large correlations with different COD tests. Lockie et al. (2014) found SL lateral jump to be moderate to largely correlated with a 505 COD test and T-test in recreational athletes that included soccer players. This correlation with the T-test is logical, as this test involves lateral displacement in 20 out of the 40m. The correlations between lateral jump and a COD test that also includes movements in the sagittal plane (e.g. T-test) are in line with findings from McCormick et al. (2014), who showed moderate relationships between lateral hop and a lateral shuffle COD test in college students involved in soccer practice. On the other hand, the same research group found small correlations between lateral jump distance and two different COD tests (COD test with 180º and COD test with 45º with turn) in young female soccer and handball players. More so, Falch et al. (2020a) found moderate to very large correlations between lateral jumps and two COD tests (COD test with 180º and COD test 45º with turn) in professional and semi-professional male soccer players (second to sixth national league level). Therefore, more research is needed to understand how lateral jumps are correlated with different COD tests and if this is dependent on the COD tests performed.

2.6.4.5.1 Training Lateral Jumps

While there are no experimental studies assessing the influence of isolated lateral jump training on COD performance in soccer players, some research has examined the influence of jump training on lateral shuffling ability. McCormick et al. (2016), using female varsity high school basketball players, found improvements in a lateral shuffle test after six weeks of lateral jump training consisting of 4-5 plyometric exercises. This is not surprising given the similarity between movements. Therefore, more research is needed to determine the effectiveness of training strategies which include lateral movements on COD performance.

2.6.4.6.1 Combination of Lateral, Vertical and Horizontal Training

While there is a lack of research looking at the benefits of vertical, horizontal or lateral jump training alone, a high number of studies have assessed the combination of these on COD performance (Table 2.4.), with most studies showing improvements (Chaabene & Negra, 2017; Ramírez-Campillo et al., 2015; Ramírez-Campillo et al., 2020; Bouguezzi, et al. 2020b; Loturco et al., 2017a; Sammoud et al., 2022; Negra et al., 2020; Chtara, et al., 2017; Jlid, et al., 2020; Ramírez-Campillo et al., 2016b; Ramírez-Campillo et al., 2018b), although other studies showed no improvements (Bouguezzi et al., 2020a; Söhnlein et al., 2014; Rædergård et al., 2020; Ramírez-Campillo et al., 2020; Bouguezzi et al., 2020a; Nonnato et al., 2022) or decreased performance (Bouguezzi et al., 2020a). In this sense, Bouguezzi et al. (2020a) conducted a study on prepubertal male soccer players, finding no improvements in a group performing vertical and horizontal CMJs and a decrease in performance in a group performing SJs. Anyhow, they lacked a control group. Similarly, Rædergård et al. (2020) found improvements in some COD tests (90°, 135° or 180° from 4 m and a 180° COD from a 20 m) but failed to find changes in other COD tests (45° from 4m and 45°, 90°, 135° from

20m). Again, this study did not include a CG that would assist in the interpretation of the results.

As seen in Table 2.4., all except for one study included either vertical and horizontal jumps or vertical, horizontal and lateral jumps. Interestingly, Ramírez-Campillo et al. (2018b) also included jumps with a rotational component (e.g. 180° CMJ). As COD actions would include rotational movements, future research should include these types of jumps as they could provide with a certain advantage over exercises that are performed in one plane.

It is worth noting that the most common test utilised to assess COD performance was the Illinois test (along with zig-zag test). The limitations of this test have been previously highlighted. (Nimphius et al., 2016). Furthermore, Söhnlein et al. (2014) utilised a COD test that included a course involving jumps over hurdles and 90° turns. As jumping over a hurdle wouldn't be considered a COD action, this test wouldn't be convenient to assess changes in performance.

Only six out of the 15 studies analysed were performed in senior players, while the other nine studies were performed in pre-pubertal or young soccer players. In addition, only three studies (Ramírez-Campillo et al., 2018b; Ramírez-Campillo et al., 2016; Nonnato et al., 2022) were performed on female soccer players. Therefore, future research should investigate how multidirectional jump training affects COD performance in female soccer players.

It is worth mentioning the study by Ramírez-Campillo et al. (2015), as this showed that a combination of horizontal and vertical jumps improved zig-zag test in young players, while horizontal or vertical jumping training alone didn't show benefits, indicating the potential benefits of a multidirectional vs unidirectional training program. Moreover, Ramírez-Campillo et al. (2020) found improvements in a group performing horizontal and vertical jumps before soccer training, while the group performing this same training protocol after soccer training showed no improvements, which could mean that to obtain the benefits of this type of training, players should avoid fatigue prior to power or jump training.

Therefore, while most studies show that multidirectional jump training could potentially enhance COD performance, future research should look to select COD tests that represent most optimally COD ability ability. Furthermore, more research needs to be performed on female players to understand to what extent this training regimen can enhance COD performance in this population.

Table 2.4. Overview of intervention studies assessing multidirectional jump and the effect in COD performance in soccer players									
Reference	Participant characteristics	Training status	Method	Weeks trained/ days per week	Set x reps and foot contact	COD Test utilised	Experimental and control group improvements	Effect size	P value
Bouguezzi et al. (2020a)	26 prepuberal male soccer Players (CMJ group = n: 13, age: 11.2 ±0.5 years, height: 149.1 ±5.8 cm, body mass: 35.7 ±8.4 kg); SJ group = n: 13, age: 11.3 ±0.3 years, height: 147.2. ±4.9 cm, body mass: 32.6	Regional level	Vertical and horizontal	8/2	1-4 x 5-12 (50 to 120 contacts)	Illinois test	CMJ group: -6% SJ group: 0.15%	CMJ group ES: -1.8 SJ group ES: 0.05	CMJ group: p<0.01 SJ group p>0.05

	±5.5 kg)								
Bouguezzi, et al. (2020b)	30 prepuberal male soccer players (Low frequency group= n: 15, age: 11.3 ±0.2 years, height: 145. ±3.5 cm, body mass: 39.0 ±6.0 kg; High frequency group= n: 15, age: 12.2 ±0.3 years, height: 145. ±5.5 cm, body mass: 35.4 ±4.7 kg)	Football club academy	Vertical and horizontal	Low frequency group: 8/1 High frequency group: 8/2	Low frequency group: 6–12 x 8–12. (50–120 jumps per session) High frequency group 3–6, x 7–14 (50–120 jumps per session)	T-test	Low frequency group: 6.6% High frequency group: 9.4%	Low frequency group ES: 1.01 High frequency group ES: 1.61	Difference between groups: p=0.57
Chaabene & Negra,	Young male soccer players	4 years of experience	Vertical and	8/2	Low volume	T-Test	T-test Low volume	Low volume	Difference between

2017	(Low volume group = n: 13, age: 12.6 ±0.2 years, height: 157. ±3.5 cm, body mass: 42.7 ±4.6 kg; High volume group = n: 12, age: 12.7 ±0.2 years, height: 155. ±9 cm, body mass: 44.9 ±8.5 kg)		horizontal		group: 5-6 x 10 to 8 x 15) (50-120) High volume group: 9-10 x 12 to 14x15 (110 to 220 foot contacts)		group: 6.97% High volume groups: 3.02%	group ES: 1.82 High volume group ES: 0.47	groups: p=0.01
Chtara, et al. (2017)	42 young male soccer players (age: 13.6 ±0.3 years, height: 165. ±7.0 cm, body mass: 54.1	Elite-level soccer players with 6 years of experience	Vertical, horizontal and lateral	6/1	2-3 x 8-12 (80 to 132 foot contacts)	Zig-zag test	EG: 2.11% CG: 0.70%	EG, ES = 0.75 CG, ES = 0.23	Differences between groups p<0.05

	±6.5 kg)								
Jlid, et al. (2020	27 male soccer players (EG= n: 11, age: 19 ±0.9 years, height: 176 ±5 cm, body mass: 67.6 ±5.9 kg; CG= n: 13, age: 19.0 ±0.7 years, height: 176 ±6 cm, body mass: 69.2 ±5.8 kg)	Tunisian 3rd league championship	Vertical, horizontal and lateral	6/2	5-6 x 4-16 (140 to 216 foot contacts)	T-test	EG: 2.99% CG: -1.15%	EG, ES = 0.75 CG, ES = 0.23	EG: p<0.001 CG: p=0.002
Loturco et al. (2017a)	11 male soccer players (n: 11, age: 22.2 ±2.4 years, height: 179. ±5 cm,	Professional soccer players	Vertical and horizontal	5/2	3-8 x 4-6	Zig-zag test	EG: 3.11%	ES: 0.84	-

	body mass: 75.5 ±11.5 kg)								
Negra et al. (2020)	22 pre-pubertal male soccer player (EG= n: 11, age: 12.7 ±0.3 years, height: 156 ±9.5 cm, body mass: 43.9 ±8.4 kg; CG= n: 11, age: 12.8 ±0.3 years, height: 153. ±8.6 cm, body mass: 42.5 ±5.5 kg)	Regional level	Vertical, horizontal and lateral	12/2	112 to 220 foot contacts	Illinois test	EG: 3.4% CG: 0.5%	EG ES: 1.9	EG: p<0.01
Nonnato et al. (2022)	15 female soccer players	Professional female soccer	Vertical, lateral and	12/1	4 x 4-6 (140	505 COD test	EG: 1.6% CG: -1.25%	EG ES: 0.41	EG: p=0.283

	(age: 24 ±4 years, height: 167 ±3.7 cm, body mass: 60.3 ±4.9 kg)	players	horiontal		jumps per session)				CG: p=0.497
Ramírez-Campillo et al. (2015)	40 pre-pubertal male soccer players (EG= n: 10, age: 11.2 ±2.3 years, height: 141. ±14.4 cm, body mass: 40.1 ±12.8 kg; CG= n: 10, age: 11.4 ±2.4 years, height: 146. ±16.2 cm, body mass: 42.5	Young soccer players	Vertical and horizontal	6/2	2 x 5-10 80 to 160 foot contacts)	Zig-zag test	EG: 4.5% CG: -1.5%	EG ES: 0.7	EG: p<0.5

	±13.2 kg)								
Ramírez-Campillo et al. (2020)	38 young male soccer players (Group before training= n: 12, age: 16.9 ±0.7 years, height: 172 ±4.9 cm, body mass: 64.9 ±4.8 kg; Group after training = n:=14, age: 17.1 ±0.3 years, height: 172 ±5.0 cm, body mass: 65.5 ±3.4 kg) (CG = n:12, age: 17.1 ±0.5	Professional young soccer players	Vertical and horizontal	7/2	1 x 5-16 Group before training: 104 to 220 foot contacts Group after training: 104 to 220 contacts	Illinois test	Group before training: 4.28% Group after training: 0.73%	Group before training ES:1.18 Group after training ES: 0.27	No information provided

	years, height: 175 ±4.4 cm, body mass: 66.8 ±4.4 kg)								
Ramírez-Campillo et al. (2016)	80 soccer players (female EG = n:19, age: 22.4 ±2.7 years, height: 161 ±6 cm, body mass: 60.7 ±6.9 kg) (female CG = n:19, age: 20.5 ±2.5 years, height: 159 ±6 cm, body mass: 60.2 ±9.3 kg; male EG =	10.5 to 12.3 years of experience	Vertical and horizontal	6/2	2 x 5-10 80 to 160 foot contacts)	Illinois test	Male EG: -2.1% Female EG: -4% Male CG: 0.2% Female CG: 0.7%	Male EG ES: -0.46 Female EG ES: -0.85 Male CG ES: 0.05 Female CG ES: 0.14	Male EG; p<0.05 Female EG: p<0.05 Male CG: p>0.05 Female CG: p>0.05

	n:21, age: 20.4 ±2.7 years, height: 174 ±6 cm, body mass: 71.5 ±6.9 kg) (male CG = n:19, age: 20.8 ±2.7 years, height: 174 ±6 cm, body mass: 71.5 ±6.9 kg)								
Ramírez-Campillo et al. (2018b)	21 female soccer players (Low frequency group = n:19, age: 22.8 ±4.3 years, height: 158 ±3 cm,	Regional level	Vertical, horizontal and rotational	Low frequency group: 8/1 High frequency group: 8/2	1 x 8-16 Low frequency group: 80-140 ground contacts per session	Zig-zag test	Low frequency group: 8.01% High frequency group: 8.01% CG: 1.2%	Group, ES: 0.13 Time ES: 0.61 Group x Time ES: 0.38	Low frequency group: p<0.01 High frequency group: p<0.01

	body mass: 54.9 ±3.7 kg; High frequency group = n:19, age: 21.5 ±2.5 years, height: 157 ±4.8 cm, body mass: 59.6 ±8.5 kg; CG = n:7, age: 20.1 ±1.7 years, height: 160.1 ±5 cm, body mass: 55.5 ±3.3 kg)				High frequency group: 40 to 70 ground contacts per session				CG: p>0.05
Rædergård et al., (2020)	11 male soccer players (age: 22.6 ±3.0 years, height: 182.3	Experienced soccer players from the 2nd to the 6th highest	Vertical, horizontal and lateral	6/2	2-6 x 3-10 (70-76 ground contacts)	COD 4 m or 20 m with a left or right cut, of	COD 4m 45°: 2.30% COD 4m 90°; 4.33% COD 4m	No data	COD 4 m 45◦, COD 4 m 180◦ and COD 20 m 180◦

	±5.7 cm, body mass: 82.5 ±7.3 kg)	level				45°, 90°, 135° or 180°	135°: 4.64% COD 4m 180°: 3.19% COD 20m 45°: 0.00% COD 20m 90°: 0.55% COD 20m 135°: 0.47% COD 20m 180°: 3.93%		$p<0.05$ All other tests $p>0.05$
Sammoud et al. (2022)	33 pre-pubertal male soccer players (EG = n:11, age: 12.7 ±0.3 years, height: 156 ±9.5 cm, body mass: 75.6 ±4.5 kg, CG = n:11,	Regional level	Vertical and horizontal	12/2	112-280 ground contacts	Zig-zag test	EG: 6.8% CG: 0.7%	EG ES: 0.96 EG ES: -0.05 to 0.20	Difference between groups: $p<0.001$

	age: 12.6 ±0.5 years, height: 153 ±8.6 cm, body mass: 62.6 ±5.6 kg)								
Söhnlein et al. (2014)	29 male academy soccer players (EG = n:12, age: 13.0 ±0.9 years, height: 162.4 ±9.6 cm, body mass: 51.0 ±6.4 kg, CG = n:11, age: 12.3 ±0.6 years, height: 154.2 ±5.8 cm, body mass: 40.8	At least 4 years of experience	Vertical, horizontal and lateral	16/2	2-5 x 6-16 (112-350 jumps per week)	Hurdle run (course involving jumps over hurdles and 90° turns)	EG: 6,09% CG: 1,51%	EG ES = 1.04 CG, ES = 0.31	EG: $p<0.001$ CG: $p>0.05$

	±4.5 kg)								
EG = Experimental group, CG: = Control group									

2.6.4.7.1 Maximal Dynamic Strength: 1RM

Another physical component that could underpin COD performance is maximal dynamic strength. This is usually assessed through one-repetition maximum (1RM), which is considered the gold standard for the evaluation of maximal strength (Levinger et al., 2009) and is performed in a concentric mode (Izquierdo et al., 2002). Other methods can calculate maximal strength estimate 1RM through higher repetition ranges such as 3RM (Andersen et al., 2018). While back squat using a barbell is commonly performed to assess maximal concentric strength (Swinton et al., 2014), other methods such as bilateral and unilateral 1RM squat using a smith machine (Marcovic, 2007; Arin et al., 2012; Falch et al., 2021) or a Keiser pneumatic machine (Papla, et al., 2020) have also been utilised in research. More so, as seen in previous sections, the COD tests selected to correlate with strength measures are divers.

It is important to note that studies usually assess absolute strength, which would represent the total kg that the athlete is able to lift and/or relative strength, which would represent the athlete´s 1RM divided by their BM (Andersen et al., 2018). When looking at the relationships between maximal strength on COD ability in soccer players research shows inconsistent results with some studies showing moderate to large associations (Andersen et al., 2018; Wisløff, et al., 2004; Arin et al., 2012; Keiner et al., 2014) and others trivial or small correlations (Loturco et al., 2019b; Papla, et al., 2020; Kadlubowski et al., 2021) as well as conflicting results (Freitas et al., 2019a; Falch et al., 2021; Falch et al., 2020b; Keiner et al., 2021a).

Some studies have separated between fast and slow performers in COD tests or high vs low half squat 1RM with interesting findings (Falch et al., 2021; Freitas et al., 2019a). In this sense, a study performed by Freitas et al. (2019a) showed that male elite soccer and rugby players with higher half squat 1RM outperformed players with lower scores in the zig-zag test. More so, Falch et al. (2021) found moderate to strong correlations between bilateral and unilateral strength and two COD tests (180º COD test and 45º COD test) but low correlations between lateral squat and the above-mentioned COD tests in young non-elite female handball and soccer players. When separating between fast and slow performers, researchers found that fast performers had higher levels of strength, jump height, higher step frequencies, shorter contact times and higher acceleration and braking power, concluding that correlations between COD and strength were derived from stronger athletes being able to produce higher workloads in shorter time.

Although a greater number of studies support the importance of higher strength levels for COD performance, there is inconsistency in the tests used and the performance levels of the subjects. There is a particular need for more research conducted on elite athletes, especially females. While evidence suggests that relative strength may be a more relevant measure than absolute strength concerning COD ability, incorporating unilateral tests could provide significant additional insights. In addition, more research is needed to ascertain how maximal strength influences COD with low or high degrees of turn.

2.6.4.7.2 Maximal Concentric Strength: Isokinetic Test

Another way to measure concentric strength and power is through an isokinetic dynamometer (Jones et al., 2017; Chaouachi, et al., 2012; Greig & Naylor, 2017). Isokinetic strength is defined as the force generated by a muscle against resistance at a constant rate of movement (American College of Sports Medicine, 1995). Isokinetic strength assessed with a dynamometer allows the measurement of strength through different speeds (e.g., 60º, 120º, 180º per second) as well as the isolation of different muscle groups [e.g., knee flexor (KF)s and knee extensor (KE)s].

While there is no experimental study looking at the effects of isokinetic strength training on COD performance, only four studies have analysed the relationship between concentric isokinetic strength and COD ability in soccer players with these showing conflicting results (Chaouachi, et al., 2012; Greig & Naylor, 2017; Young et al., 2001; Jones et al., 2009). Chaouachi, et al. (2012) found T-test but not 5-m shuttle run-sprint to have significant associations with knee concentric extensor and flexor strength (60º/s) in elite male soccer players. Jones et al. (2009) found moderate correlations between isokinetic knee concentric extensor and flexor strength (60º/s) and the 505 COD test in college team sport athletes that included soccer players. Conversely, Greig & Naylor, (2017) had senior male soccer and rugby players perform isokinetic concentric KE strength at different angular velocities (60, 180 and $300°\cdot s^{-1}$) as well as the T-test and found peak concentric KE strength to be a low determinant of COD performance compared to the other strength parameter measured (eccentric KF hamstring strength). On the other hand, Young et al. (2001) used a different methodology, where an isokinetic test was performed through a squat at a speed of 40º/s. This test did not show any correlations with seven COD tests that consisted of one right or left COD from 20º to 60º or 4 CODs of 60º in individual and team sport athletes that included soccer players. Due to the lack of studies looking at associations between concentric isokinetic strength and COD performance, it is difficult to draw further conclusions, and so more research is needed.

2.6.4.7.3. Training Maximal Dynamic Strength

Although strength training interventions and their impact on COD have been widely studied in soccer, the diverse methodologies performed in these studies, along with the contradictory outcomes increases the challenge of drawing clear conclusions (Table 2.5.). Interestingly, most of the studies reporting improvements in COD after strength training were performed in young and junior male soccer players (Hammami et al., 2017a; Hammami et al. 2018; Christou et al., 2006; Negra et al., 2020; Loturco et al., 2024; Durán-Custodio et al., 2023), while two studies showed improvements in senior soccer players (Bogdanis et al., 2009; Jarosz et al., 2023). On the other hand, other studies have shown no improvements in female competitive high school soccer players (Millar et al., 2020), female national sub-elite players (González-García et al., 2019), U-20 and U-19 male elite players (Barbalho et al. 2018; Spineti et al., 2018; de Hoyo et al., 2016a; Sanchez-Sanchez et al., 2022), young male players (Negra et al., 2020), male senior semi-professional and professional players (Coratella, et al., 2019; Rædergård et al., 2020) and amateur male soccer players (Fousekis et al., 2021; Katushabe & Kramer, 2020). In any case, some of these studies didn't report pre- to post-within-group intervention effect sizes, and so, it is difficult to conclude their practical significance (Fousekis et al., 2021; González-García et al., 2019; Rædergård et al., 2020; Millar et al., 2020)

It is important to note that the mode of strength training utilised would be important, as maximal strength training would usually involve ≥ 85% of 1RM or repetitions performed to 5RM, while ≤ 85% would usually have a strength-endurance or hypertrophy focus (Schoenfeld et al., 2021). While it´s important to note that intensities on some of these protocols were below what would be recommended for increases in maximal strength, it is also true that in the research studies showing no significant improvements in COD ability, there were improvements in either maximal strength (Barbalho et al., 2018; Katushabe & Kramer, 2020; Rædergård et al., 2020), quadriceps and hamstring strength (Coratella et al., 2019) or barbell velocity at 80% of 1RM (González-García et al., 2019), while Spineti et al. (2018) and De Hoyo et al. (2016a) didn't perform any form of strength test before and after the training regimen. Interestingly, although it has been suggested that strength training can benefit athletes with no previous strength training experience, three of the analysed studies showed no improvements in COD speed in players with no resistance training experience (Barbalho et al., 2018; Millar et al., 2020; González-García et al., 2019).

Unfortunately, only six of the 17 studies analysed were able to reach 85% of 1RM (Hammami et al., 2017a; Hammami et al., 2018; Rædergård et al., 2020; González-García et al., 2019; Fousekis et al., 2021; Barbalho et al. 2018), although only in two studies the whole protocol utilised intensities over 85% of the percentage of 1RM (Durán-Custodio et al., 2023; Bogdanis et al., 2009), which represents a big limitation. Both studies found improvements in COD performance after the strength training protocol.

Another limitation of the studies analysed is that on nine studies researchers only utilised one exercise (squat in most of the studies) (Miller et al., 2020; Negra et al., 2020; Hammami et al., 2017a; Hammami et al., 2018; González-García et al., 2019; Fousekis et al., 2021; Christou et al., 2016; Coratella, et al., 2019; de Hoyo et al., 2016a). Including a variety of exercises might have engaged a broader range of muscles, potentially leading to a better transfer to COD ability. In addition, Illinois test and T-test were among the most common tests utilised. As mentioned in previous sections, these tests would have limitations regarding the duration and movements performed.

The only two studies performed on female soccer players (adolescents), which included either a hip thrust or back squat group, failed to show any significant improvements in pro agility or T-test, with these studies using different loading protocols. While Millar et al. (2020) performed hip thrust or back squats at 30% of 3RM, increasing 10% each week for six weeks, in the study by González-García et al. (2019), these exercises were performed with loads from 60% to 90% of the 1RM. Therefore, more research is needed to gain greater understanding on how concentric strength correlates with COD ability and how gains in concentric strength can improve this physical capacity, with lack of research in female population being specially worrying.

Table 2.5. Overview of intervention studies assessing strength and the effect in COD performance in soccer players								
Reference	Participant characteristics	Training status	Weeks trained/ days per week	Training characteristics	COD test utilised	Experimental and control group improvements	Effect size	p value
Barbalho et al., (2018)	23 U-20 male players (EG = n: 11, age: 18.8 ±0.68 years, height: 178.4 ±6.2 cm, body mass: 73.1 ±6.6 kg; CG= n: 12, age: 19.1 ±0.9 years, height: 176.3 ±8.6 cm, body mass: 72.0	Professional level	15/3	Bench press, lateral pull down, shoulder press, leg press, free squatting with bar, seated leg curl, calf standing in the machine (4–15RM)	T-test	EG: -1.74% CG: -4.31%	EG ES = -0.33 CG ES = -0.71	EG: p>0.05 CG: p>0.05

	±5.9 kg)							
Bogdanis et al. (2009)	18 male soccer players (age: 22.9 ±1.1 years, height: 180 ±2 cm, body mass: 75.4 ±2.1 kg)	No mention of level	12/3	Both groups performed 8-12 upper and lower body exercises (no specific exercises mentioned). Hypertrophy group training at 70% of 1RM and strength group at 90% of 1RM. EG: Half squats. 4 sets x 5 repetitions at 90% f 1RM	T-test, Illinois test Zig-zag test	All improvements were greater in EG but no specific mention to the exact percentage	All improvements were greater in EG but no specific mention to the exact effect size	Between group differences: T-test greater improvements for EG: P<0.01 Illinois test: greater improvements for EG: P<0.05 zig-zag test: greater improvements for EG: P<0.05

				hypertrophy group: 4 sets x 12 repetitions at 70% f 1RM				
Christou et al. (2016)	26 male soccer players (EG = n: 9, age: 13.8 ±0.6 years, height: 162.0 ±3 cm, body mass: 52.0 ±3.3 kg; soccer group = n: 9, age: 13.5 ±0.6 years, height: 163.0. ±3 cm, body mass: 54.1 ±2 kg; CG= n: 8,	Reginal soccer players with 4.3 years of experience	16/2	Half squats. 2-3 sets x 8-15 repetitions at 55-80% of 1RM	10 x 5m test	EG: 5.4% Soccer group: 4% CG: -1.6%	EG ES: 1.74 Soccer group ES: 1.13 CG ES: 0.17	EG: p<0.05 Soccer group, ES: p<0.05 CG ES: p>0.05

	age: 13.3 ±0.2 years, height: 163.2 ±5 cm, body mass: 55.8 ±4.5 kg)							
Coratella et al. (2019)	40 male soccer players (age: 23.4 ±4 years, height: 180 ±11 cm, body mass: 77 ±5 kg) No CG	Italian fourth division players. At least 5 years of experience.	8/1	Squat. 4-6 sets of 8 repetitions at 80% of 1RM	T-test	EG: 2%	EG ES: 0.12	EG: p>0.05
De Hoyo et al. (2016a)	32 late adolescents (U-19) male (EG = n: 11, age: 18.1 ±1 years, height: 177.8 ±3.12 cm, body	Highly trained	8/2	Full squat. 3 sets 4–8 repetitions at 40–60% 1RM	Zig-zag test	EG: 0%	EG ES: 0	No information

	mass: 70.8 ±3.8 kg)							
Durán-Custodio et al. (2023)	20 male soccer players (EG = n: 10, age: 24.5 ±3.1 years, height: 176.6 ±3 cm, body mass: 74.7 ±5.7 kg; CG = n: 10, age: 25.8 ±2 years, height: 175. ±3 cm, body mass: 72.8 ±6.6 kg	Semi-professional soccer players	12/2	Horizontal leg press, unilateral lateral leg press with 45◦ inclination, knee extension and knee flexion at 85–95% of 1RM, 3 sets of 3–4 repetitions	505 COD test	COD 505 test dominant leg EG: 4.88% COD 505 test non-dominant leg EG: 4.99% COD 505 test dominant leg CG: 0.09% COD 505 test non-dominant leg CG: 0.09%	COD 505 test dominant leg EG ES: 5.77 COD 505 test non-dominant leg EG, ES: 3.83 COD 505 test dominant leg CG ES: 0.09 COD 505 test non-dominant leg CG ES: 0.010	EG COD 505 test dominant and non-dominant: $p<0.001$ CG COD 505 test dominant and non-dominant: $p>0.05$
Fousekis et al. (2021)	24 male soccer players (EG = n: 11,	Amateur soccer players	6/2	Semi squats. 3-4 sets of 8-10 repetitions	Illinois test	EG: 0.5% CG: No information	No effect sizes were calculated	EG: $p>0.05$ CG: $p>0.05$

	age: 19.7 ±2.1 years, height: 180 ±5.0 cm, body mass: 75.3 ±3.9 kg; CG= n: 13, age: 23.9 ±4.7 years, height: 177 ±3.2 cm, body mass: 73.3 ±3.1 kg)			at 75-85%		provided		
González-García et al. (2019)	24 (8 players on each group) adolescent female soccer players (age: 16.8 ±1.5 years, height: 164.3 ±5.5 cm, body	Adolescent female soccer players. No information on level	7/2	Squat or hip thrust. 4 sets x 4-12 repetitions from 60 to 90% RM	T-test	No information on the percentage of improvement pre- to post-intervention	No information on individual group effect sizes: Squat group vs CG ES: -0.14 (for CG) Hip thrust group vs CG	No information on individual group p values:

	mass: 58.3 ±6.2 kg)						ES: 0.21 (for hip thrust group)	
Hammami et al. (2017a)	26 junior male soccer players (EG = n: 16, age: 16.2 ±0.6 years, height: 175. ±3 cm, body mass: 58.0 ±6.2 kg; CG= n: 12, age: 16.8 ±0.2 years, height: 168 ±5 cm, body mass: 58.1 ±5.2 kg)	Experienced players	8/2	Half squat. 3-5 sets x 3-8 repetitions at 70-90% of 1RM	9-3-6-3-9 m with 180º turns 9-3-6-3-9 m sprint with backward and forward running 4 x 5 m sprint	9-3-6-3-9 m with 180º turns EG: 3.58% 9-3-6-3-9 m with 180º turns CG: 0.11% 9-3-6-3-9 m sprint with backward and forward EG: 4.4% 9-3-6-3-9 m sprint with backward and	9-3-6-3-9 m with 180º turns EG: 0.22 9-3-6-3-9 m with 180º turns CG: 0.12 9-3-6-3-9 m sprint with backward and forward EG: 0.26 9-3-6-3-9 m sprint with backward and	9-3-6-3-9 m with 180º turns EG: $p<0.001$ 9-3-6-3-9 m with 180º turns CG: $p<0.01$ 9-3-6-3-9 m sprint with backward and forward EG: $p<0.001$ 9-3-6-3-9 m sprint with backward and

						forward CG: 0.5% 4 x 5 m sprint EG: 2.29% 4 x 5 m sprint CG: 0.47%	forward CG: 0.09 4 x 5 m sprint EG: 0.293 4 x 5 m sprint CG: 0.23	forward CG: p<0.05 4 x 5 m sprint EG: p<0.001 4 x 5 m sprint CG: p<0.001
Hammami et al. (2018)	31 junior male soccer players (EG = n: 19, age: 16.2 ±0.6 years, height: 175. ±3 cm, body mass: 58.1 ±7.3 kg; CG= n: 12, age: 15.8 ±0.2 years, height: 168 ±5 cm,	Well-trained junior soccer players	8/2	Half squat. 3-5 sets x 3-8 repetitions at 70-90% of 1RM	9-3-6-3-9 m with 180º turns 9-3-6-3-9 m sprint with backward and forward running 4 x 5 m sprint	9-3-6-3-9 m with 180º turns EG: 2.81% 9-3-6-3-9 m with 180º turns CG: -0.6% 9-3-6-3-9 m sprint with backward and forward EG:	No information on effect sizes for each groups, only for both groups together: 9-3-6-3-9 m with 180º turns ES: 0.153	9-3-6-3-9 m with 180º turns EG: p<0.05 9-3-6-3-9 m with 180º turns CG: p>0.05 9-3-6-3-9 m sprint with backward and forward EG:

	body mass: 58.2 ±5.0 kg)					3.38% 9-3-6-3-9 m sprint with backward and forward CG: -1.4% 4 x 5 m sprint EG: 11.44% 4 x 5 m sprint CG: 0.97%	4 x 5 m sprint ES: 0.187	p<0.01 9-3-6-3-9 m sprint with backward and forward CG: p>0.05 4 x 5 m sprint EG: p<0.01 4 x 5 m sprint CG: p>0.05
Jarosz et al. (2023)	24 male soccer players (EG = n: 8, age: 20 ±1 years, height: 173 ±7 cm, body mass: 64 ±8 kg)	Amateur soccer players with 6 years of experience	4/2	Barbell back squats, bench presses, forward split squats, pulldowns, barbell hip thrusts, and	505 COD test	EG turn with dominant leg: 1.3 0% EG turn with non-dominant leg: -0.43%	No information	EG turn with dominant leg: p<0.05 EG turn with non-dominant leg: p>0.05

	No CG (only two other flywheel groups)			pallof press with a resistance band. 3 sets of 10 repetitions at 60% of 1RM				
Katushabe & Kramer (2020)	22 male soccer players (age: 20.47 ±1.85 years, height: 177 ±8 cm, body mass: 70.49 ±4.15 kg)	Amateur soccer players	8/2	Squats, weighted lunge, front squat, goblet squat, deadlift, sumo deadlift, nordic hamstring curls, single leg hip lifts. 3 sets x 5 - 10 repetitions (no information on % of 1RM)	Zig-zag test	EG: 0.77% CG: 1.47%	EG ES: 0.112 CG ES: 0.483	EG: p=0.746 CG, ES: p=0.215

Negra et al. (2020)	22 prepubertal male soccer player (EG= n: 12, age: 12.8 ±0.3 years, height: 159.7 ±8.4 cm, body mass: 47.8 ±8.4 kg; CG= n: 11, age: 12.8 ±0.3 years, height: 153. ±8.6 cm, body mass: 42.5 ±5.5 kg)	Regional level	12/2	Half squats. 4 x 10-12 (40-60% 1RM)	Illinois test	EG: 4.3% CG: 0.5%	EG ES: 1.8	EG: p<0.01 CG: p>0.05
Miller et al. (2020)	18 young female soccer players (squat group = n: 8,	Competitive high school soccer athletes	6/2	Squat or hip thrust. 3-4 sets of 3-6 sets 30% to 80%	Pro-agility shuttle	Squat group: -1.75% Hip thrust group:	No information on effect size	Squat group: p>0.05 Hip thrust group: p>0.05

	age: 15.3 ±0.7 years, height: 159.1 ±7.2 cm, body mass: 56.7 ±6.7 kg; hip thrusts group = n: 6, age: 15.3 ±0.7 years, height: 159.1 ±8.6 cm, body mass: 56.3 ±6.4 kg) No CG			of 1RM), overhead press, lat pull down and 30’’ plank hold		-1.54%		
Rædergård et al., (2020)	10 male soccer players (n:11, age: 22.2 ±3.0 years, height: 181.4 ±6.0	Experienced male soccer players from the 2nd to the 6th highest level	6/2	Unilateral quarter squat, parallel squat, lateral squat, nordic hamstring,	COD 4m or 20 m with a left or right cut, of 45°,	COD 4m 45°: 2.34% COD 4m 90°; -0.49% COD 4m 135°: 0.84%	No data	All tests p>0.05

	cm, body mass: 77.2 ±7.2 kg)			unilateral plantarflexion 2-3 sets x 5-8 70% to 85% 1RM	90°, 135° or 180°	COD 4m 180°: 1.23% COD 20m 45°: 2.90%: 2.90% COD 20m 90° 0.54% COD 20m 135°: 3,69% COD 20m 180°: 3.02%		
Sanchez-Sanchez et al. (2022)	55 male soccer players (stable group= n: 28, age: 17.9 ±0.6 years, height: 175.14 ±6.5 cm, body mass: 68.1 ±7.2 kg	National-level U-19 male soccer players with four or more years of experience	10/2	Bent-over row, forward lunge, front half squat, prone leg curl, over-head press and calf raise (stable group performed	Illinois test	Stable group: -0.1% Unstable group: 0.5%	Stable group ES = -0.02 Unstable group ES: 0.13	No information on p value

	(unstable group= n: 8, age: 18.0 ±0.4 years, height: 175.6 ±3.6 cm, body mass: 69.8 ±5.0 kg) No CG			exercises on a flat surface, unstable group performed exercises on a BOSU). 2 sets x 6-12 repetitions between 60-80% of 1RM				
Spineti et al. (2018)	22 male soccer players (EG= n: 10, age: 18.4 ±0.4 years, height: 179.9 ±7.5 cm, body mass: 70.2 ±9.1 kg)	Professional soccer players	8/3	Squat in Smith machine, deadlifts, knee extension and flexion, nordic hamstring, hip adduction and abduction. 2–4 sets, 4–15RM	Zig-zag test	EG: 0.98%	EG ES = 0.30	EG: p>0.05

EG = experimental group, CG = control group, ES = effect size.

2.6.4.3. Eccentric Strength

Since COD involves both braking and propulsive forces, eccentric strength may be crucial for optimal COD performance. It has been suggested that eccentric strength plays a significant role in enhancing COD ability. This is because, during strength, power, or jump training, high velocities are achieved while the muscle lengthens, a process that also occurs during CODs (Brughelli et al., 2008).

Researchers have usually performed eccentric testing using an isokinetic dynamometer (Thomas et al., 2018; Jones et al., 2009, Jones et al., 2017), although eccentric strength measured through a flywheel device has gained popularity in recent years (Beato et al., 2021b). Studies have shown moderate to large correlations between eccentric strength and faster performance in T-test (Greig & Naylor, 2017), 180º COD tests (Jones et al., 2009, Jones et al., 2017) and a 70- 90º cutting task (Jones et al., 2022) in female professional and semi-professional soccer players, although other studies have shown inconsistent results or no relationships (Thomas et al., 2018; Chaouachi, et al., 2012).

Interestingly, a study performed by Jones et al, (2017) found stronger participants [eccentric KE as well as eccentric KF strength (isokinetic dynamometer at $60°\cdot s^{-1}$)] to have significant faster approaching speed and greater reduction in speed during penultimate step compared to the weaker subjects in a COD test (5 m approach, 180◦ turn, 5 m return). This would potentially mean that having greater eccentric capabilities would lead to players being able to approach faster and decelerate more effectively compared to weaker players.

In the same line, Jones et al. (2022) in similar population found high correlations between eccentric KE strength (isokinetic dynamometer at $60°\cdot s^{-1)}$ and COD completion time (time to complete: 5 m approach, 70–90˚ cut, 3 m exit) as well as moderate correlations with eccentric KF strength. Moreover, moderate and significant correlations were found between eccentric KE strength and velocities at key instances of the cut and minimum resultant horizontal plane velocity. On the other hand, low correlations were found between eccentric KF strength and velocities at key instances of the COD. Authors suggested that eccentric KF strength may play a minor role in supporting deceleration mechanics during cutting, possibly helping produce hip extensor moments in the penultimate and final steps to control trunk flexion, as well as assist knee joint stability through co-contraction.

Therefore, collectively, while more research is needed to ascertain the relationship between eccentric strength and COD ability, a high number of studies show correlations with

COD performance, which could be related to the link between eccentric strength and deceleration ability during a COD task.

2.6.4.3.1 Training Eccentric Strength

Over the last years, there has been a rise in the number of experimental studies looking at the ability of eccentric training to improve COD ability. One of the characteristics of eccentric strength is that force production is about 20 to 60% higher than concentric strength (Hortobágyi & Katch, 1990). Therefore, it is important to differentiate between eccentric training as such and eccentric overload training, where higher than maximal concentric forces are applied. Different eccentric training methods have been utilised in the scientific literature for the improvement of COD performance in soccer (Table 2.6.).

While some researchers have utilised eccentric tempo training (Shibata et al., 2021) or BW exercises (Siddle et al., 2019) researchers have predominantly used flywheel devices (Fiorilli, et al. 2020; Coratella et al., 2019; Tous-Fajardo et al., 2016; Gonzalo-Skok et al., 2017; Núñez, et al., 2018; de Hoyo et al., 2016b; Sanchez-Sanchez, et al. 2019; Raya-González et al., 2021; Pecci et al., 2022; Jarosz et al., 2023; Fousekis et al., 2021; Gonzalo-Skok et al., 2023) with the aim of applying eccentric overload. The reasons for most studies utilising flywheel eccentric training could be related to certain advantages of this method: 1. It allows not only a wide variety of exercises but also sport-specific movements in all three planes with similar kinematics to the sport (Prieto-Mondragon et al., 2016). 2. Accommodated resistance where effort is maximal from the first repetition (Tesch et al., 2017). 3. Maximal force in every angle without a 'sticking point' (Vázquez-Guerrero, et al., 2016). 4. Accommodated resistance allowing for continuous change in movement during each repetition or each of the phases of a set (Tous, 2017). While training loads can be modified by increasing speed or adding flywheel weights, the efficacy of the use of this training method to apply eccentric overload is the intention to apply force at the maximum speed possible during the concentric phase and stop the rotating movement during the eccentric phase (Nuñez-Sanchez & Villareal, 2021; Beato & dello Iacono, 2020).

While most of the studies performed utilising flywheel training have shown improvements, certain limitations need to be considered. Only three studies out of 13 were performed on senior professional or 'highly trained' players (Tous-Fajardo et al., 2016; Fiorilli, et al., 2020; Pecci et al., 2022). More so, five studies (Shibata et al., 2021; Fousekis et al., 2021; Jarosz et al., 2023; Pecci et al., 2022; Fiorilli, et al., 2020) failed to report effect sizes pre- to post-intervention and so, it would be difficult to draw further conclusions reagrding the practical significance.

Within studies analysed in Table 2.6. the lack of research performed in female players is especially concerning, with only one study conducted (Pecci et al. (2022). In this study, researchers found no improvements in COD performance (5+5 meter shuttle run-sprint test) after six weeks of flywheel training in professional female soccer players (Pecci et al., 2022). While this study showed no enhancement in COD performance, it lacked a CG, and so, it would be difficult to draw further conclusions. Furthermore, subjects had no experience utilising this type of equipment. The authors suggested that the lack of improvements was due to the non-specific stimulus of the training protocol in the sagittal plane and the horizontal vector. This should be considered when developing training strategies to enhance performance. In this sense, one of the main advantages of flywheel devices is that they allow selection of exercises that can easily overload certain specific movements of the sport.

In a previous section multidirectional plyometrics was shown to be an effective method to improve COD performance in soccer players. Four studies utilised flywheel multidirectional exercises, with 3 out of 4 studies showing enhanced performance in the different COD tests utilised (Jarosz et al., 2023; Gonzalo-Skok et al., 2017; Gonzalo-Skok et al., 2017; Fiorilli, et al., 2020). In this sense, the only study showing contradicting results had two different groups perform different flywheel exercises. The first performed a squat and a forward split squat while the second group performed a squat and a lateral split squat, with only the first group showing improvements.

Therefore, research supports the use of flywheel devices for enhanced COD performance. Further research needs to be performed, with the use of relevant COD tests, high-level athletes and with female population. Moreover, researchers should include effect sizes to understand the meaningfulness of the findings. More so, researchers should utilize a CG to acknowledge if the findings are the result of the intervention performed or due to other factors.

