**Master's thesis**

NTNU
Norwegian University of Science and Technology
Faculty of Social and Educational Sciences
Department of Sociology and Political Science

Håvard Guldteig Rædergård

# A biomechanical analysis of change of directions of different angles and approach velocities, and the effect of strength- versus plyometric training on these tasks, and how motivation in soccer players is related to the effectiveness of this intervention.

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Kunnskap for en bedre verden

# Abstract

Twenty-one experienced male soccer players (age: 22.2 ± 2.7) volunteered to participate in this training intervention. Before being divided and paired-matched into a strength training group (n=10) and a plyometric training group (n=11), each participant completed a series of different change of direction- (COD) tests, maximal strength tests and plyometric tests at baseline with the threefold purpose of: 1) apply data with the aim of acquiring greater knowledge of different COD performances using a biomechanical analysis, tracking COD completion time, deceleration steps, center of mass (COM), contact time and lower limb joint angles in different phases of different CODs. This will contribute towards a better understanding of which physical and biomechanical aspects determine performance in different CODs, 2) comparing baseline data in the strength and plyometric training groups that employed exercises matched in direction of motion and workload to see how six weeks of strength versus plyometric training changes different COD performances at post-test. 3) examine how motivational profile (task and ego-orientation) relates to an overall change in COD performance after six weeks of training in both groups. A mixed statistical approach was used to answer the different research questions (ANOVA, RM-ANOVA, T-tests, and Pearson's correlation coefficient). Results showed that most of the biomechanical variables in the COD step are highly influenced by the angle of directional change and less influenced by approach distance. This can be attributed to loss of momentum during a braking phase prior to turning in CODs of greater approach distance. Based on the biomechanical analysis, a distinction between force and velocity-oriented CODs was suggested. Training related effects were only found in the plyometric training group in 4m 135° and 180° CODs and 20m 180° CODs deemed force-oriented. Task orientation was found to be highly related to increases in overall COD performance in this group. The strength training group failed to reach any statistically significant improvements but displayed great changes in terms of absolute numbers and effect sizes in the CODs deemed most force-oriented. In conclusion, this study showed that COD cannot be considered as one discrete ability, because current results suggests that a distinction between force and velocity-oriented CODs is required, as these represent unique biomechanical features that have different applications to training and possible match related outcomes. Both training groups displayed a positive change in all COD performances which suggests that both training programs can be effective at developing different CODs. However, the superior improvements made by the plyometric group in force-oriented CODs, suggests that the rate of force development in COD hinders maximal strength training from developing force at rates necessary to yield substantial improvements in CODs.

# Sammendrag

Tjue-en erfarne fotballspillere (alder: 22.2 ± 2.7) deltok frivillig i denne trenings-intervensjonen. Før de ble delt inn og parvis matchet i en styrketreningsgruppe (n=10) og en plyometrisk treningsgruppe (n=11), gjennomførte hver utøver en serie av forskjellige tester på hurtige retningsforandringer (CODs), maksimale styrketester og plyometriske tester ved baseline med en tredelt hensikt: 1) anvende data med et formål om å tilegne bedre kunnskap om forskjellige COD prestasjoner gjennom bruk av en biomekanisk analyse, og måling av gjennomføringstid i COD, bremstesteg, massesentrum (COM), kontakttid og leddvinkler i underekstremitetene i faser av forskjellige CODs. Dette vil bidra til en bedre forståelse av hvilke fysiske og biomekaniske aspekter som er avgjørende for prestasjon i forskjellige CODs, 2) sammenligne baseline data i styrketreningsgruppen og den plyometriske treningsgruppen hvor treningsøvelsene var sammenlignet i bevegelsesretning og arbeidsmengde for å se hvordan seks uker med styrke versus plyometrisk trening forandrer forskjellige COD prestasjoner ved post-test, 3) undersøke hvordan motivasjonsprofil (oppgave og egoorientering) relateres til en overordnet endring i COD-prestasjon etter seks uker med trening i begge grupper. En variert statistisk tilnærming ble brukt for å besvare de forskjellige forskningsspørsmålene (ANOVA, RM-ANOVA, T-tester, og Pearsons korrelasjonskoeffisient). Resultatene viste at de fleste biomekaniske variablene i COD-steget er i stor grad påvirket av vinkel på retningsforandringen og i mindre grad bestemt av inngangsdistanse. Dette kan tilskrives et tap av momentum under bremsefasen før vending i CODs med større inngangsdistanse. Basert på den biomekaniske analysen, ble en distinksjon mellom styrke- og hastighetsorienterte CODs foreslått. Treningsrelaterte effekter var kun oppnådd i den plyometriske treningsgruppen i 4m 135° og 180° CODs og 20m 180° CODs ansett som styrkeorientert. Oppgaveorientering var høyt relatert til en overordnet forbedring i COD-prestasjon i denne gruppen. Styrketreningsgruppen mislyktes i å oppnå statistisk signifikante forbedringer, men viste gode endringer i absolutte verdier og effektstørrelser i CODs ansett som styrkeorientert. Som konklusjon, viser denne studien at COD ikke kan ansees som en enkelt egenskap, fordi resultatene antyder at en distinksjon mellom styrke- og hastighetsorienterte vendinger er nødvendig, fordi de representerer unike biomekaniske funksjoner som har ulik betydning for trening og mulige kamputfall. Begge treningsgruppene viste en positiv endring i alle COD-prestasjoner som antyder at begge treningsprogrammene kan være effektive i å utvikle forskjellige CODs. Likevel, de overlegne forbedringene i den plyometriske gruppen i styrkeorienterte CODs antyder at den hurtige kraftutviklingen i COD hindrer styrketreningsgruppen i å utvikle kraft hurtig nok til å gi betydelig forbedring i COD.

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# Forord

Jeg vil rette en stor takk til min medstudent Hallvard Falch i forbindelse med utallige timer i lab og i hall i forbindelse med datainnsamling til denne masteroppgaven, i tillegg til et langt samarbeid når det gjelder fagbasert utveksling av kunnskap både på bachelor og masternivå. Jeg vil takke Roland van den Tillaar i henhold til opplæring av utstyr og spesielt til hjelp ved utregning av workload som han skal ha mye av æren for. Jeg vil også takke min veileder Ingar Mehus, der Ingar har vært en viktig ressurs for å organisere og lage en fornuftig struktur i oppgaven. I tillegg skal også min hybelkamerat Tryggve Duklæt krediteres for sine engelskspråklige bidrag.

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Håvard Guldteig Rædergård

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# 1. Introduction

Soccer is inarguably one of the most popular sports in the world, where acquisition of a wide range of skills and capacities is necessary to reach a higher level of performance. Among multiple determinant-factors in soccer, the physical components of the game have received great attention over the last two decades, accompanied by an increase in research measuring match-related outcome factors (Di Salvo et al., 2007).

Change of direction (COD) ability is one such factor, considered essential for success in most team and individual sports (Brughelli, Cronin, Levin & Chaouachi, 2008). Sheppard & Young (2006) define it as a pre-planned rapid whole-body movement with changes in velocity and direction. It has been proven to be one of the most important performance variables for predicting player selection in youth soccer (Gil, Ruiz, Irazusta, Gil & Irazusta, 2007) and it is a factor that distinguishes elite from sub-elite soccer players (Reilly, Williams, Nevill & Franks, 2000).

There is an extensive amount of research on this topic (Asadi, Arazi, Young & de Villarreal, 2016; Bourgeois, McGuigan, Gill & Gamble, 2017; Brughelli et al., 2008; Dos'Santos, McBurnie, Thomas, Comfort & Jones, 2019; Falch, Rædergård & van den Tillaar, 2019; Watts, 2015). However, the current methods of measuring COD performance and the determining factors have received "critique" and are not entirely understood (Brughelli et al., 2008; Nimphius, Callaghan, Bezodis & Lockie, 2018). There is an observable tendency among researchers to generalize and oversimplify different COD tasks (Bourgeois et al., 2017) and thus it makes room for progression and improvement of empirical quality through further research in the future.

When addressing factors that lead to increased athletic performance, research suggests that both personal characteristics (van Yperen, 2009) and individual player characteristics are both variable factors which predict changes in performance (Dalen, Ingebrigtsen, Ettema, Hjelde & Wisløff, 2016; Jiménez-Reyes, Samozino, Brughelli & Morin, 2017). While it may seem unconventional in certain areas of research, it has been proposed that a multidimensional approach where both physiological and psychological factors such as motivation must be accounted for when addressing performance (Meylan, Cronin, Oliver & Hughes, 2010).

*The critics in this field of research suggest reinvention of COD testing, making it interesting to investigate which factors different CODs depends upon, how already established training forms can improve these CODs, and how motivation is related to performance over time. These are aspects this thesis will seek to address and discuss more thoroughly.*

## 1.1 Maximal intensity actions in soccer

Soccer is an intermittent sport characterized by random repetitions of several hundred high-intensity actions during a match (Bloomfield, Polman & O'Donoghue, 2007; Bradley et al., 2009; Stølen, Chamari, Castagna & Wisløff, 2005). These high intensity actions are also known as maximal actions and requires substantial physiological demands, in both aerobic- and anaerobic power capacity (Bangsbo, 1994; Morgans, Orme, Anderson & Drust, 2014). Although aerobic utilization of energy accounts for most of the total energy expenditure during a match (Carling, Bloomfield, Nelsen & Reilly, 2008), a player's aerobic capacity (i.e. maximal oxygen consumption) enables high energy phosphates to be partly or fully restored (Bishop, Girard & Mendez-Villanueva, 2011), following brief periods of rest that will occur during a match (Rampinini, Coutts, Castagna, Sassi & Impellizzeri, 2007). High energy phosphates such as phosphocreatine, are utilized anaerobically and becomes pre-dominant in situations where maximal amount of force must be produced in relatively short time (Girard, Mendez-Villanueva & Bishop, 2011).

The ability to rapidly change direction is an example of a quality requiring forceful action in limited time. It is desirable to acquire great skill in this quality, as this can greatly increase the chance of succeed in key moments of a match, such as scoring or preventing a goal (Helgerud, Engen, Wisløff & Hoff, 2001). Training and testing aimed at assessing change of direction speed should employ short duration maximal effort COD tests (< 10 seconds) and this should be trained independently from long duration maximal effort COD tests (> 10 seconds) as this will challenge multiple energy systems at once (Brughelli et al., 2008). When developing COD speed, physical training must target the same energy pathways- and systems that replicate the skill aimed at being improved, training methodologies such as strength/power training are therefore recommended for short duration single sprints; with- or without changes in direction (Girard et al., 2011). This means that COD speed should be trained independently from aerobic power, or at least the energy contribution of this energy system should not be at expense of anaerobic power, in order to optimize these targeted aspects of COD training.

This thesis will draw attention to COD speed when addressing this movement. These are important considerations since the main source of energy during the first seconds of an explosive exercise is phosphocreatine (Gastin, 2001). Athletes that perform well in short duration COD tasks (< 10 seconds), do not necessarily perform well in longer duration COD tasks. As such, CODs that are relatively short, both in distance and duration, with only one change in direction will be employed, as recommended by Bourgeois & colleagues (2017).

## 1.2 Change of direction ability

### 1.2.1 Phenomenon

COD is a term often misunderstood and confused with agility (Sheppard & Young, 2006), despite they are two distinct skills (Young, Dawson & Henry, 2015). Sheppard & Young (2006) define agility as a “rapid whole-body movement with change of velocity and direction in response to a stimulus”, thus involving both cognition and COD. Research has shown that COD ability can account for only a small amount of an agility performance (Young et al., 2015). The cognitive aspect or the “stimulus” in agility refers to perception and decision-making. COD differs from agility since it is not capturing the cognitive aspect; the movement is preplanned and limited to the athletes physical and technical qualities (Jones, Bampouras & Marrin, 2009; Sheppard & Young, 2006).

While the COD ability is largely dependent on the COD task (Bourgeois et al., 2017), the COD task typically involves an acceleration phase, followed by a deceleration, a change of direction, and acceleration in this new direction (DeWeese & Nimphius, 2016; Spiteri et al., 2015). The acceleration phase in COD is similar to accelerations performed in sprinting, which is characterized by lowering the center of mass (COM), thus enabling exertion of horizontal ground reaction force (DeWeese & Nimphius, 2016). The deceleration phase in COD features applied force to the ground that reduces the momentum during the final stages prior to a COD maneuver (Jones, Thomas, Dos’Santos, McMahon & Graham-Smith, 2017). The change of direction step itself is characterized by lowering the center of mass (COM), often a result of planting their foot anteriorly and laterally to the opposite side to the new direction of travel, thus creating a propulsive force towards the intended direction of travel (Dos’Santos et al., 2019). However, this may depend on individual characteristics, approach speed and angle of new direction (Dos' Santos, Thomas, Jones & Comfort, 2017; Dos’Santos, Thomas, Comfort & Jones, 2018). This will be discussed in more detail.

### 1.2.2 Physical determinants

The physical determinants of a change of direction speed can be separated into technique and leg muscle qualities (Figure 1). The original model adapted from Young, James & Montgomery (2002) suggested that linear sprint speed was a determinant factor of COD. Nevertheless, the inclusion of linear sprint has received critique since the role of a deterministic model is to identify the factors that will make a functional difference to the variable of interest (Brughelli et al., 2008). While sprint is in fact a component of COD, it is not an underlying factor, but a performance variable dependent on technique and leg muscle qualities. Based on this finding, linear sprinting was excluded from the model. Among other factors in figure 1, anthropometrics will be added in and addressed in context of body lean and posture specifically. It is also worth noting that in COD literature, more complex models of determinant factors have been developed. However, the chosen model seems simple and straightforward, covering main factors of interest, without distracting the reader.