Table 2.6. Overview of intervention studies assessing strength and the effect in COD performance in soccer players								
Reference	Participant characteristics	Training status	Weeks trained/ Days per week	Training characteristics	COD Test utilised	Experimental and control group improvements	Effect size	p value
Coratella et al. (2019)	40 male soccer player (age: 23 ±4 years, height: 180 ±11 cm, body mass: 77. ±5 kg). No CG	Italian fourth division. At least 5 years of experience.	8/1	Flywheel squats. 4 to 6 sets x 8 repetitions (inertia = 0.11 kg·m2)	T-test: 20 + 20 m shuttle test:	T-test: 20 + 20 m: 7% shuttle test: 4%	T-test: 1.44 20 + 20 m shuttle test: 0.75	T-test: p<0.05 20 + 20 m shuttle test: p<0.05
Fiorilli, et al (2020)	18 Junior male players (age: 13.21 ±1.21 years, height: 165 ±7 cm, body mass:	Highly trained soccer players	6/2	2 exercises: multidirectional-unilateral exercise simulating COD	Y-test Illinois test	Y- test: 0.26% Illinois test:3.23%	No information on within group ES	Y-test: p<0.001 Illinois test: p<0.001

	51.25 ±6.7 kg) No CG			performance and simulated soccer shooting, with the device fixed to the athlete's ankle. 4 sets x 7 reps No information on inertia utilised.				
Fousekis et al. (2021)	24 male soccer players (EG = n: 11, age: 19.7 ±2.1 years, height: 180 ±5.0 cm, body mass: 75.3 ±3.9	Amateur soccer players	6/2	Semi squats. 3 sets x 10 reps (inertia = 0.05 kg/m^2 to 0.10 kg/m^2)	Illinois test	EG: 0.5% CG: No information provided	No information on ES	EG: p>0.05 CG: p>0.05

	kg; CG= n: 13, age: 23.9 ±4.7 years, height: 177 ±3.2 cm, body mass: 73.3 ±3.1 kg)							
Gonzalo-Skok et al. (2017)	48 male soccer players (age: 20.5 ±2 years, height: 180.1 ±6.3 cm, body mass: 73.2 ±9.3 kg)	Semi-professional and amateur	8/2	Vertical bilateral group: squats 6 sets x 6 to 10 reps. Multidirection unilateral group: 1 set x 6 to 10 reps of backward lunges, defensive-like shuffling steps, side-step, crossover	COD tests (running 5, 10 or 12.5 m followed by a left or right 45º turn)	Vertical bilateral group COD 10 m right leg: 2.4% COD 10 left leg: 1.1% COD 20 m right leg: 1.6% COD 20 m left leg: 2% COD 25 m right leg:	Vertical bilateral group: COD 10 m right leg: 0.47 COD 10 m left leg: 0.25 COD 20 m right leg: 0.31 COD 20 m left leg: 0.50 COD 25 m right leg: 0.28 COD 25 m left leg:0.22	No information on p values

				cutting, lateral crossover cutting and lateral squat. (inertia for both groups 0.27 kg·m2)		1.1% COD 25 m left leg: 1.4% Multidirectional unilateral group: COD 10 m right leg: 2.9% COD 10 m left leg: 3% COD 20 m right leg: 1.6% COD 20 m left leg: 2.3% COD 25 m right leg: 1.8% COD 25 m	Multidirectional unilateral group: COD 10 m right leg: 0.54 COD 10 m left leg: 0.61 COD 20 m right leg: 0.35 COD 20 m left leg: 0.43 COD 25 m right leg: 0.36 COD 25 m left leg:0.27	

						left leg: 1.1%		
Gonzalo-Skok et al. (2023)	32 male young soccer players (15.5 ±0.8 years, height: 174.6 ±6.7 cm, body mass: 62.5 ±14.1 kg)	Semi-professional soccer players	10/1	1 set x 5-10 repetitions of front step, backward lunges, defensive-like shuffling steps, and lateral crossover cutting (inertia = 0.27 kg/m^2) 1 group performed the exercises in a preplanned manner while the second group performed the	T-test	Preplanned group: 4.66% unanticipated/ unexpected group: 5.10% CG: 0.97%	Preplanned group ES: 1.34 unanticipated/ unexpected group, ES: 0.98 CG, ES: 0.49	Preplanned group: p<0.0001 unanticipated/ unexpected group: p=0.001 CG: 0.140

				same exercises in random unanticipated/ unexpected manner				
Jarosz et al. (2023)	24 male soccer players (Forward split squat group = n: 8, age: 19 ±1 years, height: 176 ±10 cm, body mass: 66 ±5 kg; Lateral split squat group = n: 8, age: 20 ±1 years, height: 176 ±10 cm, body mass: 70	Amateur soccer players with six years of experience	4/2	3 sets of 8 x 10 repetitions for both groups Forward split squat group: a squat and a forward split squat on a flywheel Lateral split squat group: a squat and a	505 COD test	Forward split squat group turn with dominant leg: 1.31% Forward split squat group turn with non-dominant leg: 0.85% Lateral forward split squat group turn with	No information on ES	Forward split squat group and lateral split squat group turn with dominant leg: $p<0.05$ Forward split squat group and lateral split squat group turn with non-

	±11 kg) No CG (only 1 traditional strength group)			lateral split squat on a flywheel device (inertia = 0.10 kg/m^2 for a back squat and 0.05 kg/m^2 for split squats).		dominant leg: 2.21% Lateral split squat group turn with non-dominant leg: 0.87%		dominant leg: p>0.05
Núñez, et al. (2018)	27 male team sport players (Unilateral lunge group = n: 14, age: 22.8 ±2.9 years, height: 177.3 ±3.7 cm, body mass: 75.3 ±8.8 kg; Bilateral squat group = n: 13,	No mention to level	6/2	4 sets x 7 reps of squat (inertia = 0.10 kg/m^2) in bilateral squat group and a unilateral squat with each leg (inertia = 0.05 kg/m^2) in the	5 m+5 m straight sprint with a 90° COD 5 m+5 m straight sprint with a 180° turn	Bilateral squat group 5 m+5 m with 90° COD dominant: 3.21% 5 m+5 m with 90° COD non-dominant: 1.63% 5 m+5 m with	Bilateral squat group 5 m+5 m with 90° COD dominant ES: 0.70 5 m+5 m with 90° COD non-dominant, ES: 0.29 5 m+5 m with	No information on p values

	age: 22.6 ±2.7 years, height: 164.2 ±7 cm, body mass: 79.5 ±12.9 kg) No CG			unilateral lunge group		180° COD dominant: 0.66% 5 m+5 m with 180° COD non-dominant: 0.06% Unilateral lunge group 5 m+5 m with 90° COD dominant: 4.04% 5 m+5 m with 90° COD non-dominant: 3.60% 5 m+5 m with	180° COD dominant, ES: 0.11 5 m+5 m with 180° COD non-dominant, ES: 0.01 Unilateral lunge group 5 m+5 m with 90° COD dominant ES: 0.75 5 m+5 m with 90° COD non-dominant, ES: 0.54 5 m+5 m with	

						180° COD dominant: 1.22% 5 m+5 m with 180° COD non-dominant: 1.55%	180° COD dominant, ES: 0.29 5 m+5 m with 180° COD non-dominant, ES: 0.33	
Pecci et al. (2022)	24 female players (EG = n: 12, age: 20.8 ±2.66 years, height: 161 ±4 cm, body mass: 57.5 ±7.3 kg; CG = n: 12, age: 20.1 ±2.6 years, height: 164 ±5.6 cm, body mass: 59.9 ±6.9 kg)	Professional soccer players	6/2	Flywheel squats 3 to 4 sets of 6 to 8 reps (Inertia 0.025 kg/m^2 and 0.050 kg/m^2)	5 + 5 m with 180° turn	EG: 1.46% CG: 3.98%	No information on within-group ES.	No information on within-group p values

Raya-González et al. (2021)	22 young male soccer players. No information regarding anthropometric measures	U-16 academy soccer players	10/1	Lateral squat 2 to 4 sets x 8 to 10 reps (inertia 0.025 kg/m^2)	5 + 5-m with 90° turn (COD 10) dominant and non-dominant 10 + 10-m with 90° turn (COD 20) dominant and non-dominant	EG COD 10 dominant: 0.23% COD 10 non-dominant: -0.20% COD 20 dominant: -0.19% COD 20 non-dominant: -0.28% CG COD 10 dominant: 0.12% COD 10 non-dominant: -0.01%	EG COD 10 dominant, ES: -1.95 COD 10 non-dominant, ES: 1.26 COD 20 dominant, ES: 1.40 COD 20 non-dominant, ES: 2.20 CG COD 10 dominant, ES: 1.30 COD 10 non-dominant, ES: -0.03	EG COD 10 dominant: p=0.001 COD 10 non-dominant: p=0.003 COD 20 dominant: p=0.04 COD 20 non-dominant: p=0.03 CG COD 10 dominant: p=0.01 COD 10 non-dominant: p=0.68

						COD 20 dominant: -0.01% COD 20 non-dominant: -0.02%	COD 20 dominant, ES: -0.20 COD 20 non-dominant, ES: -0.12	COD 20 dominant: p=0.45 COD 20 non-dominant: p=0.45
Sanchez-Sanchez, et al. (2019)	22 male soccer and basketball players (HIT + flywheel group = n: 11, age: 19.9 ±0.68 years, height: 173.6 ±4.0 cm, body mass: 65.6 ±4.9 kg; HIT = n: 11, age: 19.1 ±0.9 years, height: 170.7 ±3.1 cm, body mass:	Regional level	5/2	2 sets x 6 reps. Backwards lunges and unilateral hamstrings 'kicks' (Inertia 0.27 kg/m^2) and half squats (inertia = 0.05 kg/m^2)	Illinois test	HIT + flywheel group: 5.6% HIT group: 2.3%	HIT + flywheel group, ES: 1.01 HIT group, ES: 0.42	No information on p value

	65.6 ±4.9 kg							
Shibata et al. (2021)	24 male soccer players (C2/E4 = n: 11, age: 19.9 ±0.68 years, height: 173.6 ±4.0 cm, body mass: 65.6 ±4.9 kg; C2/E2= n: 11, age: 19.1 ±0.9 years, height: 170.7 ±3.1 cm, body mass: 65.6 ±4.9 kg)	University soccer players	6/2	Parallel back-squat. Both groups 3 sets. C2/E4 between 7.1 and 12.9 reps, C2/E2 between 9.9 and 16.7 reps. 75% of 1RM weight. Exercises were performed to failure	T-test	No information on % improvements	No information on ES	C2/E4: $p>0.05$ C2/E2: $p>0.05$
Siddle et al. (2019)	16 football and rugby male players (EG = n: 6, age: 20.3 ±1.55 years,	Sport athletes (at least two intermittent team training sessions per	6/2	Eccentric Nordic hamstring 2 to 3 sets x 5 to 10 reps	20-m, 180° COD test : 10-m sprint,	EG: 2.46% CG: -2.21%	EG, ES = 0.96 CG, ES = -0.56	EG: $p<0.05$ CG: $p>0.05$

	height: 180.88 ±6.2 cm, body mass: 75.38 ±7.1 kg; CG= n: 8, age: 20.86 ±1.57 years, height: 178.0 ±8.41 cm, body mass: 77.0 ±7.39 kg)	week and a match)			180° turn and sprint back to the starting point			
Tous-Fajardo et al. (2016)	12 young male soccer players (age: 17.0 ±0.5 years, height: 174.4 ±6.4 cm, body mass: 67.6 ±7.9 kg)	Elite U-18 soccer players	11/1	Flywheel conical pulley, flywheel squat, hamstring eccentric strength training, isometric and vibration training	V-cut test	EG: 5.7%	EG ES: 1.22	No information on p value

				2 sets × 6–10 reps. Inertia 0.27 kg.m2 or 0.11 kg.m				
EG = experimental group, CG = control group, C2/E4 = CON for 2 seconds and ECC for 4 seconds, C2/E2 = CON for 2 seconds and ECC for 2 seconds, HIT = high-intensity training, ES = effect size								

2.6.4.4. Isometric Strength

Another method to measure maximal strength is through maximal isometric tests. Unlike maximal concentric strength, during an isometric maximal strength test the athlete exerts maximal force without movement. The advantage of this method compared to a maximal concentric test is that peak force and RFD can be examined (Dos'Santos, et al.,2017b).

There is a very limited number of studies assessing relationships between COD and isometric tests in soccer players, with these commonly utilising isometric mid-thigh pull (IMTP) (Thomas et al., 2015; Thomas et al., 2018; Northeast et al., 2019; Mason et al., 2021) and squat isometric test (Marcovic, 2007) although single joint or muscle group isometric tests have also been utilised (Emmonds et al., 2019; Rouissi. Et al., 2017; Jones et al., 2021). While some studies have shown correlations between an isometric test and a COD test (Thomas et al., 2015; Emmonds et al., 2019) others have shown low correlations (Marcovic, 2007; Northeast et al., 2019; Mason et al., 2021) or low to large correlations (Thomas et al., 2018; Rouissi. et al., 2017; Jones et al., 2021).

Due to the characteristics of the research by Rouissi. et al., (2017), it is of interest to dive deeper into this study. Rouissi et al. (2017) found inconsistent results using a wide range of isometric and COD tests in young male elite soccer players. This study assessed 12 lower limb isometric strength variables and eight COD tasks consisting of a 5-m sprint followed by a COD of 45°, 90°, 135° or 180° using dominant and non-dominant legs followed by another 5-m sprint. While isometric strength of the lower limb showed to be a determinant factor for COD performance, correlations varied depending on the COD angle and muscle group as well as the limb (dominant or non-dominant). In any case, authors highlighted the importance of isometric strength of lateral muscles (e.g., external rotators, hip abductors and hip adductors) during COD.

Due to the contradicting results, low number of studies and differences in methodologies, it is difficult to determine the ability of isometric tests to associate or predict COD performance in soccer players. In any case, there is potential for isometric strength to be a determinant of COD ability as it has been previously shown that players with high relative lower body isometric strength produce greater magnitude of plant foot kinetics while achieving quicker COD performances (Spiteri, et al., 2013).

2.6.4.4.1 Isometric Strength Training

Only a few studies have examined the impact of isometric training on COD performance in team sports, with even fewer focusing specifically on soccer. To the author's knowledge, only one study in soccer players has assessed changes in COD performance after implementing an isometric training regimen. Bimson et al. (2017) found no improvements in the zig-zag test after repeated knee extension maximal voluntary isometric contractions in female university soccer players. One of the limitations of this study was that participants only performed the isometric strength training once a week for six weeks, which means that players only performed six sessions, and so, any conclusions should be drawn with caution. Due to this low number of studies performed, more research is needed to understand the benefits of isometric training on COD performance.

2.6.6. Other Methods for the Enhancement of COD Performance

2.6.6.1. COD Training

COD training would be the most specific way to improve the ability to change direction. There are limited studies in soccer that have implemented COD training before and after testing COD ability, with most of them being performed in young soccer players. Most studies have shown positive effects (Chtara et al., 2017; Chaouachi et al., 2014; Pavillon, et al., 2021; Dos'Santos et al., 2019b; Dos'Santos et al., 2021a; Dos'Santos et al., 2022a; Sariati et al., 2021). These studies have generally utilised training protocols consisting of COD tests or drills such as skipping 10 m, 505 COD, half T-test 20 m and shuttle 4 ×10 m (Chtara et al., 2017; Chaouachi et al., 2014) or zig-zag and cut drills with and without the ball (Chaalali, et al., 2016), short, intense and varied COD sprint exercises over a cumulative distance of 20 m (Pavillon, et al., 2021), zig-zag, hexagonal, lateral shuffle and back and forth exercises (Sariati et al., 2021) or zig-zag, back and forth runs, coordination ladder, crossover, shuffles and plyometric exercises (González-Fernández et al. 2021).

On the other hand 2 studies found no benefits or conflicting result (Beato, et al., 2018, Rodríguez-Osorio, et al., 2019). While the lack of improvements in the study by Beato, et al. (2018) was justified by the small amount of COD performed in this group, the study of Rodríguez-Osorio, et al. (2019) had unique characteristics. Rodríguez-Osorio et al. (2019) divided sub-elite senior and academy male players into three groups: COD training (V-cut training) with no extra load and COD training with 12.5% or 50% of their BM of external load. L-run test and V-cut test were performed before and after the intervention. The only group to show improvements was the group with 12.5% of BM of external load. While potentially 50% of BM could be an excessive added load to obtain any improvements, it is surprising that the group with no extra load showed no benefits, more so when the training consisted of execution of one of the tests (V-cut).

Interestingly, several studies have implemented strategies which included not only COD training but also movement quality or technique modification (Dos'Santos et al., 2019b; Dos'Santos et al., 2021a; Dos'Santos et al., 2022a). These 3 studies implemented COD training and technique modification (pre-planned low-intensity decelerations and turns, where the intensity was progressed through higher speed and turning angles) in elite young soccer players, amateur and semi-professional soccer, as well as rugby athletes and found improvements in COD performance. More so, improvements in the study by Dos'Santos et al., (2021a) were associated with an increase in mean horizontal propulsive forces, more horizontally orientated final foot contact propulsive force and penultimate foot contact braking force, greater pelvic rotation and penultimate foot contact hip flexion and penultimate foot contact velocity reductions. Similarly, improvements in the study by Dos'Santos et al. (2022a) were moderate to very largely related to decreased knee flexion, increased velocity profiles and augmented propulsive forces over shorter GCTs.

While there is a small number of studies looking at the effect of COD training on COD ability, most studies show beneficial effects, which would make sense as this would follow the specificity principle, especially when performing drills similar to the COD test performed. Technique modification in addition to COD training showed beneficial effects and should be considered for future research. Future studies should investigate the difference between performing COD drills in competitive vs non-competitive environment, as a previous study has shown that performing agility-type drills improved agility only in the group of players performing this under competitive conditions (Kovacikova, & Zemková, 2021). Finally, the lack of research on female soccer players grants future studies in this area.

2.6.6.2. Combined Training

While specific training methods on isolation (eccentric overload, isometric, power training, etc.) can give a better understanding of how each specific training regime can cause positive or negative effects, COD ability could be underpinned by different physical qualities (Sheppard & Young, 2006), and so, the combination of different training modalities could be more beneficial than the implementation of only one methodology. As a result, numerous researchers have implemented different combinations of the training methodologies to assess its effects on COD performance (Keller et al., 2020; de Hoyo et al., 2016a; Beato, et al., 2018; Mathisen & Pettersen, 2015; Chatzinikolaou et al., 2018; Makhlouf et al., 2018; Gil et al., 2018; McMorrow, et al., 2019; Loturco et al., 2017a; Gee et al., 2021; Alves et al., 2010; Ali et al., 2019; Brito et al., 2014; García-Pinillos et al., 2014).

COD and plyometric training together are the most common combination of training strategies found in the literature assessing changes in COD performance in soccer players (De Hoyo et al., 2016a; Beato, et al., 2018; Keller et al., 2020; Makhlouf et al., 2018; Gil et al., 2018; Mathisen & Pettersen, 2015). While most studies showed improvements after the training protocols, two out of seven studies showed no improvements (De Hoyo et al., 2016a; Beato, et al., 2018; Chatzinikolaou et al., 2018). In this sense, De Hoyo et al. (2016a) combined different plyometric (combination of unilateral and lateral jumps) and COD drills (zig zag variations exercises). Still, they found no improvements in a 20-m zig-zag test in elite male U-19 players. More so, Beato, et al. (2018) had young elite male soccer players perform COD (short shuttles runs with 45º to 180º CODs) and plyometric training (DJs and jumps over obstacles) with a 505 COD test performed before and after the training intervention. Players failed to show improvements in the COD test, which could be related to the low volume of jumps performed in this study (40 foot contacts each session).

Other researchers have implemented different combined protocols, with contradicting findings. For example, Tous-Fajardo et al. (2016) had elite U-18 players perform V-cut test before and after a training protocol consisting of a sequence of strength (lunges at 50% of BM, half squats at 100% of BM and calf raises as 50% of BM), power (10-m skipping, CMJ, calf reactive jumps) and sprint speed drills (10-m maximal sprint) but found no improvements in the COD test selected. In this case, it could be questioned whether the strength stimulus provided was enough to gain an advantage of this training method. Anyhow, in the same study, a group performing eccentric overload strength, isometric, power and vibration training showed improvements in the same test.

In addition, two studies used complex-paired, reverse-contrast or complex and contrast training (Gee et al., 2021; Alves et al., 2010) but found no improvements in COD performance. As exercises were performed consecutively, it could be argued that part of the sequence was performed under fatigue, possibly blunting certain adaptations.

In contrast, other studies have shown improvements in COD performance when combining strength, sprint, power and plyometric drills (Brito et al., 2014; Hammami et al., 2017a; Hammami et al., 2017b; Hammami et al., 2019), strength and plyometrics (Ali et al., 2019; García-Pinillos, et al., 2014) or plyometrics and short sprints (Aloui et al., 2021).

Therefore, generally, the combination of different training methods has been shown to improve COD performance in soccer players, with certain exceptions. It stands to reason that integrating various approaches known to be associated with enhanced COD performance would result in improvements in this specific physical capability. Due to the limited research on female soccer players (only 1 study performed), more research is needed to draw further conclusions in this population.

2.6.6.3. SSGs Training

While during football matches there is a high number of COD actions (Bloomfield et al., 2007a), the density of these actions is higher during SSGs (Lacome et al., 2018). As a result, various researchers have explored the efficacy of these games for the enhancement of COD performance, showing improvements in U-19 female (Nayıroğlu et al., 2022) and young male soccer players (Makar et al., 2022; Faude et al., 2014; Chaouachi et al., 2014; Arslan et al., 2020; Iacono et al., 2021), with a wide variety of protocols being employed. Specifically, two out of seven studies conducted 1vs1 small-sided games (SSGs) (Makar et al., 2022; Chaouachi et al., 2014), two study used 2vs2s (Arslan et al., 2020; Nayıroğlu et al., 2022), three studies employed 3vs3s (Chaouachi et al., 2014; Faude et al., 2014; Nayıroğlu et al., 2022), one study utilised 4vs4s (Faude et al., 2014), and one study used 5vs5s (Iacono et al., 2021). Additionally, the duration of each repetition varied among studies, ranging from 30 seconds to 5 minutes, with the total repetition time spanning from 2 to 16 minutes. On the other hand, Stojiljković et al. (2019) showed no improvements in the Illinois test after an SSG intervention consisting of 3vs3 and 4vs4. Unfortunately, researchers didn't provide work duration and rest time. As previously mentioned, the Illinois test can be regarded as a metabolic assessment tool. Interestingly, despite evidence suggesting that SSGs can enhance both aerobic and anaerobic performance (Karahan, 2020), this study did not observe any improvements in Illinois test performance.

As seen, all except one study showed improvements in COD performance, which highlights the potential effectiveness of this methodology. More research is needed in other cohorts, as most studies utilised young soccer players. For instance, only one study was performed on female players. Having in mind that soccer practice would usually involve different forms of SSGs during week periodization (Clemente et al., 2014), it could be argued that improvements after certain training protocols (i.e. power, strength, sprint, etc.) could, to some extent, come from soccer practice itself, especially in young players with low football exposure.

2.7. Factors Influencing COD Performance Based on the COD Type

Numerous researchers have examined relationships between COD performance through different tests to understand how these can improve COD ability. These studies may well look at physical capabilities that theoretically do not underpin the COD tests performed. It is important to understand that the biomechanical demands of a COD are 'angle dependent' (Dos'Santos et al., 2018a) and that the force applied occurs over GCTs over different phases (braking and propulsion) (Nimphius, 2017). Therefore, the physical qualities required to optimize a certain COD will depend on the type of COD as well as the turning angles, as this will determine the GCTs of that COD, and so, the time available to absorb and generate forces (Dos'Santos et al., 2018a). Table 2.7. shows the different types of CODs and describes the main physical qualities required and/or exercise selection proposed by different authors (or suggested by the author of this thesis when there is no proposal) as well as the various studies supporting or contradicting this.

2.7.1. Type 1 Change of Direction. Turn to New Direction From a Static or Semi-Static Type Position

To the author's knowledge, there is no research proposing specific underpinning physical qualities to perform this type of COD. As the player starts from a static or semi-static position to then turn to a new direction, the movement would likely be underpinned by slow SSC or non-countermovement power (if the player's joints are in an optimal/favourable starting position). Due to the lack of research in this specific area, more research is needed to draw further conclusions.

2.7.2. Type 2 Change of Direction. Turn or Cut to a New Direction From a Moving Position

When examining the fundamental physical attributes of this type of COD, it's essential to distinguish between different variations of this COD to assess their specific physical capabilities. For type 2 COD actions that include linear advancing (forward or backward) + deceleration + turn/cut to new direction, it will be important to take into consideration the GCT of that COD in particular. In this sense, where GCT is short, underpinning physical capacities may be more related to fast SSC, while longer GCT would be more linked to long SSC (Nimphius, 2017). For this purpose, separating CODs into ≈90° and ≤ 135° is necessary.

For CODs with shallow turns of ≈90°, Dos'Santos et al. (2018a) suggest both fast and slow SSC, while McBurnie & Dos'Santos (2021) recognized that the ability to decelerate by braking hard in CODs of >60° is of prime importance, and so, eccentric strength could play an important role. When looking at studies performed in soccer players that assessed the relationship between fast SSC and COD tests with ≈90° turns, only two studies showed moderate or higher correlations (Castillo-Rodríguez, et al., 2012; Kapidžić et al., 2011), with no studies contradicting this (Table 2.8.). On the other hand, three studies showed moderate or higher correlations between COD test with ≈90° turns and slow SSC (Castillo-Rodríguez, et al., 2012; Kapidžić et al., 2011; Köklü et al., 2015) while three studies showed no correlations (Freitas et al., 2020; Kobal et al., 2021; Rouissi et al., 2017). In the same line, two different studies show relations between COD tests and ≈90° turns with isometric (Roussi et al., 2017) and eccentric strength (KFs and KEs) (Jones et al., 2022), while two other studies show no relationships (Loturco et al., 2018; Papla et al., 2020). Therefore, while theoretically, the mentioned physical capacities would be fundamental for this type of CODs, more research is needed to confirm this, as some of the studies found no relationships.

For CODs with higher GCTs, such as turns of ≤ 135°, slow SSC actions and ballistic exercises are recommended (Dos'Santos et al. 2018a). Additionally, McBurnie & Dos'Santos (2022) emphasize the 'force' component of the force-velocity curve in resistance training due to the increased eccentric demands. Research investigating the link between slow SSC and COD tests involving turns of ≤ 135° in soccer players shows more studies reporting significant relationships than those indicating low or trivial correlations (eleven compared to six). On the other hand, concentric strength shows contradicting results, with four studies showing relationships (Falch et al., 2021; Andersen et al., 2018; Arin et al., 2012; Keiner et al., 2014) and three showing no relationships (Kadlubowski et al., 2021; Falch et al., 2021; Papla et al., 2020). In addition, two studies utilising COD tests with ≤ 135° turns shows relationships with isometric strength (Roussi et al., 2017; Emmonds et al., 2019) and two with eccentric strength (KEs) (Jones et al., 2017; Grieg et al., 2017), while one study showed no relationships with eccentric strength (KEs and KSs) (Chaouachi et al., 2012). Therefore, although research suggests a relationship between slow SSC and these types of CODs, further studies are needed to clarify the role of strength, particularly eccentric strength.

For type 2 COD actions where there is a linear advancing motion (forward or backwards) + turn/cut to new direction (usually slow approach and/or low degrees of turn), due to the shallow nature of these (i.e. CODs of ≤ 60°), deceleration and braking demands are limited (McBurnie & Dos'Santos, 2022). Therefore, fast SSC or reactive strength would be considered relevant to performance (Dos'Santos et al., 2018a; Nimphius, 2017; McBurnie & Dos'Santos, 2022). Studies analyzing the relationship between reactive or fast SSC and CODs with a turn of ≤ 60° have found no significant relationships, while two studies reported trivial or low correlations (Falch et al., 2021; Northeast et al., 2019) (Table 2.7).

Therefore, more research is needed in soccer populations to ascertain the importance of fast SSC on COD performance with shallow turns.

2.7.3. Type 3 Change of Direction. Change in Path Without a Change in the Direction that the Player is Facing

To the author's knowledge, no research proposes specific underpinning physical qualities for type 3 CODs. Due to the characteristics of this type of COD [deceleration from a linear advancing action (such a sprint) or from a lateral advancing action where CODs will be of about 90° (lateral to linear or vice versa) or 180° (linear to linear or lateral to lateral)], long SSC and maximal strength (concentric, isometric and eccentric) could play a fundamental role in executing these movements.. Typical COD tests involving these type of COD actions would be the T-test (Negra et al., 2017b; Sporiš et al., 2010; Matta et al., 2014; McFarland et al., 2016) or forward to backward COD (Hammami et al., 2017a; Sporiš et al., 2010).

As seen in Table 2.7., while 7 studies performed on soccer players showed relationships between slow SSC tests and type 3 COD tests (McFarland et al., 2016; Sonesson et al., 2021; Yanci et al., 2014; Los Arcos et al., 2017; Los Arcos et al., 2020; Andersen et al., 2018; Chaouachi et al., 2012), three studies showed no relationships (Ates, 2018; McFarland et al., 2016; Yanci et al., 2014). Two studies examined the relationship between T-test and isokinetic strength, showing relationships with eccentric (Chaouachi et al., 2012; Greig et al., 2017) but not concentric strength (Greig et al., 2017)). Therefore, more research is needed to understand the underpinning qualities of type 3 CODs.

2.7.4. Type 4 Change of Direction. Arc Run

Due to its certain similarities with straight line running and sharp cuts (i.e., <60° cut), fast SSC could be the main physical capacity required. Only one study has examined the relationships between an arched run and fast SSC in soccer players (Kobal et al., 2021). Researchers utilised 3 horizontal SL jumps in sequence, with the same leg, showing moderate to large correlations with a 17-m arc run sprint. Thus, further research is required to explore the fundamental qualities of these type of CODs.

Table 2.7. Types of COD and underpinning physical qualities

Type of COD	Variation	Proposed underpinning physical qualities and/or exercises relevant to the COD	Studies in soccer supporting proposed physical qualities	Studies in soccer contradicting proposed physical qualities
Type 1 COD: Turn to a new direction from static or semi-static (slow linear or lateral movements (e.g., walking, low-intensity shuffle)] movements type position.	-Turn to new direction	Slow SSC; non-CMJ power		
	-Linear advancing (forward or backward) + deceleration + turn/cut to new direction	≈90°. Fast SSC: reactive strength; slow SSC; maximal strength (eccentric, isometric, concentric) (1,2)	Fast SSC: (5, 6) Slow SSC: (5, 6, 10). Maximal isometric strength: (22) Isokinetic eccentric strength [33 (KF, KE)]	Fast SSC: N/A Slow SSC: [8, 22 (H), 36 (H)] Maximal concentric strength: (29, 30)

Type 2 COD: turn/cut to new direction from moving position (deceleration included unless slow velocity approach and/or low degrees of turning)		≤ 135°. Slow SSC; maximal strength (eccentric, isometric, concentric) (1,2,3)	Slow SSC: [5, 6, 9, 11, 12, 13, 15, 16 (H), 18, 19, 23 (H)] Maximal Concentric strength: (14, 25, 26, 27) Maximal isometric strength [34 (KE), 22] Isokinetic eccentric strength: [31, 32 KF, KE)]	Slow SSC: [12, 14, 20 (H), 21 (H), 22 (H), 23 (H)] Maximum concentric strength: (14, 28, 30) Isokinetic eccentric Strength: [20 (KF, KE)]
	-Linear advancing (forward or backward) + turn/cut to new direction (usually slow approach and/or low degrees of turn)	Fast SSC (1,2,3)		Fast SSC: (4, 14)
	-Lateral + deceleration + turn to new direction	Slow SSC; maximal strength (concentric, isometric, eccentric)		
	-Lateral + turn to new direction (usually slow approach and/or low degrees of turn)	Slow SSC; maximal strength (concentric, isometric, eccentric)		
Type 3 COD: change in path without a change in the direction that player is facing	-Linear forward/backward + deceleration + lateral advancing motion (or vice versa) -Lateral + deceleration + linear forward/backwards movement	Slow SSC; maximal strength (concentric, isometric, eccentric)	Slow SSC: [12, 13, 15, 16 (H), 17, 20, 25] Isokinetic eccentric strength: [(20 (KF, KE), 31 (KF)]	Slow SSC: (7, 12, 16) Isokinetic concentric strength: [31 (KE)]

	-Lateral + deceleration + lateral to opposite direction		
	-Linear + deceleration + Linear (forward to backwards or backwards to forward)	Slow SSC; maximal strength (concentric, isometric, eccentric)	Slow SSC:[(24 (H)]
Type 4 COD: arched run performed to maintain velocity	-Arc run performed with different degrees	Fast SSC	Fast SSC: (35)

H = Horizontal test. Not included studies with combined cod angles (i.e. 45 and 90 degrees) or research with team sport that included soccer (only soccer +1 other sport). (1) Dos'Santos, T., Thomas, C., Comfort, P., & Jones, P. A. (2018[a]). The effect of angle and velocity on change of direction biomechanics: An angle-velocity trade-off. *Sports medicine*, *48*(10), 2235-2253. (2) McBurnie, A. J., & Dos'Santos, T. (2022). Multidirectional speed in youth soccer players: theoretical underpinnings. *Strength and Conditioning Journal*, *44*(1), 15-33. (3) Nimphius S. Training change of direction and agility, in: Advanced Strength and Conditioning. A Turner, P Comfort, eds. Abdingdon, Oxon, United Kingdom: Routledge, 2017, pp 291-308 (4) Northeast, J., Russell, M., Shearer, D., Cook, C. J., & Kilduff, L. P. (2019). Predictors of linear and multidirectional acceleration in elite soccer players. *The Journal of Strength & Conditioning Research*, *33*(2), 514-522. (5) Castillo-Rodríguez, A., Fernández-García, J. C., Chinchilla-Minguet, J. L., & Carnero, E. Á. (2012). Relationship between muscular strength and sprints with changes of direction. The Journal of Strength & Conditioning Research, 26(3), 725-732. (6) Kapidžić, A., Pojskić, H., Muratović, M., Užičanin, E., & Bilalić, J. (2011). Correlation of Tests for Evaluating Explosive Strength and Agility Of Football Players. *Sport Scientific & Practical Aspects*, *8*(2). (7) Ates, B. (2018). Age-Related Effects of Speed and Power on Agility Performance of Young Soccer Players. *Journal of Education and Learning*, *7*(6), 93-99. (8) Freitas, T. T., Jeffreys, I., Reis, V. P., Fernandes, V., Alcaraz, P. E., Pereira, L. A., & Loturco, I. (2020). Multidirectional sprints in soccer: are there connections between linear, curved, and change-of-direction speed performances?. *The Journal of Sports Medicine and Physical Fitness*. (9) Loturco, I., Pereira, L. A., Kobal, R., Abad, C. C., Rosseti, M., Carpes, F. P., & Bishop, C. (2019). Do asymmetry scores influence speed and power performance in elite female soccer players?. *Biology of Sport*, *36*(3), 209. (10) Köklü, Y., Alemdaroğlu, U., Özkan, A., Koz, M., & Ersöz, G. (2015). The relationship between sprint ability, agility and vertical jump performance in young soccer players. *Science & Sports*, *30*(1), e1-e5. (11) Vescovi, J. D., & Mcguigan, M. R. (2008). Relationships between sprinting, agility, and jump ability in female athletes. *Journal of sports sciences*, *26*(1), 97-107. (12) McFarland, I. T., Dawes, J. J., Elder, C. L., & Lockie, R. G. (2016). Relationship of two vertical jumping tests to sprint and change of direction speed among male and female collegiate soccer players. *Sports*, *4*(1), 11. (13) Sonesson, S., Lindblom, H., & Hägglund, M. (2021). Performance on sprint, agility and jump tests have moderate to strong correlations in youth football players but performance tests are weakly correlated to neuromuscular control tests. *Knee Surgery, Sports Traumatology, Arthroscopy*, *29*(5), 1659-1669. (14) Falch, H. N., Kristiansen, E. L., Haugen, M. E., & van den Tillaar, R. (2021). Association of Performance in Strength and Plyometric Tests with Change of Direction Performance in Young Female Team-Sport Athletes. *Journal of Functional Morphology and Kinesiology*, *6*(4), 83. (15) Los Arcos, A., Mendiguchia, J., & Yanci, J. (2017). Specificity of jumping, acceleration and quick change of direction motor abilities in soccer players. *Kinesiology*, *49*(1). (16) Yanci, J., Los Arcos, A., Mendiguchia, J., & Brughelli, M. (2014). Relationships between sprinting, agility, one-and two-leg vertical and horizontal jump in soccer players. *Kinesiology: International journal of fundamental and applied kinesiology*, *46*(2), 194-201. (17) Los Arcos, A., Aramendi, J. F., Emparanza, J. I., Castagna, C., Yanci, J., Lezáun, A., & Martínez-Santos, R. (2020). Assessing change of direction ability in a spanish elite soccer academy. *Journal of Human Kinetics*, *72*(1), 229-239. (18) Loturco, I., Pereira, L. A., Kobal, R., Abad, C. C., Rosseti, M., Carpes, F. P., & Bishop, C. (2019). Do asymmetry scores influence speed and power performance in elite female soccer players?. *Biology of Sport*, *36*(3), 209. (19) Emmonds, S., Nicholson, G., Begg, C., Jones, B., &

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2.8. Conclusions

COD is a physical capacity of significant importance for soccer performance, possibly having a great influence in key moments of the game. Moreover, it has been used for talent identification as it can discriminate between different levels of performance. A large number of COD tests have been applied in research studies to identify relationships between diverse physical capabilities or in experimental studies examining how different methods can affect COD performance. Although these tests have shown to be reliable, they look at different factors of COD, as these tests vary in metabolic requirements, COD characteristics and force production.

Different characteristics have been theorized to be able to affect or influence COD performance (technique, straight sprint, leg muscle qualities, anthropometrics), although there is still a need for further research to understand their involvement in specific phases of COD. Based on how certain physical attributes can underpin COD ability, different researchers have implemented protocols for the enhancement of COD performance. While certain training methods have shown promising results (i.e., eccentric overload, technique modification, SSGs, etc.), there is a need for more research in this area, especially in elite female soccer players. Moreover, future studies should focus on enhancing the quality of research by placing greater emphasis on selecting appropriate COD tests, including CGs, and applying relevant statistical analyses that can clarify their practical significance.

It is worth highlighting that most studies have been performed on young male soccer players. This would represent a limitation as research shows that COD performance is enhanced by 2.8% in males and 3.3% in females yearly from 12 to 16 years (Tingelstad et al., 2023), and so, improvements might be related to players' physical maturation rather than the effectiveness of the training protocol utilised. In addition, the type of COD test performed could have implications on the relationships with different physical capabilities and the effectiveness of certain training strategies. Moreover, the technique utilised by a player when performing a COD could impact the relationships with the physical characteristics assessed. For example, a player that can generate more horizontal decelerative forces in the ante-penultimate and penultimate steps, potentially reducing the GCT in the ultimate step, might have certain characteristics that correlate better than others with COD performance. Furthermore, there is a noticeable difference when comparing the number of COD studies performed on male vs female elite soccer players, with a very small percentage performed on females, and so, future research should aim to increase research in the female population.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Methods for Chapter 4

3.1.1. Procedures

All the goals from EPL and Women's Super League (WSL) from the 2018/2019 season were analysed through video analysis using the same broadcast footage provider (Sky Sports). EPL is considered one of Europe's four most important leagues, while WSL is the female corresponding league in England, with all the teams having full-time professional squads.

Goal-scoring situations were chosen for analysis for several reasons. First, goals are the most crucial events in a game, determining the final score. Therefore, understanding the movements and combinations leading to these key moments is highly relevant. Second, while analysing an entire match would have been valuable, previous studies using the same system examined 15-minute segments, requiring 4 to 6 hours of analysis. Thus, analysing a single player for a full match would have taken between 24 and 36 hours, making it impractical (Bloomfield et al., 2007d). Furthermore, many of the observed actions would have been classified as non-purposeful movements, as only about 40% of movements in a match are considered purposeful (Bloomfield et al., 2007a). Therefore, there are certain biases that need to be addressed. First, the analysis would be biased towards successful actions performed by attacking players and unsuccessful actions by defensive players. Conversely, if analysis had been performed on goal-scoring opportunities or shots on goal, analysis could have been biased towards successful actions of the defenders, as only 10% of the shots end up on a goal.

Researchers had access to all goals, which could be seen in slow motion and from multiple angles. Motion analysis was evaluated for the attacking player who scored the goal (scorer), the attacking player who assisted the goal (assistant), the closest defender to the scorer (defender of scorer) and the closest defender to the assistant (defender of assistant). Motion analysis started just before the assistant (if applicable) received the ball from a teammate or when possession was regained and finished when the ball was passed to the scorer. Motion analysis for the scorer and the defender of the scorer (if applicable) started when the ball was passed to the scorer or regained the ball from the opposition and finished when the scoring player shot to the goal. Analysis was limited to the last six movements of each player, with these being noted as "-5", "-4", "-3", "-2", "-1" and "final movement". Pass and shot were always the final movement for the assistant and scorer, respectively. Goals not selected for analysis were corners, penalties, direct throw-ins, direct free-kicks, indirect free-kicks, own goals, non-intended goals and rebounds. The individual action or sequence of movements of each individual player performed before each goal was named as ‘involvement’. Defender of assistant and defender of scorer together were named as ‘defenders’. Assistant and scorer were named as ‘attackers’. The total number of possible movements with each modifier was 134. The movements preceding goals were analysed using a modified version of the BMC (Bloomfield et al., 2004). This system has previously been utilised to analyse movements and shows good strength of inter-observer agreement for movement type, direction of movement, intensity of movement and games-related activity (κ= 0.6968 - 0.7891), as well as moderate strength of agreement for turning activities (κ = 0.5639) (Bloomfield et al., 2004). This system has been previously used to analyse movements performed during a whole match (Bloomfield, et al., 2007a, Bloomfield, et al., 2007b, Bloomfield, et al., 2007c).

Coding was performed by the lead author using a computerised notation system within a customized Excel spreadsheet (Office 365 ProPlus) following the guidelines proposed for computerized performance analysis systems (O’Donoghue, 2014). As seen in Figure 3.1, coding was performed by setting up information related to each of the columns:

- Matchday: identifying the match round.
- Home team and away team: the teams involved in the match.
- Score home and score away: the score at the time of the goal.
- Player: the type of player involved in the play (e.g., "Scorer," "Assistant," "Defender of Scorer").
- Movements (-5 to final movement): the sequence of actions leading to the goal.

Each of the possible combinations for each of the movements (Linear advancing motion, turn, deceleration, cut, arc run, etc.) was initially created and then inputted on each of the columns when necessary, in the following order [1. Movement, 2. Direction (if applicable), 3. Intensity (if applicable), 4. Ball involvement. For example, movement -5: deceleration, lateral, high intensity, no ball.

Matchday	Home Team	Away Team	Score Hom	Score Awa	Player	Mov-5	Mov-4	Mov-3	Mov-2	Mov-1	Final Mov
matchday 1	Manchester United	Leicester City	1	0	Non-selectable						Penalty
Matchday 1	Manchester United	Leicester City	2	0	Assistant				Turn 0-60 Med Y	Jog For Y	Pass
Matchday 1	Manchester United	Leicester City	2	0	Def of Assistant			Cross Low N	Jog For N	Decc For Med N	turn 60-120 High
Matchday 1	Manchester United	Leicester City	2	0	Scorer		Run ForD N	Cross Med N	Run For N	Cut High N	Shoot
Matchday 1	Manchester United	Leicester City	2	0	Def of Scorer		Cross Med N	Spr ForD N	Decc Side Med N	Turn 120-180 Hi	Spr For N
Matchday 1	Manchester United	Leicester City	2	1	Scorer					Run For N	Shoot
Matchday 1	Manchester United	Leicester City	2	1	Def of Scorer						Shuff Med N

Figure 3.1. Excel coding system utilised

Analysis and coding of the goal actions were performed by a single investigator with no time limit for the analysis of each movement. Analysis was performed the week after each matchday (i.e., when a matchday was played on Saturday and Sunday, analysis was performed from Monday to Friday). Every single movement took between 5 seconds and 5 minutes of analysis and each matchday took between 3 and 6 hours and 1.5 to 3 hours to analyse for EPL and WSL, respectively (every labour day for 1 to 3 hours), with the dissimilarities between leagues related to the differences in the number of teams (WSL= 11, EPL= 20) and games for each match day (10 and 5 for EPL and WSL, respectively).

3.1.2. Definition and Interpretation of Movements

Table 3.1 shows the movement classification table modified from BMC, which was used for data collection. Movements with similar characteristics were grouped (Table 3.1). These were linear advancing motion (walk, jog, run and sprint), change in angle run (cut and arc run), lateral advancing motion (crossover and shuffle), ball blocking (dive and slide) and ball striking (pass and shot). Movements with their own individual group were turn, deceleration, impact, stand still, jump, land, fall, get up (definitions of individual and group of movements can be found in Table 3.2). As seen in Table 3.1, a direction modifier was applied to linear advancing motion, deceleration, turn and skip movements with diverse characteristics between these. Furthermore, deceleration, turn, change in angle, and lateral advancing motion had intensity modifier: low-intensity, medium-intensity, and high-intensity, while linear advancing motion intensities were defined as: walk (low-intensity), jog (low-intensity), run (medium-intensity) and sprint (high-intensity) with definitions presented on Table 3.3.

Table 3.1. Movement classification table for goal-scoring situations analysis.