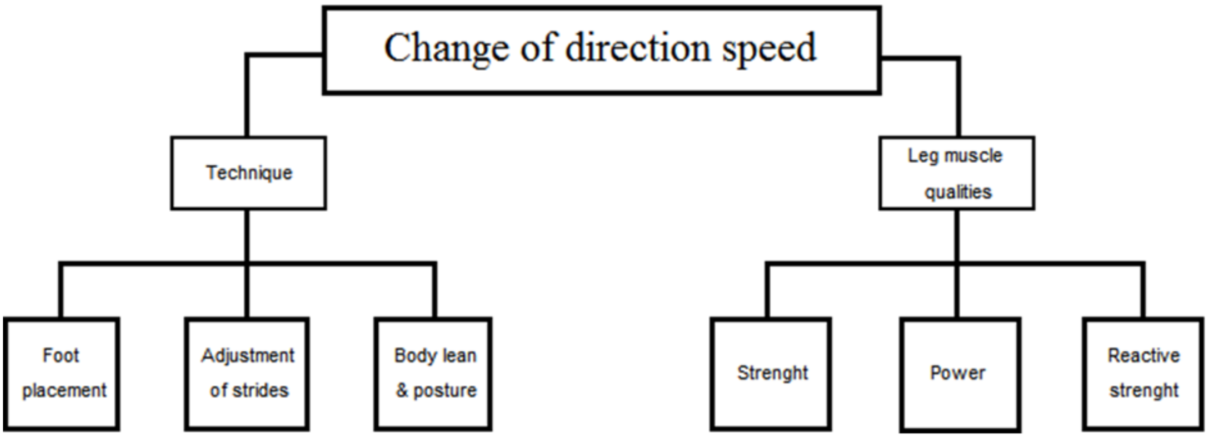

**Figure 1**. Illustration of physical determinants of change of direction speed. Modified version adapted from Young et al (2002).

### Foot placement & adjustment of strides

As previously mentioned, the change of direction phase is often recognized by a distinct plant step which is typically characterized by athletes planting their foot laterally to the opposite side to the new direction of travel (Dos'Santos et al., 2019). It is worth noting that different names for the plant step have been used (Condello, Kernozek, Tessitore & Foster, 2016; Havens & Sigward, 2015a; Nedergaard, Kersting & Lake, 2014; Rand & Ohtsuki, 2000). This step will from now on be referred to as the COD step. In the literature, the COD step is further divided into three different techniques: Side-step, crossover-cut and split-step (Dos'Santos et al., 2019).

The side-step is the most common technique and can be described by the typical characteristic as mentioned above, where one leg is working unilaterally to push against the ground (Dos'Santos et al., 2019). The crossover cut involves planting the outside leg on the same side as the new direction of travel, followed by crossing the inner leg in front of the body for the first step in new direction (Suzuki, Ae, Takenaka & Fujii, 2014). The split-step compromises a small jump prior to the step itself, where the player lands on both feet, approximately shoulder width apart. Upon landing, the foot opposite to the intended direction of travel is used to initiate a turn and accelerate in new direction (Bradshaw, Young, Russell & Burge, 2011). While there is limited data on COD steps and their relationship to performance, it appears that the crossover-cut is effective for small angle CODs, whereas the side-step is more effective for larger angles (Dos'Santos et al., 2019). This is supported by Rand & Ohtsuki (2000), who have reported greater ground contact time (GCT) and greater muscle activation in leg extensor muscles in side-steps compared to crossover-cuts. This makes sense as longer GCT is expected in larger angle CODs, resulting in greater force exertion (Bourgeois et al., 2017; Dos'Santos et al., 2019; Havens & Sigward, 2015a). Research shows that a more frequent use of side-steps occurs for larger angle CODs (Rand & Ohtsuki, 2000; Suzuki et al., 2014). As suggested by Dos`Santos et al (2018), there seems to be an angle-velocity trade-off when adopting these two techniques. The split-step technique has been reported to result in longer GCT in comparison to the side-step and crossover-cut (Bradshaw et al., 2011).

In the review by Dos`Santos et al (2019) there is limited data to support the practical application of this technique to COD performance in soccer. Despite this, the split-step is associated with longer COD completion times; the angles of direction change assessed in the mentioned review are mostly < 90°. The author states that the symmetrical landing during the split-step distributes forces more evenly across both limbs compared to the other two techniques. Based on this statement, split-steps might be effective in enhancing performance in force-oriented CODs (> 90°), but this is yet to be proven.

There are also specific characteristics with regards to the acceleration- and deceleration phase prior to and after the COD step (Young et al., 2002). In light of suggestions that acceleration prior to a COD task might mimic the acceleration phase in sprint (DeWeese & Nimphius, 2016), there seems to be a dearth of research addressing this regarding COD tasks specifically. It may be tempting to assume that an acceleration-phase is equal to sprints, but it is also reasonable to suggest that athletes may adjust their acceleration stride-mechanics to optimize and adopt certain COD step techniques, especially if the initial acceleration-step is close to the COD maneuver. With the assumption that the acceleration phase in COD is equal to sprint; Hewit, Cronin & Hume (2013) revealed that faster soccer athletes had greater forward lean, lower GCT and shorter stride length compared to slower athletes in a 5m sprint. This is supported by the work of Sayers (2000), which is the basis for the technical aspects in the model adopted by Young & colleagues (2002). Sayers (2000) suggested that athletes participating in sports that require frequent CODs should run with lower COM, greater forward lean and shorter stride lengths. Regarding the acceleration after the COD maneuver, it should be mentioned that Hewit et al (2013) compared this aspect with the acceleration phase in linear sprinting. However, the COD step was integrated as part of the acceleration in new direction of travel. While there is no clear consensus or definition of how to quantify the acceleration phase after a COD maneuver, it seems conceptually wrong to include COD step when measuring performance in the reacceleration phase, as it is generally accepted that many COD steps include deceleration; contrasting to the acceleration phase in linear sprinting.

### Body lean, posture & anthropometrics

Kinetics and kinematics in COD are largely influenced by the athlete's individual anthropometrics (Dos' Santos et al., 2017). Players who excel in linear sprint may not have the same success in COD, especially larger athletes that need to overcome greater inertia (Hewit et al., 2013). This concept is supported by Newtonian law of motion, where momentum is the product of mass times velocity, affecting the forces which an athlete approach the COD maneuver with. When accounting for this, it is desirable to possess a great amount of fat-free mass (Peterson, Alvar & Rhea, 2006). Numerous studies have proven that athletes with lower fat-percentages perform better in COD in several different sports (Chaouachi et al., 2009; Delaney et al., 2015; Lockie et al., 2014; Spiteri et al., 2015), including soccer (Chaouachi et al., 2012). Sheppard & Young (2006) suggest that shorter individuals, who typically display a lower center of gravity, will be able to exert horizontal force more rapidly than taller athletes, as they will use less time lowering their center of mass in preparation of a COD task. This statement has empirical support in elite soccer, where shorter athletes have been proven to outperform their taller counterparts in a COD task (Chaouachi et al., 2012). Aside from empirical evidence, it is worth noting that taller athletes have greater leverage, and with reference to fundamental laws of physics (moment arm principal), these athletes must resist greater mediolateral forces to stabilize their body during COD. At least this is likely to occur unless they perfectly maneuver their body towards intended direction, so that the forces are absorbed more efficiently through the sagittal plane of their body.

### Strength

The relationship between strength and COD performance has been heavily investigated (See reviews: Brughelli et al., 2008; Watts, 2015). The relationship is not entirely understood, but a common approach to quantify the determining factors of COD performance is with strength and power variables using correlation analysis (Brughelli et al., 2008). Watts (2015) suggested that when investigating different strength exercises` relationship to COD performance, one should involve motion of the full kinetic chain since CODs require a high level of motor control, as opposed to single-joint testing. On the other hand, Jones et al (2017) criticizes previous research for measuring strength as a general quality, without considering specific strength qualities that are apparent in different COD tasks. While the assessment of strength exercises that involve activation of the full kinetic chain seems legitimate, different phases of a COD task may not involve great mobilization of muscles nor an increased range of motion (ROM) across multiple joints. It must be considered that an athlete's ability to quickly change direction is dependent on eccentric hamstring strength (Chaouachi et al., 2009), and isometric and concentric leg extensor strength in deceleration steps, COD step and acceleration phase respectively (Spiteri et al., 2014), thus making measurements of single-joint force capacities more relevant to certain movement phases in COD. Research measuring the relationship between different strength exercises and COD performance has revealed small (Marcovic, 2007), moderate (Barnes et al., 2007; Jones et al., 2009; Marcovic, 2007; Negrete & Brophy, 2000; Peterson et al., 2006) and strong (Hori et al., 2008; Marcovic, 2007; Negrete & Brophy, 2000; Peterson et al., 2006; Spiteri et al., 2014) statistically significant relationships.

The results from the mentioned studies are inconsistent, and most studies are measuring maximal strength in exercises, mostly performed in the vertical direction. It is also worth noting that not all studies account for relative strength measures, which is essential because performance in COD is dependent on the athlete's capacity to generate force and their body mass (Watts, 2015). It is worth noting that in many athletic movements, the force is developed over very short time (<200ms), thus not allowing maximal potential force to exerted, which typically takes (>300ms) for must humans (Aagaard, Simonsen, Andersen, Magnusson & Dyhre-Poulsen, 2002). The rate of force development (RFD) does have practical implications, because an athlete's ability to lift a maximal amount of weight, such as a squat, may not reflect the athlete's ability to exert force within the relevant timeframe in a COD maneuver. This is a theoretical basis for stating that CODs with smaller angles of directional change are more reliant on RFD (i.e. power/speed qualities), in contrast to larger angles that have been suggested to be more reliant on maximum force capacity (Bourgeois et al., 2017).

### Power

Power can be expressed as the product of force times velocity (Samozino, Morin, Hintzy & Belli, 2008) and there are few studies that measure power and its relationship to COD directly with its expression in wattage. The most common way to address this quality is with indirect measures of jump height (Brughelli et al., 2008). With reference to Peterson et al (2006), it has been pointed out that jump height is not necessarily a measure of leg power (Brughelli et al., 2008), although other studies suggests that lower limb push-off movements such as jumping is closely related to power (Bosco, Luhtanen & Komi, 1983; Jiménez-Reyes et al., 2017; Newton & Kraemer, 1994). This disagreement could be caused by the fact that the variable could be expressed in both mean- and peak power (Cronin & Sleivert, 2005). Despite the disagreements, this thesis will acknowledge the use of different jumps as measures of power. Research measuring the relationship of power and COD performance has revealed small (Jones et al., 2009; Marcovic, 2007; Peterson et al., 2006), moderate (Jones et al., 2009; Marcovic, 2007; Negrete & Brophy, 2000; Young et al., 2002) and strong (Barnes et al., 2007; Marcovic, 2007; Negrete & Brophy, 2000; Peterson et al., 2006) relationships.

### Reactive strength

Reactive strength demonstrates an athlete's efficiency at quickly transitioning from an eccentric to a concentric muscle-work in a stretch shortening cycle (SSC), which have been suggested to be key aspects in COD (Young, 1995; Young et al., 2002). The fast eccentric muscle work in an SSC results in a more powerful muscle-contraction, in comparison to a concentric muscle-contraction alone (Komi, 2000). Spiteri et al (2015) suggested that increased force application during the deceleration prior to a COD step, results in increased storage of elastic energy during braking, and this energy is utilized in the concentric work of the COD maneuver, thus resulting in greater exit-velocity of a COD task. The elastic energy is particularly important, whereby more transfer of energy to the concentric phase can occur the faster the eccentric phase is performed (Flanagan & Comyns, 2008).

In the literature, there are difficulties in distinguishing exercises that represent power and reactive strength (Brughelli et al., 2008; Jones et al., 2009). Nevertheless, exercises that involve ground impact after being airborne with rapid and forceful stretch during the eccentric phase of a muscle-contraction prior to push-off, will be representative of reactive strength. This is commonly measured by the reactive strength index (Ebben & Petushek, 2010; Flanagan & Comyns, 2008; Flanagan, Ebben & Jensen, 2008; McClymont, 2003). Measures of reactive strength have not received much attention, and there are few studies that have addressed this quality in COD performance, revealing mostly small to moderate (r=.22-.32) and non-statistically significant relationships (Barnes et al., 2007; Jones et al., 2009). Young et al (2002) found strong and statistically significant relationships (r=.53-.71) between drop jump performance as measured by reactive strength index (RSI) and different COD tasks with small angle of directional change <60°. Several COD tasks with little variation were assessed, displaying non-significant relationship and inconsistencies in correlation strengths.

## 1.3 Motivational profile

Motivation has become a popular concept within the field of sport and exercise and may refer to the personality factors, social variables and cognitions that come into play for an athlete who is striving to attain standards of excellence (Hirota, Verardi & De Marco, 2017). Achievement goal theory (AGT) is a popular motivation theory which assumes that an individual is an intentional, rational, goal-directed organism. It states that the achievement beliefs and decision-making processes of an individual in an achievement context are governed and guided by the individual goals (Roberts, 2012). To understand what defines an achievement context for an individual and which mechanisms that regulate behaviors, it is important to understand each individual's perceptions of success and how competence is evaluated (Nicholls, 1989).

AGT posits that individuals are predisposed to act in a task- or ego-involved manner, which acts as a basis for different goal orientations (Roberts, 2012). Task-oriented individuals are interested in learning and developing skills and demonstrating mastery in the task. Ego-oriented individuals tend to participate in an activity to demonstrate superiority and to outperform others (Duda, 1989; Nicholls, 1984, 1989).

Individuals high in task-orientation are likely to approach competitive situations in a task-involving manner. It is considered as an adaptive characteristic since their perception of ability is self-referential, and they are expected to persist when facing failure (Lemyre, Roberts & Ommundsen, 2002).

Individuals high in ego-orientation are more likely to approach a competitive situation in an ego-involved manner and this is often considered maladaptive. Since their perception ability is other-referential they are likely to exhibit maladaptive behavior when facing failure, and the focus shifts towards trying to avoid displaying incompetence. In these situations, the ego-involved athletes are trying to cover their lack of competence by expressing a low amount of effort. From a performance-perspective, athletes high in ego orientation can display adaptive patterns when exceeding performance of others (Nicholls, 1984, 1989).

Furthermore, in AGT, goal involvement (i.e. task, ego) is determined by both their goal orientation and their perception of motivational climate (Gershgoren, Tenenbaum, Gershgoren & Eklund, 2011). A mastery climate occurs when the criteria for success and failure are self-referential and ego-involving, in contrast to a performance climate where the criteria for success and failure is self-referenced (Roberts, 2012). It is worth noting that goal orientations are not fixed concepts, they are orthogonal and varies in magnitude. This means that an athlete can be high or low in either or both orientations at the same time (Roberts, 2012).