Group of movements	Movements	Modifier 1: direction	Modifier 2: intensity	Modifier 3: ball
Linear Advancing	Walk	Forwards, Forwards	Walk (Low),	Yes, No

Motion	Jog Run Sprint	Diagonally, Backwards	Jog (Low), Run (Medium), Sprint (High),	
Lateral Advancing Motion	Shuffle Crossover		Low, Medium, High	Yes, No
Change in Angle Run	Cut Arc Run		Low, Medium, High	Yes, No
Ball Striking	Pass Shoot			
Ball Blocking	Dive Slide			
Turn		0º-60º, 60º-120º, 120º - 180º, 180º-270º, 270º-360º,	Low, Medium, High	Yes, No
Deceleration		Forwards, Forwards Diagonally, Backwards, Sideways	Low, Medium, High	Yes, No
Skip		Forwards, Backwards, Sideways		Yes, No
Impact				Yes, No
Stand Still				Yes, No
Jump				
Land				
Fall				
Get Up				

Table 3.2. Interpretation and definitions of movement group and movements.

Movement Group	**Definition**
Linear advancing motion	Actions where a player accelerates or maintains speed in a sagittal plane.
Lateral advancing motion	Actions where a player accelerates or maintains speed in a frontal

	plane.
Change in angle run	Actions were a player advancing on a linear direction manoeuvres without or with very little loss in speed.
Ball blocking	Drive purposefully the lower limb or head in a certain manner to stop a ball or an attacker with
Ball striking	Contact made with the ball with the objective of passing or scoring a goal.
Movement	**Definition**
Walk:	Moving slowing by stepping.*
Jog:	Moving at a slow monotonous pace (slower than running, quicker than walking).*
Run:	Manifest purpose and effort, usually when gaining distance.*
Sprint:	Maximal effort, rapid motion.*
Shuffle:	Sideways advancing movement in which head, shoulders and hips face forward while legs and feet do not cross.
Crossover:	Sideways advancing movement in which head, shoulders and hips face forward while legs and feet cross.
Deceleration:	To slow down or brake suddenly.**
Turn:	To rotate while standing, decelerating or accelerating/sprinting.
Cut:	Path changes of less than 45º with this involving little or non-previous deceleration to accomplish the task.
Arc Run:	Player (often leaning to one side) moving in a semicircular direction.*
Skip:	Moving with small bound-like movements.*
Impact:	Any intense contact made with another player.*
Stand Still:	Stationary or staying in one spot.*
Jump:	Spring free from the ground or other base by the muscular action of feet and legs.*
Land:	Entered after jump when contact with ground is made.*
Dive:	To purposefully and controllably propel the body rapidly through the air either feet or head first.*
Slide:	To purposefully and controllably drive the body along the floor with

	feet leading the movement.
Fall:	Descending to the ground.*
Get up:	Ascending from the ground.*
Pass:	Any attempt to give the ball to a team-mate. Entered as contact made with the ball along with how.*
Shoot:	Any attempt on goal. Entered as contact made with the ball along with how.*

*Definition from Bloomfield et al. (2004)

** Modified definition from Bloomfield, et al. (2004)

Table 3.3. Interpretation and definitions of different modifiers.

Modifiers	Definition
Direction	
Forward (Linear advancing motion)	Head, shoulders, hips all face forward moving in a forward direction.
Forward (deceleration)	Player braking with both or one limb and stopping body inertia pushing linearly forward.
Forward Diagonal (linear advancing motion)	Player's body turned about 45° left/right, head turned left/right, player looks over left/right shoulder, legs facing forward or slightly rotated advancing in a forward direction.**
Forward Diagonal (deceleration)	Player braking with both or one limb and body position turned approximately 45° left/right stopping body inertia pushing diagonally forward.
Backward (Linear advancing)	Head, shoulders, hips all face forward moving in a backward direction.
Backward (deceleration)	Head, shoulders, hips all face forward stopping body inertia pushing in a backward direction.
0º-60º:	Turn $\leq {}^{1}/_{6}$circle.
60º-120º:	Turn > ${}^{1}/_{6}$ circle and $\leq {}^{1}/_{3}$ circle.
120-180º:	Turn > ${}^{1}/_{3}$ circle and $\leq {}^{1}/_{2}$ circle.
180º-270º:	Turn > ${}^{1}/_{2}$ circle and $\leq {}^{3}/_{4}$ circle. *

270º-360º	Turn > $^3/_4$circle and ≤ full circle. *
Intensity	
Low:	Little effort.*
Medium:	Some to great effort.*
High:	Maximal effort.*
Ball	
Yes:	When the player is in possession of the ball
No:	When the player is not in possession of the ball

*Definition from Bloomfield, et al. (2004)

** Modified definition from Bloomfield, et al. (2004)

3.1.3. Classification of Change of Direction Actions

COD was defined as a sudden or gradual change in movement path from a moving or static position. A COD could occur both when the player starts from a static or semi-static position and moves into a different direction (type 1) and when this advances in a certain direction prior to having to manoeuvre into a new direction (type 2). The main difference between these 2 types would be that the first would not involve a deceleration, while the latter would generally do, although this will depend on the angle and approaching velocities (Dos'Santos et al., 2021b). The third type of COD would be a change in the initial path without changing the direction that the player is facing with a combination of linear (backwards or forward) and lateral movements where deceleration is always present. Finally, the fourth type of COD would involve an arc run or curvilinear type run. The different types of COD with the different variations can be found in Table 2.1. Based on this, individual movements that an action would integrate to be considered as a COD where: turn, cut, arc run and deceleration, although the latter is delimited by certain factors to consider. While during turn and cut there is a body rotation and a change of initial path direction as well as a change in the direction that the player is facing, which also occurs in an arc run, performing a deceleration wouldn't always imply that the next movement involves a change in the initial direction. Regardless, deceleration would always be the link when, during a COD, there is a change in path without the player changing the way they face (Table 2.1., type 3 CODs). For example, when performing a lateral movement to the left followed by a lateral movement to the right or when performing a lateral movement (e.g., shuffle or crossover) before a linear forward action (e.g., sprinting) as seen in Table 2.1. In these scenarios, the only combination of movements where there is a deceleration, but the action is not considered as a COD is: 1. When there is a linear advancing action + deceleration + linear advancing action in the same direction. 2. When there is a lateral action + deceleration + lateral action in the same direction. In these two scenarios, deceleration did not count as part of a COD action.

3.2. Methods for Chapters 5 and 6

3.2.1. Experiment Design

These studies examined the within-session reliability (Chapter 5) and correlations (Chapter 6) of different physical tests. The reason for performing within-session reliability was related to the fact that changes in week-to-week training load could have affected reliability scores. Two trials were performed on each test due to time constraints. To determine within-session reliability, participants performed two trials of the following tests:

- Anthropometric measures (height and BM)
- 30 m speed test (5-, 10-, 20- and 30-m split).
- 505 COD.
- 75-90° COD.
- CMJ.
- SL CMJ.
- DJ
- SL DJ
- SL BJ.
- Flywheel squat concentric strength (FSCS) and flywheel squat eccentric strength (FSES).
- Nordics hamstring eccentric strength (NHES).
- IMTP.

3.2.2. Subjects

Female elite soccer players participated in this study. All participants were injury-free and had been professional soccer players for at least 2 years. Participants' usual week consisted of four football training sessions, one match and three gym sessions per week. All participants were injury-free and did not suffer any injury during the testing that could affect the results. The study was approved by the university ethics committee (application ID: 3168) and conducted according to the Declaration of Helsinki of 2000.

3.2.3. Familiarization

Players were already familiar with each of the tests as these were performed as part of their regular (4 times/ year) testing battery. This included the same number of trials and tests as described in section 3.2.3. Furthermore, all players had prior experience with the Nordic hamstring exercise, as it was incorporated in various forms into their lower-body strength training sessions for at least one month (four sessions). Additionally, all players were accustomed to using the flywheel device utilised for FSCS and FSES, performing squats and lunges for at least one month (four sessions). Players who did not include these exercises in their regular GYM programs were excluded from these tests. Furthermore, players completed two familiarization sessions with the IMTP. Regarding power tests (CMJ, SL CMJ, DJ, SL DJ, SL BJ), the same exercises or variations of these were integrated into their power training program for at least one month (four sessions). Lastly, sprint and COD tests were incorporated into both extensive and intensive warm-ups for at least one month (four sessions) before testing.

Verbal explanations and demonstrations of each of the tests were performed during their GYM programs, warm-up, as well as during the testing day.

To improve players' familiarization with the tests, the exact exercises used in the testing protocols could have been incorporated into all training programs, rather than using variations of basic exercises, which was done in some of the players who had higher training experience. For example, performing the flywheel squat with braking in the last third of the eccentric phase instead of the flywheel side-to-side squat braking in the last third of the eccentric phase.

3.2.4. Procedures

Tests were performed in a covered 3g pitch. Before performing the tests, a warm-up consisting of lower limb dynamic stretching (i.e. walking lunges, leg swings, leg circles, etc.), (5 minutes), jogging (3 minutes) and high-intensity activities (i.e. sprints and COD activities increasing the distance and turning angles) (3 minutes) was performed. Prior to performing each of the tests, a familiarization/warm-up trial was allowed.

3.2.2.1. COD Tests:

Two COD tests with different turning angles (75-90° and 180°) were included in this study, where players sprinted in a linear forward direction and had to decelerate and turn prior to reaccelerating to the final gate.

505 COD test

Electronic timing gates were placed 2 m apart, facing each other, 10 m from the starting line, with a line marked 15 m from this, where the players had to turn 180°. Timing gates were placed at approximately hip height. Participants sprinted maximally from the start line, turn 180° at the turning point, before accelerating back through the timing gate. One warm-up trial to each side was completed before performing the test, two times changing direction with the right limb and two with the left limb with 90 to 150 seconds of rest between repetitions. Participants were encouraged to complete the test as fast as possible. If the player slipped or turned before hitting the line, the trial was discarded, and the player had to repeat the trial 90 seconds later.

75-90° COD test

The initial set of timing gates (2 m apart, facing each other) was positioned 10 m away from the starting line, which was placed 15 m away from the right/left turn, with another pair of timing gates set up 5 m away from the turn, between 75 and 90° from the centre of the turning point. Two practice attempts (1 to each direction) were allowed to familiarize with the test trials. The test was performed with participants changing direction twice to the right and left with at least 90 seconds of rest between repetitions. Participants were encouraged to complete the test as fast as possible. If the player slipped, the trial was discarded, and the player had to repeat the trial 90 seconds later. Figure 3.2. shows the test set up.

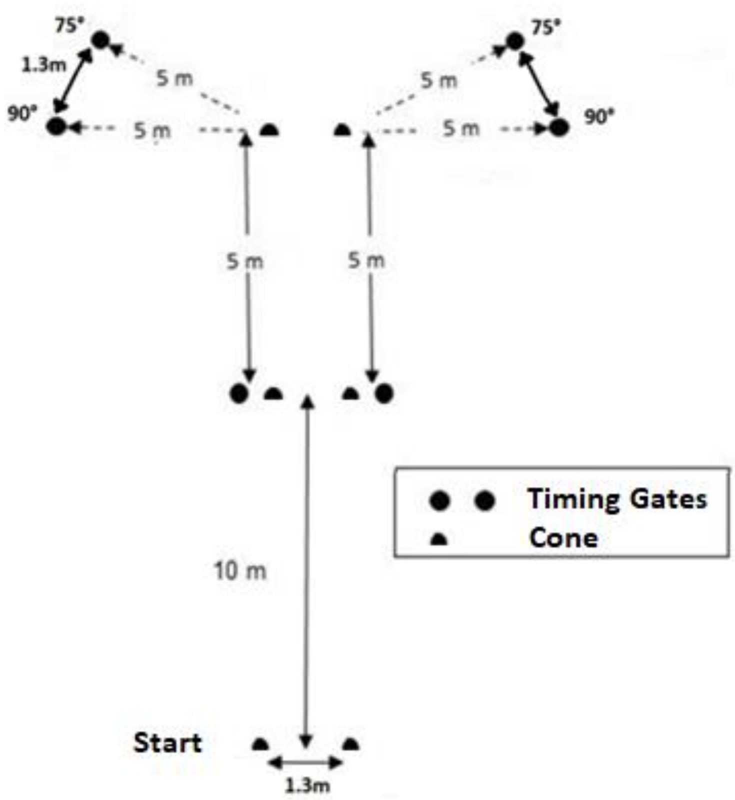


Figure 3.2. 75 – 90° COD test

3.2.2.2. Speed Test:

Speed was evaluated using electronic timing gates (Brower Timing Systems, IRD-T175). Timing gates were placed facing each other, 2 m apart, at approximately hip height. These were placed in a starting line, at 5, 10, 20 and 30 m. Participants started 0.5 m behind the starting gate in a split stance and performed a 30 m sprint on a 3g pitch with times taken at 5, 10, 20 and 30 m. One warm-up trial was performed before two tests over the 30 m. Participants were encouraged to sprint as fast as possible.

3.2.2.3. Jump Tests:

Countermovement Jump and Single Leg Countermovement Jump:

CMJ was measured using Optojump microcell system (Microgate, Bolzano, Italy). Participants started with knees and hips extended, trunk in an upright position, and performed a CMJ with hands on hips trying to achieve the highest jump height possible. A similar procedure was performed for SL CMJ, but with participants only using one limb. Two warm-up jumps were performed followed by two test jumps with 30 seconds of rest between them. Participants were encouraged to jump as high as possible without tucking their legs to artificially increase flight time. If the player tucked their legs during jumping, the corresponding attempt was omitted, and an additional attempt was performed after 30 seconds of rest. These characteristics were closely monitored by the researcher.

Drop Jump and Single Leg Drop Jump

DJ and SL DJ were measured using Optojump microcell system (Microgate, Bolzano, Italy). A 30 cm box was utilised, in line with previous research on elite female soccer players (Emmonds et al., 2019; Krosshaug et al., 2016). Participants started with knees and hips extended, trunk in an upright position on a platform 30 cm from the floor. Participants then stepped off the box with their preferred leg for the DJ, while the designated test leg stepped off the box first for the SL DJ. Previous research has shown very poor relative reliability of actual dropping height from a DJ test (Costley et al., 2017), with a study estimating drop height to be 28.6–37.4% different from box height when sport students performing DJs from 0.20–0.50 m high boxes (Geraldo et al., 2019). In order to mitigate this, participants were instructed to step forward rather than step down (Celik et al., 2024) and were given verbal descriptions and visual demonstrations. Subsequently, the participant landed on a surface amid the Optojump system. Upon landing, participants had to jump vertically as high as possible, minimising GCT. Two warm-up jumps were performed followed by two test jumps with 30 seconds of rest between these. Participants were encouraged to jump as high as possible without tucking their legs to artificially increase flight time. If the player tucked the legs during jumping, the corresponding attempt was omitted, and an additional attempt was performed after 30 seconds of rest. These characteristics were closely monitored by the researcher.

Single Leg Broad Jump

SL BJ was measured using a measuring tape placed in a 3g pitch. Participants started with knees and hips extended, trunk in an upright position behind the starting line and performed a SL horizontal jump with hands placed on hips, trying to reach as far as possible without losing balance on the landing. Two warm-up jumps were performed followed by two test jumps with 30 seconds of rest between these. Participants were encouraged to jump as far as possible.

3.2.2.4. Strength Tests:

FSCS and FSES.

Flywheel exercise and testing allows for both concentric and eccentric contractions. In addition, it allows mechanical eccentric overload by returning inertia accumulated by the rotating wheel during prior concentric phase (Beato et al., 2021a). The movement starts until the rope is totally unrolled (concentric phase). The device then continues rotating due to inertia, making the rope recoil. The kinetic energy from the concentric phase is then transferred to the eccentric phase and an equal impulse is needed to stop the rotation of the disc (Nuñez-Sanchez & Villareal, 2017).

Participants performed a half squat using a flywheel ergometer (D Line, Desmotec, Biella, Italy). A high inertia (0.12 kg·m^2) was utilised to assess the force area of the force-velocity curve (McErlain-Naylor & Beato, 2021). Participants started from approximately 90° knee angle position (measured with a goniometer) and performed a concentric upward movement to full knee extension. During the downward phase, participants were instructed to delay the braking action to the last two-thirds of the eccentric phase, which enables the subject to attain eccentric overload (Beato et al., 2021b). To perform this, subjects needed to execute the first part of the downward phase of the squat (approximately 1/4 squat) faster than the rope recoiling, to then be ‘caught’ by the rope and perform the rest of the downward movement (Martínez-Hernández, 2024). These was closely monitored by the researcher. Participants performed familiarization trial sets before the test. Participants performed 2 sets of 4 repetitions with at least 90 seconds of rest between trial, taking the highest peak power of each set for analysis. Players were encouraged to perform the upward phase as fast as possible and delay the braking action to the last third of the downwards phase as fast as possible. Only peak force measure was extracted. Data was normalised by dividing by BM.

NHES:

Participants were tested on eccentric hamstring strength using a Nordbord device (Nordbord, Vald Performance, Australia) with a sampling rate of 50 Hz. From a kneeling position, participants had to lean forward gradually maintaining an upright and neutral trunk posture, while maximally resisting the drop with both limbs. Two warm-up trials were performed followed by 2 tests with at least 90 seconds rest between these. Participants were encouraged to delay the ‘braking point’ as much as possible. Only the peak force measure was extracted. Data was normalised by dividing by BM.

IMTP.

Isometric maximal strength (absolute peak vertical force) was assessed through an IMTP test using a standard IMTP rack and force plates (Force Decks, Vald Performance, Newstead, QLS, AUS) attached on the base with a sampling rate of 1000 Hz. Participants had the bar resting midway up the thigh by selecting the hip and knee joint angles that they utilised when performing a midthigh clean pull. Researchers ensured that knee and hip angles were within optimal parameters (knees = 125-145°, hips = 140-150°), due to the importance of body position in force generation (McCormick, et al, 2022, Comfort et al., 2019). As recommended by Comfort et al. (2019), the thighs were in contact with the bar, with the torso upright. Knees were slightly flexed which resulted in some dorsiflexion, and the shoulder girdle retracted and depressed and slightly behind the vertical plane of the bar. Players had feet centered under the bar, hip-width apart, with knees beneath and in front of the bar. Participants were strapped to the bar (immovable cold rolled steel bar) using lifting straps and athletic tape and pulled as hard as possible for 5 seconds, performing 2 sets with at least 1 minute 30 seconds rest between these. Participants were encouraged to pull *"as hard and fast as possible"* (McCormick, et al, 2022). If the athlete performed a countermovement, excessive pre-tension, or the trials scores did not fall within 250N, the trial was omitted and an additional attempt was performed (Comfort et al., 2019). Only the peak force (gross) measure was extracted, as is this is indicative of 'maximum strength', while the rate of force development would be a measure of the force that can be generated in the early phase of muscle contraction (Aagaard et al., 2002; Stone et al., 2002). Data was normalised by dividing by BM.

3.4. Methods for Chapter 7

3.4.1. Subjects

Thirty-six outfield elite female soccer players (age: 25.27 ±4.6 years, height: 167 ±5.2 cm, BM: 63.03 ±4.5 kg) from the first team of a FA WSL club participated in this study. This was formed by a CG (n = 12, age: 23.58 ±4.3 years, height: 166 ±6.4 cm, BM: 63.36 ±4 kg), attacker group (AG) (n = 9, age: 25.85 ±3.6 years, height: 170 ±6.6 cm, BM: 62.4 ±6.4 kg) and defender group (DG) (n = 15, age: 26.34 ±3.9 years, height: 167 ±4.5 cm, BM: 64.57 ±4 kg). Based on an effect size of 0.38 for pre- to post-changes (ANOVA group × time) in COD speed performance in female soccer players following multidirectional unilateral and lateral plyometric training (Campillo et al., 2018c), a priori analysis, using G*Power (Version 3.1, University of Dusseldorf, Dusseldorf, Germany), indicated that a minimum total sample size of 21 was required to achieve a power of 0.80, and type 1 error or alpha level of 0.05. This would mean a minimum of 7 subjects in each group.

Players were advised on the potential risks and benefits of taking part in the study and signed a written informed consent. The study was approved by the university ethics committee and conducted according to the Declaration of Helsinki.

3.4.2. Procedures

Two different COD tests were performed on the left and right sides. 505 COD left, 505 COD right, 75-90° COD left and 75-90° COD right. The calculation of the total time of left and right performance was included for analysis as 505 COD total and 75-90° COD total. While the 505 COD test was considered a test reflective of COD actions commonly performed by defenders, 75-90° COD was a test considered for attackers. The COD tests were performed on an outdoor 3g pitch. In addition, CMJ, SL CMJ left, SL CMJ right, SL BJ left and SL BJ right tests were performed within the same week as COD tests. Pre- and post-intervention tests were performed during the in-season period. Before performing these tests, a warm-up consisting of lower limb dynamic stretching (i.e., walking lunges, leg swings, leg circles, etc.), (5 minutes), jogging (3 minutes) and high-intensity activities (i.e., sprints and COD activities increasing the distance and turning angles) (3 minutes) were performed. Prior to performing each of the tests, a familiarization/warm-up trial was allowed. After this, players performed twice each of the tests. Players had previous experience with all tests as this same battery of tests was performed throughout the previous season, and so, familiarization sessions were not needed.

3.4.3. Training Intervention

The training intervention was designed considering the team week, season periodization and team aims. Table 3.4. shows the structure of a common week for the participants. Participants performed two strength gym sessions, one power session, and one movement power session (this involved band-resisted exercises that mimicked movements performed in the sport, such as a turn with an acceleration step, resisted sprinting or arched resisted sprints). Players performed their habitual gym sessions with a particular focus on the exercises that would potentiate COD performance specific to their role based on findings from Chapter 6, as well as previous research (Table 3.5.). AG prioritised medio-lateral exercises, short and long SSC exercises, low to mid inertias in flywheel exercises and COD training with shallow cuts. On the other hand, DG prioritised antero-posterior exercises, long SSC exercises and mid to high inertias in flywheel training. The gym strength session performed on matchday (M)-4 consisted of upper body and core strength which also included a lower body strength micro-dosing session. The main lower body strength session was performed on M-3 (afternoon). Players also performed one power session on M-4 and a movement power session on M-3, although the latter did not include position specific drills. Players performed four football training sessions and one match. During the warm-up of the intensive session, where special focus was placed on COD performance development, players were separated at the end of this warm-up for 5 - 7 minutes to work on COD drills specific to their position. The general training characteristics of these two training interventions can be found in Table 3.5. The CG followed the same weekly structure as the intervention groups (IGs), but their strength and power program did not have a position specific target and the COD drills performed during intensive training warm-ups were not divided based on the player's role. If the player did not complete at least 70% of the sessions, this was excluded from the analysis. All training programs and sessions were delivered by qualified strength and conditioning coaches.

While the number of sets and reps stayed consistent through the weeks, the program followed the training principles of progressive overload and variation. Thus, exercises were progressed from DL to SL (i.e., power: from DL CMJ to SL CMJ), the level of complexity, planes of movement, as well as load/inertia. For example, a flywheel lateral lunge with low inertia would be progressed to a flywheel lateral rotation lunge with low inertia, followed by a flywheel lateral rotation lunge with medium inertia). While the training protocol was specific to the player's position, an extra level of individualization was needed, as this experimental study was performed in a very applied environment. Therefore, two out of six exercises in the power session were based on the player's needs rather than on the player's position specificity. Moreover, two out of three exercises in the strength microdosing session were based on the player's injury prevention needs.

Table 3.4. Week structure

Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Morning	-	Off	Core + Soccer Training (bridge session)	Power + Soccer Training (intensive session)	Movement Power + Soccer Training (extensive session)	Off	Soccer Training (M-1 activation session)	-
Afternoon	Match	Off	Off	Upper Body Strength and Core + Lower Body Strength Micro dosing	Lower Body Strength	Off	Off	Match

M = matchday

Table 3.5. Training intervention characteristics for the different positions

Player	Attackers	Defenders
Method and characteristics	Priority - preference	
Direction of forces **(applies to all methods below)**	Medio-lateral	Antero–posterior
Power / plyometrics	Short and long SSC	Long SSC
Eccentric strength (flywheel)	Low to mid inertias	Mid to high inertias
COD specific training	Shallow CODs	Sharp CODs

COD = change of direction, SSC = stretch shortening cycle

Table 3.6. Training intervention general characteristics

	Sets	Reps	Load/ Intensity
Strength	2 – 3	3 - 8	3RM to 8RM / Maximum intent for isometric exercises
Strength microdosing	1 – 2	3 - 6	3RM to 8RM
Power/ plyometrics	1 – 2	3 - 6	Maximum intent
COD Specific Training	1	2 - 4	Maximum intent

COD = change of direction, RM = repetition maximum

CHAPTER 4: MOST COMMON MOVEMENTS PRECEDING GOAL-SCORING SITUATIONS IN MALE AND FEMALE ELITE SOCCER

Aspects of this chapter have been published in the following:

- Martínez-Hernández, D., & Jones, P. A. (2024). Change Of Direction Actions in Goal Scoring Situations in Male and Female Professional Soccer. *International Journal of Strength and Conditioning*, *4*(1).
- Martínez-Hernández, D., Quinn, M., & Jones, P. (2024). Most common movements preceding goal scoring situations in female professional soccer. *Science and Medicine in Football*, *8*(3), 260-268.
- Martínez-Hernández, D., Quinn, M., & Jones, P. (2023). Linear advancing actions followed by deceleration and turn are the most common movements preceding goals in male professional soccer. *Science and Medicine in Football*, *7*(1), 25-33.

4.1. Introduction

Soccer is a team sport where players need technical and tactical ability (Forsman et al., 2016) and a high level of athleticism to be successful (Turner & Stewart, 2014). Soccer match activities have been widely analysed for both males and females (Akenhead et al., 2013; Bradley et al., 2010; Dalen et al., 2016; Datson et al., 2017; Griffin et al., 2021; Mara et al., 2017a; Sarmento et al., 2014). There has been a great evolution in the way players are being tracked. In the '70s and '80s motion analysis was utilised to track players performance (Reilly, 1976; Van Gool et al., 2013). Subsequently, in the 90s and 2000s, semi-automatic video systems started to be utilised and validated (Valter et al., 2006). Also in the 2000s, Global Positioning System (GPS) began to gain popularity and has become more sophisticated in the metrics it provides (Hennessy & Jeffreys, 2018). More recently, Inertial Measurement Units have started to be utilised. This consists of an accelerometer, a 3D gyroscope and/or magnetometer (Torres-Ronda et al., 2022) and are commonly added to the global positioning system utilised by the athletes (Hennessy & Jeffreys, 2018).

Researchers have generally utilised static or linear direction activities such as standing, walking, jogging, running, sprinting, high-intensity running, and very high-intensity running (Barros et al., 2007; Bradley et al., 2010; Mallo et al., 2015) with acceleration and deceleration activities gaining interest in recent years (Harper et al., 2019; Mara et al., 2017). Moreover, lateral movements during matches have also been analysed, with senior male players covering mean distances ranging from 263 to 548 m (Da Silva et al., 2007; Rienzi et al., 2000). In addition, different researchers have investigated the number of changes in direction or turning activities during matches in male soccer (Baptista et al., 2018; Bloomfield, et al., 2007a; Dos'Santos et al., 2022b; Granero-Gil et al., 2020; Morgan et al., 2022; Nedelec et al., 2014). These studies have shown considerable differences, going from 11.9 hard changes of direction to 700 turns and swerves (Bloomfield et al., 2007a; Nedelec et al., 2014). In addition, several researchers have analysed how movements combine during a whole match using the BMC (Bloomfield, et al., 2007b; Bloomfield et al., 2007c). Bloomfield et al. (2017b) found decelerations to be preceded by sprints in 77% of the occasions. In addition, a different study from the same group found jogging and shuffling frequently preceding and following turns of ≤90° while turns of >90° were performed while skipping, stopping and slowing down (Bloomfield et al., 2017c).

From a tactical perspective, different researchers have emphasised the complexity of the effective creation and conversion of goal-scoring opportunities (Wright et al., 2011). In this sense, it is essential to consider contextual factors and tactical concepts and how they interrelate with each other, with evidence suggesting that enhancement of attacking players' physical output is fundamental for perturbing defensive tactical organisation, creating space for goal chances (Schulze et al., 2022). Therefore, physical characteristics could have an impact on goal-scoring actions, and so, a clear knowledge of these movements and how they combine could lead to further understanding. This movement data, commonly obtained with GPS, has limited significance regarding subtle manoeuvres taking place in goal-scoring situations such as accelerations, decelerations or COD actions, as these activities have shown high variability when comparing different brand GPS units (Buchheit et al., 2014a; Jennings et al., 2010).

In this regard, only one study has analysed the movements occurring before goal-scoring situations. Faude et al. (2012) analysed 360 goals of the German National League 2007/2008 using multiple replays and categorising them into one of the following: straight sprint, rotation, jump, change-in-direction sprint, a combination or absence of these movements. Results showed that 83% of the goals were preceded by at least one powerful action of the scoring or the assisting player, with a straight sprint showing to be the most common action. This pioneering study highlights the importance of powerful actions before a goal in scoring and assisting players. Nevertheless, it is of interest to determine movement characteristics of other leagues besides the German National League, such as the EPL, especially when it has been demonstrated that European teams from the four leagues display different tactical strategies in possessions leading to the creation of goal-scoring opportunities (Mitrotasiso et al., 2019). Moreover, there is no such analysis performed in a female professional soccer league, and so, there is a lack of understanding of whether trends found in male soccer are comparable to female soccer. In addition, there is a need for a more detailed analysis which includes a wider range of movements, intensities and directions. Furthermore, the inclusion of players with defending roles would bring insight into common patterns performed by these as well as the main differences with their attacking counterparts. Moreover, gaining insights into the typical amalgamation of these movements and understanding the frequency of COD actions executed in scenarios leading to goals scored can significantly augment our comprehension of the significance of these actions and inform effective training methods to enhance performance as well as the selection of the most applicable physical tests.

The aim of this study was to gain a clear understanding of the movements that occur before a goal in male and female elite soccer. To achieve this aim, the study had the following objectives: 1. Acknowledge the most frequent movements preceding a goal and the percentage of involvements they are present in. 2. Identify similarities and differences between players based on their roles. 3. Examine the movement intensity, direction and interaction with the ball. 4. Acknowledge the most frequent actions occurring before and after certain movements. 5. Examine the percentage of involvements where a COD action is performed.

4.2. Methods

4.2.1. Procedures

A more detailed description of the methodology can be found in Chapter 3. Goals from 2018/2019 season in EPL and WSL were analysed through video analysis utilising the same broadcast provider. All goals were analysed by the lead researcher, who had access to goals recorded in slow motion and from different angles. Analysis was performed for the following players involved in each goal: scoring player, assisting player (assistant), closest defender to the scorer (defender of scorer) and closest defender to the assisting player (defender of assistant). Scorer and assistant were named as ‘attackers’ while defender of scorer and defender of assistant were named as ‘defenders’. Analysis was performed on the last six movements of each player, with this sequence of movements being called ‘involvement’.

4.2.2. Definition and Interpretation of Movements

A modified version of BMC was utilised, with changes in definitions described in Chapter 3.1. COD was defined as a sudden or gradual change in movement path from a moving or static position, with more details on the different types of CODs in section 3.1.3. (page 147).

4.2.3. Statistical Analyses

Data was analysed using SPSS for Windows software version 22.0 (SPSS, Inc., Chicago, IL). Kolmogorov-Smirnov test was performed to assess for normal distribution, while the significance level was set at $p < 0.05$. Data was not normally distributed. Pooled and individually coupled differences in frequencies between movements (individual and group of movements), players (individual and group of players) and movement modifiers (intensities, directions and ball) were analysed through chi-square (x^2). Data was presented with total frequency, percentage and CI.

To obtain the reliability of the movement classification system used, intra-rater reliability and inter-rater reliability measures were obtained. For intra-reliability statistics, the same match day games (10 games) were analysed twice by the same researcher with four weeks between evaluations. This included 72 players involved in 22 goals, with a total of 239 movements analysed, which included the three types of modifiers. This was analysed through ICC (two-way mixed model, single rater, consistency), obtaining values of 0.87, which is considered a good level of agreement (Koo & Li, 2016). To obtain inter-rater reliability, videos corresponding to 10 clips of each movement were analysed by two different investigators. The benchmark scales for Kappa’s value were: <0.0 = poor; 0.00 to 0.2 = slight; 0.21 to 0.40 = Fair; 0.41 to 0.60 = Moderate; 0.61 to 0.80 = substantial; 0.81 to 1.0 = almost perfect, as proposed by Landis & Koch (1977). Weighted Cohen’s Kappa showed movement agreement of moderate to almost perfect agreement (movement agreement: K = 0.864, direction agreement: K = 0.588, intensity agreement: K = 0.762, ball agreement: K = 0.844). Regarding individual movements, stand still, cut and jump showed moderate agreement k = 0.60), deceleration, turn, crossover and slide showed substantial agreement (k = 0.80), with the rest of the movements showing almost perfect agreement (k = 1). The lower agreement in the direction modifier could be related to the lower number of measurements performed. In this sense, inter-rater analysis was performed over 100 movements. However, there were movements without a direction component (lateral advancing motion, change in angle run, ball blocking, ball striking, etc.), and so, the data count was lower compared to movement, intensity or ball modifier, which could have had an impact in Kappa score, as the observed agreement was 79%.

4.3. Results.

4.3.1. Total frequency and percentages of movements

1072 and 336 goals were scored, with 769 and 256 being selected for analysis in EPL and WSL, respectively. A total of 9348 and 2985 movements were recorded, which, without the inclusion of pass and shot gave a total of 7984 and 2548 for EPL and WSL, respectively. There were 2503 players involvements in EPL (scorer = 769, assistant = 595, defender of scorer = 642, defender of assistant = 497) and 813 in WSL (scorer = 256, assistant = 181, defender of scorer = 222, defender of assistant = 154).

Chi-square analysis showed significant differences between movements (EPL = $x^2_{(7)} = 5694$, $p < 0.01$; WSL = $x^2_{(7)} = 2131$, $p < 0.01$). As seen in Table 4.1. and Table 4.2., overall, in EPL and WSL the most common movement preceding a goal was a linear advancing motion, which was followed by deceleration and turn, with no significant difference between these (EPL: $p = 0.526$; WSL = $p = 0.16$). Other frequent movements can be found in Table 4.1. and Table 4.2. Attackers performed higher percentages of linear actions compared to defenders (EPL: $x^2_{(1)} = 51$, $p < 0.01$; WSL: $x^2_{(1)} = 5$, $p = 0.02$) as well as turns (only in EPL, $x^2_{(1)} = 10$; $p < 0.01$) and cuts (EPL: $x^2_{(1)} = 102$; $p < 0.01$ WSL: $x^2_{(1)} = 32$, $p < 0.01$), while defenders performed higher percentages of lateral movements (EPL: $x^2_{(1)} = 43$, $p < 0.01$; WSL: $x^2_{(1)} = 10$, $p < 0.01$) arc runs (only EPL) ($x^2_{(1)} = 102$, $p < 0.01$) and ball blocking actions (EPL: $x^2_{(1)} = 455$, $p < 0.01$; WSL: $x^2_{(1)} = 132$, $p < 0.01$).

Chi-square analysis showed significant differences for percentage of involvements where each movement was performed at least once (EPL: $x^2_{(6)} = 2051$, $p < 0.01$; WSL: $x^2_{(6)} = 1419$, $p < 0.01$) as well as percentage of involvements where movement was performed at least once at high-intensity (EPL: $x^2_{(6)} = 4216$, $p < 0.01$; WSL: $x^2_{(6)} = 899$, $p < 0.01$) (Figure 4.3. and Figure 4.4.).

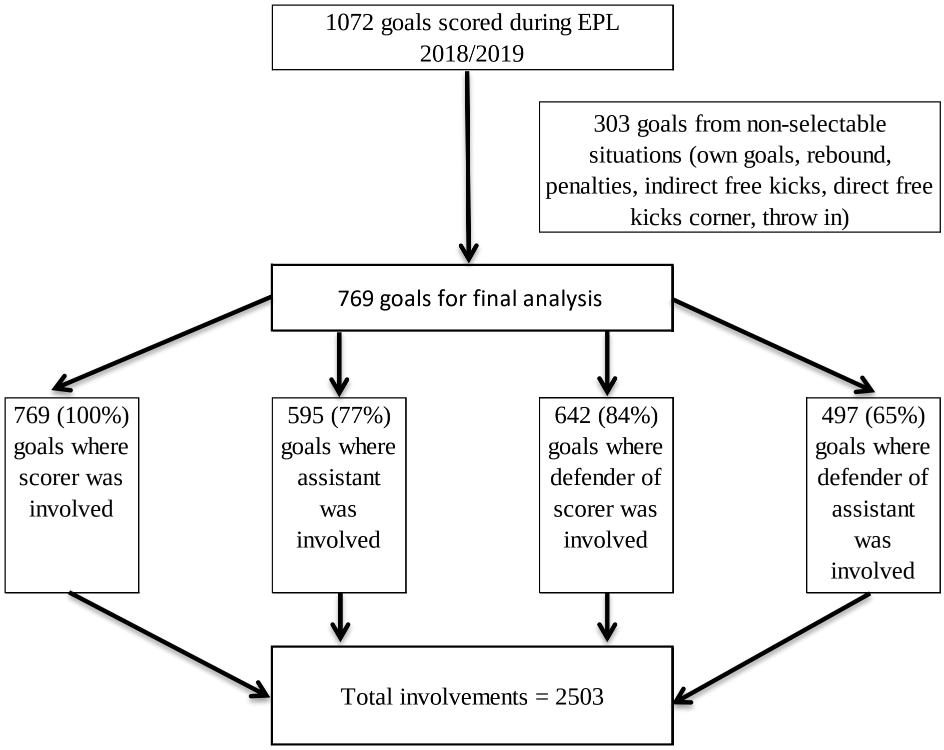


Figure 4.1. Flow chart of goals selected for analysis as well as total involvements in EPL

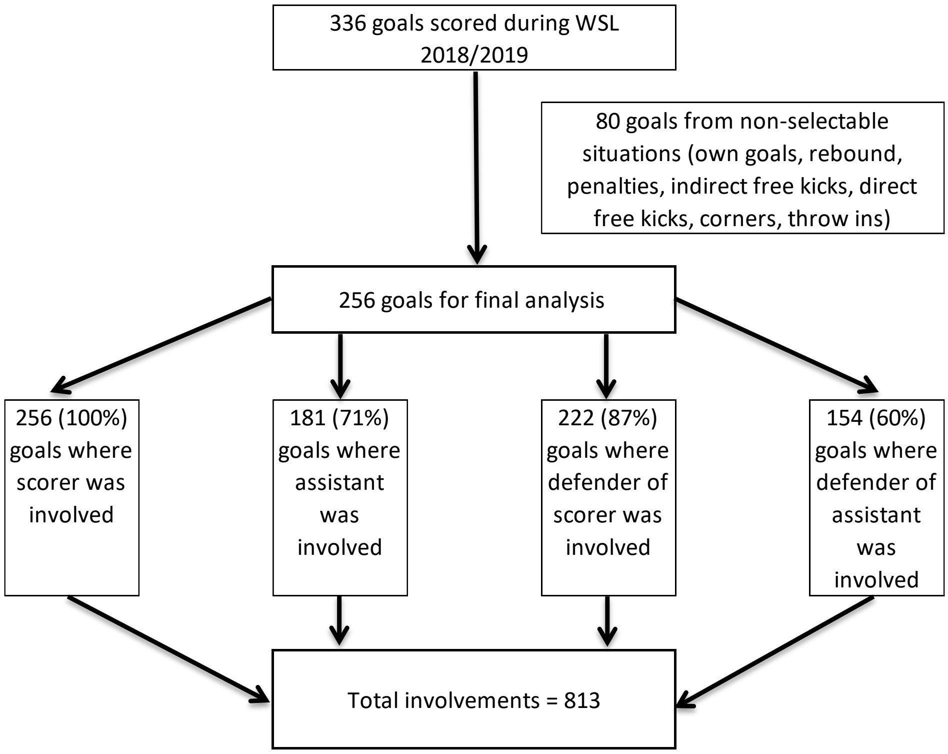


Figure 4.2. Flow chart of goals selected for analysis as well as total involvements in WSL

Table 4.1. Frequencies and percentages of movements in EPL overall, for individual players and groups of players

Movements		Assistant (%)	Scorer (%)	Defender of Assistant (%)	Defender of Scorer (%)	Attackers (%)	Defenders (%)	Movement Total
Linear Advancing Motion		594 (35%±2.3%)$^{¥x}$	862 (36.9 ±2%)$^{¥x}$	484 (29.8±2.2%)	648 (27.8 ±1.8%)	1456 (36.1±1.5%)$^{\#}$	1132 (28.6 1.4%)	2588 (32.4 ±1%)*
Deceleration		381 (22.5 ±2%)$^{\&x}$	431 (18.5 ±1.6%)$^{¥}$	399 (24.6 ±2.1%)^{x}	400 (17.2 ±1.5%)	812 (20.2 ±1.2%)	799 (20.2 ±1.3%)	1611 (20.2 ±0.9%)**
Turn		388 (22.9 ±2%)$^{\beta}$	466 (20±1.6%)$^{¥}$	267 (16.4 ±1.8%)^{x}	458 (19.6 ±1.6%)	854 (21 ±1.3%)$^{\#}$	725 (18.3 ±1.2%)	1579 (19.8 ±0.9%)**
Change in Angle Run	Arc Run	67 (4 ±0.9%)$^{\Omega}$	88 (3.8 ±0.8%)$^{x\Omega}$	72 (4.4 ±1%)$^{\Omega}$	118 (5.1 ±0.9%)$^{\Omega}$	155 (3.8±0.6%)$^{\#}$ $^{\Omega}$	190 (4.8 ±0.7%)$^{\Omega}$	345 (4.3 ±0.4%)
	Cut	104 (6.1% ±1.1%)$^{¥x}$	163 (7% ±1%)$^{¥x}$	31 (1.9% 0.6%)	48 (2.1 ±0.6%)	267 (6.6 ±0.8%)$^{\#}$	79 (2 ±0.4%)	346 (4.3 ±0.4%)
	Totals	171 (10.1 ±1.4%)$^{¥x}$	251 (10.8±1.3%)$^{¥x}$	103 (6.3 ±1.2%)	166 (7.1% ±1%)	422 (10.5% ±1%)$^{\#}$	269 (6.8% ±0.8%)	691 (8.7% ±0.6%)*
Lateral Advancing Motion	Crossover	26 (1.5 ±0.6%)$^{\beta}$	65 (2.8 ±0.7%)$^{¥x}$	64 (3.9 ±0.9%)	94 (4 ±0.8%)	91 (2.3 ±0.5%)$^{\#}$	158 (4 ±0.6%)	249 (3.1 ±0.4%)
	Shuffle	36 (2.7 ±0.8%)$^{¥x}$	49 (2.1 ±0.6%)$^{¥x}$	68 (4.2 ±1%)	91 (3.9 ±0.8)	85 (2.1 ±0.4)$^{\#}$	159 (4 ±0.6%)	244 (3.1 ±0.4%)
	Totals	62 (3.7 ±0.9%)$^{¥x}$	114 (4.9 ±0.9%)$^{¥x}$	132 (8.1 ±1.3%)	185 (7.9 ±1.1%)	176 (4.4 ±0.6%)$^{\#}$	317 (8 ±0.9%)	493 (6.2 ±0.5%)*
Ball Blocking	Dive	9 (0.5 ±0.3%)$^{¥x}$	10 (0.4 ±0.3%)$^{¥x€}$	125 (7.7 ±1.3%)$^{€}$	186 (8 ±1.1%)	19 (0.5 ±0.2%)$^{\#}$	311 (7.9 ±0.8%)$^{€}$	330 (4.1 ±0.4%)$^{€}$
	Slide	3 (0.2 ±0.2%)$^{\beta}$	21 (0.9 ±0.4%)$^{\beta}$	38 (2.3 ±0.7%)$^{\beta}$	183 (7.9 ±1.1%)	24 (0.6 ±0.2%)$^{\#}$	221 (5.6 ±0.7%)	245 (3.1 ±0.4%)
	Totals	12 (0.7 ±0.2%)$^{¥x}$	31 (1.3 ±0.5%)$^{¥x}$	163 (10 ±1.5%)^{x}	369 (15.8 ±1.5%)	43 (1.1 ±0.3%)$^{\#}$	532 (13.4 ±1%)	575 (7.2 ±0.6%)*
Jump		25 (1.5±0.6%)	93 (4 ±0.8%)$^{\beta}$	17 (1 ±0.5%)^{x}	46 (2 ±0.6%)	118 (2.9 ±0.5%)$^{\#}$	63 (1.6 ±0.4%)	181 (2.3±0.3%)
Other (skip, impact, stand still, land, fall, get up)		61 (3.6 ±0.9%)	86 (3.7 ±0.8%)	60 (3.7 ±0.9%)	59 (2.5 ±0.6%)$^{\beta}$	147 (3.6 ±0.6%)	119 (3 ±0.5%)	266 (3.3 ±0.4%)
Player totals		1694 (100%)	2334 (100%)	1625 (100%)	2331 (100%)	4028 (100%)	3956 (100%)	7984 (100%)

Data expressed as frequency (percentage ±95% confidence intervals).