Drawing on different AGT models, a number of questionnaires have been developed to measure goal orientation. However, these models have failed to capture the different concepts of success (Roberts, 2012). Task- and Ego Orientation in Sport Questionnaire (TEOSQ) and Perception of Success in Sport Questionnaire (POSQ), are developed by Duda & Nicholls (1992) and Roberts, Treasure & Balague (1998) respectively. These questionnaires do capture different concept of success and are widely used in the sports domain (See review: Lochbaum, Kazak Çetinkalp, Graham, Wright & Zazo, 2016).

While many studies have measured goal orientation in soccer athletes, only a few studies have addressed this in context of functional performance capacities and skills (Coelho et al., 2010; Figueiredo, Coelho, Cumming & Malina, 2010, 2019; Figueiredo, Gonçalves, Coelho & Malina, 2009a; Huijgen, Elferink-Gemser, Lemmink & Visscher, 2014; Reilly et al., 2000), without providing any relationship with goal orientation and performance variables. A handful of studies have addressed this issue with respect to repeated measures (Figueiredo, Gonçalves, Coelho & Malina, 2009b; Gershgoren et al., 2011; Höner & Feichtinger, 2016; van Yperen & Duda, 1999).

Höner & Feichtinger (2016) found the task orientation to be a significant predictor of future performance. On the other hand, van Yperen & Duda (1999) found these goal orientations to be important with respect to current performance and performance over the course of the season in young soccer players.

## 1.4 Background of this thesis

Criticism has been levelled towards current methods of measuring COD performance, where total time has been used as the dependent variable of measurement (Nimphius et al., 2018; Spiteri, Cochrane, Hart, Haff & Nimphius, 2013). The issue with using total time in COD tests is that a considerable amount of time is completed during linear sprinting (Sayes, 2015). Taking this into consideration, such approaches fail to capture the defining aspects of COD, often masking actual COD performance (Nimphius et al., 2018). With this in mind, attention will be drawn towards part-time in COD testing.

With reference to fundamental laws of physics, Bourgeois et al (2017) explain how different COD tasks are either force-and/or velocity-oriented, depending on the magnitude of both approach speed and the angle of direction change. Furthermore, the authors highlight the tendency of research to generalize and oversimplify different COD tests and the determining factors of performance, without accounting for the magnitude of force and velocity that different COD tasks represent. With respect to Bourgeois and colleagues, focus will be shifted towards different types of CODs, accounting for both the magnitude of force and velocity.

Despite its limitations, a common approach to quantifying the determining factors of COD performance is correlation analysis of strength and power variables (Brughelli et al., 2008). Biomechanical analysis is considered ideal for detailed analysis of factors that determine performance (Carling, Reilly & Williams, 2008). Sampling kinematic data can provide a greater picture of those factors that predict greater COD performance because it assesses determinant factors directly. This can be a great option to collecting kinetic data of motion only (Sasaki, Nagano, Kaneko, Sakurai & Fukubayashi, 2011). When accounting for this, both kinematic and kinetic data will be addressed to investigate differences between different COD tasks.

Most of the research in soccer and sport in general has been concerned with the biological/physiological aspects of performance (Carling, Bloomfield, et al., 2008; Raglin, 2001; Williams & Hodges, 2005) and it has been suggested that factors such as motivation could be difficult to address when identifying reasons behind whether athletes are advancing or not (Mehus, 2015), which could contribute to the neglect of psychological factors in previous research. This makes it interesting to see how motivation may influence performance over time. With this approach, accounting for multiple dimensions, this can give a nuanced understanding of soccer players development (Meylan et al., 2010) and provide practical knowledge as a practicing strength and conditioning coach.

## 1.5 Research questions

This thesis will be organized by three research questions. The first of which will address measures from baseline and the significance of different COD tasks that are considered force/velocity-oriented. The second research question will address how traditional training regimens such as strength and plyometric training influences strength and velocity-oriented COD tasks. The third research question is based on the effects of research question 2. It addresses how motivational profile are related to individual effects of the training interventions. It is worth noting that data regarding research question 3 is meant to give some insight into how motivational orientations influence general measures of performance over time, as there is a lack of research addressing this. Regarding length and depth of analysis, research question 1 will be given the highest priority, less with research question 2 and the least with research question 3.

**Research questions**

1. What characterizes strength- and velocity-oriented change of direction tasks, with respect to descriptive kinetic and kinematic performance measures in COD, and how does lower limb muscle qualities relate to faster COD performance?
2. Does 6-weeks of strength- vs. plyometric training promote different effects in strength- and velocity-oriented change of direction tasks in experienced soccer players?
3. How do characteristics with respect to motivational profile influence changes in performance prior to strength- or plyometric training?

**Hypothesis to each research question**

1. Linear trends with respect to kinetic and kinematic parameters are expected to increase by velocity and angle of the COD tasks.
2. It is expected that plyometric training is more effective at improving velocity-oriented CODs, whereas strength training is expected to be more effective at improving force-oriented CODs.
3. It is expected that task orientation is related to better improvement in change of direction in general (dependent variable, see scale at chapter 2.7), whereas task- and ego-orientations are expected to be equally related to improvement in treatment exercises.

# 2. Method

## 2.1 Experimental approach

A between-subject design with repeated measures was employed. Baseline data from the training intervention was used to answer research question 1. Therefore, it functioned as a within-subject design experiment where differentiation was not made between groups. The between-subject design aimed at using both baseline data (pre-test) and post-test measures to answer research questions 2 and 3. Research question 2 and 3 addresses performance variables and how these change over time with respect to individual characteristics, and this part does differentiate between groups.

Prior to the intervention study, the participants underwent two sessions of familiarization, where they performed different COD tests and different strength and plyometric exercises to get physically, technically and mentally adapted to the exercises and test-assessments used in the study. The strength training group was also adapted at performing selected plyometric exercises and vice versa for the plyometric group. This was done to provide a greater sample size for correlation analysis at baseline and to investigate how both strength- and plyometric qualities changed from pre- to post-test.

A preparation period was implemented in August and September 2018 with a twofold aim. The first aim was to set up, organize and build testing and exercise platforms needed in the study and to get familiar with test assessments, protocols and technical equipment. The second purpose was to test exercises used both in strength and plyometric training programs and to customize these exercises with the intention of providing optimal performances, guided by previous research knowledge. The basis behind selection of exercises can be found in Appendix section A.

Prior to the intervention, 4-9 soccer players performed targeted exercises. These exercises needed additional investigation in addition to what previous research could provide. These athletes were also used to determine the total workload from strength and plyometric training respectively. This made it possible to compare the two training-interventions based on quantifiable and objective terms, accounting for the total training volume each regimen presented. The study was conducted in collaboration with another master student. Both conducted data and functioned as personal trainers for the players. Due to the large number of players participating in the study, data from training intervention was collected during two periods. The first period was in the autumn/winter of 2018 (in season/post season) and the second period was in the winter/spring of 2019 (preseason).

## 2.2 Participants

Twenty experienced soccer players volunteered for the study. Participants were randomly selected and subsequently distributed evenly across the strength training group and the plyometrics training group based on performance in total time COD tests. Eleven players were assigned to the plyometric training intervention (age: 22.2 ± 2.7, mass: 77.1 ± 7.6kg, height: 181.4 ± 5.7cm). Nine athletes were assigned to strength training (age: 22.5 ± 2.6, mass: 82.5 ± 7.3kg, height: 182.3 ± 5.7cm).