Statistical differences ($p < 0.05$): horizontal axis, difference between players: $^{\beta}$ significant difference from the rest of the players, $^{\&}$ significant difference from scorer, $^{¥}$ significant difference from defender of assistant, ^{x} significant difference from defender of scorer, $^{\#}$ significant difference from defenders.

Vertical axis, difference only between movement totals (includes change in angle run totals, lateral advancing motion totals and ball blocking totals): * significant difference from the rest of the movements, ** significant difference from linear advancing motion, change in angle run, lateral advancing motion, ball blocking, jump.

Vertical axis, differences between movements in the same group (arc run and cut or dive and slide): $^{\Omega}$significant difference from cut, $^{€}$ significant difference from slide.

Table 4.2. Frequencies and percentages of movements in WSL overall, for individual players and groups of players

Movements		Assistant (%)	Scorer (%)	Defender of Assistant (%)	Defender of Scorer (%)	Attackers (%)	Defenders (%)	Movement Total
Linear Advancing Motion		171 (35. ±4.3%)	308 (38.2±3.4%)^{x}	164 (34.3±4.3%)^{x}	246 (31.7 ±3.3%)	479 (37 ±2.6%)$^{\#}$	410 (32.7 ±2.6%)	889 (34.9 ±1.9%)*
Deceleration		114 (23.4 ±3.8%)	164 (20.3 ±2.8%)	104 (21.8 ±3.7%)	127 (16.4 ±2.6%)$^{\beta}$	278 (21.5 ±2.2%)	231 (18.4 ±2.1%)	509 (20 ±1.6%)**
Turn		109 (22.4 ±3.7%)$^{\beta}$	145 (18 ±2.7%)	75 (15.7 ±3.3%)	141 (18.2 ±2.7%)	254 (19.6 ±2.2%)	216 (17.2 ±2.1%)	470 (18.4 ±1.5%)**
Change in Angle Run	Arc Run	22 (4.5 ±1.8%)$^{¥}$	40 (5 ±1.5%)	33 (6.9 ±2.3%)$^{\Omega}$	44 (5.7 ±1.6%)$^{\Omega}$	62 (4.8±1.2%)$^{\Omega}$	77 (6.1 ±1.3%)$^{\Omega}$	139 (5.5 ±0.9%)
	Cut	32 (6.6 ±2.2%)$^{¥x}$	55 (6.8 ±1.7%)$^{¥x}$	8 (1.7 ±1.2%)	18 (2.3 ±1.1%)	87 (6.7 ±1.4%)$^{\#}$	26 (2.1 ±0.8%)	113 (4.4 ±0.8%)
	Totals	54 (11.1±2.8%)	95 (11.8 ±2.2%)	41 (8.6 ±2.5%)	62 (8 ±1.8%)	149 (11.5 ±1.7%)$^{\#}$	103 (8.2 ±1.5%)	252 (9.9 ±1.2%)*
Lateral Advancing Motion	Crossover	6 (1.2 ±1%)$^{¥x}$	16 (2 ±1%)$^{¥x}$	15 (3.1 ±1.6%)	28 (3.6 ±1.3%)	22 (1.7 ±0.7%)$^{\#}$	43 (3.4 ±1%)	65 (2.6 ±0.6%)
	Shuffle	5 (1 ±0.9%)	17 (2.1 ±1%)	14 (2.9 ±1.5%)$^{\beta}$	19 (2.4 ±1.1%)	22 (1.7 ±0.7%)	33 (2.6 ±0.9%)	55 (2.2 ±0.6%)
	Totals	11 (2.3 ±1.3%)$^{¥x}$	33 (4.1 ±1.4%)$^{¥}$	29 (6.1 ±2.2%)	47 (6.1 ±1.7%)	44 (3.4 ±1%)$^{\#}$	76 (6.1 ±1.3%)^{v}	120 (4.7 ±0.8%)*
Ball Blocking	Dive	2 (0.4 ±0.6%)$^{¥x}$	5 (0.6 ±0.5%)$^{¥x}$	41 (8.6 ±2.5%)$^{€}$	64 (8.2 ±1.9%)	7 (0.5 ±0.4%)$^{\#}$	105 (8.4 ±1.5%)$^{€}$	112 (4.4 ±1.1%)$^{€}$
	Slide	1 (0.2 ±0.4%)$^{¥}$	8 (1 ±0.7%)	9 (1.9 ±1.2%%)	47 (6.1 ±1.7%)*	9 (0.7 ±0.5%)$^{\#}$	55 (4.5 ±1.5%)	65 (2.6 ±0.6%)
	Totals	3 (0.6 ±0.7%)$^{¥x}$	13 (1.6 ±0.9%)$^{¥x}$	50 (10.5 ±2.8%)	111 (14.3 ±2.5%)	16 (1.2 ±0.6%)$^{\#}$	161 (12.8 ±1.9%)	177 (6.9 ±1%)*
Jump		6 (1.2 ±1%)$^{\&}$	27 (3.3 ±1.2%)$^{¥}$	2 (0.4% ±0.6%)^{x}	22 (2.8% ±1.2%)	33 (2.6% ±0.9%)	24 (1.9% ±0,8%)	57 (2.2% ±0.6%)
Other (skip, impact, stand still, land, fall, get up)		19 (3.9% ±1.7%)	22 (2.7% ±1.1%)	13 (2.7 ±1.5%)	20 (2.6 ±1.1%)	41 (3.2 ±1%)	33 (2.6 ±0.9%)	74 (2.9 ±0.6%)
Player totals		487 (100%)	807 (100%)	478 (100%)	776 (100%)	1294 (100%)	1254 (100%)	2548 (100%)

Data expressed as frequency (percentage ±95% confidence intervals).

Statistical differences ($p < 0.05$): horizontal axis, difference between players: $^{\beta}$ significant difference from the rest of the players, $^{\&}$ significant difference from scorer, $^{¥}$ significant difference from defender of assistant, ^{x} significant difference from defender of scorer, $^{\#}$ significant difference from defenders.

Vertical axis, difference only between movement totals (includes change in angle run totals, lateral advancing motion totals and ball blocking totals): * significant difference from the rest of the movements, ** significant difference from linear advancing motion, change in angle run, lateral advancing motion, ball blocking, jump.

Vertical axis, differences between movements in the same group (arc run and cut or dive and slide): $^{\Omega}$significant difference from cut, $^{€}$ significant difference from slide.

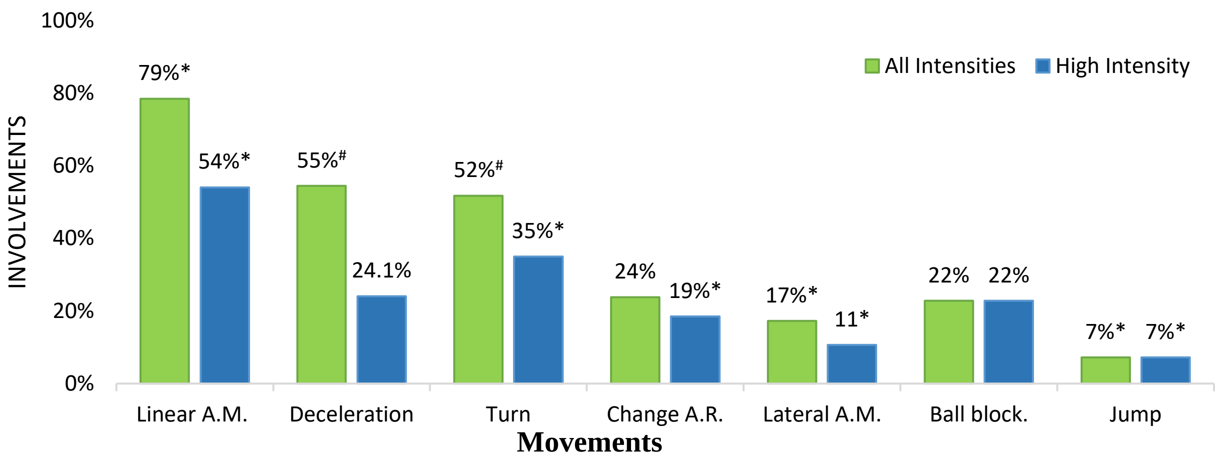


Figure 4.3. Percentage of involvements where movements were performed at least once in EPL. Jump and ball blocking actions are always considered high-intensity movements for analysis. Statistical differences ($p < 0.05$): *Significant difference from the rest of the movements of same group (all intensities or high intensity). #Significantly different from linear advancing motion, change in angle run, lateral advancing motion, ball blocking and jump. Linear A.M.: linear advancing motion; Change A.R.: change in angle run; Lateral A.M.: lateral advancing motion; Ball block: ball blocking.

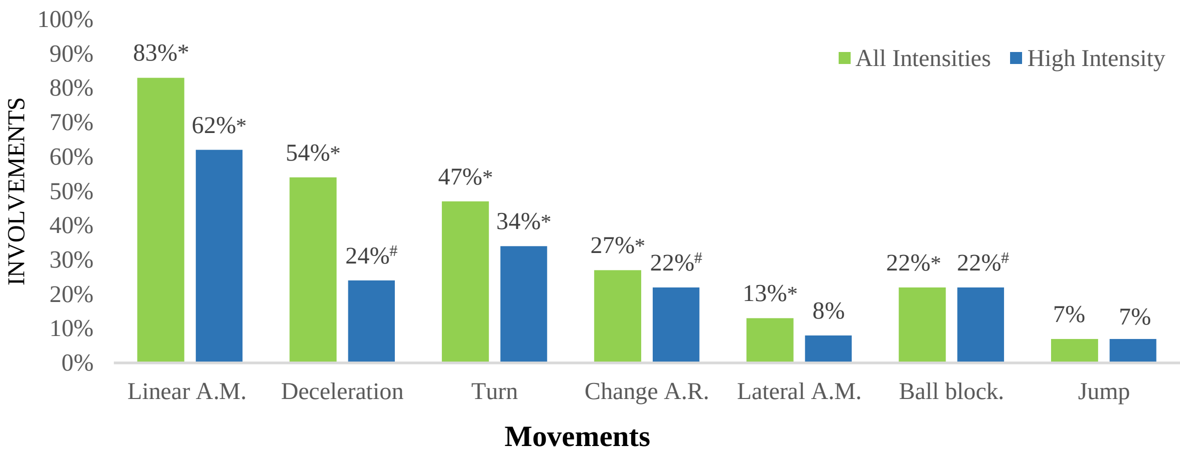


Figure 4.4. Percentage of involvements where movements were performed at least once in WSL. Jump and ball blocking actions are always considered high-intensity movements for analysis. Statistical differences ($p < 0.05$): *Significant difference from the rest of the movements of same group (all intensities or high intensity). #Significantly different from linear advancing motion, turn, lateral advancing motion and jump. Linear A.M.: linear advancing motion; Change A.R.: change in angle run; Lateral A.M.: lateral advancing motion; Ball block: ball blocking.

4.3.2. Intensity Modifier

Chi-square analysis showed significant differences for frequency of involvements where players performed at least one high-intensity action (EPL: $x^2_{(3)} = 235$, $p < 0.01$; WSL $x^2_{(3)} = 72$, $p < 0.01$), with defender of scorer showing the highest percentages (Table 4.3.). Significant differences were found between the three intensities in all movements when players were pooled together ($p < 0.01$) (Figure 4.5. and Figure 4.6.). When looking at the differences between groups of players, defenders compared to attackers showed a significantly greater number of actions at high intensity in linear advancing motion ($p < 0.01$), decelerations ($p < 0.01$) and turns (only in EPL) ($p < 0.01$).

Table 4.3. Frequency and percentage of involvements were players performed at least 1 high-intensity action

Player	EPL Frequency (percentage)	WSL Frequency (percentage)
Assistant	379 (63.7 ±1.9%)*	122 (67.4 ±3.2%)*
Scorer	653 (84.9 ±1.4%)^	221 (86.3 ±2.4%)^
Defender of assistant	428 (86,1 ±1.4%)^	135 (87.1 ±2.3%)^
Defender of scorer	615 (95.8 ±0.8%)	216 (97.3 ±1.1%)
Total Sum	2075 (82.9 ±1.5%)	694 (85.4 ±2.4%)

Data expressed as frequency (percentage ±95% confidence intervals). Jump, ball blocking actions and impact are considered as high-intensity movements for analysis. Statistical differences ($p < 0.05$): *significant difference from the rest of the players, ^significant difference from assistant and defender of scorer.

When movements were separated and analysed based on the intensity (low, medium and high), differences were found between intensities in all movements when players were pooled together (assistant, scorer, defender of assistant, defender of scorer) ($p < 0.01$). In this sense, all movements showed greater amounts of actions at high intensity except for deceleration and shuffle, where similar percentages were found between high-intensity and medium-intensity (WSL: deceleration, $p = 0.6101$, shuffle, $p = 0.84$; EPL: deceleration, $p = 0.8231$; shuffle, $p = 0.8625$.).

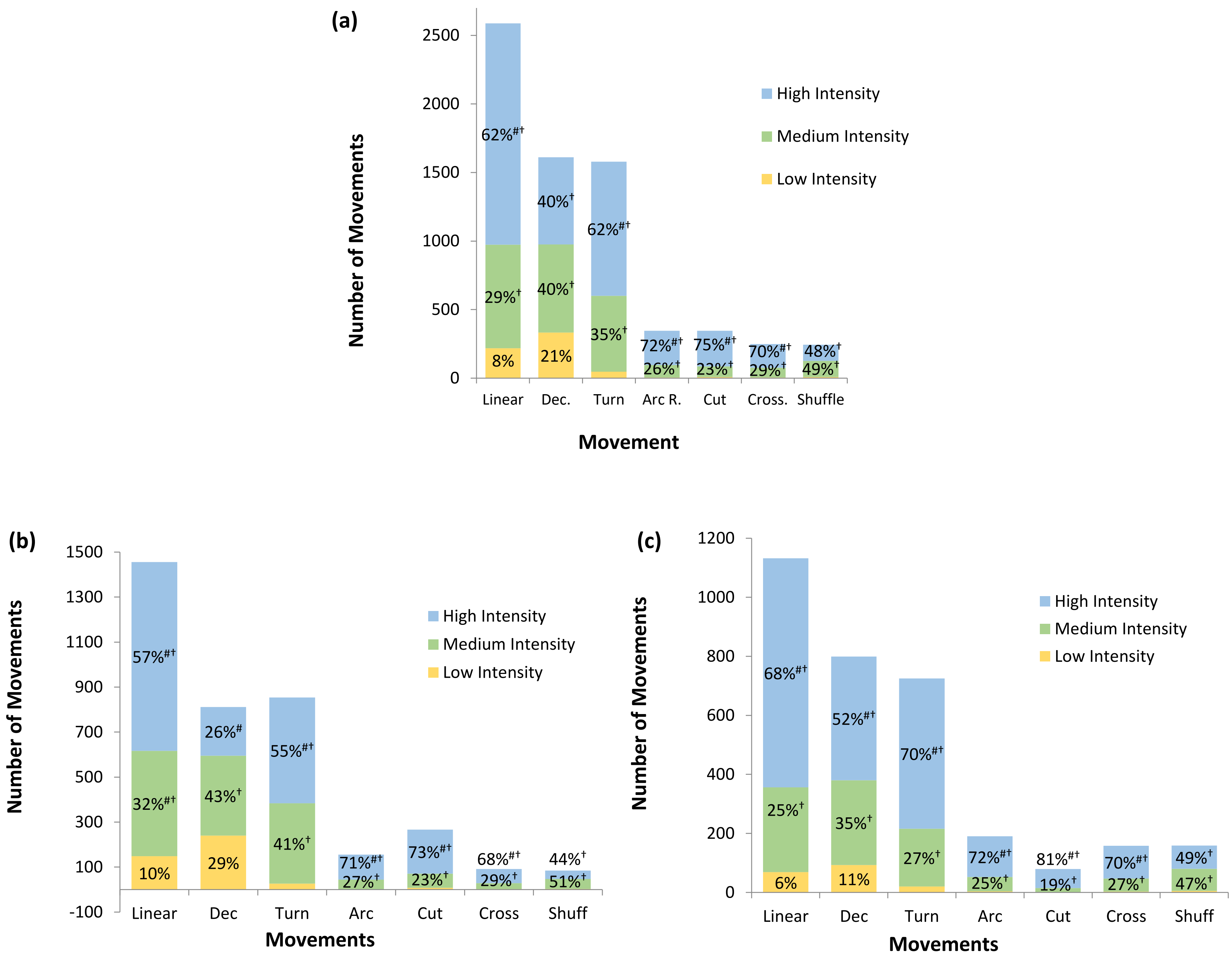


Figure 4.5. Movement intensity percentages for all players in EPL. Pooled (panel a), attackers (panel b) and defenders (panel c). [#]Significant difference from medium intensity. [†]Significant difference from low intensity. Linear: linear advancing motion; Dec.: deceleration; Arc R.: arc run; Cross.: crossover.

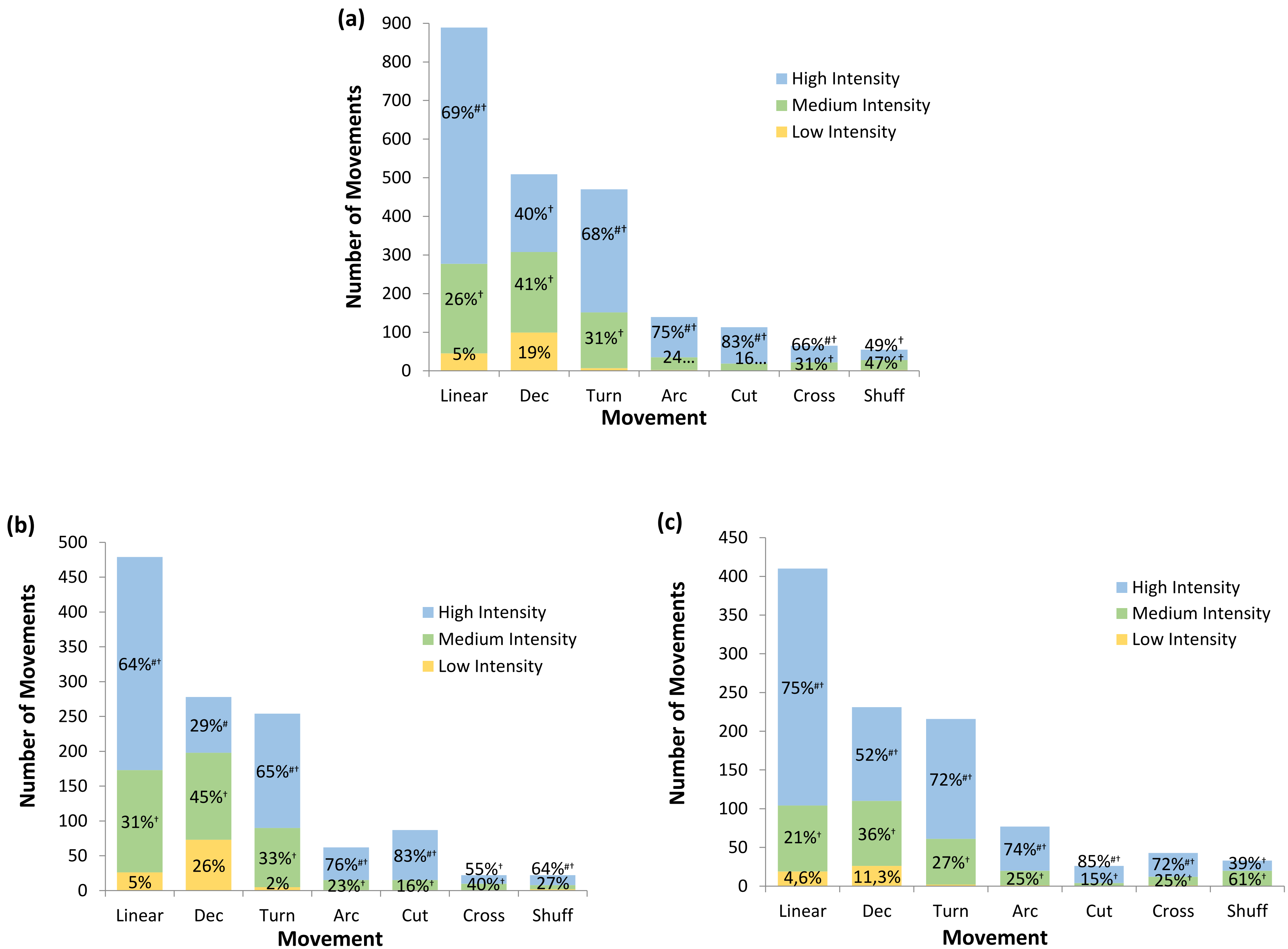


Figure 4.6. Movement intensity percentages for all players in WSL. Pooled (panel a), attackers (panel b) and defenders (panel c). #Significant difference from medium intensity. †Significant difference from low intensity. Linear: linear advancing motion; Dec.: deceleration; Arc R.: arc run; Cross.: crossover.

4.3.3. Direction Modifier

When analysing direction modifier for each movement, chi-square analysis showed significant differences in linear advancing motion (EPL: $x^2_{(2)} = 4380$, $p < 0.01$; WSL: $x^2_{(2)} = 1732$, $p < 0.01$), deceleration (EPL: $x^2_{(3)} = 690$, $p < 0.01$; WSL: $x^2_{(3)} = 351$, $p < 0.01$) and turn (EPL: $x^2_{(4)} = 2139$, $p < 0.01$; WSL: $x^2_{(4)} = 499$, $p < 0.01$). Most linear advancing motion activities had a forward direction (EPL = 82.8% ±1.4%; WSL = 86.8% ±2.2%) followed by forward diagonal direction (EPL = 15.3% ±1.4%, WSL = 10.7% ±2%), with backward direction (EPL = 1.9 ±0.5%, WSL = 2.3% ±1%) being the least frequent. Most decelerations had a forward direction (EPL = 43% ±2.4%; WSL = 54.2% ±3.9%), followed by sideways (EPL = 28.6% ±2.2%; WSL = 21.6% ±3.6%) and forward diagonal deceleration (25% ±2.1%; WSL = 19.1% ±3.4%). The most common turning degree ranges in EPL were 0-60º with 48.1% ±2.5%, while 60 -120º (38.3% ±2.4%) was the second most common. Similarly, the most common turning degree ranges in WSL were 0-60º (44.3% ±4.5%) and 60-120º (39.8% ±4.4%), with no significant difference found. This trend proved to be different between positions as attackers showed a significantly higher percentage of turns of 0-60º ($p < 0.01$) while defenders presented significantly higher percentages of turns from 60 -120º ($p < 0.01$) in both leagues.

Table 4.4. Direction modifier during deceleration in EPL

	Assistant (%)	Scorer (%)	Defender of Assistant (%)	Defender of Scorer (%)	Attackers (%)	Defenders (%)	Total
Forward	182 (47.8 ±5%)*	194 (45 ±4.7%)*†	178 (44.6 ±4.9%)*$^{\beta\dagger}$	139 (34.8 ±4.6%)$^{\&\beta}$	376 (46.3 ±3.4%)*$^{\Omega}$	317 (39.7 ±4.3%)*	693 (43 ±2.4%)*
Diagonal Forward	77 (20.2 ±4%)*$^{\&}$	103 (23.9 ±4%)	116 (29.1 ±4.4%)*$^{\beta}$	107 (26.8 ±4.3%)*$^{\beta}$	180 (22.2 ±2.9%)*$^{\Omega}$	223 (27.9 ±3.1%)	403 (25 ±2.1%)
Sideways	103 (27 ±4.5%)*	122 (28.3 ±4.2%)	98 (24.6 ±4.2%)*	137 (34.3 ±4.6%)$^{¥\beta}$	225 (27.7 ±3.1%)*	235 (29.4 ±3.2%)	460 (28.6 ±2.2%)
Backwards	19 (5±2.2%)$^{¥}$	12 (2.8 ±1.6%)*	7 (1.8 ±1.4%)	17 (4.3 ±2%)*$^{¥}$	31 (3.8 ±1.3%)	24 (3 ±1.2%)*	55 (2.4 ±0.9%)*

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant difference from the rest (when comparing forward, diagonal forward, sideways, backwards),

&significant difference from the rest (when comparing assistant, scorer, defender of assistant, defender of scorer), ¥significant difference from defender of assistant, βsignificant difference from assistant, †significant difference from defender of scorer, Ωsignificant difference from defender.

Table 4.5. Direction modifier during deceleration in WSL

	Assistant (%)	Scorer (%)	Defender of Assistant (%)	Defender of Scorer (%)	Attackers (%)	Defenders (%)	Total
Forward	67 (58.8 ±8.9%)*†	89 (54.3 ±7.5%)*β	62 (59.6 ±9.3%)*†	58 (45.7 ±8.5%)*	156 (56.1 ±5.7%)*	120 (51.9 ±6.4%)*	276 (54.2 ±3.9%)*
Diagonal Forward	19 (16.7 ±6.8%)	38 (23.2 ±6.4%)	16 (15.4 ±6.9%)	24 (18.9 ±6.8%)*	57 (20.5 ±4.7%)	40 (17.3 ±4.9%)*	97 (19.1 ±3.4%)
Sideways	21 (18.4 ±7.1%)	30 (18.3 ±5.9%)	20 (19.2 ±7.5%)	39 (30.7 ±7.9%)*	51 (18.3 ±4.5%)Ω	59 (25.5 ±5.6%)*	110 (21.6 ±3.6%)
Backwards	7 (6.1 ±4.7%)*	7 (0.9 ±3.2%)*	6 (5.8 ±4.7%)*	6 (3.8 ±3.9%)*	14 (5 ±2.6)*	12 (5.2 ±2.6%)	26 (5.1 ±1.9%)*

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant difference from the rest (when comparing forward, diagonal forward, sideways, backwards), &significant difference from the rest (when comparing assistant, scorer, defender of assistant, defender of scorer), ¥significant difference from defender of assistant, βsignificant difference from assistant, †significant difference from defender of scorer, Ωsignificant difference from defender.

Table 4.6. Direction modifier during turning in EPL

	Assistant (%)	Scorer (%)	Defender of Assistant (%)	Defender of Scorer (%)	Attackers (%)	Defenders (%)	Total
0º-60º	206 (53.1 ±5%)#*	312 (67 ±4.3%)#*	103 (38.6 ±5.8%)#@	138 (30.1 ±4.2%)*	518 (60.7 ±3.3%)β*	241 (33.2 ±3.4%)*	759 (48.1 ±2.5%)*
60º-120º	134 (34.5 ±4.7%)#*	126 (27 ±4%)#*	122 (45.7 ±6%)#@	222 (48.5 ±4.6%)#*	260 (30.4 ±3.1%) β*	344 (47.4 ±3.6%)*	604 (38.3 ±2.4%)*

120º-180º	36 (9.3 ±2.9%)†Ω*	22 (4.7 ±1.9%)#*	36 (13.5 ±4.1%)*	76 (16.6 ±3.4%)*	58 (6.8 ±1.7%) β*	112 (15.4 ±2.6%)*	170 (10.8 ±1.5%)*
180º-270º	9 (2.3 ±1.5%)	5 (1.1 ±1%)°	6 (2.2 ±1.9%)	20 (4.4 ±1.9%)	14 (1.6 ±0.9%)β	26 (3.6 ±1.4%)*	40 (2.5 ±0.8%)

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant difference from the rest (when comparing 0º-60º, 60º-120º, 120º-180º, 180º-270º and 270º-360º), @significant difference from 120º-180º, 180º-270º and 270º-360º,).°Significant difference from 0º-60º, 60º-120º and 120º-180º) #significant difference from the rest (when comparing assistant, scorer, defender of assistant, defender of scorer), ¥significant difference from defender of assistant and defender of scorer, †significant difference from defender of scorer, ΩSignificant difference from scorer, βsignificant difference from defenders.

Table 4.7. Direction modifier during turning in WSL

	Assistant (%)	Scorer (%)	Defender of Assistant (%)	Defender of Scorer (%)	Attackers (%)	Defenders (%)	Total
0º-60º	46 (42.2 ±9.3%)@	90 (62.1 ±7.9%)#*	30 (40 ±11.1%) @	42 (29.8 ±7.6%)*	136 (53.5 ±6.1%)*β	72 (33.3 ±6.3%)*	208 (44.3 ±4.5%)@
60º-120º	44 (40.4 ±9.2%)@†	41 (28.3 ±7.3%)*	36 (48 ±11.3%) @	66 (46.8 ±8.2%)*	85 (33.5 ±5.8%)*β	102 (47.2 ±6.7%)*	187 (39.8 ±4.4%)@
120º-180º	12 (11 ±5.9%)	13 (9 ±4.7%)*†	7 (9.3 ±6.7%)	25 (17,7 ±6.3%)*	25 (9.8 ±3.7%)*β	32 (14.8 ±4.7%)*	57 (12.1 ±3%)*
180º-270º	6 (5.5 ±4.5%)¥	1 (0.7 ±1.4%)†	2 (2.7 ±3.7%)	8 (5.7 ±3.8%)	7 (2.8 ±2%)	10 (4.6 ±2,8%)	17 (3.6 ±1.7%)º

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant difference from the rest (when comparing 0º-60º, 60º-120º, 120º-180º and 180º-270º), @significant difference from 120º-180º and 180º-270º).°Significant difference from 0º-60º, 60º-120º and 120º-180º, #significant difference from the rest (when comparing assistant, scorer, defender of assistant, defender of scorer), ¥significant difference from scorer, †significant difference from defender of scorer, ΩSignificant difference from scorer, βsignificant difference from defenders.

Table 4.8. Direction modifier during turning in EPL

	Assistant (%)	Scorer (%)	Defender of Assistant (%)	Defender of Scorer (%)	Attackers (%)	Defenders (%)	Total
0-60º	206 (53.1 ±5%)$^{\#*}$	312 (67 ±4.3%)$^{\#*}$	103 (38.6 ±5.8%)$^{\#@}$	138 (30.1 ±4.2%)*	518 (60.7 ±3.3%)$^{\beta*}$	241 (33.2 ±3.4%)*	759 (48.1 ±2.5%)*
60-120º	134 (34.5% ±4.7%)$^{\#*}$	126 (27% ±4%)$^{\#*}$	122 (45.7% ±6%)$^{\#@}$	222 (48.5% ±4.6%)$^{\#*}$	260 (30.4% ±3.1%) $^{\beta*}$	344 (47.4% ±3.6%)*	604 (38.3% ±2.4%)*
120-180º	36 (9.3% ±2.9%)$^{\dagger\Omega}$ *	22 (4.7% ±1.9%)$^{\#*}$	36 (13.5% ±4.1%)*	76 (16.6% ±3.4%)*	58 (6.8% ±1.7%) $^{\beta*}$	112 (15.4% ±2.6%)*	170 (10.8% ±1.5%)*
180-270º	9 (2.3% ±1.5%)	5 (1.1% ±1%)°	6 (2.2% ±1.9%)	20 (4.4% ±1.9%)	14 (1.6% ±0.9%)$^{\beta}$	26 (3.6% ±1.4%)*	40 (2.5% ±0.8%)

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *Significant difference from the rest (when comparing 0º-60º, 60º-120º, 120º-180º, 180º-270º and 270º-360º), $^{@}$significant difference from 120º-180º, 180º-270º and 270º-360º,).°Significant difference from 0º-60º, 60º-120º and 120º-180º) $^{\#}$significant difference from the rest (when comparing assistant, scorer, defender of assistant, defender of scorer), $^{¥}$significant difference from defender of assistant and defender of scorer, †significant difference from defender of scorer, $^{\Omega}$Significant difference from scorer, $^{\beta}$significant difference from defenders.

4.3.4. Ball Modifier

In EPL, assistant performed a higher percentage of actions with the ball than without the ball in most of the movements, while the opposite occurred in scorer except for cut, where the latter also showed higher percentages with the ball ($p < 0.01$). On the other hand, in the WSL assistant performed a higher percentage of actions with the ball than without the ball in all movements except for deceleration, arc run, crossover and shuffle, where no differences were found. In contrast, scorers performed actions more commonly without the ball except for turn and cut, which showed no differences. Further detail can be found in Supplementary Table 1 and Supplementary Table 2.

4.3.5. Movements Before and After

The different movements occurring before and after a particular movement were analysed in both EPL and WSL, with both leagues following similar trends (Table 4.9. and Table 4.10.). For attackers and defenders, movements before and after linear advancing motion, deceleration and turn (the three most common movements) were also analysed (Supplementary table 3, Supplementary Table 4, Supplementary Table 5 and Supplementary table 6). Chi-square showed significant differences for movements occurring before and after the selected movement for attackers, defenders and both pooled for EPL and WSL (Chi-square values for this section can be found in appendix 6).

Linear advancing motion, deceleration and turn combined subsequently in different manners were found in 25.3% ±1.7% and in 22.9% ±2.9% of the involvements in EPL and WSL, respectively. The most common movement before and after a linear advancing motion was a turn and a deceleration, respectively. The most frequent movement before and after a deceleration was a linear advancing motion and a turn, respectively. Turns were most frequently preceded by deceleration and followed by linear advancing motion. Cut as well as arc run were most frequently preceded and followed by linear advancing motion in both EPL and WSL. Crossover was most preceded by a turn in EPL and turn and deceleration in WSL and followed by a deceleration in EPL and deceleration and turn in WSL. Finally, shuffle was preceded mostly by turn and deceleration in WSL and EPL and followed by deceleration in EPL and deceleration and turn in WSL.

Table 4.9. Movements occurring before and after each movement in EPL

BEFORE							
Linear Advancing	0 (0%, 0 - 0,3%)	680 (56.9 ±2.8%)*	238 (22.2 ±2.5%)*	285 (92.2 ±3%)*	159 (68.5 ±6%)*	5 (4.5 ±3.8%)[def]	4 (3.1 ±3%)fg
Deceleration	190 (13.8 ±1.8%)*	0 (0%, 0 - 0,3%)*	663 (61.8 ±2.9%)*	1 (0.3 ±0.6%)[cde]	31 (13.4 ±4.4%)[defg]	41 (36.6 ±8.9%)*	62 (48.8 ±8.7%)[adefg]
Turn	754 (55 ±2.6%)*	238 (19.9 ±2.3%)*	36 (3.4 ±1.1%)*	8 (2.6 ±1.8%)	30 (12.9 ±4.3%)[defg]	60 (53.6 ±9.2%)*	52 (40.9 ±8.6%)[adefg]
Cut	278 (20.3 ±2.1%)*	18 (1.5 ±0.7%)*	6 (0.6 ±0.5%)[fg]	8 (2.6 ±1.8%)	4 (1.7 ±1.7%)	0 (0%, 0 - 3,3%)	0 (0%, 0 - 2.9%)[f]
Arc Run	116 (8.5 ±1.5%)*	77 (6.4 ±1.4%)	12 (1.1 ±0.6%)[fg]	7 (2.3 ±1.7%)	1 (0.4 2 ±0.8%)	0 (0%, 0 - 3,3%)	1 (0.8 ±1.6%)[f]
Crossover	23 (1.7 ±0.7%)*	99 (7.9 ±1.5%)	60 (5.6 ±1.4%)	0 (0%, 0 - 1.2%)[cde]	4 (1.7 ±1.7%)	0 (0%, 0 - 3,3%)	8 (6.3 ±4.2%)
Shuffle	11 (0.8 ±0.5%)*	88 (7.4 ±1.5%)	57 (5.3 ±1.3%)	0 (0%, 0 - 1.2%)[cde]	3 (1.3 ±1.5%)	6 (5.4 ±4.2%)[def]	0 (0%, 0 - 2.9%)[f]
MOVEMENT	LINEAR ADVANCING MOTION	DECELERATION	TURN	CUT	ARC RUN	CROSSOVER	SHUFFLE
AFTER							
Linear Advancing	0 (0%, 0 - 0,3%)*	190 (19.2 ±2.5%)*	754 (64 ±2.5%)*	278 (88.5 ±3.5%)*	116 (54.2 ±6.7%)*	23 (12.1 ±4.6%)*	11 (6.7 ±3.8%)[deg]
Deceleration	680 (49.6 ±2.7%)*	0 (0%, 0 - 0.4%)[efg]	238 (20.2 ±2.5%)*	18 (5.7 ±2.6%)[cdefg]	77 (36 ±6.4%)*	96 (50 ±7.1%)*	88 (53.3 ±7.6%)*
Turn	238 (17.4 ±2%)*	663 (67.1 ±2.9%)*	36 (3.1 ±1.1%)[f]	6 (1.9 ±1.5%)[fg]	12 (5.6 ±3.1%)[efg]	60 (31.6 ±6.6%)*	57 (34.5 ±7.3%)*
Cut	285 (20.8 ±2.2%)*	1 (0.1 ±0.2%)[efg]	8 (0.7 ±0.5%)*	8 (2.5 ±1.7%)[fg]	7 (3.3 ±2.4%)[efg]	0 (0, 0 - 2%)	0 (0%, 0 - 2.3%)
Arc Run	159 (11.6 ±1.7%)*	31 (3.1 ±1.1%)[g]	30 (2.5 ±1%)[fg]	4 (1.3 ±1.3%)[fg]	1 (0.5 ±1%)	4 (2.1 ±2%)	3 (1.8 ±2%)
Crossover	5 (0.4% ±0.3%)	41 (4.1 ±1.2%)	60 (5.1 ±1.4%)	0 (0%, 0 - 1.2%)	0 (0, 0 -1.8%)	0 (0, 0 - 2%)	6 (3.6 ±2.8%)[dg]
Shuffle	4 (0.3% ±0.3%)	62 (6.3 ±1.5%)	52 (4.4 ±1.3%)	0 (0%, 0 - 1.2%)	1 (0.5% ±1%)	8 (4.2 ±2.9%)*	0 (0, 0 - 2.3%)

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant different from the rest, [a]significant different from linear advancing motion, [b]significant different from deceleration, [c]significant different to turn, [d]significant different to cut, [e]significant difference to arc run, [f]significant difference to crossover, [g]Significant difference to shuffle

Table 4.10. Movements occurring before and after each movement in WSL

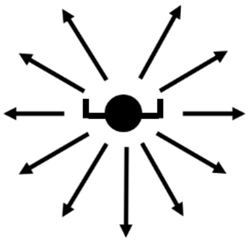
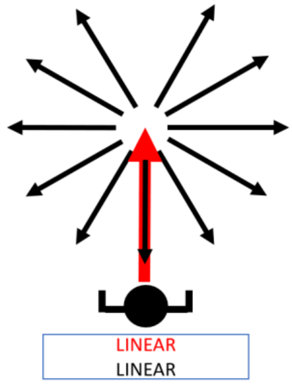
MOVEMENT	LINEAR ADVANCING MOTION	DECELERATION	TURN	CUT	ARC RUN	CROSSOVER	SHUFFLE
BEFORE							
Linear Advancing	0 (0%, 0 - 0.8%)bcdef	236 (64.8 ±4.9%)*	60 (19.1 ±4.4%)*	94 (94 ±4.7%)*	74 (74.7 ±8.5%)*	1 (2.5 ±4.8%)	1 (2.9 ±5.6%)
Deceleration	53 (11.7 ±2.3%)^{dfg}	0 (0%, 0 - 1%)^{efg}	205 (65.3 ±5.3%)*	3 (3 ±3.3%)	11 (11.1 ±6.2%)^{defg}	15 (37.5 ±15%)^{adefg}	16 (47.1 ±16.8%)^{adefg}
Turn	241 (53.3 ±4.6%)*	67 (18.4 ±4%)*	10 (3.2 ±2%)^{de}	0 (0%, 0 - 3.7%)	12 (12.1 ±6.4%)^{defg}	22 (55 ±15.9%)^{adefg}	16 (47.1 ±16.8%)^{adefg}
Cut	89 (19.7 ±3.7%)^{efg}	3 (0.8 ±0.9%)^{efg}	2 (0.6 ±0.9%)	0 (0, 0 - 3.7%)	2 (2 ±2.7%)	0 (0%, 0 - 8.8%)	0 (0%, 0% - 10.2%)
Arc Run	63 (13.9 ±3.2%)^{fg}	21 (5.8 ±2.4%)	3 (1 ±1.1%)	3 (3 ±3.3%)	0 (0%, 0 - 3.7%)	0 (0%, 0 - 8.8%)	0 (0, 0% - 10.2%)
Crossover	4 (0.9 ±0.9%)	22 (6 ±2.4%)	20 (6.4 ±2.7%)^{de}	0 (0%, 0 - 3.7%)	0 (0%, 0 - 3.7%)	0 (0%, 0 - 8.8%)	1 (2.9 ±5.6%)
Shuffle	2 (0.4 ±0.6%)	15 (4.1 ±2%)	14 (4.5 ±2.3%)^{de}	0 (0%, 0 - 3.7%)	0 (0%, 0 - 3.7%)	2 (5 ±7%)	0 (0%, 0 - 10.2%)
AFTER							
Linear Advancing	0 (0, 0 - 0.8%)	53 (17.5% ±4.3)*	241 (65.5 ±4.9%)*	89 (92.7 ±5.2%)*	63 (70 ±9.5%)*	4 (8.5 ±8.1%)^{abcdef}	2 (6.1 ±8.4%)
Deceleration	236 (50.6 ±4.5%)*	0 (0%, 0 - 1.3)^{efg}	67 (18.2 ±4%)*	3 (3.1 ±3.5%)	21 (23.3 ±8.7%)*	22 (46.8 ±14.4%)^{defg}	15 (45.5 ±17.5%)^{adefg}
Turn	60 (12.9 ±3%)^{adfg}	205 (67.7% ±5.3)*	10 (2. ±1.7%)^{f}	2 (2.1 ±2.9%)	3 (3.3 ±3.7%)	20 (42.6 ±14.3%)^{defg}	14 (42.4 ±17.4%)^{adefg}
Cut	94 (20.2 ±3.6%)^{afg}	3 (1% ±1.1)^{efg}	0 (0, 0 - 1%)^{efg}	0 (0%, 0 - 3.8%)	3 (3.3 ±3.7%)	0 (0%, 0 - 7.6%)	0 (0%, 0 - 10.4%)
Arc Run	74 (15.9 ±3.3%)^{fg}	11 (3.6% ±2.1)	12 (3.3 ±1.8%)	2 (2.1 ±2.9%)	0 (0%, 0 - 4.1%)	0 (0%, 0 - 7.6%)	0 (0%)
Crossover	1 (0.2% ±0.4)	15 (5% ±2.5)	22 (6 ±2.4%)	0 (0%, 0 - 3.8%)	0 (0%, 0 - 4.1%)	0 (0%, 0 - 7.6%)	2 (6.1 ±8.4%)
Shuffle	1 (0.2% ±0.4)	16 (5.3% ±2.5)	16 (4.3 ±2.1%)	0 (0%, 0 - 3.8%)	0 (0%, 0 - 4.1%)	1 (2.1 ±4.1%)	0 (0%, 0 - 10.4%)

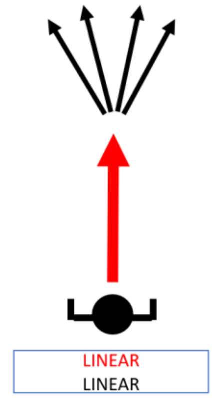
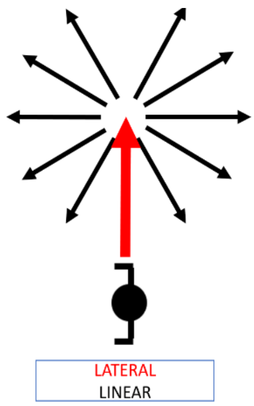
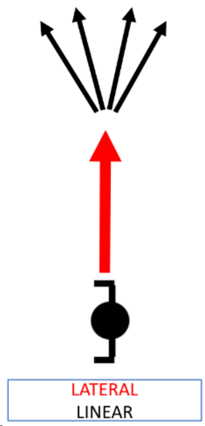
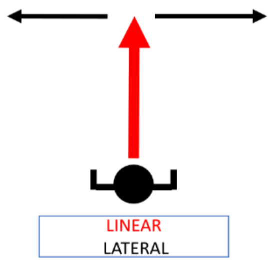
Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *Significant different from the rest, ^{a}significant different from linear advancing motion, ^{b}significant different from deceleration, ^{c}significant different to turn, ^{d}significant different to cut, ^{e}significant difference to arc run, ^{f}significant difference to crossover, ^{g}Significant difference to shuffle

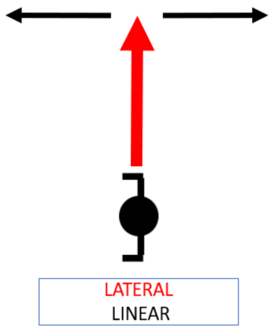
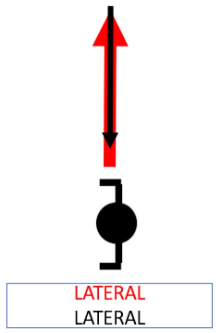
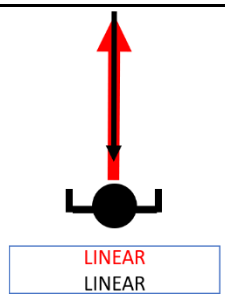
4.3.6. Change of Direction Actions

In 71.6% (±1.7%) and 70.6% (±3.1%) of players involvements in EPL and WSL there was a COD action. Moreover, attackers performed COD actions in 71.9% (±2.3%) and 72.9% (±4.1%) of the involvements for EPL and WSL, respectively, while defenders executed these in 71.2% (±2.6%) and 67.8% (±4.7%) of the involvements, respectively. Chi-square analysis showed no differences between attackers and defenders in EPL ($x^2_{(1)}$ = 0.121, p = 0.727) or WSL ($x^2_{(1)}$ = 2.611, p = 0.106). When looking at COD actions with at least one movement at high intensity [turn, deceleration (only on certain occasions considered COD), cut and arc run] EPL and WSL showed similar percentages. In EPL and WSL a COD action at high intensity was performed in 56.1% (±1.9%) and 57.1% (±3.3%) of the involvements. Table 4.11. shows the frequency of the different types of CODs represented in Table 2.1.