Original, there were ten players in the strength training group, but one player got injured before the training intervention started. On the first of two familiarization days in total, participants received a written informed consent form wherein relevant risks and benefits of the test procedure were presented. Participants could choose to withdraw from the study at any time, without needing to offer an explanation. None of the remaining participants stated any injury or illness prior to the proceedings of the research project. The pre-test was finished within 2-3 weeks after the first familiarization day.

## 2.3 Protocol

The test day was scheduled to take place at least 24 hours after any high intensity physical activity. In order to minimize the influence of fatigue, participants were instructed to eat a light meal one hour before meeting at the testing facility. Each of them was fitted with a full body motion capture suit prior to a weigh-in which was used to measure kinematic variables in COD and to ensure that knee-joint angles in different strength tests did not exceed ±5° angle at post-test compared to pre-test.

Before testing they performed standardized warm-up protocol based on van den Tillaar, Lerberg & von Heimburg (2016). Participants were instructed to perform 5 minutes of general warm-up at a pace of their own choosing. They were encouraged to avoid exerting high effort, as a specific warm-up was to follow. The specific warm-up involved 3 runs of 20m, performed at 60%, 70% and 80% of estimated maximal sprinting velocity with 60s of rest in between.

Finally, they completed the specific warm up with 10m accelerations, followed by a change of direction and reacceleration of 4m in the new direction. The COD angles were 110° and 65°, performed leftward and rightward at 90% of estimated maximal velocity with 1min of rest in between. The testing started with 2 maximal 30m linear sprints that were part of the data sampling, but that will not be assessed in this thesis. They then performed 16 randomized maximal COD tests, performed with different approach distances and angles of new direction.

After performing the mentioned tests, participants had a 30min break where they consumed a light serving of instant oatmeal (396kcal), in order to prevent decline in performance of subsequent strength and plyometric tests to be performed in randomized order. The break took place in a warm indoor environment with a temperature of approximately 21° Celsius on average, thus reducing the need for a new general warm-up.

Five strength tests were assessed, and the measure of performance was the weight lifted in kilograms (kg) for one repetition maximum (1RM), with the exception of one exercise. The participants performed two lifts at approximately 50% of 1RM and one lift at 80% of one 1RM as specific warm-up. This was completed before each consecutive strength test. A goal with all strength exercises was to find 1RM with one attempt, but a second and third attempt (maximum) was performed if they failed to reach their max on the first attempt.

Six plyometric tests were assessed, and the measure of performance was presented in vertical jump height (cm), contact time (ms) and by the reactive strength index (RSI= jump height in meter/contact time in centiseconds). Participants were allowed 2-3 specific warm-up attempts before each plyometric exercise. Three test attempts were allowed for each exercise and the best trial was used for analysis.

Both strength and plyometric tests that required push-off by one limb were always performed unilaterally. Unilateral tests were performed with the participant`s dominant leg, defined as their preferred leg when kicking a soccer ball. The dominant leg was the right leg for all participants.

## 2.4 Test descriptions

### 2.4.1 Change of direction tests

The dependent variable in this study was a modified/based version of a 505-agility test (Draper, 1985), which has proven to be a valid and reliable measure of evaluating the ability to quickly change direction (Stewart, Turner & Miller, 2014) and is commonly used to test performance in soccer players (Alves, Rebelo, Abrantes & Sampaio, 2010; Beato, Bianchi, Coratella, Merlini & Drust, 2018; Chaalali et al., 2016; Thomas, French & Hayes, 2009; Yanci, Castillo, Iturricastillo, Ayarra & Nakamura, 2017). The 505-agility is considered ideal because it minimizes the influence of linear sprinting with the use of part-time (Ellis et al., 2000).

In the modified 505 agility test, participants had to approach the COD maneuver from a 4 or 20m approach distance, where the angle of the turn was 45°, 90°, 135° and 180°. These angles of directional change were performed leftward and rightward forming 16 COD tests in total. An illustration of the COD track with relevant dimensions are exemplified with left angles of direction change in figure 2.

For the purpose of replicability, the two cones placed at each timing gate around the circle of the COD track are 4.03m from the center of the COD track. The center between the two cones marking the location and placement of the two-timing gates (as exemplified by 45° COD in figure 2) is 4m from the center of the COD track. This distance defines the 4m approach and 4m exit distance that are the dependent variables of the study (COD time) for both 4m and 20m approach distances (herein referred to as 4m CODs and 20m CODs respectively).

All COD tests began with a standing start with the front foot placed 20cm behind the timing gates, which were placed on each side of a 2m long line. Timing gates measuring initial time were set at a height of 30cm. Timing gates measuring part-time (COD time) were set at a height of 95cm. When testing, the athletes were instructed to place one toe on the starting line and avoid any countermovement. They were instructed not to step over the middle cone in the COD maneuver area, except in 180° CODs where the cone was removed. For an attempt to be approved, participants had to perform the 90° 135° and 180° CODs without overstepping the far end of the COD area (as this would increase their test duration) where both feet had to be placed inside the COD area. In 45° COD conditions, crossing the far end of the COD area was necessary to complete the test and no regulations were given.

Participants performed each test condition once but were allowed additional attempts if the test criterion was not met or in case they slipped. For each condition, the participants received their 4m COD time. In 20m CODs, only total time was given (initial 16m sprint + 4m x 4m COD time), thus manipulating what they assumed was the dependent variable and securing maximal approach speeds in 20m CODs.