Table 4.11. COD actions and frequency

Type of COD	Variation	Diagram	Frequency
Type 1 COD: Turn to new direction from static or semi-static [slow linear or latera movements (e.g. walking, low-intensity shuffle)] movements type position.	-Turn to new direction		+ Defender + Attacker
	-Linear advancing (forward or backward) + deceleration + turn/cut to new direction		+++++ Defender ++++ Attacker

Type 2 COD: turn/cut to new direction from moving position (deceleration included unless slow velocity approach and/or low degrees of turning)	-Linear advancing (forward or backward) + turn/cut to new direction (usually slow approach and/or low degrees of turn)		++ Defender +++ Attacker
	-Lateral + deceleration + turn to new direction		++ Defender + Attacker
	-Lateral + turn to new direction (usually slow approach and/or low degrees of turn)		++ Defender + Attacker
	-Linear forward/backward + deceleration + lateral advancing motion (or vice versa)		++ Defender + Attacker

Type 3 COD: change in path without a change in the direction that player is facing	-Lateral + deceleration + linear forward/backwards movement		++ Defender + Attacker
	-Lateral + deceleration + lateral to opposite direction		++ Defender + Attacker
	-Linear + deceleration + Linear (forward to backwards or backwards to forward)		+ Defender + Attacker
Type 4 COD: arched run performed to maintain velocity	-Arc run performed with different degrees		++ Defender + Attacker

Scale of frequency: + = Low, ++ = Low - medium, +++ = medium, ++++ = medium – high, +++++ = high

4.4 Discussion

This study aimed to gain a clear understanding of the movements that occur before a goal in male and female elite soccer. The results highlight that the most common movement occurring before goal-scoring situations in EPL and WSL is a linear advancing movement, followed by deceleration and turn. Players showed similar trends, with attackers performing higher proportions of linear advancing motion, cuts and subtle turns (0-60º), while defenders performed higher percentages of sharper turns (60º-120º and 120º-180º), lateral movements, arc runs (only EPL) and ball blocking actions. Moreover, defenders performed higher percentages of high intensity decelerations, linear advancing movements and turns (only EPL). In 82.9% and 85.4% of players' involvements in EPL and WSL, respectively, there was at least one high-intensity action, with defender of scorer showing the highest and assistant the lowest percentages. In addition, results show that COD actions occur in 71.6% (±1.7%) and 70.6% (±3.1%) of players' involvements, while in 56.1% (±1.9%) and 57.1% (±3.3%) at least one of these COD actions was performed at high intensity in EPL and WSL, respectively. Finally, the combination of linear advancing motion, turn and deceleration is the most commonly performed, usually following a particular order.

4.4.1. Most Common Movements Performed Before Goals

As observed in a study in male professional soccer (Faude et al., 2012), linear advancing motion was the most common action prior to a goal, showing similar percentages between leagues (EPL = 32.4% ±1%, WSL = 34.9% ±1.9%). Moreover, linear advancing motion was present in more involvements than any other movements, at all intensities and when only high-intensity movements were analysed. Interestingly, WSL compared to EPL showed a slightly higher percentage of involvements where linear advancing motion was present overall (WSL = 82.8% ±2.6%; EPL = 78.5% ±1.6%) and when only sprints (WSL = 62.1% ±3.4%; EPL = 54.1% ±2%) were analysed. These differences could be related to WSL potentially having a more direct style of play due to possibly recovering possession further up the field, as previously found in female football compared to males (Espada et al., 2018).

Moreover, when comparing different intensities (walk, jog, run and sprint) sprint showed the highest proportions in both leagues, which highlights the importance of fast acceleration and/or speed in goal-scoring actions. The importance of fast acceleration and or/speed has already been highlighted by Haugen et al. (2012) who found female national-team players to be 1 m ahead of second-division players over both 0 to 20 m and 20 to 40 m, with these differences being big enough to be decisive in 1 vs 1 duels.

When examining different roles, defenders showed lower percentages of linear activities compared to attackers in both leagues. This difference could be due to the orientation of the players. While attackers would commonly face the goal, as this would be their ultimate target, defenders would be protecting this by standing between the attacker and the goal. In this scenario, while the objective of attackers is set to advance in a straight direction towards the goal, a defender naturally would start with their back to the goal and could be more biased towards defensive-type movements. Finally, as in the study by Faude et al. (2012), the assistant performed linear actions commonly with the ball and scorer without the ball, having to sprint to get into an advantageous position before receiving and shooting.

Deceleration was shown to be the second most common action along with turn and showed to be present in half of the involvements, and one-fourth when only considering involvements at high intensity. The greater amount of high-intensity decelerations for defenders could be related to higher turning degrees (60–120°), while attackers commonly performed turns of less than 60º. This is of special interest as it has been reported that during the deceleration phases of 45° and 90° cuts, greater frontal plane loading at the knee occurs when performing the 90° cut (Havens & Sigward, 2015b).

Turn showed to be the second most common movement along with deceleration, and was performed in almost half of the involvements, and on one-third when only counting turns at high intensity in both leagues. On the other hand, Faude et al. (2012) found lower frequencies despite this movement being the second and third most common action for scoring and assisting players, respectively. While 0º-60º turns showed higher percentages compared to turns of 60-120º, this only reached significance in EPL. Anyhow, differences between positions were found in both leagues, with attackers performing more 0-60º turns compared to defenders, and defenders performing a higher percentage of turns from 60-120º and 120-180º when compared to attackers. This again could be related to where attackers and defenders would be initially and end up facing, where defenders would have their backs to the goal, but would have to turn to the goal as soon as the ball or opposition goes past them.

Change in angle run was the fourth most common movement and was present in almost a quarter of the involvements when only high-intensity actions were analysed. In both leagues, attackers showed to perform higher percentages of cuts vs arc runs, while the opposite happened in defenders. Indeed, players performing change in angle run type actions would perform these to beat a player or create advantageous situations (attackers) and to regain position (defenders), which would usually need a maximum effort. Interestingly, assistant performed cuts most commonly with the ball in both leagues and scorers showed similar percentages with and without the ball in EPL and higher percentages with the ball in

WSL, which would mean that cuts would not only be performed to gain an advantage with the ball but also to get into favourable positions to receive the ball.

Lateral advancing motion was performed at a higher rate in defenders compared to attackers, which is in the same line as seen in a whole match (Bloomfield et al., 2007a). EPL showed higher proportions compared to WSL when the percentage of involvements with at least one lateral movement was analysed (EPL = 17.3% ±1%; WSL = 12.8 ±2.3%). This could be due to WSL players recovering the ball further up the field or having a more direct style of play when compared with EPL, as lateral movements would possibly be more habitual in goals coming from possession-type attacks rather than fast attacks or counterattacks. Finally, in both leagues crossover vs shuffle was shown to be the preferred strategy for both attackers and defenders to advance laterally in a faster manner.

Jump was shown to be the seventh most common action in both leagues, which contrasts with Faude et al. (2012), who found this action to be the second and third most common for scorer and assistant, respectively. This could be due to this study analysing a higher number of movements as well as including defenders and the fact that 303 and 80 goals were excluded from analysis for EPL and WSL, respectively (some of these coming from set plays).

On average, for EPL and WSL, in 85.4% ±2.4% and 82.9% ±1.5% of the players' involvements there was at least one high-intensity action. Defenders performed superior percentages of movements at high intensity compared to their attacker counterparts, with defender of scorer performing at least one high-intensity action in almost every goal. This could be related to defenders commonly being in a disadvantageous position at some point during each involvement, where they would have to perform high-intensity actions (i.e., sprint, fast turn) to try to regain a stable defending state. Furthermore, the fact that the defender of the scorer had superior percentages of at least one high-intensity action compared to the defender of assistant would suggest that this is an unstable situation and is more evident when the scorer comes into play. This could be partially explained by the fact that the movements analysed in this study were unsuccessful defending actions, and so, it would be more likely that this analysis would bias defending players in an unfavourable position due to different physical or technical-tactical reasons.

For most variables, WSL showed slightly greater percentages at high intensity compared to EPL, which could be due to differences in where possession of the ball is regained and the position where the final pass and shot take place. In this sense, females vs males tend to recover the ball in offensive areas at a higher percentage (Espada et al., 2018; Mitrotasios et al., 2019), perform less combinative attacks (Mitrotasios et al., 2019) and score and assist closer to the goal (Espada et al., 2018; Althoff et al., 2010) which could explain this trend.

4.4.2. Most Common Combination of Actions

The most common movements before and after a linear advancing motion were a turn and a deceleration, respectively. Decelerations were most frequently preceded by a linear advancing motion and followed by a turn. Turns were most preceded and followed by deceleration and turn, respectively. This tendency was very similar in both leagues as well as positions, and while it makes sense that the three most common actions combine between them more frequently than not it is worth mentioning that this was performed habitually in a certain cycle (Figure 4.7.), which would suggest that in order to read, adjust and turn into a new direction when performing a linear advancing movement (e.g., sprinting) there needs to be a deceleration. The player would then turn and advance in this new direction, being a linear advancing motion, as a sprint, the fastest way to manoeuvre. Indeed, if a player advancing linearly forward, which is the most common action during a match (Bloomfield et al., 2007a) needs to turn, generally this will require a reduction in linear momentum to move into a new path. The manner and characteristics of this combination would mainly depend on: 1. The degree of turn, requiring progressively increasing braking demands the sharper the turn (Havens & Sigward, 2015b), 2. The approaching velocity, with greater deceleration demands with higher approaching speed (Kimura & Sakurai, 2013), and 3. The strategy utilised, with early or late pre-orientation towards the new direction (David et al., 2018), which would be influenced by the situation and the potential need to perceive the environment.

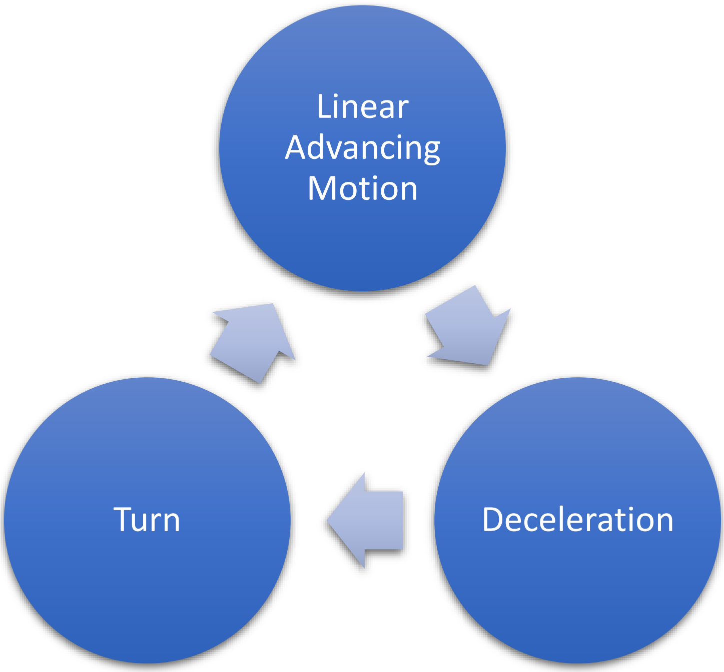


Figure 4.7. Most common cycle of movements

Previous researchers have analysed movements before and after turning and decelerating in a whole game of soccer using the BMC (Bloomfield et al., 2007b; Bloomfield et al., 2007b). For instance, Bloomfield et al. (2007b) found decelerations to be preceded by sprints in 77% of the occasions and mostly followed by a shuffle, with turning actions not being mentioned in the analysis. The differences in movements occurring after a deceleration can be related to the difference in the analysis conditions as in the above-mentioned study players were recorded over a 15-minute period where these could or could have not been exposed to goal-scoring situations. These differences in contextual factors could also explain the results found in this study in comparison with Bloomfield et al. (2007c). When looking at movements before and after turns these same authors found jogging and shuffling frequently preceding and following turns of ≤90°, while turns of >90° were performed while skipping, stopping, and slowing down.

While these combinations of actions usually occur in a certain order (Figure 4.7.), in this study, the combination of linear advancing motion, deceleration and turn in various orders accounted for 25.3% and 22.9% of individual involvements in EPL and WSL, respectively. This brings insight into the importance of these three actions, with combinations occurring in different manners (i.e., different turning degrees and intensities, diverse deceleration directions and intensities or different linear advancing motion approaching velocities and intensities).

4.4.3. Change of Direction Movements

Based on data from this study concerning the movements and how these are commonly combined, differences in the frequency of the diverse types of CODs are represented in Table 4.11., including differences between positions.

Results show that COD actions occur in 71.6% (±1.7%) and 70.6% (±3.1%) of players' involvements while in 56.1% (±1.9%) and 57.1% (±3.3%) at least one of these actions were performed at high intensity in EPL and WSL, respectively. Moreover, genders, as well as different players' roles, showed similar trends, with no significant difference between these. The high percentage of CODs at all intensities and at high intensity is in contrast with findings from Faude et al. (2012), who found COD sprint in assisting and scoring players to be performed in 8% and 9% of the goals and rotations in 8% and 13% in assisting and scoring players, respectively. This could be related to the definitions provided for these actions, which could have potentially excluded a certain number of movements. In this study, COD was defined as "*a very high intensity run with two distinct and identifiable accelerations in different directions (more than 50° from the initial sprint line)*", meaning it would have to include the three movements mentioned, which explain the low ratios. Moreover, these would only represent type 2 CODs, with the other three types not being represented.

While attackers and defenders show similar percentages of COD actions, there would be some differences in the type of CODs they are exposed to, as attackers perform more linear actions, subtle turns and cuts, while defenders perform more lateral movements, arc runs (only EPL) as well as high-intensity linear actions, high-intensity turns (only EPL) and high-intensity decelerations. It has been previously mentioned the importance of linear actions and how this can have an impact on performance (female players playing at international level would be at least 1m ahead compared to second division players of the same country) when performing a 20 metre sprint (Haugen et al., 2012). Similarly, it could be hypothesized that being able to change direction in a faster manner would allow players to have a certain advantage over slower players. For example, when the attacker is facing the defender (this being between the attacker and the goal), if the first can turn to one side and accelerate faster than the defender, this could be in a more advantageous position to shoot to the goal. Therefore, the ability of a player to perform CODs at high intensity could be crucial in key moments of the game, and drills could be tailored based on the players' role.

4.5. Limitations

A limitation of this study is that the investigation was performed on goal-scoring situations only, which would represent only 1% of the attacks (Pollard, & Reep, 1997) and 10% of the shots (Hughes & Franks, 2005), and so, analysis would be biased towards successful actions of scorers and unsuccessful actions of defenders (especially defender of scorer) while also not taking into consideration successful actions of assistant not leading to a goal. Another limitation was the fact that analysis was performed on the last six movements of each player, and so, in certain involvements, some movements were not analysed. A further limitation was the fact that 303 out of 1072 and 80 out of 336 goals were not included for analysis due to the characteristics of these (own goals, rebounds, penalties, indirect free kicks, free kicks, corners, throw-ins). Furthermore, although this is the first study to use video motion analysis to examine actions in goal situations among female English elite soccer players, caution should be exercised when generalizing these findings to other female leagues. Finally, additional variables, including pitch surface, weather conditions, game time, individual ability, team tactics, and positions, may have also had an impact on the specific movements identified in this study.

4.6. Conclusion

As a conclusion, the most common movement occurring before goal-scoring situations in EPL and WSL are linear advancing movements, followed by deceleration and turn. The combination of these three movements is the most performed, usually following a particular order. Players showed similar trends, with attackers performing higher proportions of linear advancing motion, cuts and subtle turns (0-60º) and defenders performing higher percentages of sharper turns (60º-120º and 120º-180º), lateral movements, arc runs (only EPL), ball blocking actions, as well as more high-intensity decelerations, high-intensity linear advancing movements and high-intensity turns (only EPL). High-intensity actions were shown to be predominant, with three out of four involvements having a high-intensity movement, with defender of scorer showing the highest and assistant the lowest percentages. Both attackers and defenders in EPL and WSL are shown to perform COD actions in more than 2/3 of the involvements. Moreover, CODs with at least one movement at high intensity show to be performed in more than half of the involvements, showing the importance of performing these actions in an explosive manner, with faster outputs potentially influencing players' chances of success in certain game situations. Moreover, considering the ample variety of CODs (Table 4.11.) that players are exposed to, these also need the ability to effectively perform a wide range of multidirectional movements. While attackers and defenders show similar percentages of COD actions, these would be exposed to some extent to particular type of CODs, and so, training strategies for performance enhancement could vary based on the role.

4.7. Practical Applications

Due to the high percentage of CODs performed in goal-scoring situations by attacking and defending players, COD actions should be prioritised and trained, taking special consideration to the most common combination of movements. When individualising COD training, defending players should prioritise drills with sharp turns and fast-approaching velocities, which allow high-intensity decelerations. These players would be exposed to longer GCTs and higher eccentric forces. Therefore, eccentric strength development, especially for quadriceps muscles (Jones et al., 2017; Zhang et al., 2021) to enhance the absorption of greater kinetic energy to decelerate (Zhang et al., 2021) is recommended. Moreover, long SSC plyometric exercises (Dos'Santos et al., 2018a) as well as power exercises applying rotational movements would also be beneficial. On the other hand, attackers would benefit from drills with shallow turns and cuts where lower intensity decelerations are required compared to defenders. These players would be exposed to shorter GCTs and would preferentially enhance reactive strength with short SSC plyometric drills (Dos'Santos et al., 2018a) performed in a multidirectional manner, as well as other exercises that replicate repeated rapid braking and propulsive actions (Allen et al., 2023).

While, as seen in Table 4.11, there is a wide ample of COD actions, when selecting a COD test the most common combination of actions should be considered. Findings from this study can assist on the selection of determined tests that can replicate in a more realistic manner key moments of the game. For example, the 505 COD test would involve linear advancing motion before decelerating, a 180º turn and a reacceleration, which would represent the most common cycle of movements, especially for defenders. On the other hand, 70-90º cutting task (Jones et al., 2022) would involve linear advancing motion before decelerating, one turn of 70-90º and reaccelerating, which would be more suitable for attackers.

CHAPTER 5: RELIABILITY OF SPEED, JUMP, STRENGTH AND CHANGE OF DIRECTION TESTS IN ELITE FEMALE SOCCER PLAYERS

5.1. Introduction

Soccer is considered one of the most popular sports worldwide and has been shown to be the most studied sport, with almost 60% more research articles than the next most studied sport (Kirkendall, 2020). Despite this, there is still a large difference between research performed in male and female soccer, with only one in five articles published in soccer including women, and just 15% of the research in elite soccer performed on women (Kirkendall & Krustrup, 2022). Therefore, there is a clear need for more investigations to be performed on elite female soccer players.

COD ability is considered one of the most important physical capacities in soccer and is theorised to involve different type of actions based on the field position during matches (McBurnie & Dos'Santos, 2022). It is important to note that COD is a sub-component of agility, and so, COD tests should be differentiated from agility tests, which would include reaction to a stimulus (Sheppard & Young 2006). While different researchers have looked at the amount of COD actions through a whole soccer match (Nedelec et al., 2014: Granero-Gil et al., 2020; Robinson et al., 2011; Baptista et al., 2018; Morgan, et al., 2022; Bloomfield et al., 2007a), Chapter 4 examined how these are performed in the most relevant moments of the game; goal-scoring situations. Based on this study, the most common movements performed are linear advancing motion, deceleration and turn, with these being performed commonly in a certain cycle.

Multiple COD tests have been utilised by researchers with differences and similarities based on approaching distances to the COD, turning angles, number of changes of direction and time to complete the test (Altmann et al., 2019; Nimphius et al., 2018). Due to the diverse characteristics of the different COD tests, these may well examine different factors of COD speed (Svensson & Drust, 2005) as they vary in energy requirements, turn angles and force production (Brughelli et al., 2008). COD tests are usually measured using timing gates generally showing to be reliable in male and female soccer players (Altmann et al., 2019; Sporiš et al., 2010). Depending on the role, players tend to perform CODs of certain characteristics, and so, based on the COD test selected, this can be more specific to a certain role. While CODs during matches will vary on the type, approaching distances, cutting or turning angles and deceleration characteristics, as demonstrated in Chapter 4**,** the most common CODs are those including a linear advancing motion, turn and deceleration. More so, the most common combination of actions would follow a certain cycle: The most common movement before a linear advancing motion is a turn, while the most common movement performed after is a deceleration. Decelerations are most frequently preceded by a linear advancing motion and followed by a turn. Turns are most preceded and followed by deceleration and turn, respectively. Additionally, on average, mean sprint distances in female soccer are performed over 8.5 m (Mara et al., 2017b), commonly starting at speed (Oliva-Lozano, et al., 2020). Therefore, relevant COD tests should ideally involve a certain approaching distance at speed before turning. In this sense 505 COD test would involve linear advancing motion before decelerating, a turn of 180º and a reacceleration, which would represent the most common cycle of movements, with a 10-m approaching distance before hitting the gate. This would allow high-intensity deceleration and turning angles slightly higher than the most common turn required in defenders. In any case, a COD test with less sharp turns would result in a lower-intensity deceleration. However, such a test would be more relevant for defenders, so a more suitable COD test for attackers should be explored in the literature. In this case, while shallow CODs would be more common for attackers, turns of less than 60º to 45º, would imply that the COD test has low to moderate braking (Dos'Santos et al., 2018a) and/or players would likely adopt arched run strategies. Therefore, a test with slightly higher turning angles, similar to the recently implemented by Jones et al. (2022) (70-90º Cut) would accommodate attackers' COD physical demands.

While we have addressed the importance of COD performance as well as tests that could represent more accurately COD ability in soccer, to understand the determinants of successful COD performance, it is important to comprehend how different physical capabilities are related to this. This would provide a further understanding of the underpinning physical attributes that players need to be successful in these actions. Before any relationships are analysed, it is important to recognize if the tests selected are reliable or not.

The ability of a player to run fast in a linear forward direction is considered important in soccer players (Faude et al., 2012). Therefore, speed tests are usually utilised in testing batteries performed by soccer players (Walker & Turner, 2009). Speed tests are usually performed using timing gates or phone apps, which have shown high reliability in soccer players (Fílter et al., 2020a; Altmann., 2019). To distinguish between the acceleration phase and maximal speed phase, different splits are usually utilised, with up to 10 m to assess acceleration and 20 m and 30 m to assess maximum speed (Loturco et al., 2017b; Sporiš et al., 2011).

Jump tests are usually utilised as part of soccer player assessment (Stern et al., 2020; Bishop et al., 2021b). More so, within vertical jump assessment, while squat jump or SL squat jump would be utilised purely as a concentric test, during a CMJ, SL CMJ, DJ or SL DJ there is an eccentric component on the downward phase (McCurdy et al., 2010; Meylan et al., 2010). Other jump tests have been utilised to measure horizontal jump ability, such as the SL BJ. In this case, it is important to understand that this test not only reflects the ability to generate horizontal propulsive impulse but also the ability of the player to decelerate the horizontal momentum of the body during flight, where eccentric strength plays an important role. In this context, the player's ability to generate an impulse must align with its capacity for attenuating force (braking impulse) during the landing phase. This necessitates that the impulse during the landing phase equals that of the propulsive phase if motion is to be arrested. CMJ and DJ are usually measured using force plates, accelerometers and gyroscope as well as mobile apps and have been shown to be reliable in diverse populations and genders (Lombard et al., 2017; Staunton et al., 2021; Bogataj et al., 2020; Nuzzo et al, 2011). On the other hand, horizontal jumps such as BJ can be easily measured using a tape measure (Stern et al., 2020). This only provides with a measure of distance, which may be a limitation. CMJ, SL CMJ, DJ, SL DJ and SL BJ have shown to be reliable in youth male and female soccer players (Stern et al., 2020; Bishop et al., 2021b, Bishop et al., 2019).

Strength is considered of great importance in soccer, not only for injury mitigation but also for performance enhancement (Beato et al., 2021c). Common tests utilised to assess maximal strength are performed using dynamic or isometric methods. Unlike maximal concentric strength, during an isometric maximal strength test the athlete exerts maximal force without movement. The most utilised isometric test is the IMTP and is usually performed using a force platform (Thomas et al., 2018; Northeast et al., 2019; Dos'Santos et al., 2018c) and has shown to be a reliable test in male youth professional soccer players (Dos'Santos et al., 2018d).

Flywheel exercise and testing allow for mechanical eccentric overload by returning inertia accumulated by the rotating wheel during the prior concentric phase (Beato et al., 2021a). This test can provide mean and peak concentric and eccentric power and force (Spudić et al., 2020) in a vertical direction. More so, depending on the inertia utilised it will potentially target different parts of the force-velocity curve (low inertias stimulating rightward shift and high inertias upward shift of force-velocity curve) (McErlain-Naylor, & Beato, 2021). Testing performed on flywheel devices has shown excellent relative reliability (ICC >0.90) and very good absolute reliability (CV <10%) in different spectrums of the force-velocity curve in male sport athletes and physically active males and females (Spudić et al., 2020; Beato et al., 2021b).

Hamstring eccentric strength is considered of high importance when sprinting (Petersen et al., 2011) and decelerating (Small et al., 2010); movements frequently performed in soccer matches (Faude et al., 2012; Harper et al., 2019). The hamstring eccentric strength test measures the eccentric strength of KF muscles using a NordBord (Nordbord, Vald Performance), which has shown to be a reliable testing tool in male youth soccer players and recreationally active males (Opar et al, 2013; Fernandes et al., 2020).

While these tests have shown to be reliable, guaranteeing consistency of measurements, there is a lack of reliability studies performed on female soccer players (Altmann et al., 2019), especially at an elite level. Therefore, the aim of this study was to assess within-session reliability of different tests measuring speed, jump, strength and COD ability in elite female soccer players. It was hypothesized that these tests would be reliable in the targeted population.

5.2. Methods

The study examined the within-session reliability of different physical tests. The reason for performing within-session reliability was related to the fact that changes in week-to-week training load could have affected reliability scores. Two trials were performed on each test due to time constraints. Players had extensive familiarization with these tests. To determine within-session reliability, participants performed two trials of the following tests:

- Anthropometric measures (height and BM)
- 30-m speed test (5-, 10-, 20- and 30-m split).
- 505 COD test.
- 75-90° COD test.

- CMJ.
- SL CMJ.
- DJ.
- SL DJ.
- SL BJ.
- FSCS and FSES.
- NHES.
- IMTP.

5.2.1. Subjects

The minimum sample size was calculated before performing the study utilising calculations recommended by Borg et al. (2022). While the minimum sample from G*Power calculations was 26, which is similar to the squad size in a professional soccer team, it was not possible to reach this number. A convenience sample of eleven female elite soccer players (age 26.6 ±4.8 years, height 166 ±6.8 cm, BM 61.6 ±5.2 kg) participated in this study. The aim was to recruit the highest possible number of players within a twenty-five-player squad but there were several constraints: seven players were with COVID-19, four players were on international duties and three players were injured or coming back from injury.

Eight and nine players performed the flywheel strength tests and the NHES, respectively. This was due to players four and three players, respectively, not being familiarized with these exercises.

5.2.2. Procedures

Specific testing protocols and devices utilised can be found in the section 3.2. Methodology for Chapter 5.

5.2.2.1. COD tests

Two COD tests with different turning angles (75-90° and 180°) were included in this study, COD 505 test and 75-90° COD test.

5.2.2.2. Speed Test:

Speed was assessed using splits at 5 and 10 m to assess acceleration and, 20 and 30 m to assess maximal speed.

5.2.2.3. Jump Tests

CMJ, SL CMJ, DJ, SL DJ and SL BJ were utilised to assess jump performance. This was evaluated through jump height for CMJ, SL CMJ, DJ and SL DJ while SL BJ was evaluated through jump distance.

5.2.2.4. Strength Tests

FSCS and FSES were utilised to assess concentric and eccentric strength, while IMTP was utilised to evaluate maximal isometric strength and NHES to test hamstring eccentric strength. All strength tests were normalised by dividing by BM.

5.2.3. Statistical Analyses

Statistical analyses were performed utilising SPSS version 27 (SPSS, Chicago, Ill, USA). Normality for all variables was assessed using Shapiro Wilks-test. All data was normally distributed. Within-session reliability was evaluated through ICC, CV, SEM and smallest worthwhile change (SWC). To assess the level of ICC, threshold values were interpreted as follows: 0 = no correlation; < 0.5 = poor reliability; 0.5–0.75 = moderate reliability; 0.75–0.9 = good reliability; > 0.9 = Excellent reliability (Koo & Li, 2016). Because of the constraints when collecting the data, instead of using the conservative low bound CI, the point estimate was utilised as large CIs would be expected with a small and homogeneous group. Standard error measurement (SEM) was calculated as of the formula [(SD (pooled) × (√1-ICC)] (Thomas et al., 2005), while SWC was calculated utilising the formula 0.2 x SD.

5.3. Results

All data showed to be normally distributed. Table 5.1. shows data regarding both trial means with SD, ICC and CV with 95% CI, SEM and SWC. COD tests showed moderate to good reliability, except for COD 505 to the right, which showed poor reliability [ICC = 0.49 (CI = -0.19 – 0.85)]. Except for 5-m split, which had poor relative reliability [ICC = 0.47 (CI = (-0.16 – 0.81)], the speed test splits showed moderate to good ICCs. All jump tests showed moderate to excellent reliability, Finally, strength tests showed moderate ICCs on the FSCS and FSES, while NHES showed good to excellent ICCs and IMTP excellent ICCs. All tests showed acceptable consistency, with CVs below 10% except for FSCS and FSES tests which showed greater variation (24.6% and 18.8%, respectively). SWC showed percentages between 0.61% and 1.08% for speed, 0.78% and 1.12% for COD tests, 1.22% and 4.36% for jumps tests and 2.63% and 4.97% on strength tests.

Table 5.1. **Within-session reliability measures**

	Trial 1	Trial 2	ICC (95% CI)	CV (95% CI)	SEM	SWC
5 m (s)	1.09 ±0.07	1.13 ±0.07	0.47 (-0.16 – 0.81)	5.4% (±1.21%)	0.04	0.012 (1.08%)
10 m (s)	1.88 ±0.09	1.89 ±0.08	0.69 (0.24 – 90)	1.9% (±0.39%)	0.03	0.012 (0.63%)
20 m (s)	3.24 ±0.10	3.23 ±0.11	0.7 (0.16 – 0.91)	2.6% (±0.53%)	0.05	0.02 (0.61%)
30 m (s)	4.49 ±0.15	4.47 ±0.14	0.86 (0.57 – 0.96)	0.9% (±0.18%)	0.05	0.03 (0.66%)
505 COD left (s)	2.34 ±0.09	2.29 ±0.1	0.60 (0.09 – 0.87)	2.2% (±0.45%)	0.04	0.02 (0.86%)
505 COD right (s)	2.28 ±0.08	2.29 ±0.09	0.49 (-0.19 – 0.85)	3.9% (±0.58%)	0.07	0.018 (0.78%)
75-90° COD left (s)	1.98 ±0.1	1.94 ±0.1	0.7 (0.23 – 0.91)	1.7% (±0.35%)	0.05	0.022 (1.12%)
75-90° COD right (s)	1.97 ±0.1	1.94 ±0.12	0.87 (0.14 – 0.97)	1.6% (±0.33%)	0.04	0.02 (1.02%)
CMJ (cm)	32.23 ±2.5	32.5 ±2.56	0.86 (0.59 – 0.96)	2.4% (±1.92%)	0.49	0.78 (2.1%)
SL CMJ L (cm)	20.6 ±3.71	22.5 ±3.5	0.84 (0.41 – 0.96)	5.2% (±1.88%)	1.43	0.58 (2.68%)
SL CMJ R (cm)	20.55 ±2.88	21.26 ±3.19	0.87 (0.6 – 0.96)	5.9% (±1.95%)	1.47	0.6 (2.73%)
DJ (cm)	30.62 ±2.57	32.5 ±1.98	0.58 (-0.09 – 0.88)	4.7% (±1.3%)	1.58	0.49 (1.53%)
SL DJ L (cm)	18.65 ±4.1	19.79 ±4.12	0.9 (0.57 – 0.97)	6.3% (±2.01%)	1.28	0.81 (4.22%)
SL DJ R (cm)	18.82 ±3.39	19.6 ±4.64	0.9 (0.69 – 0.97)	4.2% (±2.01%)	1.32	0.83 (4.36%)
SL BJ L (cm)	1.63 ±0.93	1.65 ±0.11	0.53 (-0.4 – 0.84)	2.4% (±0.49%)	0.08	0.02 (1.22%)
SL BJ R (cm)	1.62 ±0.97	1.63 ±0.93	0.52 (-0.87 – 0.84)	1.4% (±0.29%)	0.07	0.02 (1.22%)

FSCS (Rel) (N/kg)	13.8 ±3.39	14.8 ±3.49	0.65 (-0.07 – 0.92)	24.6% (±6.15%)	2.09	0.70 (4.97%)
FSES (Rel) (N/kg)	16.25 ±3.6	17.17 ±2.31	0.69 (-0.09 – 0.92)	18.8% (±5.28%)	1.7	0.61 (3.77%)
NHET L(Rel) (N/kg)	4.92 ±0.67	4.88 ±0.67	0.87 (0.55 – 0.97)	3.3% (±0.67%)	0.17	0.130 (2.66%)
NHET R (Rel) (N/kg)	5.27 ±0.74	5.25 ±0.63	0.91 (0.65 – 0.99)	2.8% (±0.57%)	0.18	0.138 (2.63%)
IMTP PVF (Rel) (N/kg)	33.51 ±5.41	32.14 ±4.82	0.96 (0.24 – 0.99)	2.8% (±0.57%)	1.03	1.03 (3.15%)

BJ = broad jump, COD = change of direction, CMJ = countermovement jump, CV = coefficient of variation, DJ = drop jump, FSCS = flywheel squat concentric strength, FSES = flywheel squat eccentric strength, ICC = intraclass correlation coefficient, IMTP = isometric mid-thigh pull, Kg = kilograms, Rel = relative, SL = single leg, N = newtons, NHES = Nordic hamstring eccentric strength, SEM = systematic error measurement, SWC = smallest worthwhile change.

5.4. Discussion

The aim of this study was to assess within-session reliability of tests to assess speed, jump, strength and COD ability. COD tests showed moderate to good reliability except for 505 COD test right, which showed poor reliability (ICC = 0.49). COD 505 test left, 75-90° COD right and 75-90° COD left showed moderate to good reliability, with ICC scores between 0.6 and 0.87 while CVs ranged from 1.6% to 3.9%, showing a substantial level of reliability. This is in line with previous studies examining within-session reliability in female soccer players performing COD tests using timing gates (ICCs= 0.81 – 0.99, CVs= 2.1 - 4%) (Meylan et al., 2017; Shalfawi et al., 2013; Kutlu et al., 2017; Emmonds et al., 2019, Roso-Moliner et al., 2023). SWC was lower than CV, which shows that COD tests in these conditions lack the ability to detect SWC. In scenarios where CV is higher than SWC, it is recommended to use CV as the threshold to evaluate the meaningfulness (Beattie & Flanagan, 2015). This is similar to a study performed by Lockie & Jalilvand (2017), with a different study showing SWC to be higher than CV (Kutlu et al., 2017).

Except for 5-m speed, which showed a poor ICC score, speed test splits (10, 20 and 30m) showed moderate to good within-session reliability, with ICCs between 0.69 and 0.86 while CV values were between 0.9% and 5.4%, showing high precision of the test. This agrees with previous studies looking at the within-session reliability of female soccer players performing speed tests (ICC= 0.68 – 0.98, CV= 1.1 - 4%) (Meylan et al., 2017; Shalfawi et al., 2013; Kutlu et al., 2017; Emmonds et al., 2019, Roso-Moliner et al. 2023). This is in contrast with findings from Kutlu et al. (2017) who found SWC scores to be higher than CV for all splits.

Jump tests showed moderate to excellent reliability, with ICC scores ranging from 0.52 to 0.53 on SL BJ tests, 0.84 to 0.87 on CMJ and SL CMJ and 0.58 to 0.9 on DJ and SL DJ. Moreover, CV scores were low, especially for SL BJ which showed percentages between 1.4% and 2.4%, while vertical jumps ranged from 2.4% to 6.3%. Different researchers have analysed SL CMJ within-session reliability in female adult and young soccer players utilising Optojump, obtaining similar CVs (3.9 – 7.5%) and ICCs (0.84 – 0.96) (Bishop et al., 2019; Raya-González et al., 2021, Pardos-Mainer et al., 2021) when compared to this study (CV = 5.2 - 5.9%, ICC = 0.86 – 0.87). While to the author's knowledge no studies in female players have analysed ICC and CV's of CMJ, studies in male elite academy soccer players show slightly higher ICC scores (Raya-González et al., 2020a) (ICC = 0.96, CV = 3.4%), or a more ample ICC range and slightly lower CVs (Sherwood et al., 2021) (ICC = 0.57 – 0.97, CV = 2.1 - 3.0%). To the author's knowledge only one study has examined DJ or SL DJ's within-session reliability utilising Optojump in female soccer players, with only SL DJ being analysed (Bishop et al., 2019) (CV = 6.1 – 6.4%, ICC = 0.91 – 0.92), obtaining similar scores when compared to this study (CV = 4.2 – 6.3%, ICC = 0.9). SL BJ has been shown to be a reliable test in female semi-professional soccer players (Roso-Moliner et al. 2023) and youth female soccer players (Bishop et al., 2021a) with larger ICCs scores (0.81 – 0.94) but also higher CVs (CV 1.9 – 4.1%) when compared to data obtained in this study. Finally, SWC showed to be lower than CV. Therefore, jump tests in these conditions showed a lack of ability to detect SWC.

When looking at tests assessing strength, FSCS and FSES tests showed moderate correlations, while absolute reliability was low, with CVs of 24.15% and 18.8%, respectively. To the author's knowledge only one study has assessed within-session reliability utilising a flywheel device, which was performed in physically active subjects (Spudić et al., 2020). This study obtained higher ICCs (0.97 – 0.99) and lower CVs (4.39 - 5.93%) compared to this study. While participants in this study were experienced in the use of flywheel devices and overtook familiarization sessions, the fact that players were encouraged to stop the inertia in the last third of the travel path of the eccentric phase could have reduced the consistency of the scores, more so when the peak power was utilised for analysis. The reason for utilising this particular methodology is that it would allow for eccentric overload (Raya-González et al., 2020b, Martínez-Hernández, 2024). Based on these results, to potentially obtain higher reliability scores during testing, more familiarization sessions would be advised. In addition, SWC was shown to be lower than CV.

NHES showed good to excellent reliability, with ICCs between 0.87 and 0.93, while CVs were also low (2.8 - 3.3%), showing to be highly reliable. This is in line with previous studies performed on male and female professional soccer players (Moreno-Pérez et al., 2020; Cuthbert et al., 2021). While Moreno-Pérez et al. (2020) found ICCs of 0.97 to 0.99 and CVs of 1.1% to 3.2% in male soccer players, Cuthbert et al. (2021) found ICCs scores of 0.81 to 0.87 and CVs of 4.2% to 4.8% in female soccer players participating in the same competition as participants in this study. SWC was lower than CV, although the difference was relatively low (CV = 2.8 – 3.3%, SWC = 2.6%).

Finally, IMTP showed excellent of reliability, with an ICC of 0.96 and CV of 2.8%. While multiple researchers have assessed the within-session reliability of this test in diverse populations, generally obtaining high reliability scores (Brady et al., 2018), there are no studies performed on female soccer players. Anyhow, research on male professional youth soccer players found similar ICCs (0.84 – 0.98) and slightly higher CVs (4.05 – 10%) (Dos'Santos et al., 2018d), confirming good within-session reliability. SWC showed to be higher than CV, showing good practicality.

5.5. Limitations

A limitation of the current study was that, due to time restrictions, players only performed two trials of each of the tests. A higher number of trials could have potentially increased the reliability of the tests. Moreover, while DJ was tested as a measure of reactive strength index, only jump height was calculated due to errors in the measuring device to determine contact time. In addition, the study only counted with 11 elite female soccer players, which didn’t reach the minimum sample size estimation. Small and homogeneous groups are problematic in the assessment of reliability, with low ICCs and wide CIs related to a lack of variability and a small number of subjects (Koo and Li, 2016; Roberts et al., 2001; Borg et al., 2022). Due to this, the ICC point estimate was utilised instead of the conservative lower bound CI. Moreover, as the study was underpowered, the ability to detect significant effects may have been limited, reducing the generalizability of the findings to a broader population of female professional soccer players. In addition, SWC was used to acknowledge if there were meaningful changes, which could be affected by group homogeneity (Buchheit, 2016).

Another limitation was the fact that warm-up trials were not recorded. This would have guaranteed that the two recorded trials were a true estimate.

5.6. Conclusion

As conclusion COD, speed, jump and strength tests showed moderate to excellent levels of reliability with several exceptions. In this sense, the 5-m split and COD 505 test right side only showed poor ICCs scores, and so, an additional trial could be required. Moreover, FSCS and FSES presented large ICC values but showed high CV scores compared to the rest of the test, demonstrating low consistency. This could be due to the protocol utilised, which could possibly benefit from more familiarization sessions to obtain higher consistency. Finally, most tests show SWC to be lower than CV, and so, for these tests, it would be recommended to use CV to measure changes in performance variables.

Several limitations can occur in a very applied environment such as professional soccer. For example, the small sample size and homogeneity of the sample were primarily because of the availability of a convenient sample of 25 elite soccer players from the same team during the COVID-19 pandemic, which significantly limited the number of players available.

Furthermore, there were several players on international duty as well as injured. This highlights the inherent nature of working in elite-level football, limiting the number of subjects available as mentioned elsewhere (Emmonds et al., 2019). To address these issues, the upcoming study, which will examine the relationships between COD tests and various underlying physical qualities, will conduct the testing protocols over an extended period of time to ensure a larger sample size.

5.7. Practical Applications

The COD, speed, jump and strength tests utilised in this study are reliable and practitioners should be able to use these when testing female elite soccer players. Given that the 5-m split and the 505 COD test to the right side showed lower reliability, (poor ICCs scores), practitioners should aim to perform an additional trial when performing these tests. Moreover, additional familiarization sessions would be recommended when performing FSCS and FSES tests.

CHAPTER 6: RELATIONSHIPS BETWEEN CHANGE OF DIRECTION AND SPEED, JUMP AND STRENGTH TESTS IN ELITE FEMALE SOCCER PLAYERS

6.1. Introduction

Changes in direction are performed repeatedly during a soccer match (Nedelec et al., 2014: Granero-Gil et al., 2020; Robinson et al., 2011; Baptista et al., 2018; Morgan, et al., 2022; Bloomfield et al., 2007a) with studies differing on the total amount, going from 11.9 hard changes of direction to more than 700 turns and swerves (Nedelec et al., 2014; Bloomfield et al., 2007a). Moreover, COD ability has been demonstrated to be crucial in goal-scoring situations (Faude et al., 2012), with CODs being performed in 71.6% and 70.6% of players' involvements as demonstrated in Chapter 4. In addition, findings from Chapter 4 illustrate that based on players' roles, COD actions show specific characteristics. In this sense, CODs with high-intensity decelerations and sharp turns would be more specific for defending players while COD tests with a lower intensity deceleration and less sharp turns would be more adequate for attackers.

COD tests are frequently used to assess soccer players' fitness as part of testing batteries (Reilly et al., 2000; Walker & Turner, 2009; Risso et al., 2017: Gonçalves et al., 2021). There is an ample variety of COD tests performed by researchers, not only to assess physical capacities in soccer players (Walker & Turner, 2009) or for talent identification purposes (Reilly et al., 2000; Mirkov, 2010) but also to assess changes in performance after specific training protocols (Tous-Fajardo et al., 2016; Aloui et al., 2021). Depending on the role, players tend to perform CODs of certain characteristics and so, based on the COD test selected, this can be more specific for one role or the other. In this sense, the 505 COD test would be more appropriate for defending players while the 75-90° COD test would be more suitable for attackers.

From a training perspective, it is important to understand which physical qualities (i.e., speed, strength, power, etc.) underpin COD performance (Sheppard & Young, 2006) so that adequate training strategies can be implemented. COD performance is linked to the ability of an athlete to attenuate force (braking) and produce force (propulsion) within a force-time curve (impulse) (Nimphius et al., 2017), with specific underpinning qualities depending on the type of COD performed (Dos’Santos et al., 2018a).

To understand how different speed, strength and jump and/or power characteristics relate to COD performance, researchers have explored correlations between these and COD tests. Unfortunately, there are a limited number of studies performed on female soccer players relating COD performance with speed, jump and/or power and strength characteristics (Emmonds et al., 2019).

Speed has been shown to have moderate to very large correlations with COD performance in both female young soccer players (Mathisen & Pettersen, 2015: Sonesson et al., 2021) as well as female senior professional players (Emmonds et al., 2019) (r= 0.58 – 0.86). In this sense, tests used for the measurement of COD ability include some kind of linear acceleration or reacceleration, and so, it would be reasonable to think that straight sprint speed would correlate somehow with COD tests.

Evaluating correlations between jump and COD tests from previous studies, Emmonds et al. (2019) found SJ and CMJ but not DJ to be correlated with the 505 COD test. Other studies in female players have also found moderate to strong correlations between COD and CMJ tests in college and young female soccer players (Vescovi & Mcguigan, 2008; Sonesson et al., 2021) (r= -0.35 to -0.65), while the only study reporting relationships between SL CMJ and COD tests in elite female players found weak to moderate and non-significant correlations (r = -0.37 to -0.47) (Loturco et al., 2019b). Not only vertical jumps but also SL horizontal hop jump has shown moderate to large correlations (r= -0.43 to -0.65) with COD performance in male and female college athletes that included soccer players (Thomas et al., 2018). Finally, regarding strength tests, researchers have found a wide range of correlation values between COD tests and different strength tests (Andersen et al., 2018; Falch et al., 2021; Thomas et al., 2018; Emmonds et al., 2019; Jones et al., 2009, Jones et al., 2017, Jones et al., 2022). In this sense, researchers have found correlations between COD tests and maximal absolute and relative strength or conflicting results (Andersen et al., 2018; Falch et al., 2021). Andersen et al. (2018) assessed concentric strength through 3RM back squat in female NCAA Division II soccer players and found large to very large correlations between two COD tests (505 COD test and T-test) and maximal absolute and relative strength (r= -0.51 to -0.75). Falch et al. (2021) showed low to large correlations between bilateral and unilateral squat and two COD tests (180° and a 45° COD test) (r= -0.17 to -0.64) while lateral squat showed trivial to low correlations (r= 0.07 – 0.28). The authors justified these findings by suggesting that strength tests demand more balance and control, not allowing the athlete to maximize loads at the given velocity.

While Emmonds et al. (2019) found strong correlations between 505 COD test and isometric strength (KE muscles isometric strength measured with a custom-made isometric device) (r = -0.55), Thomas et al. (2018) found trivial to small correlations between IMTP and 505 COD test and modified 505 COD test in female team sport athletes which included soccer players (r = -0.01 to 0.12). In addition, researchers have shown moderate to large correlations between both KE and KF eccentric strength and faster performance COD tests (Jones et al., 2009, Jones et al., 2017, Jones et al., 2022) in female professional and semi-professional soccer players as well as team sport athletes which included female soccer players (r = -0.50 to -075).

The purpose of this study was to determine whether different speed, jump and strength tests have any relationship with the COD tests selected. It was hypothesized that speed, jump and strength tests would have relationships with the COD tests selected.

6.2. Methods

Female elite soccer players were tested once throughout the course of a year and three months. This was done to avoid issues that occurred in the previous study related to the lack of player availability due to illness (COVID-19), international duties, injuries, etc. This would allow higher opportunities for testing the whole squad at some point throughout the year, as well as testing of new players signed the following season. Anthropometric measures, COD, speed, jump and strength were tested. All players had no reported injuries at the time of testing. Players were not involved in any strenuous physical activity in 72 hours before the tests. Before the tests were performed a general standardized warm-up was delivered while a specific warm-up was performed before each specific test. Verbal encouragement was provided by researcher and coaches in every test performed. The following tests were performed:

- Anthropometric measures (height and BM)
- 30-m speed test (5-, 10-, 20- and 30-m split).
- 505 COD test.
- 75-90° COD test.
- CMJ
- SL CMJ
- DJ

- SL DJ
- SL BJ
- FSCS and FSES
- NHES.
- IMTP.

Testing was performed through a maximum of a week period. Prior to this, the study performed in Chapter 5 showed that the tests utilised for this purpose were overall reliable. COD, speed, jump and strength tests showed moderate to excellent levels of reliability with several exceptions. 5-m split and COD 505 test right side showed poor reliabiliy. Furthermore, FSCS and FSES presented large ICC values but showed high CV scores.

6.2.1. Subjects

Thirty-six female soccer players (age 25.1 ±5.7 years, height 166 ±5.5 cm, BM 62.8 ±5 kg) were tested. Players performed the testing protocol on a single occasion from May 2021 to July 2022 (May 2021: n=18, July 2021: n=6, December 2021: n=4, May 2022, July 2022: n=8). In total, 36 COD, CMJ, SL CMJ, SL BJ, NHES, and speed tests, 20 FSCS and FSES tests, 14 DJ and SL DJ tests and 12 IMTP tests were performed. The reason for only 20 players performing FSCS and FSES tests was that these were only performed on two occasions and with players familiarized with this test, while players only had access to equipment to perform IMTP on two of the testing days. Due to limitations in personnel, equipment, and time, the DJ and SL DJ were conducted on only two of the testing occasions.

6.2.2. Procedures

Specific testing protocols and devices utilised can be found in Chapter 5**.**

6.2.2.1. COD tests

Two COD tests with different turning angles (75-90° and 180°) were included in this study, the COD 505 test and the 75-90° COD test.

6.2.2.2. Speed Test:

Speed was assessed using splits at 5 and 10 m to assess acceleration and, 20 and 30 m to assess maximal speed.

6.2.2.3. Jump Tests

CMJ, SL CMJ, DJ, SL DJ and SL BJ were utilised to assess jump performance. This was evaluated through jump height for CMJ, SL CMJ, DJ and SL DJ while SL BJ was evaluated through jump distance

6.2.2.4. Strength Tests

FSCS and FSES were utilised to assess concentric and eccentric strength, while IMTP was utilised to evaluate maximal isometric strength and NHES to test hamstring eccentric strength. All strength tests were normalised by dividing by BM.

6.2.3. Statistical Analyses

Descriptive data is presented as mean ± SD. The assumption of normality was tested with the Shapiro-Wilk test. To explore relationships between the different tests, Pearson's product-moment correlation coefficients were calculated along with coefficients of determination (calculated as r^2). Correlations were evaluated as follows: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; and >0.9, nearly perfect (Hopkins et al., 2009). This was presented along with 95% confidence intervals (95% CI). All P-values were Bonferroni adjusted to control for type 1 error. The criterion for statistical significance of the correlation was set at $p \leq 0.05$.

6.3. Results

Data was normally distributed. Table 6.1 shows descriptive data for the different tests performed. Table 6.2., Table 6.3., Table 6.4. and Table 6.5. shows correlation variables between COD tests and different speed, jump and strength tests.

COD 505 test right and left showed very large and significant correlations [r= 0.7 (0.49 to 0.83)], both showing nearly perfect correlations with the COD 505 total. The 75-90° COD test right and left showed significant and very large correlations [r= 0.77 (0.62 to 0.87)], both showing almost perfect correlations with 75-90° COD total. Analysis showed significant large correlations between the two different COD tests (r= 0.57 - 0.69). The 505 COD test and 75-90° COD test showed a shared variance of 32% to 44%.

Examining the relationships between COD and speed tests, 5-, 10-, 20- and 30-m showed small to moderate correlations with 505 COD tests and 75-90° COD tests (r = 0.14 to 0.49).

Regarding relationships between COD and jump tests SL BJ left and right leg showed moderate to large correlations with 505 COD tests (r= -0.38 to -0.60) while showing moderate correlations with 75-90° COD tests (-0.36 to -0.48). CMJ showed large and significant correlations with all COD 505 tests (r= -0.51 to -0.58) while low and moderate correlations were found with the 75-90° COD test left (r= -0.23 to -0.36). In addition, SL CMJ showed moderate correlations with all 505 COD tests (r= -0.30 to -0.39). In contrast, SL CMJ tests showed small correlations with the 75-90° COD tests except for 75-90° COD test right and total, which showed moderate correlations with SL CMJ right (r = -0.15 to -0.36). DJ and SL DJ showed trivial to very large correlations with the COD 505 test (DJ, r= -0.05 to -0.71 and SL DJ, r= -0.07 to -0.56) and trivial to large correlations with 75-90° COD test (DJ, r= -0.46 to -0.67 and SL DJ, r= -0.07 to -0.66).

Relationships between COD and strength tests revealed trivial to small correlations between FSCS and all COD tests (r = -0.06 to -0.29), while FSES showed moderate correlations with 505 COD tests (r = -0.31 to -0.46) but trivial to small correlations with 75-90° COD tests (r = 0.01 to -0.29). Both NHES right and left showed trivial to small correlations with COD tests (r = 0.05 to -0.2). On the other hand, IMTP showed large correlations with COD 505 tests (r = -0.53 to -0.68) and moderate correlations with 75-90° COD tests (r = -0.36 to -0.44).

Table 6.1. Descriptives for measured variables

	Number of Subjects	Mean	Standard Deviation
Height (m)	36	1.66	0.06
BM (kg)	36	63.29	5.27
5 m (s)	36	1.07	0.07
10 m (s)	36	1.85	0.08
20 m (s)	36	3.21	0.11
30 m (s)	36	4.49	0.13
COD 505 test right (s)	36	2.29	0.08
COD505 test left (s)	36	2.28	0.08
COD 505 test total (s)	36	4.56	0.15
COD 75-90° test right (s)	36	1.95	0.09
COD 75-90° test left (s)	36	1.93	0.09

COD 75-90° test total (s)	36	3.88	0.16
CMJ (cm)	36	32.3	2.45
CMJ left (cm)	36	21.9	2.95
CMJ right (cm)	36	21.33	3.41
DJ (cm)	14	32.7	3.75
SL DJ left (cm)	14	19.22	4.06
SL DJ right (cm)	14	19.19	4.18
SL BJ left (cm)	36	1.66	0.13
SL BJ right (cm)	36	1.63	0.11
FSCS (N/kg)	20	12.89	3.31
FSES (N/kg)	20	15.68	3.49
NHES right (N/kg)	36	5.22	0.56
NHES left (N/kg)	36	5.14	0.6
IMTP (N/kg)	12	33.45	5.6

BJ = broad jump, COD = change of direction, CMJ = countermovement jump, DJ = drop jump, , FSCS = flywheel squat concentric strength, FSES = flywheel squat eccentric strength, IMTP = isometric mid-thigh pull, Kg = kilograms, SL = single leg, N = newtons, NHES = Nordic hamstring eccentric strength

Table 6.2. Correlation between COD tests

	COD 505 test right (95% CI)	COD 505 test left (95% CI)	COD 505 test total (95% CI)	COD 75-90° test right (95% CI)	COD 75-90° test left (95% CI)	COD 75-90° test total (95% CI)
COD 505 test right	1	0.70** (0.49 - 0.83)	0.91** (0.85 -0.95)	0.57** (0.32 - 0.75)	0.57** (0.32 - 0.75)	0.61** (0.38 - 0.77)
COD 505 test left	.70** (0.49 - 0.83)	1	0.92** (0.86 - 0.96)	0.65** (0.43 - 0.80)	0.57** (0.32 - 0.75)	0.65** (0.43 - 0.82)
COD 505 test total	0.91** (0.85 - 0.95)	0.92** (0.86 - 0.96)	1	0.67** (0.45 - 0.81)	0.62** (0.38 - 0.78)	0.69** (0.48 - 0.82)
COD 75-90° test right	0.57** (0.32 - 0.75)	0.65** (0.43 - 0.80)	0.67** (0.45 - 0.81)	1	0.77** (0.62 - 0.87)	0.94** (0.89 - 0.96)
COD 75-90° test left	0.57** (0.32 - 0.75)	0.57** (0.32 - 0.75)	0.77** (0.62 - 0.87)	0.77** (0.62 - 0.87)	1	0.94** (0.89 - 0.97)
COD 75-90° test total	0.61** (0.38 - 0.77)	0.65** (0.43 - 0.82)	0.69** (0.48 - 0.82)	0.94** (0.89 - 0.96)	0.94** (0.89 - 0.97)	1

* $p < 0.05$. ** $p < 0.01$, COD = change of direction

Table 6.3. Correlation between COD tests and speed tests

	5 m (95% CI)	10 m (95% CI)	20 m (95% CI)	30 m (95% CI)
COD 505 test right	0.34 (0.0 – 0.62)	0.31 (-0.04 – 0.60)	0.32 (-0.03 – 0.61)	0.47 (0.13 – 0.71)
COD 505 test left	0.27 (0.00 – 0.57)	0.30 (-0.05 – 0.59)	0.30 (-0.05 – 0.6)	0.44 (0.16 – 0.72)
COD 505 test total	0.33 (-0.2 - 0.61)	0.33 (-0.23 - 0.61)	0.34 (-0.01 - 0.62)	0.49* (-0.12 - 0.54)
COD 75-90° test right	0.32 (-0.03 – 0.60)	0.32 (-0.02 – 0.6)	0.32 (-0.03 – 0.60)	0.32 (-0.03 – 0.60)
COD 75-90° test left	0.19 (-0.16 – 0.5)	0.20 (-0.15 – 0.51)	0.14 (-0.22 – 0.474)	0.21 (-0.14 – 0.53)
COD 75-90° test total	0.27 (-0.08 - 0.56)	0.28 (-0.07 - 0.57)	0.24 (-0.12 - 0.54)	0.28 (-0.08 - 0.57)

COD = change of direction, * p < 0.01.

Table 6.4. **Correlation between COD tests and jump tests**

	CMJ (cm) (95% CI)	SL CMJ left (cm) (95% CI)	SL CMJ right (cm) (95% CI)	DJ (cm) (95% CI)	SL DJ left (cm) (95% CI)	SL DJ right (cm) (95% CI)	SL BJ left (cm) (95% CI)	SL BJ right(cm) (95% CI)
COD 505 test right	-0.51** (-0.71 to - 0.24)	-0.31 (- 0.57 to - 0.24)	-0.34 (- 0.59 to - 0.04)	-0.46 (- 0.77 to - 0.58)	- 0.1 (- 0.61 to 0.47)	-0.30 (- 0.57 to 0.53)	-0.50** (-0.7 to -0.23)	-0.60** (-0.76 to -0.35)
COD 505 test left	-0.55** (0.73 – 0.28)	-0.30 (- 0.52 to 0.56)	-0.38* (0.01 to -0.62)	-0.71 (0.89 to – 0.32)	-0.56 (- 0.84 to 0.00)	-0.49 (- 0.81 to - 0.09)	-0.46 (0.03 to -0.67)	-0.38 (0.13 to -0.62)
COD 505 test total	-.058** (-0.76 to -	-.031* (- 0.57 to - 0.00)	-.0.39* (-0.63 to -	-0.05 (- 0.56 to 0.63)	-0.07 (- 0.790 to 0.62)	-0.1 (- 0.71 to 0.60)	-0.52** (-0.72 to -0.25)	-.053** (-0.72 to -0.26)

	0.33)		0.09)					
COD 75-90° test right	-0.36 (-0.6 to -0.06)	-0.27 (-0.53 to 0.03)	0.39 (0.62 to -0.10)	-0.67 (-0.86 to -0.26)	-0.40 (-0.76 to 0.18)	-0.66 (-0.86 to -0.26)	-0.48** (-0.68 to -0.2)	-0.44 (-0.66 to -0.16)
COD 75-90° test left	-0.23 (-0.5 to -0.07)	-0.15 (-0.44 to 0.15)	-0.22 (-0.49 to -0.08)	-0.46 (-0.76 to 0.04)	-0.07 (-0.58 to 0.47)	-0.30 (-0.71 to 0.28)	-0.36 (-0.6 to -0.05)	-0.39 (-0.62 to -0.09)
COD 75-90° test total	-0.32* (-0.57 to -0.01)	-0.22 (-0.49 to -0.08)	-0.32* (-0.57 to -0.02)	-0.61** (-0.84 to -0.17)	-0.27 (-0.69 to -0.37)	-0.54* (-0.82 to -0.00)	-0.44** (-0.66 to -0.15)	-0.44** (-0.66 to -0.15)

BJ = broad jump, COD = change of direction, CMJ = countermovement jump, DJ = drop jump, SL = single leg. * $p < 0.05$. ** $p < 0.01$.

Table 6.5. Correlation between COD tests and strength tests

	FSCS (N/kg)	FSES (N/kg)	NHES L (N/kg)	NHES R (N/kg)	IMTP (N/kg)
COD 505 test right	-0.23 (-0.62 to 0.24)	-0.46 (-0.75 to -0.02)	-0.12 (-0.44 to -0.21)	-0.2 (-0.53 to 0.13)	-0.6 (-0.88 to -0.0)
COD 505 test left	-0.29 (-0.67 to -0.19)	-0.31 (-0.67 to 0.04)	0.1 (-0.42 to 0.23)	-0.09 (-0.41 to 0.24)	-0.68 (-0.91 to 0.13)
COD 505 test total	-0.21 (-0.62 to -0.27)	-0.42 (-0.73 to -0.27)	-0.12 (-0.43 to -0.21)	-0.16 (-0.46 to -0.18)	-0.53 (-0.85 to -0.10)
COD 75-90° test right	-0.20 (-0.59 to 0.26)	-0.29 (-0.64 to 0.16)	0.05 (-0.27 to 0.37)	0.03 (-0.3 to 0.35)	-0.41 (-0.79 to 0.2)
COD 75-90° test left	-0.06 (-0.49 to 0.38)	0.01 (-0.42 to 0.44)	-0.07 (-0.39 to 0.25)	0.1 (-0.41 to 0.23)	-0.44 (-0.81 to 0.17)
COD 75-90° test total	-013 (-0.54 to -0.32)	-0.15 (-0.54 to -0.29)	-0.01 (-0.33 to -0.31)	-0.04 (-0.36 to -0.29)	-0.36 (-0.77 to -0.26)

COD = change of direction, FSCS = flywheel squat concentric strength, FSES = flywheel squat eccentric strength, IMTP = isometric mid-thigh pull, Kg = kilograms, N = newtons, NHES = nordic hamstring eccentric strength.

6.4. Discussion

505 COD test showed large correlations with 75-90° COD test, but shared variance was below 50%, representing different COD qualities. 5-, 10- 20- and 30-m splits showed low to moderate correlations with the COD tests. SL CMJ and CMJ, respectively, showed moderate and large correlations with 505 COD test while 75-90° COD test showed small and moderate correlations with SL CMJ and CMJ, respectively. SL BJ also demonstrated higher correlations for the 505 COD test (moderate to large) vs 75-90° COD test (moderate). On the other hand, DJ and SL DJ showed trivial to very large and trivial to large correlations with the 505 COD and 75-90° COD tests but with a tendency for higher correlations with the latter. IMTP and FSES showed large and moderate correlations with the 505 COD test, respectively, while only showing moderate and trivial to low correlations with the 75-90° COD test, respectively.

While COD tests showed large and significant correlations between them, it is worth mentioning that the percentage of shared variance between the COD 505 test and 75-90° COD test was under 50%, showing to be COD tests assessing different physical qualities. This is in line with previous research analysing shared variance of different COD tests in elite youth soccer players. Kadlubowski, et al. (2019) analysed relationships between six COD tests and found variance between 10% and 55%. The number of CODs ranged from one to nine, degrees of turn from 60° to 180° while the completion time ranged from 2 to 18 seconds. The only tests that showed shared variance had certain similarities, with both two CODs (triangle test right and square test left, r^2 = 55%), taking 2.9 to 3.5 seconds to complete and angles being 60° and 90°, respectively. This indicates that although comparable physical qualities can support similar COD tests, the COD 505 test and the 75-90° COD test are likely to rely on distinct physical abilities in this case.

5-, 10-, 20- and 30-m splits showed moderate correlations with the COD 505 tests and the 75-90° COD tests right but not with the 75-90° COD test left and total which showed small correlations. This would somehow contrast the limited number of studies analysing the relationships between speed and COD ability in female soccer players. In a study utilising a similar population (female professional soccer players participating in the same league) (Emmonds et al., 2019), researchers found significant and strong correlations between COD 505 test and 10-m and 20-m splits. Similar results were found in a study performed on young female soccer players (Mathisen & Pettersen, 2015), where 10 m and 20 m sprints showed significant correlations with a COD test that involved 90° and 180° turns. Finally, Sonesson et al, (2021) in male and female young soccer players found strong correlations between the COD 505 test and 10-m and 20-m sprints. While results from this study show conflicting results, COD tests would include some sort of linear acceleration or reacceleration, and so, it would be reasonable to think that straight sprint speed would have some relationships with COD tests, especially on short splits such as 5 m and 10 m.

SL CMJ showed small correlations with 75-90° COD tests, except for SL CMJ right and 75-90° COD tests right, as well as SL CMJ right and 75-90° COD total, which showed moderate correlations. On the other hand, the 505 COD test showed moderate correlations with SL CMJ, except for COD 505 left with SL CMJ left, which showed small correlations. Studies performed on female soccer players show inconsistent results when establishing relationships between SL CMJ and COD performance. Loturco et al. (2019b) found moderate and non-significant correlations between SL CMJ and zig-zag test in elite female players. On the other hand, Falch et al. (2021) found low correlations between unilateral CMJ and COD performances in a 180° and a 45° COD test in young soccer and handball players. Researchers justified this finding by stating that the CMJ test was performed unilaterally and could demand a certain balance which would inhibit the pre-stretch. While this could be the case, players performed two familiarization sessions, and so, should have been habituated to some extent to this movement. Additionally, studies performed on male soccer players have shown conflicting results when analysing correlations between SL CMJ and COD tests (Northeast et al., 2019; Castillo-Rodríguez et al., 2012). Northeast et al. (2019) found trivial to moderate correlations between SL CMJ and a COD test consisting of a 45° COD in EPL players. This could be due to the characteristics of both tests, as the time available to produce force during a SL CMJ would be higher than the time available to produce force during a 45° turn. Castillo-Rodríguez et al. (2012) found low to large correlations between SL CMJ and two different COD tests (COD with 180° turn and COD with 90° turn). Interestingly, only the left side showed low correlations with the COD tests, while the right side showed moderate to large correlations. While during the 180° COD test players only turned to one side, which could explain the low correlations, during the 90° COD test athletes turned to the left and right side, with higher correlations found between left turn and left jump vs right turn and left jump.

CMJ showed large correlations with the 505 COD tests while showing small to moderate correlations with the 75-90° COD test. Other studies in professional, college, female team sport athletes (including soccer players) and youth female soccer players have also shown moderate to large correlations between COD tests and CMJ height (Sonesson et al., 2021; Edmonds et al., 2019; McFarland et al., 2016; Castillo-Rodriguerz et al., 2012; Thomas et al., 2018) while two other studies have shown low correlations (Kobal et al., 2021) or conflicting results (Vescovi & Mcguigan, 2008). Vescovi & McGuigan, (2008) found moderate correlations between CMJ and Illinois test (which wouldn’t represent the most suitable test to measure COD ability due to the long-time taken to complete this test) but found low correlations with pro-agility test, which consisted of two 180° CODs.

Similar to the correlations observed in this study between COD tests and SL CMJ, higher associations were found between CMJ and 505 COD test vs 75 – 90° COD test, which could be due to CMJ showing similar characteristics to sharp CODs when compared to CODs with lower angles of direction change (Dos’Santos et al., 2018a). In the same line, SL BJ demonstrated higher correlations for the 505 COD test vs 75-90° COD test, with moderate to large and moderate correlations, respectively. This higher correlation of the SL BJ with the 505 COD tests could be related to the nature of the tests. 505 COD test compared to 75-90° COD would have higher angles of turn, and so, higher level of deceleration and, thus, more influenced by eccentric strength (Dos’Santos et al., 2018a). In this regard, SL BJ reflects the ability to produce horizontal propulsive impulses and the ability to produce horizontal braking impulses to reduce the momentum of the body during landing, with the latter dependent on eccentric strength (Taylor et al., 2016). In this sense, the player would only be able to generate an impulse that is capable of absorbing in the landing phase. Other studies on female soccer players have shown similar findings (Sonesson et al., 2021; Thomas et al., 2018). Sonesson et al. (2021) found large correlations between SL BJ and 505 COD test in young female and male soccer players. In the same line, Thomas et al. (2018) found large correlations between the 505 COD test and SL horizontal hop jump in male and female college athletes that included soccer players.

DJ and SL DJ tests, overall, showed a tendency for higher correlations with the 75-90° COD tests vs the 505 COD tests. Other studies have shown conflicting results when analysing relationships between DJ and COD tests (Sonesson et al., 2021; Jones et al., 2009; Emmonds et al., 2019). Sonesson et al. (2021) found small correlations between the DJ and 505 COD test as well as the T-test in youth female and male soccer players. Moreover, Jones et al. (2009) found very low to non-significant associations between DJ height and the 505 COD test in male and female college team sport athletes including soccer players. On the other hand, Emmonds et al. (2019) found a lack of relationship between the 505 COD test and DJ height on female elite soccer players. This absence of relationships between DJ and the COD tests may be related to the characteristics of the COD tests, as these studies utilised CODs of 180° with this reactive test potentially being more related to COD tests with shallower angles (Dos'Santos et al., 2018a).

IMTP showed large correlations with the 505 COD test and moderate correlations with the 75-90° COD test. Only two other research groups have analysed the relationship between isometric strength and COD performance in female soccer players. For example, Thomas et al. (2018) found low correlations between IMTP and the 505 COD test and the Modified 505 COD test in female team sport athletes that included soccer players. Interestingly, this same study, found moderate to large correlations in male athletes. On the other hand, Edmonds et al. (2019) found isometric strength (KE muscles isometric strength measured with a custom-made isometric device) to have strong correlations with the 505 COD test. Due to the characteristics of the isometric test utilised, where only a single joint was involved on a custom-made device, not commonly utilised in research, caution should be taken when drawing further conclusions. While limited research has assessed this relationship in female soccer players there is a potential for isometric strength to be determinant in COD ability as it has been shown previously that players with higher relative lower body isometric strength produce a greater magnitude of plant foot kinetics while achieving quicker COD performances (Spiteri, et al., 2013). This could be more relevant in sharper CODs due to more time available to generate forces compared with shallow CODs.

Regarding the results of the FSCS and FSES assessments, it is important to understand that depending on the inertia utilised, different aspects of the force-velocity curve (McErlain-Naylor, & Beato, 2021) are targeted (e.g., low inertias stimulating rightward shift and high inertias upwards shift of force-velocity curve). In this case, as high inertia was utilised, this would be specific to the force side of the curve. When looking at FSCS, the analysis showed trivial to small correlations with COD performance. This is partly in contrast with the two studies assessing relationships between concentric strength and COD tests in female soccer players (Andersen et al., 2018; Falch et al., 2021). Andersen et al. (2018) assessed concentric strength through a different methodology (3RM back squat) in female NCAA Division II soccer players and found large to very large correlations between two COD tests (505 COD test and T-test) and maximal absolute and relative strength. In addition, Falch et al. (2021) showed moderate and significant correlations between bilateral squat and two COD tests (180° and 45°) while lateral squat showed low correlations with the 45° COD and 180° test. This was justified by the authors by reasoning that this strength test demands more balance and control, not allowing the athlete to maximize loads at the given velocity. The difference between findings from previous research and this study could be related to the differences between testing equipment utilised, as in this study a flywheel device was used while the above-mentioned studies utilised free weights or a smith machine.

In contrast, FSES showed moderate correlations with the 505 COD test but trivial to low correlations with the 75-90° COD test. This could be linked to the increased eccentric demands required when executing larger turning angles that involve a higher level of deceleration. (e.g., reducing horizontal momentum from the approach to zero) (Dos'Santos et al. 2018a). No other researchers have analysed associations between COD performance and multi-joint eccentric strength. Taking into account that during squat movements KEs are the muscles with highest activation (Schwanbeck et al., 2009), comparisons can be made with studies assessing KE strength using an isokinetic device. Thomas et al. (2018), found small correlations between eccentric KE torque (isokinetic dynamometer at $60°·s^{-1}$) and COD 505 test in female sport athletes that included soccer players. Interestingly, similar to what occurred in the IMTP test in this same study, male participants showed higher correlations (moderate correlations) compared to female athletes. On the other hand, in a similar population Jones et al. (2009) found moderate correlations between the 505 COD test and isokinetic KE and flexor eccentric strength (60°/s). On the same line, Jones et al. (2017) found large correlations between COD performance (5-m approach, 180◦ turn, 5-m return) and eccentric KE and eccentric KF (isokinetic dynamometer at $60°·s^{-1)}$ in professional and semi-professional female soccer players. In addition, stronger participants compared to weaker ones, showed a significantly faster-approaching speed and greater reduction in speed during the penultimate step. This would potentially mean that having greater eccentric capabilities would help players to decelerate faster. In the same line, Jones et al. (2022) in a similar population found very large correlations between eccentric KE strength (isokinetic dynamometer at $60°·s^{-1)}$ and COD completion time (time to complete: 5-m approach, 70–90˚ cut, 3-m exit). Moreover, moderate and significant correlations were found between eccentric KE strength and velocities at key instances of the cut and minimum resultant horizontal plane velocity. Therefore, although more research needs to be performed, especially on multi-joint eccentric strength assessments, this physical quality appears to be important for COD performance, especially for sharp COD angles due to higher deceleration demands.

NHES showed trivial to low correlations with all COD tests. To the author's knowledge, this is the only study in male or female soccer players assessing correlations between NHES and COD performance. Other researchers have assessed relationships between hamstring eccentric strength through dynamometer tests and COD, with a study by Jones et al. (2017) showing large correlations between COD performance and eccentric KF strength (isokinetic dynamometer at $60°·s^{-1}$) in professional and semi-professional female soccer players. More so, Jones et al. (2022) in a similar population found large correlations between a 70–90˚ cut COD test and eccentric KF strength. Authors suggested that eccentric KF strength may play a minor role in supporting deceleration mechanics during cutting, possibly helping to produce hip extensor moments on the penultimate and final steps to control trunk flexion and assist knee joint stability through co-contraction.

6.5. Limitations

This study holds several limitations. While 36 players performed the different tests, the testing protocol was performed on different occasions. While every effort was made to attain the highest number of subjects possible in order to have an acceptable statistical power, generalizability and robustness of the sample, this meant performing the tests at different times of the season to gather as many players as possible. While ideally, all subjects would have performed the testing protocol on the same occasion, the singularities and complexity of female professional soccer, alongside COVID-19, made this unattainable. Along the same line, not all the tests were performed the same number of times due to a lack of access to different equipment, illnesses such as COVID-19, players on international duties or injuries, discomforts, etc. In some cases, this lack of sample size could have influenced the lack of significant correlations. For instance, although moderate to large correlations were observed between IMTP and COD tests, they did not reach statistical significance. Additionally, due to equipment issues, the reactive strength index could not be determined from the DJ and SL DJ tests, which would have provided valuable information regarding the relationship between this physical characteristic and COD ability.

6.6. Conclusion

The COD 505 test and the 75-90° COD exhibited significant correlations. However, they only shared 32% and 44% of their variance, indicating that they represent distinct COD qualities. Sprint split times (5, 10, 20 and 30 m) showed low to moderate correlations with both COD tests. SL CMJ and CMJ, respectively, showed moderate and large correlations with the 505 COD test, while the 75-90° COD test showed small and moderate correlations with SL CMJ and CMJ. In addition, SL BJ showed higher correlations for the 505 COD test (moderate to large) vs 75-90° COD test (moderate), while DJ and SL DJ showed a tendency for higher correlations with the 75-90° COD test compared to the 505 COD test. Finally, IMTP and FSES showed some relationships with COD performance, with large and moderate correlations, respectively, with the 505 COD test, but only showed low to moderate correlations with the 75-90° COD test. This could be due to more time available to generate forces as well as higher eccentric requirements during sharper CODs vs shallow CODs. Therefore, while speed tests show similar relationships with both COD tests, jump and strength tests show higher links with the 505 COD tests, except for DJ and SL DJ. This could be related to the specific muscle actions of the jump and strength tests utilised, linked to the characteristics of the COD test.

6.7. Practical Applications

To provide the most targeted training for soccer players, it's crucial to understand how these differences relate to distinct physical abilities. Firstly, the low shared variance between COD tests demonstrates that these two tests measure different COD capacities. This would mean that COD drills with sharp turning degrees would preferentially increase performance on the 505 COD test, while drills with shallow turns would increase COD performance on the 75-90° COD test. Moreover, this study supports the different specific physical qualities underpinning the two COD tests, which would be related to the time available to create forces in the different tests performed. The 75-90° COD test tended to have higher correlations with DJ and SL DJ tests compared to the 505 COD test. Therefore, fast SSC should be prioritised when trying to increase the performance of sharp CODs. CODs with shallow angles involve some degree of braking (McBurnie & Dos'Santos, 2022) and could, therefore, benefit from eccentric training, as this study demonstrated moderate relationships between SL BJ and 75-90° COD tests.

On the other hand, SL CMJ and CMJ, considered as slow SSC, as well as eccentric strength and isometric maximal strength test tended to favour the 505 COD test vs 75-90° COD test. In addition, SL BJ which not only assesses the ability to generate horizontal propulsive impulse but also the ability to generate horizontal braking impulse, showed moderate and large significant correlations with the 505 COD test, meaning that eccentric strength could be of increased relevance, especially during sharper CODs. Therefore, slow SSC as well as strength training, especially eccentric training would be a priority when looking to increase performance during sharp CODs.

CHAPTER 7: EFFECTS OF A POSITION SPECIFIC TRAINING INTERVENTION FOR THE ENHANCEMENT OF CHANGE OF DIRECTION PERFORMANCE IN FEMALE ELITE SOCCER PLAYERS

7.1. Introduction

CODs are performed repeatedly in a soccer match (Nedelec et al., 2014: Granero-Gil et al., 2020; Robinson et al., 2011; Baptista et al., 2018; Morgan, et al., 2022; Bloomfield et al., 2007a; Dos'Santos et al., 2022b) with the frequency going from 11.9 hard changes of direction (defined as *"hard change in direction while running"*) to more than 700 turns and swerves (Nedelec et al., 2014; Bloomfield et al., 2007a). Their frequency further highlights the importance of these actions during goal-scoring situations. The results from Chapter 4 showed that attackers performed COD actions in 71.9 ±2.3% and 72.9 ±4.1% of the involvements for EPL and WSL, respectively, while defenders executed these in 71.2 ±2.6% and 67.8 ±4.7% of the involvements, respectively. Moreover, in 56.1±1.9% and 57.1±3.3% of the involvements, there was at least one COD at high intensity in EPL and WSL, respectively. Previous studies have yielded varying conclusions when examining the differences between playing positions throughout a full match. One study found no significant differences in COD estimated angle or direction, with most of these being ≤90° (Morgan et al., 2022). Bloomfield et al. (2007a) found the majority of turns to be of ≤90°, with attackers and defenders performing higher amounts of COD actions of ≤90° when compared to midfielders, while no differences were found on turns of 90-180°, 180-270° and 270-360°.

When it comes to CODs performed in goal-scoring situations, research has shown that players follow similar trends, but with some differences (Faude et al., 2012). Faude et al. (2012) found very small differences for COD sprints between assisting and scoring players with 8% (5-11%) and 9% (6-12%), respectively, while rotations showed bigger differences, with 8% (5-11%) and 13% (9-17%), respectively. On the other hand, research in Chapter 4 showed a higher percentage of cuts and subtle turns (0-60°) for attackers while defenders performed a higher ratio of sharp turns (60-120°), arc runs (only EPL) and high-intensity linear advancing motion and decelerations in both EPL and WSL, as well as high-intensity turns in WSL. Therefore, although the frequency of COD actions has shown to be similar, the characteristics of the CODs performed would somehow differ between attackers and defenders, with this being relevant for performance, more so when attacking vs defensive agility shows to have different characteristics in team sports (Drake et al., 2017; Young & Murray, 2017; Young et al., 2022).

It is essential to understand how these differences can be related to separate physical capabilities in order to apply the most specific training stimulus for soccer players. Based on previous research considering GCTs associated with different COD angles (usually from 45-180°), it has been suggested that training protocols should be specific to the COD angle (Dos'Santos et al., 2018a). While fast SSC has been recommended for CODs of ≤60°, a combination of fast and slow SSC exercises is recommended for 90° CODs. Therefore, while it is true that the shallow COD test utilised in this study (75-90° COD test) could sit in between these categories, a recent study using a similar test (70-90° cutting task) in similar population as this study showed that only ultimate contact in the low-performance group had GCT of >250 ms (0.281s). In contrast, penultimate contact in both groups (0.164s and 0.202s) and ultimate contact in the fast group (0.238s) were all <250 ms (Jones et al., 2022). Therefore, for improvement of shallow CODs, fast SSC would be the preferred strategy, with the addition of slow SSC without this being the priority, which is in alignment with the study in Chapter 6, as the 75-90° COD test tended to have higher correlations with DJ and SL DJ tests compared to the 505 COD test. Moreover, CODs with shallow angles would involve some braking (McBurnie & Dos'Santos, 2022), and so, could also benefit from eccentric training, as the study in Chapter 6 showed moderate relationships between SL BJ and 75-90° COD test, with other studies in similar populations showing the importance of eccentric strength in key instances of a comparable COD test (70–90˚ cut) (Jones et al., 2019).

On the other hand, research suggests that sharper CODs (≥ 135°) would benefit from slow SSC actions and ballistic exercises as well as strength (especially eccentric strength) (Dos'Santos et al., 2018a; McBurnie & Dos'Santos, 2022) which is further supported by the study in Chapter 6, where CMJ and SL CMJ, considered as slow SSC, as well as eccentric strength and isometric maximal strength test tended to favour the 505 COD test vs 75-90° COD test. In addition, SL BJ which not only reflects the ability to generate horizontal propulsive impulse but also the ability of the player to generate horizontal braking impulse, showed moderate and large significant correlations with the 505 COD test and moderate correlations with 75-90° COD test, suggesting eccentric strength could be of increased relevance to help generate horizontal braking impulse, especially on sharper CODs, and so, this should be considered for training strategies. In addition, it has been suggested that while a 180° COD, such as the 505 COD test, would have a more anterior-posterior dominance, this would likely shift towards higher medio-lateral kinetic demands on laterally oriented exits (such as the 75-90° COD test) on the final foot contact (Mc Burnie et al., 2021; Arboix-Alió et al., 2024). In this sense, higher medio-lateral GRFs would likely enable greater propulsion during these type of actions (McBurnie & Dos'Santos, 2022; Arboix-Alió et al., 2024), with the derived training implications. Unfortunately, in the correlation study performed in Chapter 6 players did not perform any lateral power or lateral jump tests, which would have also helped direct future training strategies.

When examining training approaches aiming to improve COD ability in female soccer, some researchers have integrated multiple training methods such as strength, power, plyometrics, core exercises, agility drills, sprints, etc. (Mathisen & Pettersen, 2015; Pardos-Mainer et al., 2020; Lindblom et al., 2012; Pardos-Mainer et al., 2019), while others have isolated a particular training methodology (Millar et al., 2020; González-García et al., 2019; Bimson et al., 2017; Ramírez-Campillo et al., 2016; Ramirez-Camapillo et al., 2018c; Nonnato et al., 2022; Pecci et al., 2022). Pecci et al. (2022) had a group of elite female soccer players performing flywheel squat training twice a week for six weeks during the in-season and found no improvements in the 5+5 metres shuttle run-sprint test. Players were not familiar with the use of this technology, and so, these results should be considered with caution. Moreover, Millar et al. (2020) performed hip thrust or back squats at 30% of 3RM, increasing 10% each week, while in the study by González-García et al. (2019) these exercises were performed with loads from 60 to 90% of the 1RM. Both studies failed to show any significant improvements in pro agility or T-test. However, the level of the athletes, with no previous experience in resistance training, as well as the intensity of the lifts, which may be considered insufficient to develop maximum strength, and the low variety of exercises (only performing either squats or hip thrust), suggests that these findings should be considered with caution. In addition, Bimson et al. (2017) found no improvements in the zig-zag test after repeated knee extension maximal voluntary isometric contractions in female university soccer players. This study involved low frequency and duration (one day a week for six weeks) of training, which could have had an impact on the results of this study. Moreover, the protocol utilised involved only knee extensors, with no focus on hip extensors or multi-joint training.

In contrast, Ramírez-Campillo et al. (2016) and Ramírez-Campillo et al. (2018b) had amateur female soccer players perform six weeks and eight weeks of varied multidirectional plyometric exercises and found improvements on the Illinois test and zig-zag test, respectively. Whereas Nonnato et al. (2022) found no improvements in the 505 COD test after 12 weeks of varied multidirectional plyometric exercises on female professional soccer players. The lack of performance improvements in these studies could be explained in some cases to the methodological approach (as highlighted above) and/or because these are single-component COD studies, and so, it would be more challenging for these protocols to impact COD performance, as this is a complex skill that involves a combination of physical attributes and technical skills. Therefore, employing a holistic training approach that considers the multifactorial nature of the skill would be potentially more effective.