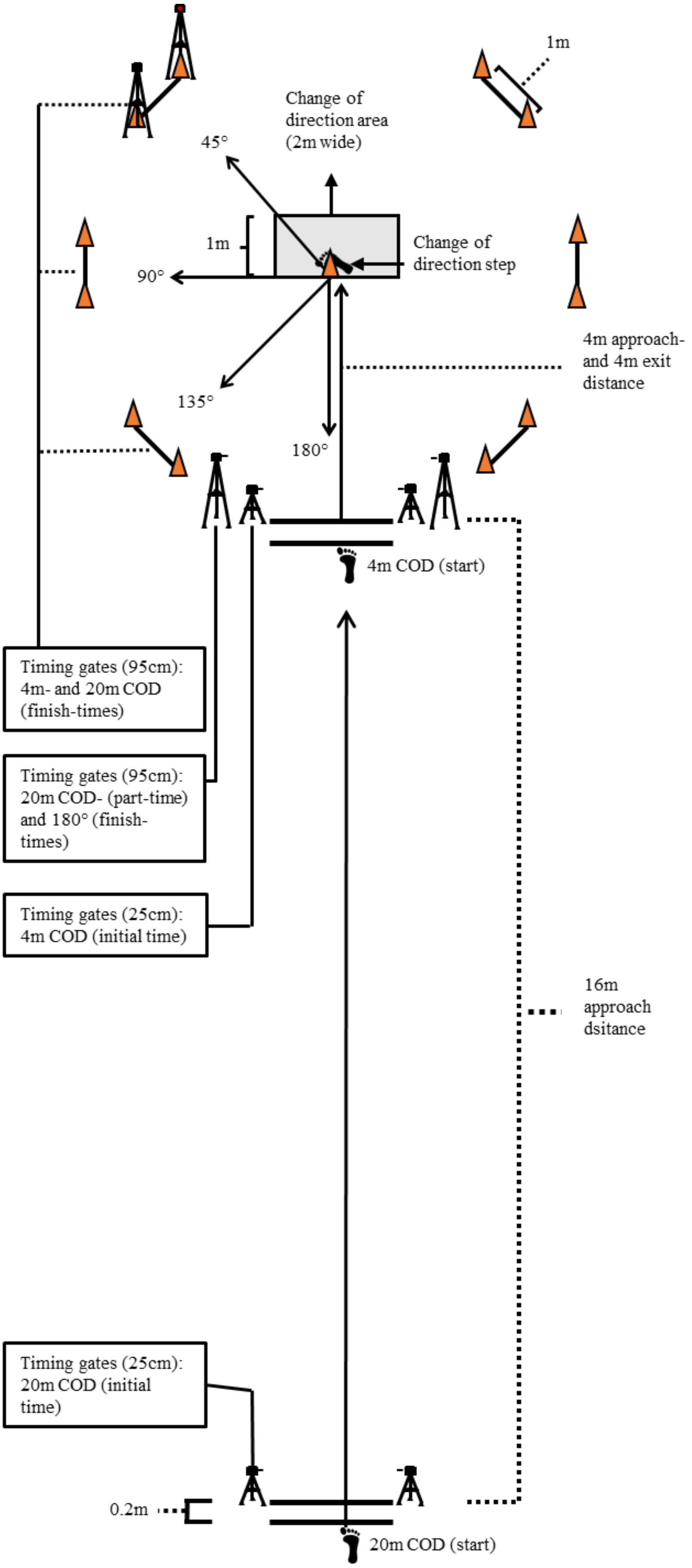

**Figure 2.** Change of direction test set up with approach of 4 or 20 m with timing gates on 4 and 20m with COD of 45, 90, 135 and 180° followed by 4m sprint.

### 2.4.2 Strength assessments

**Unilateral quarter squat** in the smith machine is illustrated in figure 3a. In this exercise, the participants had to place their dominant foot under their center of mass, with the toe pointed forward, on the edge of the platform and reach a depth of between 40 to 60 degrees in the knee joint, following definitions in Schoenfeld (2010). The non-dominant foot was to remain isometric in elevated position. The participants were free to flex their hips as long as no rounding of the torso occurred; no rotation of the hip joint was aloud.

**The bilateral parallel squat** is illustrated in figure 3b. Participants were instructed to reach a parallel dept which corresponds to a visualized line between trochanter major and patella that is parallel to the ground. The barbell was placed on the upper trapezius. This barbell position was used in all back-squat exercises. There was no standardization regarding stance width. Participants adopted either a self-taught stance or a stance that was instructed by the researchers during familiarization, with the aim of reaching approved depth and optimizing force application.

**The lateral squat** (figure 3c) started with the participants having both feet planted on the ground at about hip-width, before planting their dominant foot to the side. The distance the dominant foot would have to travel laterally had to be substantial enough to allow for the supporting limb to extend. When the dominant foot was planted laterally, the downward movement was initiated by ‘pushing the hips backwards’, followed by flexing the dominant knee. In the push off phase of the movement, the supporting limb had to remain relatively straight without locking out the knee joint. Vertical force had to be exerted in the bottom of the movement while finishing with a more lateral exertion of force, making it possible for the supporting leg to be in a stable and extended position during the entire movement. The heel of the dominant foot could not be planted in front of the toe of the participants supporting limb. Furthermore, participant had to distribute the loads evenly across their foot tripod to ensure proper foot alignment (Arunakul et al., 2013), this was learned with cues adopted during familiarization. A depth between 40-60 degrees was necessary to complete an approved lift as defined in Schoenfeld (2010).

**The Nordic hamstring exercise** was performed unilaterally on a custom made platform with the ankle of the dominant foot locked in place (figure 3d). The participants were instructed to lower themselves as slowly as possible to the lowest position without bending at the hip.

**Unilateral plantarflexion** in smith machine required the participants to place the distal end of the metatarsal bone over the edge of the platform (figure 3e). They were cued to distribute the load on their big toe as inversion of the ankle commonly occurred when the loads where increased. The starting position was with the heel lowered on a wooden platform.

On signal, participants were to extend maximally at the ankle and perform an isometric hold of two seconds in this position of maximal extension. The knee joint had to be in a fixed position during the entire movement, as extension of the knee could influence the test result. The weight chosen to represent 1RM had to be performed in an angle that was close to the angle of plantarflexion they could demonstrate when lifting the bar only.

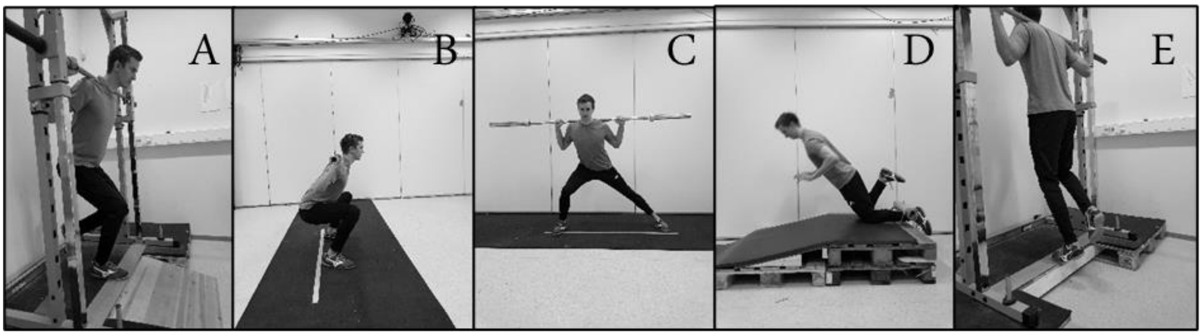

**Figure 3.** Performance of strength exercises. (A) Unilateral quarter squat. (B) Bilateral parallel squat. (C) Lateral squat. (D) Unilateral plantarflexion. (E) Unilateral Nordic hamstring. Figure D and E are displayed for the purpose of the strength-training program, but not used as a measure of performance. Exercise A, B and C are representatives of unilateral, bilateral and lateral lower limb maximal strength, respectively.

### 2.4.3 Plyometric assessments

**Bilateral drop jumps** (figure 4A) were performed on a hard indoor surface with individualized drop heights of 30, 45 or 60cm. The drop heights were chosen based on measures of reactive strength conducted on the second day of familiarization as measured by RSI. The drop height resulting in the highest RSI-score were used for testing. If this score was equal between two drop heights, the highest drop height was chosen. The participants were instructed to keep their arms akimbo, minimize the contribution of momentum created by forward lean of the torso and to mimic the instant of take off at landing. Participants were allowed up to five attempts at this exercise; the attempt with the highest RSI score were used for analysis.

**Unilateral Countermovement jump** (figure 4B) was performed with arms kept akimbo and the instructions were to minimize the contribution of momentum created by forward lean. Furthermore, they had to perform the moment explosively, extending at the ankle at both take-off and landing, and be able to perform a three second isometric hold upon landing. The non-dominant limb had to remain passive during the entire movement and the highest jump of 3 attempts which satisfied the test criteria were used for analysis.