Studies combining different training methodologies have shown conflicting results. Mathisen and Pettersen (2015) had regional young female soccer players perform resisted sprints, straight line sprints (20 m straight sprints) and COD drills [eight COD sprints (20 m) with 60° and 90° turns, and relay race with 90° turns] and found improvements in a COD test consisting of sprints with 2×90º and 2×180º turns. However, researchers didn’t report effect sizes, and so, it is difficult understand the impact of these findings. Pardos-Mainer et al. (2020) found improvements in the V-cut test and in a 180° COD test to the left but not to the right in elite adolescent female soccer players performing strength [diver, one-legged pelvic tilt, SL box step-up, forward lunge, backward lunge, one-legged hip thrust, Russian belt posterior chain, Russian belt anterior chain, power (eccentric box drops) and core (plank, lateral plank, lumbar bridge)]. All exercises were performed with body weight except for the diver, forward lunge and backward lunge (although no information was provided regarding the intensity), with only 1 set performed per exercise, which might not have been enough stimulus to produce adaptations. On the other hand, Lindblom et al. (2012) found no improvements in the Illinois test after an intervention consisting of 11 weeks of one-legged knee squat, two-legged knee squat, the lunge, the bench and jump landing on female young soccer players. Different factors could have affected the study’s results such as the low player adherence (59.6 ±14.3%) and the COD test selected (Illinois test).

Finally, Pardos-Mainer et al. (2019) found no improvements on a 180° COD test as well as V-cut test after performing the FIFA 11 protocol, which consisted of trunk and lower extremities’ strength, balance, plyometric and agility components, in adolescent female soccer players. This lack of improvements could be related to the fact that FIFA 11 protocol is a generic warm-up and conditioning protocol aiming to address several injury risk factors rather than performance enhancement. In addition, the FIFA 11 protocol lacks adherence to important training principles such as individualisation, progressive overload or variation. Moreover, while FIFA 11 includes strength and power/ jump elements, it is questionable whether these method would provide enough stimulus for significant strength and/or power adaptations, especially in athletes with a certain strength and power training history.

Based on the above, the small number of intervention studies performed on female soccer players show conflicting results as to whether a specific methodology of training (combined or isolated) can enhance COD performance. More so, the different methodologies utilised as well as the population (elite, amateur, young players) and the wide range of tests used for assessments make it difficult to draw any further conclusions. Furthermore, it could be questioned whether the training interventions utilised are specific to the COD test selected. In addition, there is a need for specific COD training interventions based on the movements performed more habitually by players with different roles in key movements of the game. Therefore, this study aimed to investigate whether two distinct training intervention programs designed for attackers and defenders, which include specific exercises and drills, can improve position-specific COD performance. It was hypothesised that the attacker group (AG) would improve performance in the COD 75-90° test, the defender group (DG) would improve performance in the COD 505 test and the CG would show no improvements in the tests selected.

7.2. Methods

This study was performed during 16 weeks of the in-season period of 2021/ 2022 for the CG (n = 12) and 2022/23 for the IG (n = 24). Players in the IG were divided into AG and DG. The AG (n=9) were players who would be more habitually involved in attacking actions, while DG (n=15) consisted of players more commonly involved in defending actions. A different training intervention based on COD characteristics of their positions was implemented throughout the in-season period for the AG and DG while CG performed their habitual strength and power training.

7.2.1. Subjects

Thirty-six outfield elite female soccer players (age: 25.27 ±4.6 years, height: 167 ±5.2 cm, BM: 63.03 ±4.5 kg) from the first team of a FA WSL club participated in this study. This was formed by a CG (age: 23.58 ±4.3 years, height: 166 ±6.4 cm, BM: 63.36 ±4 kg), AG (age: 25.85 ±3.6 years, height: 170 ±6.6 cm, BM: 62.4 ±6.4 kg) and DG (age: 26.34 ±3.9 years, height: 167 ±4.5 cm, BM: 64.57 ±4 kg). Based on an effect size of 0.38 for pre- to post-changes (ANOVA group × time) in COD speed performance in female soccer players following multidirectional plyometric training (Campillo et al., 2018c), a priori analysis, using G*Power (Version 3.1, University of Dusseldorf, Dusseldorf, Germany) indicated that a minimum total sample size of 21 was required to achieve a power of 0.80, and type 1 error or alpha level of 0.05. This would mean a minimum of seven subjects in each group. Participants had at least 2 years of resistance training experience. To ensure players were familiarized with the equipment utilised, such as flywheel technology, they underwent at least 2 months of training with the relevant equipment before the protocol started.

7.2.2. Procedures

Two different COD tests were performed on the left and right sides before and after the training intervention. These were the 505 COD left, 505 COD right, 75-90° COD left and 75-90° COD right. In addition, CMJ, SL CMJ left, SL CMJ right, SL BJ left and SL BJ right tests were performed within the same week as COD tests. Prior to performing each of the tests, a familiarization/warm-up trial was allowed. After this, players performed twice each of the tests. Players had previous experience with all tests as this same battery had been performed four times in the previous season, as well as once during pre-season, and so, familiarization sessions were not needed.

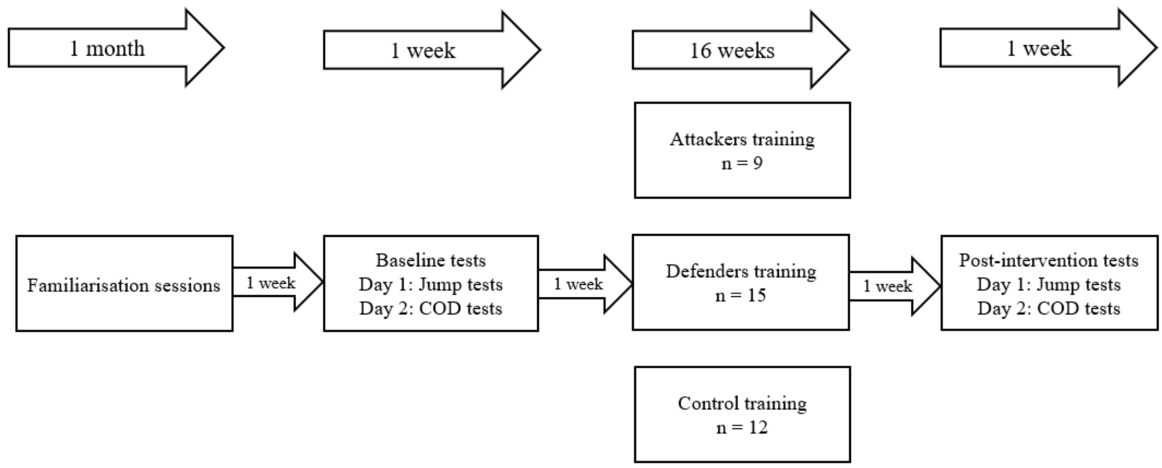


Figure 7.1. Graphical representation of the intervention

7.2.3. Training Intervention

Players in the IG performed their habitual gym sessions with a particular focus on exercises that would potentiate COD performance specific to their role (Table 7.1., Table 7.2. and Table 7.3.). More so, during the warm-up of the intensive session, special focus was placed on position-specific COD development. On the other hand, CG performed these sessions without a particular focus on position-specific COD enhancement.

Table 7.1. First 5 weeks

	Attacker	Defender	Control	Sets x reps/ seconds
Power	1. Vertical short DL 2. Diagonal forward Short DL 3. Lateral short DL 4. Lateral long DL 5 and 6 individual needs	1. Vertical long DL 2. Horizontal forward Long DL 3. Horizontal brake Long DL 4. Lateral long DL 5 and 6 individual needs	1. Vertical 2. Horizontal 3. Lateral 4, 5 and 6. Individual	1 – 2 sets 3 – 6 reps
Strength High	1. Flywheel lateral and low inertia 2. Flywheel vertical low to medium inertia 3. Traditional big lift 1. (deadlift, squat, hip thrust, split squat, etc…) 4. Traditional big lift 2. (deadlift, squat, hip thrust, split squat, etc…) 5. Quadriceps (knee extension exercise) 6. Hamstring	1. Flywheel horizontal and medium inertia 2. Flywheel vertical and medium inertia 3. Traditional big lift 1. (deadlift, squat, hip thrust, split squat, etc…) 4. Isometric lift. (squat, IMTP, split squat, etc…) 5. Quadriceps (knee extension eccentric biased) 6. Hamstring (eccentric biased)	1. Flywheel exercise 2. Flywheel exercise 3. Traditional big lift 1. (deadlift, squat, hip thrust, split squat, etc…) 4. Traditional big lift 2. (deadlift, squat, hip thrust, split squat, etc…) 5. Quadriceps (knee extensions) 6. Hamstring	1 - 3 sets 4 - 10 reps / 5 – 10 seconds
Strength Microdosing	1. Flywheel lateral and low inertia 2. Individual IP 3. Individual IP	1. Flywheel horizontal and medium 2. Individual IP 3. Individual IP	1. Flywheel exercise 2. Individual IP 3. Individual IP	1 – 2 sets 4 – 8 reps
COD	COD drill with 1 COD x 1-2 repetitions each side x 60-90° COD with 5-10 m approach with finish on mini goal	COD drill with 1 COD x 1-2 repetitions each side x 135-180° COD with 5-10 m approach with finish on goal	None	1 set 2 – 4 reps

COD = change of direction, DL = double leg, IMTP = isometric mid-thigh pull, IP = injury prevention

Table 7.2. Second 5 weeks

	Attacker	Defender	Control	Sets x reps/ seconds
Power	1. Vertical short DL to SL 2. Diagonal forward Short SL 3. Lateral short DL to SL 4. Lateral long DL to SL 5 and 6 individual needs	1. Vertical long DL to SL 2. Horizontal forward long DL to SL 3. Horizontal brake long SL to DL 4. Horizontal lateral long DL to SL 5 and 6 individual needs	1. Vertical 2. Horizontal 3. Lateral 4, 5 and 6. Individual	1 – 2 sets 3 – 6 reps
Strength High	1. Flywheel lateral with rotation and Low inertia 2. Flywheel vertical side to side and low inertia 3. Traditional big lift 1. (deadlift, squat, hip thrust, split squat, etc…) 4. Traditional big lift 2. (deadlift, squat, hip thrust, split squat, etc…) 5. Quadriceps (knee extensions exercise) 6. Hamstring	1. Flywheel horizontal with rotation and medium to high inertia 2. Flywheel vertical high inertia 3. Traditional big lift 1. (deadlift, squat, hip thrust, split squat, etc…) 4. Isometric lift. (squat, IMTP, split squat, etc…) 5. Quadriceps (knee extensions eccentric biased) 6. Hamstring (eccentric biased)	1. Flywheel exercise 2. Flywheel exercise 3. Traditional big lift 1. (deadlift, squat, hip thrust, split squat, etc…) 4. Traditional big lift 2. (deadlift, squat, hip thrust, split squat, etc…) 5. Quadriceps (knee extensions) 6. Hamstring	1 – 3 sets 3 – 6 reps / 3 – 8 seconds
Strength Microdosing	1. Flywheel lateral and low to medium Inertia 2. Individual IP 3. Individual IP	1. Flywheel horizontal medium Inertia 2. Individual IP 3. Individual IP	1. Flywheel exercise 2. Individual IP 3. Individual IP	1 – 2 sets 4 – 6 reps
COD	- COD drill with 2 COD x 1-3 repetitions each side x 60-90° COD with 5-10 m approach with finish on mini goal	- COD drill with 2 COD x 1-3 repetitions each side x 135-180° COD with 5-10 m approach with finish on goal	None	2 – 4 sets

COD = change of direction, DL = double leg, IMTP = isometric mid-thigh pull, IP = injury prevention, SL = single leg

Table 7.3. Third 5 weeks

	Attacker	Defender	Control	Sets x reps/ seconds
Power	1. Vertical short SL 2. Diagonal forward short SL 3. Lateral short SL 4. Lateral long SL 5 and 6 individual needs	1. Vertical long SL 2. Horizontal forward long DL to SL 3. Horizontal brake long SL to DL 4. Horizontal lateral long DL to SL 5 and 6 individual needs	1. Vertical 2. Horizontal 3. Lateral 4, 5 and 6. Individual	1 – 2 sets 3 – 6 reps
Strength High	1. Flywheel lateral rotation and low to medium inertia 2. Flywheel vertical side to side 3. Traditional big lift 1. (deadlift, squat, hip thrust, split squat, etc…) 4. Traditional big lift 2. (deadlift, squat, hip thrust, split squat, etc…) 5. Quadriceps (Knee extensions eccentric exercise) 6. Hamstring	1. Flywheel horizontal rotation and medium inertia 2. Flywheel vertical high inertia 3. Traditional big lift 1. (Deadlift, squat, hip thrust, split squat, etc…) 4. Isometric lift. (squat, IMTP, split squat, etc…) 5. Quadriceps (knee extensions eccentric biased) 6. Hamstring (eccentric biased)	1. Flywheel exercise 2. Flywheel exercise 3. Traditional big lift 1. (deadlift, squat, hip thrust, split squat, etc…) 4. Traditional big lift 2. (deadlift, squat, hip thrust, split squat, etc…) 5. Quadriceps (knee extensions) 6. Hamstring	1 – 3 sets 3 – 6 reps/ 3 – 5 seconds
Strength Microdosing	1. Flywheel lateral and low to mid inertia 2. Individual IP 3. Individual IP	1. Flywheel horizontal high inertia 2. Individual IP 3. Individual IP	1. Flywheel exercise 2. Individual IP 3. Individual IP	1 – 2 sets 4 – 6 reps
COD	-COD drill with 2-3 COD x 2-3 repetitions each side 60-90° COD with 5-10 m approach with finish on mini goal	-COD drill with 2-3 COD x 2-3 repetitions each side 135-180° COD with 5-10 m approach with finish on	None	2 – 4 sets

		goal		
COD = change of direction, DL = double leg, ISMTP = isometric mid-thigh pull, IP = injury prevention				

7.2.4. Statistical Analyses

Within-session reliability was evaluated through ICC, CV, SEM and SWC. To assess the level of ICC, threshold values were interpreted as follows: 0 = no correlation; < 0.5 = poor reliability; 0.5–0.75 = moderate reliability; 0.75–0.9 = good reliability; > 0.9 = Excellent reliability (Koo & Li, 2016). ICC was interpreted based on the lower bound for a more conservative approach (Koo & Li, 2016). SEM was calculated using the formula [(SD (pooled) × (√1-ICC)] (Thomas et al., 2005), while SWC was calculated as 0.2 × between-subject SD (Mendiguchia et al., 2020). It has been suggested that for measurements to be useful in detecting SWC, the error associated with measurement needs to be less than SWC. If CV was higher than SWC, CV was used as the threshold to evaluate the meaningfulness (Beattie & Flanagan, 2015).

Normality for all variables was assessed using Shapiro-Wilks-tests. A two-way mixed ANOVA was used to explore any significant interactions (group × time) between groups with time (pre vs. post) for each variable. If a significant interaction effect was observed, Bonferroni-corrected pairwise comparisons were applied. Paired-sample t-tests were utilised to assess pre- to post-changes in variables. Comparisons in pre- and post-intervention primary results and between groups were also assessed using one-way ANOVA for the three groups. If a significant interaction effect was detected, Bonferroni-corrected pairwise comparisons were performed. Differences in magnitudes were evaluated utlising Hedges' g effect sizes, mean change, and percentage change (calculated as (post-pre)/pre * 100), accompanied by 95% CI. Hedges' g effect sizes adhered to the methodology outlined in a previous study (Hedges et al., 1994) and were interpreted as follows: trivial (≤ 0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), very large (2.0–3.99), and extremely large (≥ 4.00). Comparisons in mean changes between pre- and post-outcomes between groups were assessed using independent sample t-tests (CG vs DG, CG vs AG, DG vs AG). Subjects for both experimental groups (AG and DG) were median split into ‘fast’ and ‘slow’ performance based on their pre-test COD scores. As both groups were uneven (15 DG and 9 AG), the subject with pre-test scores standing in the median was not counted for analysis. Comparisons between pre-and post-tests for fast and slow performers were calculated using paired t-test. Statistical significance was set at ≤ 0.05 for all tests. Reliability values from within-session were obtained from pre-intervention testing.

Responses were classified as indicative of an individual change if they were >SWC (or CV when this was higher than SWC), whereas responses that were considered trivial or non-responsive were those falling ≤SWC or CV. The SWC, SEM, and CV scores for the 505 COD test (left and right) and the 75-90° COD test (left and right) were derived using pre-test data from the participants.

7.3. Results

7.3.1. Within-Session Reliability.

ICC scores for the COD test showed moderate to good reliability while CV scores showed to be < 5%. On the other hand, SEM ranged from 0.9% to 1.4%, while SWC showed to be between 0.6% and 0.7%.

Table 7.4. Reliability characteristics

	Mean (SD)	CV (95% CI)	ICC (95% CI)	SEM (%)	SWC (%)
COD 505 test left	2.33 (±0.07)	2.9% (2.3 – 3.5%)	0.85 (0.69 – 0.92)	0.02s (1.1%)	0.01s (0.6%)
COD 505 test right	2.33 (±0.07)	2.9% (2.3 – 3.5%)	0.76 (0.52 – 0.88	0.03s (1.4%)	0.01s (0.6%)
COD 75-90° test left	1.98 (±0.07)	3.5% (2.8 - 4.2%)	0.84 (0.67 – 0.92)	0.02s (1.3%)	0.01s (0.7%)
COD 75-90° test right	1.96 (±0.08)	4% (3.1 - 4.9%)	0.94 (0.89 – 0.97)	0.01s (0.9%)	0.01s (0.8%)

BJ = broad jump, COD = change of direction, CV = coefficient of variation, ICC = intraclass correlation coefficient, SEM = systematic error measurement, SWC = smallest worthwhile change.

7.3.2. Between-Group Differences

505 COD Left

Significant main effects for time were found for 505 COD left (p = 0.049, $\eta 2$ = 0.010), while non-significant interaction effects of time and group were observed (p = 0.240, $\eta 2$ = 0.007), with no significant differences between groups in the pre-test (p = 0.713, $\eta 2$ = 0.03) or post-test times (p = 0.642, η2 = 0.005). Moreover, slower post-intervention times were performed in the CG (p = 0.012, g = -0.838, 2.23%, 0.051 s) being higher than SEM (0.02 s) and SWC (0.01s) and lower than CV (2.9%), while faster post-intervention times were seen in the DG (p = 0.044, g =-0.55, -1.49%, -0.035 s), being higher than SEM and SWC, but lower than CV (Table 7.4). Mean improvements were greater for the DG compared to the CG, with large effect sizes (p= 0.002, g = 1.307). More so, mean improvements were greater for the AG compared to the CG, with moderate effect sizes (p = 0.039, g = 0.698).

505 COD Right

Non-significant main effects for time (*p* = 0.897, η2 < 0.001) and non-significant interaction effects of time and group were observed for COD 505 right (*p* = 0.672, η2 = 0.004), with no significant differences between groups in pre- (p = 0.791, η2 = 0.03) or post-intervention times (p = 0.294, η2 = 0.018). Moreover, faster post-intervention times were seen in the DG (p = 0.018, g = 0.73, -1.53%, -0.036 s), with these improvements being higher than SEM (0.03 s), SWC (0.01 s) and lower than CV (2.9%) (Table 7.4.). No significant differences in mean improvements were seen between groups (Table 7.6., Table 7.7. and Table 7.8.).

505 COD Total

Non-significant main effects were found for time (*p* = 0.235, η2 = 0.012) or time and group (*p* = 0.300, η2 = 0.021), with no significant differences between groups in pre-intervention (p < 0.990, η2 < 0.001) or post-intervention times (p = 0.281, η2 = 0.042). Moreover, slower post-intervention times were seen in the CG (p = 0.044, g = 0.633, 1.81%, -0.064 s), while faster post-intervention times were seen in the DG (p = 0.013, g = 0.734, 1.51%, -0.071 s) (Table 7.5.). Mean improvements were greater for the DG compared to the CG, with large effect sizes (p = 0.001, g = 1.395).

75-90° COD Left

Non-significant main effects for time (*p* = 0.320, η2 = 0.003) or time and group were observed for 75-90° COD left (*p* = 0.430, η2 = 0.006). Non-significant differences between groups in pre-intervention (p = 0.917, η2 = 0.001) or post-intervention times (p = 0.211, η2 = 0.019) were seen between groups. Slower post-intervention times were seen in the CG (p = 0.016, g = -0.795, 2.05%, 0.041 s), being higher than SEM (0.02s) and SWC (0.01 s) but lower than CV (3.5%). No significant differences in mean improvements were seen between groups (Table 7.6, Table 7.7. and Table 7.8.). Mean improvements were greater for the DG compared to the CG, with moderate effect sizes ($p = 0.026$, $g = 0.890$).

75-90° COD Right

Non-significant main effects for time ($p = 0.774$, $\eta2 = 0.006$) or time and group ($p = 0.764$, $\eta2 = 0.007$) were found for 75-90° COD right. No significant differences between groups in pre-intervention ($p < 0.893$, $\eta2 = 0.002$) or post-intervention times ($p = 0.551$, $\eta2 = 0.009$) were seen between groups. No differences in pre- to post-intervention times were seen in any of the groups (Table 7.5.). Mean improvements showed no differences between groups (Table 7.6., Table 7.7. and Table 7.8.).

75-90° COD Total

Non-significant main effects for time ($p = 0.502$, $\eta2 = 0.006$) or time and group ($p = 0.560$, $\eta2 = 0.016$) were found for 75-90° COD Total. No significant differences between groups in pre-test ($p < 0.905$, $\eta2 = 0.005$) or post-test times ($p = 0.281$, $\eta2 = 0.055$) were seen between groups. Slower post-intervention times were seen in the CG ($p = 0.026$, $g = -0.714$, 1.87%, -0.069 s). No significant differences in mean improvements were seen between groups (Table 7.6., Table 7.7. and Table 7.8.). Mean improvements were greater for the DG compared to the CG, with moderate effect sizes ($p = 0.021$, $g = 0.960$).

Table 7.5. Pre- to post-changes.

		Pre		Post			% Change	Mean difference				Hodges' g effect size		
		Mean	SD	Mean	SD	p	Mean	Mean	SD	LB	UB	g	LB	UB
DG	COD 505 test left (s)	2.346	0.066	2.311	0.060	0.044	-1.49	0.035	0.061	0.001	0.069	0.557	-0.015	1.081
	COD 505 test right (s)	2.346	0.077	2.310	0.075	0.018	-1.53	0.036	0.052	0.007	0.064	0.673	0.112	1.214
	COD 505 test total (s)	4.693	0.136	4.622	0.136	0.013	-1.51	0.071	0.097	0.017	0.125	0.734	0.147	1.262
	COD 75-90° test left (s)	1.978	0.078	1.971	0.085	0.641	-0.35	0.006	0.054	-0.023	0.036	0.120	-0.377	0.612
	COD 75-90° test right (s)	1.980	0.074	1.973	0.052	0.631	-0.35	0.007	0.057	-0.024	0.039	0.123	-0.373	0.616
	COD 75-90° test total (s)	3.958	0.036	3.944	0.031	0.484	-0.35	0.014	0.019	-0.027	0.055	0.181	-0.319	0.674
AG	COD 505	2.300	0.077	2.287	0.100	0.496	-0.56	0.022	0.093	-0.049	0.094	0.226	-0.412	0.851

	test left (s)													
	COD 505 test right (s)	2.281	0.081	2.27	0.088	0.730	-0.48	0.012	0.102	-0.066	0.091	0.113	-0.515	0.735
	COD 505 test total (s)	4.591	0.135	4.556	0.161	0.537	-0.76	0.034	0.160	-0.088	0.157	0.205	-0.431	0.829
	COD 75-90° test left (s)	1.955	0.100	1.937	0.068	0.570	-0.92	0.017	0.089	-0.051	0.086	0.188	-0.446	0.811
	COD 75-90° test right (s)	1.942	0.068	1.915	0.072	0.529	-1.39	0.026	0.121	-0.066	0.120	0.209	-0.428	0.833
	COD 75-90° test total (s)	3.897	0.152	3.853	0.117	0.470	-1.12	0.044	0.175	-0.090	0.179	0.241	-0.399	0.866
CG	COD 505 test left (s)	2.278	0.052	2.330	0.015	0.012	2.23	-0.051	0.059	-0.089	-0.013	-0.838	-1.471	-0.178
	COD 505 test right (s)	2.299	0.69	2.311	0.084	0.564	0.51	-0.012	0.072	-0.058	0.033	-0.172	-0.738	-0.402
	COD 505 test total (s)	4.557	0.111	4.641	0.129	0.044	1.81	-0.064	0.097	-0.126	-0.002	-0.633	-1.227	-0.016
	COD 75-	1.950	0.075	1.991	0.072	0.016	2.05	-0.041	0.050	-0.073	-0.009	-0.795	-1.419	-0.145

	90° test left (s)													
	COD 75-90° test right (s)	1.930	0.089	1.957	0.090	0.178	1.37	-0.027	0.066	-0.069	-0.014	-0.401	-0.964	0.178
	COD 75-90° test total (s)	3.880	0.158	3.954	0.144	0.026	1.87	-0.069	0.093	-0.128	-0.009	-0.714	-1.322	-0.081
AG = attacker group, CG = control group, DG = defender group, COD = change of direction														

Table 7.6. Mean differences pre- to post-test between control and defenders

	Control		Defenders				
	Mean	SD	Mean	SD	Mean difference	p	Hedges g
COD 505 test left	0.051	0.059	-0.035	0.068	0.087	0.002	1.307
COD 505 right	0.012	0.072	-0.036	0.052	0.048	0.054	0.758
COD 505 test total	0.064	0.978	-0.071	0.075	0.135	0.001	1.395
COD 75-90° test left	0.041	0.050	-0.067	0.054	0.048	0.026	0.890
COD 75-90° test right	0.027	0.074	-0.073	0.057	0.034	0.157	0.548
COD 75-90° test total	0.069	0.093	-0.014	0.075	0.083	0.021	0.962

COD = change of direction, SD = standard deviation

Table 7.7. Mean differences pre- to post-test between control and attackers

	Control		Attackers				
	Mean	SD	Mean	SD	Mean difference	p	Hedges g
COD 505 test left	0.057	0.059	-0.022	0.093	0.073	0.039	0.698
COD 505 right	0.012	0.072	-0.012	0.102	0.024	0.525	0.618
COD 505 test total	0.064	0.978	-0.034	0.160	0.098	0.096	0.887
COD 75-90° test left	0.041	0.050	-0.017	0.089	0.059	0.069	0.568
COD 75-90°	0.027	0.066	-0.026	0.118	0.054	0.205	0.527

test right							
COD 75-90° test total	0.069	0.93	-0.044	0.175	0.113	0.071	0.663

COD = change of direction, SD = standard deviation

Table 7.8. Mean differences pre- to post-test between defenders and attackers

	Defenders		Attackers				
	Mean	SD	Mean	SD	Mean difference	p	Hedges g
COD 505 test left	-0.035	0.068	-0.022	0.093	-0.013	0.695	-0.162
COD 505 right	-0.036	0.052	-0.012	0.102	-0.023	0.457	-0.308
COD 505 test total	-0.071	0.097	0.034	0.160	-0.036	0.487	-0.288
COD 75-90° test left	-0.006	0.054	-0.017	0.089	0.011	0.708	0.155
COD 75-90° test right	-0.007	0.057	-0.026	0.118	0.019	0.602	0.220
COD 75-90° test total	-0.014	0.075	-0.044	0.175	0.030	0.560	0.241

COD = change of direction, SD = standard deviation

7.3.3. Differences Between Fast and Slow Performers

When separating between fast and slow performers, fast performers in both DG and AG showed no improvements from pre- to post-test (Figure 7.2. and Figure 7.4.). Slow performers in the DG showed very large improvements in COD 505 left ($p < 0.001$, g= -2.1) and large improvements in COD 505 right ($p = 0.026$, g= -1.17) and COD 505 total ($p < 0.001$, g= -1.47) but did not improve on COD 75-90° left, right and total (Figure 7.3). Slow performers in the AG showed very large improvements in the COD 75-90° right ($p< 0.001$, g= -2.57), moderate improvements in COD 75-90° left ($p< 0.001$, g= -1.09) and COD 75-90° total ($p< 0.001$, g= -0.895), and large improvements in COD 505 right ($p< 0.001$, g= -1.79) (Figure 7.5.). Individual responses can be seen in Table 7.9.

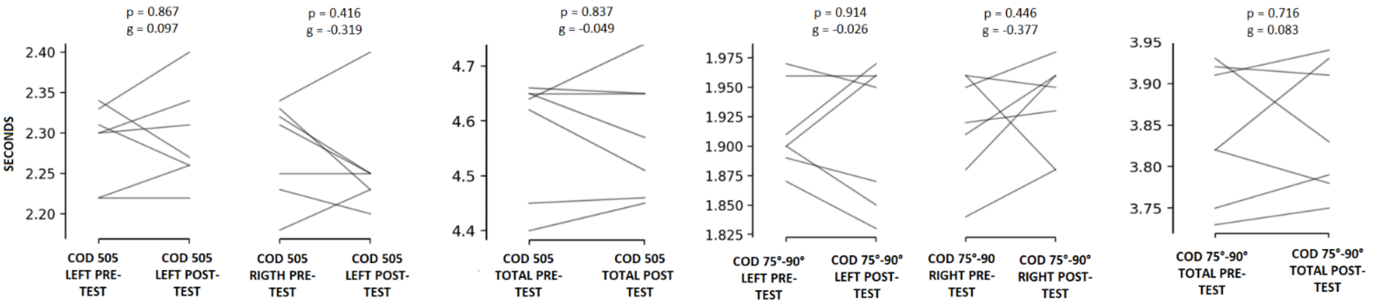


Figure 7.2. Pre- to post-test results in defenders fast group

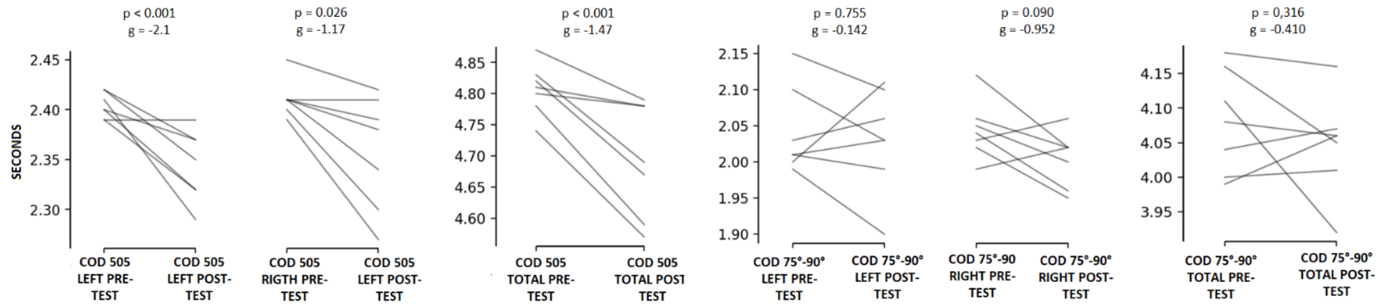


Figure 7.3. Pre- to post-test results in defenders slow group

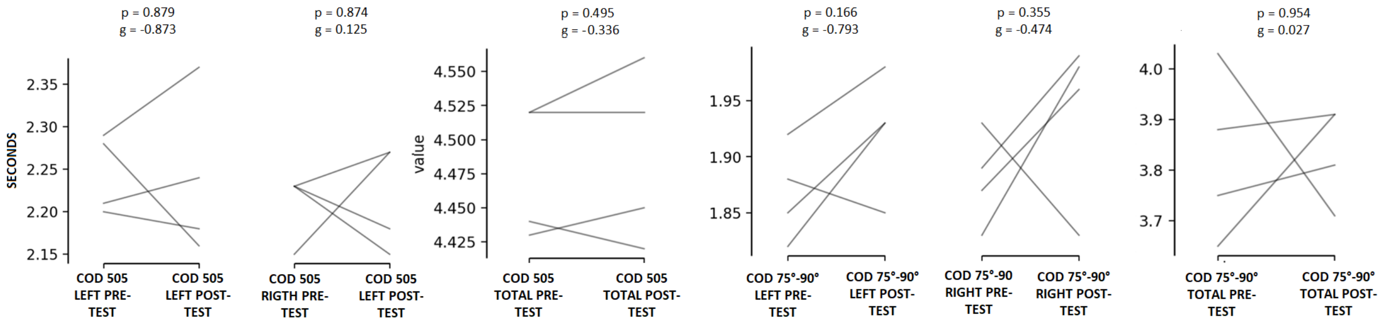


Figure 7.4. Pre- to post-test results in attackers fast group

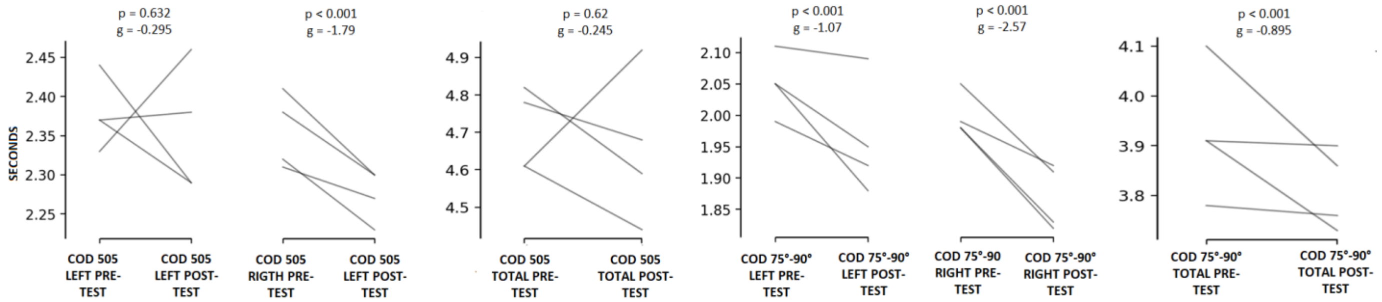


Figure 7.5. Pre- to post-test results in attackers slow group

Table 7.9. Individual responses

Group	COD Test	Individual response based on CV (positive, non, negative)
Defenders fast group	COD 505 test left	2-4-1
	COD 505 test right	2-3-1
	COD 75-90° test left	0-5-2
	COD 75-90° test right	1-5-1
Defenders slow group	COD 505 test left	4-3-0
	COD 505 test right	2-5-0
	COD 75-90° test left	2-4-1
	COD 75-90° test right	3-4-0
Attackers fast group	COD 505 test left	1-2-1
	COD 505 test right	1-2-1
	COD 75-90° test left	0-1-3
	COD 75-90° test right	0-2-2
Attackers slow group	COD 505 test left	2-1-1
	COD 505 test right	3-1-0
	COD 75-90° test left	3-1-0
	COD 75-90° test right	3-1-0

COD = change of direction

7.3.4. Jump Tests

No significant main effects for time or time and group were found for CMJ (time: $p = 0.613$, $\eta 2 = 0.737$, power = 0.078; time x group: $p = 0.787$, $\eta 2 = 1.362$, power = 0.084), SL CMJ left (time: $p = 0.504$, $\eta 2 = 1.139$, power = 0.100; time x group: $p = 0.808$, $\eta 2 = 1.069$, power = 0.080), SL CMJ right (time: $p = 0.704$, $\eta 2 = 0.300$, power = 0.066; time x group: $p = 0.379$, $\eta 2 = 4.100$, power = 0.208), SL BJ left (time: $p = 0.919$, $\eta 2 < 0.001$, power = 0.051; time x group: $p = 0.886$, $\eta 2 = 0.001$, power = 0.067) and SL BJ right (time: $p = 0.648$, $\eta 2 = 0.001$, power = 0.073; time x group: $p = 0.783$, $\eta 2 = 0.003$, power = 0.085). In addition, no significant differences were found from pre- to post-intervention in the CG for CMJ (p = 0.491, g = -0.217), SL CMJ left (p = 0.907, g = 0.35), SL CMJ right (p = 0.338, g = 0.292), SL BJ left (p = 0.908, g = 0.33) and SL BJ right (p = 0.645, g = 0,132). Similarly, no significant differences were found from pre- to post-intervention in the DG for CMJ (p = 0.817, g = 2.296), SL CMJ left (p = 0.548, g = 2.185), SL CMJ right (p = 0.634, g = 1.864), SL BJ left (p = 0.830, g = 0,117) and SL BJ right (p = 0.443, g = 0,097). Alike, no significant differences were found from pre- to post-intervention in the AG for CMJ (p = 0.627, g = -0.170), SL CMJ left (p = 0.460, g = -0.261), SL CMJ right (p = 0.346, g = -0.337), SL BJ left (p = 0.704, g = -0,132) and SL BJ right (p = 0.757, g = -0,108).

7.4. Discussion

The aim of this study was to investigate if two distinct training programs designed for attackers and defenders, which include specific exercises and drills, could improve position specific COD performance. The primary findings were that DG improved performance on the tests that were relevant to the specific training executed (505 COD test), while AG showed no improvements and CG showed sustained (COD 505 right and COD 75-90° right) and reduced performance (COD 505 test left and total, and COD 75-90° test left and total). In addition, mean improvement times were higher for DG vs CG in the COD 505 test left and the COD 505 test total, with large effect sizes. When separated into fast and slow groups, the fast groups showed no improvements in any of the tests, while the slow groups showed significant improvements, mainly in the specific COD test targeted through the training intervention. Slow performers in the DG showed large to very large improvements in all COD 505 tests, while slow performers in the AG showed moderate to very large improvements in COD 75-90° tests and large improvements in the COD 505 test right.

As shown in Chapter 4, COD actions are highly common in goal-scoring situations, with the player’s role being an essential factor, as CODs with high-intensity decelerations and sharp turns would be more specific for defending players, while CODs with a lower intensity deceleration and less sharp turns would be more adequate for attackers. The results of the present study show that a training protocol designed to improve position-specific COD performance can be successful. In this sense, DG improved pre- to post-test performance on the 505 COD tests, with moderate effect sizes. The fact that the AG and CG showed no improvements, as well as decreased performance in the CG for some of the tests (COD 505 test left and total, COD 75-90° test left and total) could be related to the lack of specificity in the CG or the period of the season in both groups, as previous studies have shown elite female soccer players to reduce or maintain COD performance during the in-season period (Karlsson et al., 2021; Stepinski, 2020, Lesinski et al., 2017), with researchers highlighting challenges in achieving meaningful variations in performance during the in-season period when specific training protocols are applied in elite players (Nonnato et al., 2022).

The fact that CG showed maintained or reduced performance could imply that in-season training focused on general strength, power, and COD abilities has a low potential to enhance or sustain COD performance. Conversely, targeted strength, power, and COD training has the potential to, at the very least, uphold or even enhance performance levels. In this sense, experimental studies utilising multiple training methods (i.e., strength + power/ + speed) have shown generally low transfer to COD performance when the training prescribed was not specific to the test performed in female soccer players. For example, Lindblom et al. (2012) found no improvements in the Illinois test after an intervention involving 11 weeks of one-legged knee squat, two-legged knee squat, the lunge, the bench and jump landing on female young soccer players, while Pardos-Mainer et al. (2019) found no improvements on a 180° COD test as well as V-cut test after performing the FIFA 11 protocol, which consisted of trunk and lower extremities' strength, balance, plyometric and agility components, in adolescent female soccer players. Conversely, Mathisen and Pettersen (2015) had regional young female soccer players perform resisted sprints, straight line sprints (20 m straight sprints) and COD drills [eight COD sprints (20 m) with 60° and 90° turns, and relay race with 90° turns] and found improvements in a COD test consisting in sprints with 2×90º and 2×180º turns. In this case, improvements could be attributed to the training drills executed being, to some extent, specific to the tests performed.

Although overall AG did not show improvements in COD performance, when separating between pre-intervention fast and slow groups, slow performers showed moderate to large improvements in the tests specific to the training performed (75-90° COD test). More so, 75% of the slow performer scores (6 out of 8) in the above-mentioned test, showed positive responses post-intervention, while only 25% (2 out of 8) showed positive responses post-intervention in the fast group. In addition, while DG showed significant improvements pre- to post-intervention, slow performers but not fast performers showed large to very large improvements in the specific COD test related to the training program completed (505 COD test). In this regard, six out of 14 players in the slow group showed positive responses post-intervention, while four out of 14 showed positive responses in the fast group. Therefore, slow performers would indeed benefit from this specific type of training, while the lack of improvement in fast players raises the question of whether players who are already performing at a high level may not necessarily gain significant benefits from targeted training aimed at improving their COD ability. In this case, programs might need to be further adapted based on the underlying qualities of the COD test aimed to be improved taking into consideration the needs analysis of the player. For example, a defender could be considered a fast performer on the 505 COD test but have a relatively low score on the CMJ test. Therefore, the program should have a focus on improving COD ability but should have a stronger focal point on improving the long SSC of the player. Previous studies have shown that fast vs slow performers in a modified COD 505 test demonstrated shorter final ground contacts, produced lower vertical impact forces, lower horizontal braking force ratios, and greater horizontal propulsive force (Dos'Santos et al., 2017a). In addition, Falch et al. (2021) found in young female soccer and handball players that fast compared to slow performers in a 180° COD test and a 45° COD test were significantly stronger in the bilateral and unilateral squat and jumped significantly higher in the unilateral countermovement jump. This was not the case in a lateral jump test, a reactive strength test and a lateral squat strength test.

Jones et al. (2022) found that elite female players with high (upper 50th percentile) knee eccentric strength showed significantly greater velocities at key instances during a 70°-90° COD test, implying that these players were able to approach with faster velocities and tolerate the higher load related with the faster approach. It could be inferred that slower individuals, through a targeted training routine tailored to the specific physical demands of the COD test, would develop and enhance their proficiency in completing such assessments. Moreover, by identifying individual strengths and weaknesses in kinetic variables, specific training programs can be developed to enhance COD ability, especially in fast performers. While in this study, unfortunately, we did not assess kinetic variables that could have affected changes in COD performance, a previous study has shown how COD-specific training, in the form of eccentric overload exercises, can induce kinetic changes. In this regard, in a study by de Hoyo et al. (2016b) U-19 male soccer players performed a 10-week training protocol consisting of multi-joint (squat) and single-joint (leg curl) eccentric overload exercises in a flywheel squat and flywheel prone leg curl flywheel. After the intervention, players produced significantly lower braking and propulsive contact times, as well as greater braking and propulsive forces and impulses in the side-step COD test (45º cut) and crossover COD test (60º crossover cut).

While in this study jump outcomes were assessed pre- to post-test, none of the groups showed performance increases. This contrasts with previous research, as studies have shown improvements in jump and/ or strength tests parallel to COD performance enhancement (Pardos-Mainer et al., 2019; González-García et al., 2019; Ramirez-Campillo et al., 2018; Ramírez-Campillo et al., 2016), although other studies have shown no improvements in COD ability but enhanced performance in jump or strength tests (Millar et al., 2020; Bimson et al., 2017; Pecci et al., 2022), or no improvements in COD tests along with no increases in jumping height (Nonnato et al., 2022). While the lack of improvements in AG and CG as well as the reduced performance in the CG pre- to post-tests could be explained by the absence of improvement in jump tests, the enhanced performance in the DG without improvements in jump tests could be explained by gains in strength and/or specific kinetic and kinematic variables not assessed in this study. In this sense, a novel study from Dos'Santos et al. (2021a) performed on senior male multidirectional sports athletes (amateur/semi-professional) focused on pre-planned low-intensity decelerations and turns where intensity was progressed through higher speed and turning angles, as well as the introduction of stimulus with increased intensity. Authors found improvements in COD performance (measured through modified 505 COD test), but also in kinetic variables associated with an enhancement in COD ability (increase in mean horizontal propulsive forces, more horizontally orientated final foot contact propulsive force and penultimate foot contact braking force, and greater pelvic rotation, penultimate foot contact hip flexion, and penultimate foot contact velocity reductions). Therefore, future studies should investigate how specific COD training can modify kinetic and kinematic variables in specific COD tests.

7.5. Limitations

Firstly, estimating an appropriate sample size for this study proved challenging due to the scarcity of analogous research and the numerous limitations documented in prior literature. Another limitation was the mixed number of participants for each of the groups (CG = 12; DG = 15, AG = 9), which would inevitably produce a reduction in statistical power. Moreover, when the median split analysis was performed to separate between fast and slow performers, AG had only four subjects in each group, which could be considered too small, and thus, not enough to generalize findings to a larger population. In addition, due to a lack of time and resources, the different muscle strength and power or jump characteristics evaluated in previous chapters could not be measured in this study. This evaluation could have helped to understand whether changes in strength and power or jump individual qualities would influence changes in COD performance. In this sense, the jump tests executed would be considered slow SSC tests, which would be mainly related to the sharp COD test performed. Moreover, the groups did not perform the training intervention in the same season. During the 2021/2022 in-season, the CG conducted the training intervention, while DG and AG performed the training intervention in the subsequent 2022/2023 in-season period. Differences in training variables between these two seasons may have had an impact on the study's findings.

The COD deficit was not calculated in this study. Although COD deficit could represent a step forward towards the isolation of certain parts of a COD, this still doesn't give precise information on which specific parts of that COD have a "deficit" (i.e., deceleration, turn), while also not having the same phases of a sprint (Drobnič, 2020). Moreover, a recent study showed that COD deficit could be biased towards slower athletes (Fernandes et al., 2020). This would be supported by other studies showing faster players to have higher COD deficits in young elite soccer players (Loturco et al., 2018a) and professional rugby players (Freitas., 2019b). Faster players would not only have the disadvantage of being quicker in the 10-m test (which would predispose them to a higher COD deficit) but would also have to manage greater momentum derived from higher speeds obtained prior to the deceleration and turn.

During the 1st 5 weeks, some players with less experience performed the strength exercises with repetitions ranging from 6RM to 10RM. While this number of repetitions would be higher than the recommended for maximal strength training, as these would be considered hypertrophy training (Schoenfeld et al., 2021), this decision was made to ensure a smoother progression towards maximal strength training for those players with less strength training experience. In addition, while it's been proven that 2-3 sets are associated with bigger improvements in strength vs 1 set (Krieger, 2009), some strength microdosing sessions on M-4 and very occasionally strength sessions on M-3 were performed executing 1 set. This would occur when trying to reduce general or individual fatigue levels. Similar occurred with the power sessions. While generally, players would perform 2 sets, occasionally this was reduced to 1 set due to the same reasons highlighted above.

Finally, not all the exercises and drills in the program for the IGs were position specific, as two out of six exercises in the power session were based on the player's individual needs rather than the player's position, while two out of three exercises in the strength microdosing was based on player's injury mitigation needs. In any case, it's important to understand that this study was conducted in a professional applied setting, where individualization is a key priority.

7.6. Conclusion

In conclusion, DG improved pre- to post-intervention in the COD tests that were relevant to the specific training intervention performed (COD 505 left and COD 505 right), and when the group was split (median split analysis) into pre-test slow vs fast performers, only slow performers showed improvements in these tests. Furthermore, while AG showed no improvements pre- to post-intervention, when the group was split into fast vs slow performers, the latter showed improvements in the tests specific to their training intervention (75-90° COD left, 75-90° COD right and 75-90° COD total). Therefore, while a program based on specific exercises to improve role-specific COD ability was enough to improve COD performance in slow players, this was unsuccessful in fast players, and so, an effective program for the latter should further emphasize specific training based on their individual profiling.

7.7. Practical Applications

Based on the findings from this study, practitioners working with female soccer players should consider designing distinct training programs for attackers and defenders, recognising the specific COD demands of each role. These programs should consider a holistic approach, including exercises and drills that target specific physical requirements that have been shown to improve position-specific COD performance. This should include drills that mimic these role-specific COD actions. In addition, practitioners should adopt an individualised approach, as not all players may benefit equally from the same training intervention. Thus, to optimize COD ability, especially for fast performers, an extensive player profile should be performed to identify training targets (i.e., eccentric training, deceleration training, etc) alongside position-specific considerations.

8. SYNTHESIS OF FINDINGS

8.1. Global Discussion

The aim of this thesis was to inform assessment and training strategies to enhance COD performance in elite female soccer players based on the position-specific COD demands in key moments of matches. In order to achieve this aim, the thesis had the following objectives: 1. To examine the movements and combination of them that occur before a goal in male and female elite soccer players, as well as acknowledge differences between sex and roles (attackers and defenders). 2. Identify the movements classified as COD actions and determine their frequency in goal-scoring scenarios. 3. Investigate which speed, jump and strength tests are associated with relevant COD tests. 4. To compare the effects of a position-specific training intervention to improve COD performance in elite female soccer players.

The research confirms that COD actions are integral to crucial match moments, such as goal-scoring opportunities, in both male and female soccer. The fact that these movements are performed in 2/3 of player involvements leading to goals underscores the need to prioritize COD training. By improving COD performance, players can be better equipped to influence these critical game moments, directly impacting match results. More so, the thesis highlights the different COD demands based on player positions. Attackers were shown to perform higher proportions of linear advancing motion, cuts and subtle turns, while defenders perform higher percentages of sharper turns, lateral movements, arc runs (only EPL), as well as more high-intensity decelerations, high-intensity linear advancing movements and high-intensity turns (only EPL). This differentiation is crucial as it allows coaches to tailor training programs to meet the specific demands of each position, enhancing overall team performance and player effectiveness. It is also important to note that, while we divided COD actions into four different types, the variety and/or combination of movements for each type of COD would be unlimited. While based on the role, players tend to perform a higher frequency of a certain type of COD in goal-scoring situations, it is unlikely that players would repeat the same COD action, and so, when designing training drills and exercises, variety should be a priority. Based on the findings from the first study, the 505 COD test and 75-90° COD test were identified as the most appropriate tests to assess COD ability in defenders, and attackers, respectively. By identifying specific COD tests that align with the demands of different positions, coaches can more accurately assess and track the COD capabilities of their players.

The next step was to select different tests that would allow us to understand which physical capabilities best relate to the COD test selected to create optimal training interventions designed for the different roles. Different strength, power and speed tests were selected (Chapter 5). Before assessing any relationships, within-session reliability of different tests was performed, with tests generally showing moderate to excellent reliability. In any case, due to our findings, it would be advised for practitioners to perform an additional trial when performing the 505 COD test or acceleration tests. Moreover, additional familiarization sessions would be recommended when performing FSCS and FSES tests due to their high CV scores, especially for players not familiarized with the use of flywheel devices, as the motion characteristics would differ from other traditional tests or exercises prescribed.

After having assessed the reliability of these tests, a correlation study was performed (Chapter 6). Results showed that the two tests selected (defenders: 505 COD test, attackers: 75-90° COD test) represent distinct COD qualities. Therefore, it makes sense that the physical qualities underpinning these two COD tests differ. In this sense, long SSC jump tests and strength tests tended to favour the COD test with the sharper turn, while fast SSC jumps (DJ and SL DJ) tended to show higher correlations with the shallow COD test, supporting previous recommendations (Dos'Santos et al., 2018a). These findings demonstrate that different physical qualities, such as strength and jump capabilities, are associated with different types of COD actions. This knowledge enables practitioners to design specific drills that enhance the physical attributes most relevant to the COD demands of each position.

The final step was to perform an experimental study on elite female soccer players to investigate if two distinct training programs designed for attackers and defenders, including specific exercises and drills, can improve position-specific COD performance. The experimental study provided evidence that tailored training programs based on positional demands can improve COD ability, particularly for players who are not elite performers in this area. This highlights the importance of individualized training approaches, where slow performers may benefit from specific drills, while advanced players may require a more nuanced approach to avoid performance plateaus.

Overall, these findings equip coaches and sports scientists with a detailed understanding of the COD dynamics in female soccer, enabling them to implement more effective, data-driven training regimens. This thesis provides actionable insights that can transform how COD training is approached in women's football. By focusing on position-specific demands, using appropriate assessment tools, and tailoring training interventions, coaches can significantly enhance their team's performance in key match situations. In this sense, the significance of linear speed and its impact on performance has been highlighted previously, with a study showing that female players at the international level are at least 1 m ahead of second-division players from the same country (Haugen et al., 2012). Similarly, the ability to change direction faster could give players an advantage over slower opponents. Therefore, specific training strategies described in this thesis could enhance a player's ability to execute quick changes of direction, which could provide an advantage in crucial moments of the game.

Tailored programs for the enhancement of COD performance could also have a direct impact on the prevention of ACL injuries, which has shown a higher proportion in female vs male players (Montalvo et al., 2019). Programs looking to enhance COD ability would include gym exercises that increase strength and stability in key muscles that support knee function, such as the quadriceps and hamstrings, reducing the likelihood of ACL injury (Hewett et al., 2016). In addition, COD training focusing on technique could not only enhance performance but also optimise movement mechanics and reduce ACL injury risk (Dos'Santos et al., 2019b).

8.2. Limitations, Considerations, and Recommended Future Directions of Research

Limitations for each of the studies have already been discussed in previous chapters, and so, in this section, we will discuss wider limitations.

Firstly, the PhD analysed COD performance rather than agility. COD is considered part of agility, which means focusing solely on COD might oversimplify the multi-faceted nature of agility, potentially leading to incomplete findings and applications. In this sense, research focused solely on COD might miss the broader implications of agility, particularly in team sports, such as soccer, where cognitive and perceptual skills are critical. Anyhow, measuring agility can be complex as it involves physical, cognitive, and perceptual components, making it challenging to develop comprehensive measurement tools that capture all these aspects. In addition, unlike COD, which can be measured with relatively straightforward physical tests, accurate measurement of agility often requires advanced technology (e.g., motion capture systems, and reaction time sensors).

The first part of this thesis involved analyzing goal-scoring situations through video analysis. This method was utilised due to tracking devices such as GPS having limited significance regarding subtle manoeuvres taking place in goal-scoring situations such as accelerations, decelerations or COD actions, as these activities have shown high variability (Buchheit et al., 2014a; Jennings et al., 2010). However, video analysis has its own limitations, such as the subjectivity of the researcher assessing this. While inter-rater and intra-rater reliability showed good levels of agreement, future research should seek to incorporate both subjective and objective measures. For example, the development of inertial sensors and optical tracking technologies offers the promise of simpler objective assessment.

Another limitation was the restricted access to testing equipment. In an ideal situation, this thesis would have had unlimited access to extensive equipment (force plates, isokinetic device, etc.). Even though the club participated in the highest level of English women’s football, WSL, resources were still limited compared to the men’s first team or the academy . In this case, testing equipment was loaned from the academy. This meant that access to equipment and space was limited to the period when the academy wasn’t using these apparatuses, which ultimately restricted or limited the time available for testing and the dates when these could be used. The impact of women's teams being under-resourced could affect the number and quality of research being performed, with only one out of five articles published in football including women, and just 15% of the research in elite soccer performed on women (Kirkendall & Krustrup, 2022). This would have an impact on the holistic understanding of women’s football and affect not only performance but also injury prevention strategies. In this case, programs might be designed based on male soccer players rather than female.

8.3. Conclusions

The most common movement before a goal showed to be linear advancing movement, followed by deceleration and turn, which are commonly combined in a particular order. Both attackers and defenders in EPL and WSL perform COD actions in more than 2/3 of the involvements. This thesis shows that there are differences in how attackers and defenders perform these actions during goal-scoring situations. Attackers perform higher proportions of linear advancing motion, cuts and subtle turns (0-60º) while defenders perform higher percentages of sharper turns (60º-120º and 120º-180º), lateral movements, arc runs (only EPL), ball blocking actions, as well as more high-intensity decelerations, high-intensity linear advancing movements and high-intensity turns (only EPL) (Chapter 4). The reliability of the tests used to examine the relationships between the selected position-specific COD tests (based on Chapter 4) was found to be, in general, high, except for 5 m and COD 505 right side, which exhibited poor ICCs. Moreover, FSCS and FSES tests presented low consistency and would benefit from more familiarization (Chapter 5). The two COD tests selected (COD 505 test and 75-90° COD) were shown to represent distinct COD qualities, supporting the targeted selection of these tests for the different positions. Speed tests showed moderate correlations with both COD tests. On the other hand, slow SSC tests showed higher correlations with the CO5 505 test while short SSC tests showed a tendency for higher correlations with the 75-90° COD test. Moreover, IMTP and FSES showed higher correlations with the COD 505 test, while FSCS and NHES showed no correlations with the COD tests. Generally, these correlations obtained could be related to the similarities in the time available to generate forces on the test performed (Chapter 6). In Chapter 7, it was found that only DG improved pre- to post-intervention in the COD tests that were relevant to the specific training intervention performed but when groups were split into fast and slow performers, both DG and AG showed significant improvements in the slow groups, again on the tests relevant to their training intervention, which underscores the importance of implementing tailored training interventions focused on specific physical attributes that improve role-specific COD performance in elite female soccer players. Anyhow, for players who are already quick performers, more tailored interventions are necessary, considering their individual strengths and weaknesses. (Chapter 7).

8.4. Recommendations

8.4.1. Practical Applications

- Linear advancing motion is the most common action, followed by deceleration and turn, and are usually performed on a certain cycle.
- While attackers and defenders show common trends, Attackers perform higher proportions of linear advancing motion, cuts and subtle turns while defenders perform higher percentages of sharper turns (60º-120º and 120º-180º), lateral movements, arc

runs (only EPL) high-intensity decelerations, high-intensity linear advancing movements and high-intensity turns.

- To evaluate COD performance effectively, it is recommended to employ specific tests that mirror the actions typically carried out by various roles, such as attackers and defenders. In this sense, the COD 505 test would represent a test suitable for attackers while the COD 75º -90º test would be more appropriate for defending players.
- COD tests (COD 505 test and COD 75º -90º) along with jump (CMJ, SL CMJ, SL BJ, DJ and SL DJ), speed (5, 10, 20 and 30 m) and strength (FSCS, FSES, NHES and IMTP) tests, generally show to be reliable tests in elite female soccer players.
- Slow SSC tests, as well as isometric and eccentric strength tests, tend to favour the 505 COD test, while short SSC tends to favour the 75º - 90º COD test.
- A targeted training intervention focused on specific physical attributes that contribute to improving role-specific COD performance proved effective, particularly for slower performers.
- Practitioners working with female soccer players should consider designing distinct training programs for attackers and defenders, recognising the specific COD demands of each role.
- Practitioners should adopt an individualized approach to optimize COD ability by identifying specific training targets alongside position-specific considerations.

8.4.1. Future Direction of Research

- Analysis of movements and COD actions during goal-scoring chances and other scenarios such as corners or tactical specific situations (e.g. high press, counterattack, etc.) utilising both objective (i.e. GPS) and subjective measures (video analysis). In addition, a combined analysis of the physical, technical and tactical would bring a holistic approach rather than a reductionist assessment.
- Investigation of the physical underpinning qualities of each type of COD.
- Training interventions aiming to enhance the different types of COD.
- Exploration of the relationships between kinetic variables and COD performance during the execution of the selected test.
- Training interventions investigating how specific COD training can modify kinetic and kinematic variables in specific COD tests.

APPENDIX:

Appendix 1: Ethical Approval:

The Ethics Panel has reviewed your application: Relationships Between Speed, Power, Strength and Change of Direction in Soccer Players
Application ID: 3168

The decision is: Application Approved.

The Ethics Panel has reviewed your application: Effects of a Position Specific Training Intervention for The Enhancement of Change of Direction Performance in Female Professional Soccer Players
Application ID: 7910

The decision is: Application Approved.

Appendix 2: Research Articles Published

Research Published 1

Routledge
Taylor & Francis Group

Science and Medicine in Football

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rsmf20

Linear Advancing Actions Followed by Deceleration and Turn Are the Most Common Movements Preceding Goals in Male Professional Soccer

David Martínez Hernández, Mark Quinn & Paul Jones

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Research Published 2

Science and Medicine in Football

Routledge
Taylor & Francis Group

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rsmf20

Most common movements preceding goal scoring situations in female professional soccer

David Martínez-Hernández, Mark Quinn & Paul Jones

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Article Published 3

Flywheel Eccentric Training: How to Effectively Generate Eccentric Overload

David Martínez-Hernández, MSc[1,2]
[1]Directorate of Sport, Exercise and Physiotherapy, University of Salford, Salford, United Kingdom; and [2]Medical and Sports Science Department, Tottenham Hotspur Women Football Club, London, United Kingdom

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (http://journals.lww.com/nsca-scj).

ABSTRACT

Eccentric resistance training has been shown to elicit beneficial effects on performance and injury prevention in sports because of its specific muscular and neural adaptations. Within the different methods used to generate eccentric overload, flywheel eccentric training has gained interest in recent years because of its advantages over other methods such as its portability, the ample exercise variety it allows and its accommodated resistance. Only a limited number of studies that use flywheel devices provide enough evidence to support the presence of eccentric overload. There is limited guidance on the practical implementation of flywheel eccentric training in the current literature. In this article, we provide literature to support the use of flywheel eccentric training and present practical guidelines to develop exercises that allow eccentric overload. See Supplemental Digital Content 1, http://links.lww.com/SCJ/A380 for a video abstract of this article.

Address correspondence to David Martínez-Hernández, d.martinezhernandez@edu.salford.ac.uk.

INTRODUCTION

Resistance training has been shown to play an important role in the enhancement of sports performance. Indeed, different reviews and meta-analyses have shown that muscular strength can improve various general sports skills such as jumping, sprinting, and change of direction (COD), and reduce injury risk (3,100,102,107). Within the multiple training methods used to enhance strength, eccentric training has gained a special interest in recent years (47). Eccentric contraction corresponds to the active lengthening phase of muscle action. During this eccentric contraction, the muscle absorbs energy that is created by the external load (1).

Although the specific neural strategies during eccentric contractions are not fully understood, adjustments at spinal and supraspinal level assist in particular modulation of voluntary activation during eccentric contractions (29). Eccentric strength has been shown to be ~40% greater than concentric strength in men and women and shown to be higher at faster movement speeds (78). Eccentric exercise is less metabolically demanding and requires less motor unit recruitment compared with concentric exercise for the same mechanical output (82,83). This reduced motor unit activation has implications on eccentric coordination, with reduced fine motor control, because fewer motor units are needed for the same work (48). In contrast to the force–velocity curve during concentric contractions, force during eccentric contractions increases with higher speeds up to a point where it plateaus or slightly decreases (86). Higher speeds would also produce higher mechanical stress to active fibers (21), with some studies suggesting that high-velocity eccentric contractions do not follow the size-based order of motor unit recruitment (49,72). In addition, after eccentric contraction, there is residual force enhancement, which refers to an increase in steady-state isometric force after the lengthening action when compared with isometric force not preceded by an eccentric contraction (46), which could be related to the passive action of a structural protein, titin, interacting with actin and myosin (45).

KEY WORDS:
resistance training; eccentric training; injury prevention; physical performance; strength and power

Article Published 4 (Accepted, in process of being published)

International Journal of Strength and Conditioning

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Change Of Direction Actions In Goal Scoring Situations In Male And Female Professional Soccer

David Martínez-Hernández[1,2] & Paul Jones[1]

[1]Directorate of Sport, Exercise and Physiotherapy, University of Salford, Salford, Greater Manchester, United Kingdom, [2]Medical and Sports Science Department, Tottenham Hotspur Women Football Club. London, United Kingdom

ABSTRACT

The aim of this study was to analyse the frequency of COD actions in goal scoring situations. Data was collected through time motion analysis of goal scoring actions from teams participating in English Premier League (EPL) and Women's Super League (WSL) during the 2018/2019 season using a modified version of the Bloomfield Movement Classification with differences analysed through chi-square ($p < 0.05$).

In (total percentage [95% CI] 71.6% (±1.7%) and 70.6% (±3.1%) of players involvements in EPL and WSL there was a COD action. For EPL and WSL, respectively, attackers performed COD actions in 71.9% (±2.3%) and 72.9% (±4.1%) of the involvements while defenders in 71.2% (±2.6%) and 67.8% (±4.7%). In 56.1% (±1.9%) and 57.1% (±3.3%) of the involvements there was at least 1 COD action performed at high intensity for EPL and WSL, respectively.

Soccer players are frequently exposed to different COD actions during goal involvements, with these being performed frequently at high intensity and so, this physical ability could play an important role in the performance outcomes of a match. Therefore, emphasis should be placed on increasing player's COD speed capabilities taking into account the tendency for specific COD actions for different players' based on their roles.

Keywords: Agility; Soccer; Sprint; Goal Scoring Situations; Women's Super League; English Premier League

INTRODUCTION

Change of direction (COD) ability is considered one of the most important physical capabilities in soccer and is theorised to involve different types of actions based on the field position during matches (McBurnie & Dos'Santos, 2021). COD actions can be included as part of an agility task but also as part of a movement where there is no need to react to a stimulus (Sheppard & Young, 2006). COD ability has shown to discriminate between levels of performance (Kutlu et al., 2017; Kaplan et al., 2009) with males compared to females showing faster performances (Mujika et al., 2009). More so, COD ability has shown to predict high intensity accelerations and decelerations on a match (Gonçalves et al., 2021). It is therefore not surprising that COD ability is habitually targeted by practitioners as a physical capacity to enhance through specific training methods (De Keijzer et al., 2021). COD actions have shown to lead to different joint and muscle injuries in both male and females. In particular, movements such as cutting and decelerating commonly performed in COD actions have shown to lead to ACL injuries in both male and females, with higher recurrence for the latter (Lucarno et al., 2021; Della Villa et al., 2020). On the other hand, hamstring injuries, which show to be more common

Appendix 3: Poster Presented in XI International Symposium of Strength Training

SIMPOSIO DE FUERZA

POLITÉCNICA

University of Salford MANCHESTER

Most Common High Intensity Movements Preceding a Goal in Male and Female Professional Soccer Pilot Study: Are We Training in the Right Direction?

David Martinez Hernandez & Paul A. Jones

Sport, Exercise & Physiotherapy, University of Salford, Salford, UK

BACKGROUND

During matches soccer players cover 9 –14 km of distance (Di Salvo et al., 2009) with 150 – 250 high intensity (HI) actions (Mohr et al, 2003). These intense actions could potentially influence the final outcome of a game. For example, Faude et al. (2012) revealed that 83% of the goals in the Bundesliga during 2007/2008 were preceded by a powerful action (e.g., a sprint) of the scoring or the assisting player. Limited studies have examined the speed and agility demands of male and female soccer through the exploration of the frequency of movement actions during match play.

OBJECTIVES

To determine the frequency of movement actions (i.e., sprints, deceleration, turns, cuts) of soccer players (scorer, assistant, defender of scorer and defender of assistant) and their intensity just before a goal in English Premier League (EPL) and Women's Super League (WSL).

METHODS

Movements preceding a goal of the first 10 (100 matches) and 7 matchdays (34 matches) of EPL and WSL 2018/2019 season respectively were analyzed through British public sport program highlights and goals. Own goals, penalties, direct throw-ins, direct free-kicks, crossing free-kicks, non-intended actions and rebounds were excluded from analysis. Movements preceding goals were examined using a modified version of The Bloomfield Movement Classification (Bloomfield et al., 2004) as seen in Figure 1. Analysis was performed for a maximum of 5 movements previous to the shot or assist for the scorer and assistant respectively and the counterpart last defensive action from the defender of scorer and the defender of assistant. Kappa coefficients for intra-observer reliability of movements in a same matchday were analyzed with 4 weeks in between obtaining a score of k= 0.92.

TABLE 1 Modified Version of The Bloomfield Movement Classification

MOVEMENTS	MODIFIER 1: DIRECTION	MODIFIER 2: INTENSITY	MODIFIER 3: BALL
LINEAR			
Sprint Run Jog Walk	Forwards, Forwards Diagonally Backwards		Yes, No
LATERAL			
Shuffle Crossover Step		Low, Medium, High	Yes, No
LINEAR & LATERAL BRAKING			
Deceleration	Forwards, Forwards Diagonally Backwards, Sideways	Low, Medium, High	Yes, No
CHANGE OF DIRECTION			
Turn	0º-60º, 60º-120º, 120-180º, 180º-270º, 270º-360, >360	Low, Medium, High	Yes, No
Cut		Low, Medium, High	Yes, No
Arc Run		Low, Medium, High	Yes, No
OTHER			
Skip	Forwards, Backwards, Sideways		Yes, No
Impact Stand Still			Yes, No
Jump, Tackle, Dive, Slide, Jump, Land, Fall, Get Up, Pass, Shoot			

RESULTS

267 and 99 goals were scored with 180 and 73 being selected for analysis in EPL and WSL, respectively. Results are presented in Table 2, Figures 1, and 2.

FIGURE 1: Frequencies of the Most Common Actions Preceding a Goal and Percentage Occurring at High Intensity

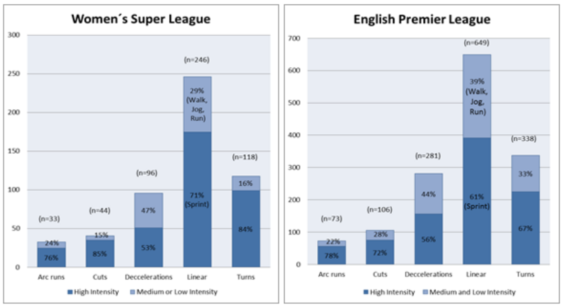


TABLE 2: Movements (all intensities) occurring before and after a certain movement at HI

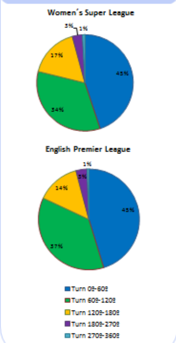
ENGLISH PREMIER LEAGUE

MOVEMENT	ARC RUN (HI)	CUT (HI)	DECCELERATION (HI)	SPRINT	TURN (HI)
BEFORE					
Arc run	X	2	7	15	1
Cut	1	X	0	41	2
Deccelaration	1	0	X	16	84
Linear	32	58	67	X	31
Turn	5	4	15	106	X
AFTER					
Arc run	X	4	1	4	5
Cut	0	X	0	1	4
Deccelaration	8	5	X	18	21
Linear	19	52	12	X	115
Turn	1	5	66	1	X

WOMEN'S SUPER LEAGUE

MOVEMENT	ARC RUN (HI)	CUT (HI)	DECCELERATION (HI)	SPRINT	TURN (HI)
BEFORE					
Arc run	x	1	1	10	0
Cut	0	x	0	19	1
Deccelaration	0	5	x	12	29
Linear	18	22	20	x	15
Turn	2	0	12	40	x
AFTER					
Arc run	x	0	1	20	5
Cut	This Photo by Unknown Author is licensed under CC BY-SA			22	0
Deccelaration	2	2	x	24	11
Linear	16	51	7	x	59
Turn	0	1	28	17	x

FIGURE 2: Percentages of Frequencies for Different Turning Degree Ranges



CONCLUSIONS

Initial results suggest that the most common movement prior to a goal is a straight sprint substantiating previous research (Faude et al., 2012). In addition, actions involving decelerations and changes in direction also show to be of considerable importance.

PRACTICAL APPLICATIONS

Physical preparation for soccer should consider the importance of high intensity actions such as sprinting in match deciding events. Furthermore, the high frequency of decelerations and >60° change of direction actions highlight the importance to develop specific muscle strength qualities such as eccentric strength in male and female soccer players.

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CONTACT

+44(0)784580067 davidmartinez_90@hotmail.com

Appendix 4: Presentation for SheWins Symposium

https://www.youtube.com/watch?v=SFUvgtHwzx4&t

Appendix 5: Article at Sportsmith

https://www.sportsmith.co/articles/change-of-direction-training-on-the-field-and-in-the-gym/

Appendix 6: Supplementary Tables

Supplementary Table 1. Movements with and without the ball for assistants and scorers in EPL.

	With/without the ball	Assistant (%)	Scorer (%)	HI actions with ball (%)
Jog	Without ball	21 (24.1% ±9%)*#	35 (79.5% ±11.9%)*	
	With the ball	66 (75.9% ±9%)#	9 (20.5% ±11.9%)	
Run	Without ball	71 (33.5% ±6.4%)*#	158 (61.7% ±5.6%)*	
	With the ball	141 (66.5% ±6.4%)#	98 (38.3% ±5.6%)	
Sprint	Without ball	115 (40.9% ±5.8%)*#	370 (66.3% ±3.9%)*	
	With the ball	166 (59.1% ±5.8%)#	188 (33.7% ±3.9%)	
Total Linear Advancing Motion	Without ball	214 (36% ±3.9%)*#	566 (65.7% ±3.2%)*	354 (52.3% ±3.7%)
	With the ball	380 (64% ±3.9%)#	296 (34.3% ±3.2%)	
Deceleration	Without ball	159 (41.7% ±5%)*#	281 (65.2% ±4.5%)*	100 (26.9% ±4.5%)
	With the ball	222 (58.3% ±5%)#	150 (34.8% ±4.5%)	
Turn	Without ball	102 (26.3% ±4.4%)*#	263 (56.4% ±4.5%)*	248 (50.7% ±4.4%)
	With the ball	286 (73.7% ±4.4%)#	203 (43.6% ±4.5%)	
Arc Run	Without ball	38 (56.7% ±11.9%)#	72 (81.8% ±8.1%)*	25 (56% ±14.2%)

	With the ball	29 (43.3% ±11.9%)#	16 (18,2% ±8.1%)	
Cut	Without ball	11 (10.6% ±5.9%)*#	61 (37.4% ±7.4%)*	139 (71.3% ±6.4%)
	With the ball	93 (89,4% ±5.9%)#	102 (62.6% ±7.4%)	
Crossover	Without ball	19 (73.1% ±17%)*#	62 (95.4% ±5.1%)*	5 (50% ±40%)
	With the ball	7 (26.9% ±17%)	3 (4.6% ±5.1%)	
Shuffle	Without ball	29 (80.6% ±12.9%)*	43 (87,.8% ±9.2%)*	7 (53.8% ±27.1%)
	With the ball	7 (19.4% ±12.9%)	6 (12.2% ±9.2%)	

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant different from with the ball, #significant different from scorer

Supplementary Table 2. Movements with and without the ball for assistants and scorers.

	With/without the ball	Assistant (%)	Scorer (%)	HI actions with ball (%)
Jog	Without ball	3 (23.1%, 8.2 - 50,3%)*#	6 (66.7%, 35.4 - 87,9%)	
	With the ball	10 (76.9%, 49.7 - 91,8%)#	3 (33.3%, 12.1 - 64.6%)	
Run	Without ball	16 (25.4 ±11.9%)*#	53 (62.4 ±10.3%)*	
	With the ball	46 (74.2 ±11.9%)#	32 (37.6 ±10.3%)	
Sprint	Without ball	26 (27.7	129 (60.8	

		±9.1%)*#	±6.6%)*	
	With the ball	68 (72.3 ±9.1%)#	83 (39.3 ±6.6%)	
Total Linear Advancing Motion	Without ball	46 (26.9 ±6.7%)*#	190 (61.7 ±5.4%)*	151 (62.1 ±6.1%)
	With the ball	125 (73.1 ±6.7%)#	118 (38.3 ±5.4%)	
Deceleration	Without ball	63 (55.3 ±9.1%)	107 (65.2 ±7.3%)*	27 (25 ±8.2%)
	With the ball	51 (44.7 ±9.1%)	57 (34.8 ±7.3%)	
Turn	Without ball	34 (31.2 ±8.7%)*#	73 (50.3 ±8.1%)	104 (70.7 ±7.4%)
	With the ball	75 (68.8 ±8.7%)#	72 (49.7 ±8.1%)	
Arc Run	Without ball	12 (54.5, 34.7 - 73.1%)	28 (70 ±14.2%)*	16 (72.7%, 51,8 - 86,8%)
	With the ball	10 (45.5, 26.9 - 65.3%)	12 (30 ±14.2%)	
Cut	Without ball	4 (12,5 ±11.5%)*#	24 (43.6 ±13%)	40 (81.4 ±10.9%)
	With the ball	28 (87,5 ±11.5%)#	31 (56.4 ±13%)	
Crossover	Without ball	4 (67%, 30 - 90.3%)	13 (81%, 57 - 93.4%)*	2 (40%, 11.8 - 76.9%)
	With the ball	2 (33%, 9.7 - 70%)	3 (19%, 6.6 - 43%)	
Shuffle	Without ball	2 (40%, 11.8 - 76.9%)#	15 (88%, 65.7 - 96.7%)*	4 (80%, 37,6 - 96,4%)
	With the ball	3 (60%, 23.1 - 88.2%)#	2 (12%, 3.3 - 34.3%)	

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant different from with the ball, #significant different from scorer

Supplementary Table 3. Movements occurring before and after each movement in attackers for EPL.

BEFORE			
Linear Advancing	0 (0%, 0 - 0.5%)	338 (58.3 ±4%)*	146 (24.1 ±3.4%)*
Deceleration	120 (15.4 ±2.5%)*	0 (0%, 0 - 0.7%)*	373 (61.6 ±3,9%)*
Turn	385 (49.4 ±3.5%)*	134 (23.1 ±3.4%)*	29 (4.8 ±1.7%)
Cut	214 (27.8, ±3.1%)*	11 (1.9 ±1.5%)*	5 (0.8 ±0.8%)[cfg]
Arc Run	52 (6.7 ±1.7%)*	25 (4.3 ±1.7%)	7 (1.2 ±0.9%)[cfg]
Crossover	6 (0.8 ±1.7%)[a]	33 (5.7 ±2%)	26 (4.3 ±1.6%)
Shuffle	3 (0.4 ±0,04%)	39 (6.7 ±2%)	20 (3.3 ±1.4%)
MOVEMENT	LINEAR ADVANCING MOTION	DECELERATION	TURN
AFTER			
Linear Advancing	0 (0%, 0 - 0,4%)	120 (22.7 ±3.6%)*	385 (65.5 ±3.8%)*
Deceleration	338 (44.1%, ±3.5%)*	0 (0%, 0 - 0.7%)[efg]	134 (22.8 ±3.4%)*
Turn	146 (19 ±2.8%)*	373 (70.6 ±3.9%)*	29 (4.9 ±1.7%)*
Cut	214 (27.9 ±3.2%)*	1 (0.2 ±0.5%)[efg]	5 (0.9 ±0.8%)
Arc Run	67 (8.7 ±2%)*	14 (2.7 ±1.4%)	10 (1.7 ±1.1%)

Crossover	1 (0.1%, ±0.07%)	9 (1.7 ±1.2%)	13 (2.2 ±1.2%)
Shuffle	1 (0.1 ±0.07%)	11 (2.1 ±1.3%)	12 (2 ±1.2%

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant different from the rest, [a]significant different from linear advancing motion, [b]significant different from deceleration, [c]significant different to turn, [d]significant different to cut, [e]significant difference to arc run, [f]significant difference to crossover, [g]Significant difference to shuffle

Supplementary Table 4. Movements occurring before and after each movement for Defenders in EPL.

MOVEMENT	LINEAR ADVANCING MOTION	DECELERATION	TURN
BEFORE			
Linear Advancing	0 (0%, 0 - 0,6%)[fg]	342 (55.5 ±4%)*	92 (19.7 ±3.6%)*
Deceleration	70 (11.8 ±2.6%)[afg]	0 (0%, 0 - 0.6%)*	290 (62.2 ±4.4%)*
Turn	369 (62.3 ±3.9%)*	104 (16.9 ±3%)*	7 (1.5 ±1.2%)
Cut	64 (10.8 ±2.5%)[afg]	7 (1.1 ±0.9%)*	1 (0.2 ±1.2%)[c]
Arc Run	64 (10.8 ±2.5%)[afg]	52 (8.4 ±2.2%)	5 (1.1 ±1%)
Crossover	17 (2.9 ±1.4%)	62 (10.1 ±2.4%)	34 (7.3 ±2.4%)[cde]
Shuffle	8 (1.4 ±1%)	49 (8 ±2.2%)	37 (7.9 ±2.5%)[cde]
MOVEMENT	LINEAR ADVANCING MOTION	DECELERATION	TURN
AFTER			
Linear Advancing	0 (0%, 0 - 0.6%)[cdef]	70 (15.2 ±3.2%)[bd]	369 (62.5 ±3.9%)*

Deceleration	342 (56.6 ±3.9%)*	0 (0%, 0 - 0.8%)	104 (17.6 ±3.1%)*
Turn	92 (15.2 ±2.9%)	290 (63 ±4.4%)*	29 (4.7 ±1.7%)[fg]
Cut	71 (11.8 ±2.6%)	0 (0%, 0 - 0.8%)	3 (0.5 ±1.4%)*
Arc Run	92 (15.2 ±2.9%)	17 (3.7 ±1.7%)*	20 (3.4 ±1.5%)[fg]
Crossover	4 (0.7 ±0.7%)[cde]	32 (7.1 ±2.3%)*	47 (8 ±2.2%)
Shuffle	3 (0.5 ±0.6%)[cde]	51 (11.1 ±2.8%)[bd]	40 (6.8 ±2.0%)

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant different from the rest, [a]significant different from linear advancing motion, [b]significant different from deceleration, [c]significant different to turn, [d]significant different to cut, [e]significant difference to arc run, [f]significant difference to crossover, [g]Significant difference to shuffle

Supplementary Table 5. Movements occurring before and after each movement for attackers in WSL.

BEFORE			
Linear Advancing	0 (0%, 0 - 1.5%)	127 (65.1 ±6.6%)*	36 (20.9 ±6.1%)*
Deceleration	36 (14.1 ±4.3%)[afg]	0 (0%, 0 - 1.9%)[efg]	114 (66.3 ±7%)*
Turn	122 (47.8 ±6.1%)*	40 (20.5 ±5.6%)*	10 (5.8 ±3.6%)[deg]
Cut	70 (27.5 ±5.5%)*	3 (1.5 ±2%)[eg]	1 (0.6 ±1.6%)
Arc Run	24 (9.4 ±3.6)[afg]	11 (5.6 ±3.3%)	1 (0.6 ±1.6%)
Crossover	2 (0.8 ±1.3%)	4 (2.1 ±2.2%)	7 (4.1 ±3.1%)de
Shuffle	1 (0.4 ±1.1%)	10 (5.1 ±3.2%)	3 (1.7 ±2.2%)
MOVEMENT	LINEAR	DECELERATION	TURN

	ADVANCING MOTION		
AFTER			
Linear Advancing	0 (0%, 0 - 1.5%)	36 (21.7 ±6.2%)*	122 (65.6 ±6.8%)*
Deceleration	127 (48.5 ±6%)*	0 (0%, 0 - 2.3%)[eg]	40 (21.5 ±5.9%)*
Turn	36 (13.7 ±4.2%)[fg]	114 (68.7 ±7%)*	10 (5.4 ±3.3%)*
Cut	71 (27.1 ±5.4%)*	3 (1.8 ±2.3%)	0 (0%, 0 - 2%)
Arc Run	28 (10.7 ±3.8%)[fg]	5 (3 ±2.8%)	5 (2.7 ±2.5%)
Crossover	0 (0%, 0 - 1.5%)	3 (1.8 ±2.3%)	5 (2.7 ±2.5%)
Shuffle	0 (0%, 0 - 1.5%)	5 (3 ±2.8%)	4 (2.2 ±2.3%)

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant different from the rest, [a]significant different from linear advancing motion, [b]significant different from deceleration, [c]significant different to turn, [d]significant different to cut, [e]significant difference to arc run, [f]significant difference to crossover, [g]Significant difference to shuffle

Supplementary Table 6. Movements occurring before and after each movement for defenders in WSL.

BEFORE			
Linear Advancing	60 (0%, 0 - 1.9%)	109 (64.5 ±7.1%)*	24 (16.9 ±6.1%)[cdeg]
Deceleration	17 (8.6 ±3.9%)[afg]	0 (0%, 0 - 2.2%)	91 (64.1 ±7.8%)*
Turn	119 (60.4 ±6.8%)*	27 (16 ±5.5%)[bde]	0 (0%, 0 - 2.6%)
Cut	19 (9.6 ±4.2%)[afg]	0 (0%, 0 – 2.2%)	1 (0,7 ±1.9%)

Arc Run	39 (19.8 ±5.5%)*	10 (5.9 ±3.6%)[bd]	2 (1,4 ±2.3%)
Crossover	2 (1 ±1.7%)	18 (10.7 ±4.7%)[bdg]	13 (9.2 ±4.8%)[cde]
Shuffle	1 (0.5 ±1.7%)	5 (3 ±2.7%)[bd]	11 (7.7 ±4.5%)[cde]
MOVEMENT	LINEAR ADVANCING MOTION	DECELERATION	TURN
AFTER			
Linear Advancing	0 (0%, 0 - 1.8%)	17 (12.4%, ±5.6%)[bde]	119 (65 ±6.8%)*
Deceleration	109 (53.4%, ±6.8%)*	0 (0%, 0 - 2.7%)	27 (14.8% ±5.1%)[cdeg]
Turn	24 (11.8%, ±4.4%)[afg]	91 (66.4%, ±7.8%)*	0 (0%, 0 - 2.1%)
Cut	23 (11.3%, ±4.4%)[afg]	0 (0%, 0 - 2.7%)	0 (0%, 0 - 2.1%)
Arc Run	46 (22.5%, ±5.7%)*	6 (4.4%, ±3.6%)[bd]	7 (3.8 ±2.9%)[cdf]
Crossover	1 (0.5%, ±1.3%)	12 (8.8%, ±4.8%)[b]	17 (9.3 ±4.2%)[cd]
Shuffle	1 (0.5%, ±1.3%)	11 (8%, ±4.6%)[bd]	12 (6.6 ±3.6%)[cd]

Data expressed as frequency (percentage ±95% confidence intervals). Statistical differences ($p < 0.05$): *significant different from the rest, [a]significant different from linear advancing motion, [b]significant different from deceleration, [c]significant different to turn, [d]significant different to cut, [e]significant difference to arc run, [f]significant difference to crossover, [g]Significant difference to shuffle

Appendix 7: Chi-square for Movements Occurring Before and After the Selected Movement for Attackers, Defenders and Both Pooled for EPL and WSL

Chi-square for EPL when pooled: Linear advancing motion (before: x2 (6) = 2006, p = 0.000; after x2 (6) = 2093, p = 0.000), deceleration (before: x2 (6) = 2306, p = 0.000; after x2 (6) = 2832, p = 0.000), turn (before: x2 (6) = 2590, p = 0.000; after x2 (6) = 3019, p = 0.000), cut (before: x2 (6) = 1790, p = 0.000; after x2 (6) = 165xx5, p = 0.000), arc run (before: x2 (6) = 686, p = 0.000; after x2 (6) = 1655, p = 0.000), crossover (before: x2 (6) = 256, p = 0.000; after x2 (6) = 347, p = 0.000), shuffle (before: x2 (6) = 278, p = 0.000; after x2 (6) = 359, p = 0.000). For WSL when pooled: Linear advancing motion (before: x2 (6) = 788, p = 0.000; after x2 (6) = 746, p = 0.000), deceleration (before: x2 (6) = 951, p = 0.000; after x2 (6) = 871, p = 0.000), turn (before: x2 (6) = 838, p = 0.000; after x2 (6) = 936, p = 0.000), cut (before: x2 (6) = 606, p = 0.000; after x2 (6) = 563, p = 0.000), arc run (before: x2 (7) = 358, p = 0.000; after x2 (6) = 296, p = 0.000), crossover (before: x2 (6) = 83, p = 0.000; after x2 (6) = 93, p = 0.000), shuffle (before: x2 (6) = 278, p = 0.000; after x2 (6) = 67, p = 0.000).

Appendix 8: List of Publications

- Martínez-Hernández, D., & Jones, P. A. (2024). Change Of Direction Actions in Goal Scoring Situations in Male and Female Professional Soccer. *International Journal of Strength and Conditioning*, *4*(1).
- Martínez-Hernández, D., Quinn, M., & Jones, P. (2024). Most common movements preceding goal scoring situations in female professional soccer. *Science and Medicine in Football*, *8*(3), 260-268.
- Martínez-Hernández, D., Quinn, M., & Jones, P. (2023). Linear advancing actions followed by deceleration and turn are the most common movements preceding goals in male professional soccer. *Science and Medicine in Football*, *7*(1), 25-33.
- Martínez-Hernández, D. (2024). Flywheel eccentric training: how to effectively generate eccentric overload. *Strength & Conditioning Journal*, *46*(2), 234-250.
- Speaker at 2021 Online Symposium in Strength and Conditioning, University of Suffolk (May 2021) with the communication "Eccentric Overload Training Using Flywheels in Professional Female Football Players"
- Speaker at #SheWins Online Webminar (April 2020) with the communication "Most Common Movements Preceding Goals in Male and Female Professional Soccer"
- Participation in IX International Strength Simposium in Madrid 15 of December 2018 with a poster presentation "Most Common High Intensity Movements Preceding a Goal in Male and Female Professional Soccer Pilot Study: Are We Training in the Right Direction?"

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