**The Hurdle jump exercise** (figure 4C and 4D) included two distinct test conditions that were performed bilaterally and unilaterally. The distance between each hurdle was 1.70m for the bilateral condition and 1m for the unilateral condition. Hurdles were set at a height of 20, 30, 40, 50 and 60cm. Based on the familiarization phase, the height at which each athlete demonstrated the shortest contact time was chosen as their respective standard used for testing. The bilateral condition, the feet had to be placed next to each other upon ground contact. The participants were instructed to complete each test as fast as possible with minimal ground contact time between each hurdle.

**The skate jump** (Figure 4E) started with the participants placing their dominant foot on a marked spot. On signal, they had been instructed to jump laterally and land on their non-dominant foot, aiming for maximal lateral jumping distance. The participants had to demonstrate control in the landing and were required to perform a three second isometric hold immediately following ground impact. Three attempts were allowed, and the longest attempt was used in the analysis.

**The laying kick** (figure 4F) was performed with the dominant foot planted on the ground with a small and fixed flexion of the knee. The knee angle was to remain static, while hip extension contributed to the push off force applied to the heel. No instructions were given regarding the non-dominant limb, as some participants needed the limb as an assistant to create momentum in the push-off phase. In the negative phase of the movement, participants were instructed to mimic the concentric push-off phase of the movement.

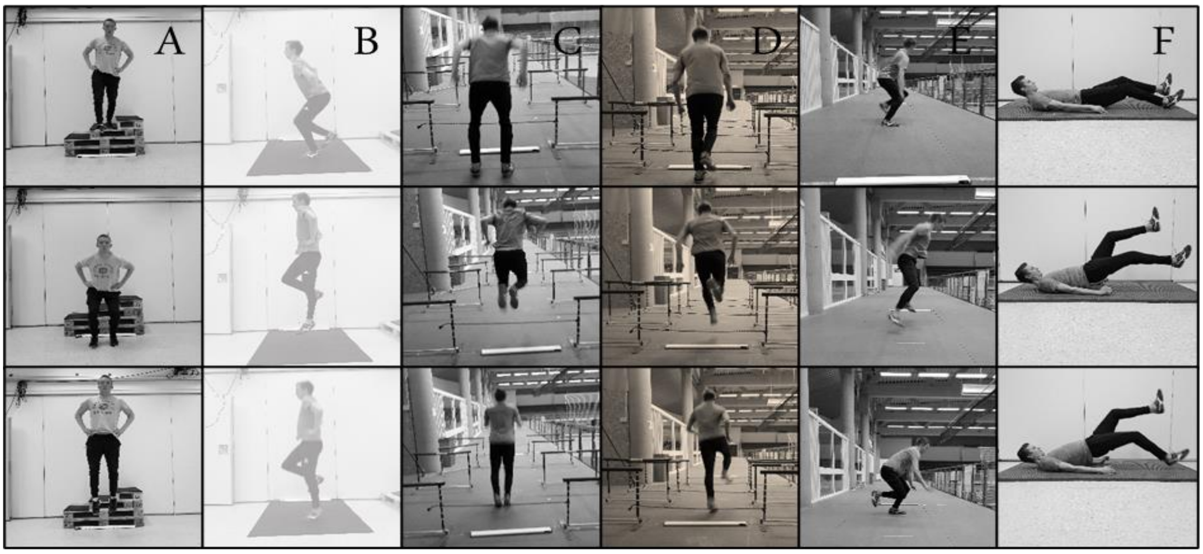

**Figure 4.** Different plyometric exercises. (A) Drop jump. (B) Countermovement jump. (C) Bilateral hurdle jump. (D) Unilateral hurdle jump. (E) Skate jump (F) Laying kick (displayed for the purpose of the plyometric training program, but not used as a measure of performance). Exercise A, B and E are representatives of bilateral, unilateral and lateral lower limb power respectively.

## 2.5 Equipment

Xsens MVN 3D motion capturing system, a product by Xsens technologies (B.V Enschede, the Netherlands), was used to sample biomechanical data during COD testing and to control for joint angles during different tests. The Xsens MVN is a full body suit with 17 small inertial and magnetic motion tracking sensors that are wired to an on-body data hub, which is wirelessly connected to a PC. This provides live monitoring and recording of human motion. The inertial sensors were placed according to the Xsens Technologies guidelines, detailed in the product description. Participants' body dimensions were plotted in the software named: Xsens MVN analyze. In combination with coordination of all inertial sensors, this made it possible to obtain body segments and positions, creating a complete biomechanical model after a standardized calibration procedure.

The MVN system sampled data at 240hz and data used for statistical analysis was later reprocessed in HD to get a more precise and consistent positions and orientations of body segments (Schepers, Giuberti & Bellusci, 2018). The Xsens MVN provided joint angle definitions according to the ISB recommendations for standardization (Wu & Cavanagh, 1995; Wu et al., 2002). The angles are defined relative to the joint angles displayed during a static N-pose of the calibration process (Schepers et al., 2018). These joint angles are relatively close to zero, which means that they are defined by their displacement from a standing position with a negative or positive value depending on the movement. The Xsens system is considered reliable and consistent in (Schepers et al., 2018), under the direction of Xsens technology. As the Xsens system is relatively new to the field of sports science, an Inertial measurement unit (IMU, Ergotest innovation, Porsgrund Norway, ML Gyros/ML6IMU01) was placed on the right upper leg on top of the Xsens sensor to compare data from two different systems, thus providing some external validation and control.

Browser timing system (Salt Lake Utah, USA, CML5 MEM) registered time for the 4m COD test and split-time + part-time for the 20m COD test. The system consists of a laser gate and a receiver gate, which start/stops the time when crossing the laser beam (figure 2).

Infrared optical contact grids from Ergotest innovation (IR contact mat ML6TJP02) measured contact time, jump height and RSI in plyometric exercises. The systems consist of two contact grids, which send and reflect infrared light. When this beam of light between sender and reflector is broken (interfered with), the system records flight time and converts this to the variables of interests.

## 2.6 Training programs

**Matching of workload**

The total work (Workload) of both the strength program and the plyometric program their respective exercises was calculated and matched in force application as measured by impulse. Impulse is the integral of force over- time and has been used to match the total mechanical work of human motion in different training-programs (Ettema, Gløsen & van den Tillaar, 2008). To match exercises from strength and plyometric training the peak impulse in the movements was calculated based on similar approaches in Ettema et al. (2008); (Marques et al., 2012; van den Tillaar & Marques, 2009, 2011). Peak impulse was calculated as follows: mass of the subject + external load (if applied) multiplied by the maximal velocity during the push-off phase of the movements.

Peak impulse for strength exercises was calculated with the help of a linear encoder attached to the squat-bar, measuring maximum velocity in the movement. The players participating in the project prior to the intervention study performed strength-exercises using 3-4 attempts with randomized and evenly distributed loads between 60-90% of estimated 1 rep maximum (1RM). Using linear regression, the peak impulse at different percentages of 1 rep maximum was estimated. Peak impulse for the plyometric exercises was estimated using indirect measures of flight time using a contact grid. Maximal velocity during jumping will occur at the instant of takeoff, where no forces act upon the motion with the exception of gravitational force when rising. Using an equation by Linthorne (2001), it was possible to calculate maximal velocity during jumping:

$$V_{max} = \frac{\mathrm{g}\ t_{flight}}{2}$$

G refers to the gravitational constant of 9,81 m/s. $t_{\mathrm{flight}}$ refers to flight time in seconds. For an accurate prediction, participants must have the same body configuration at the instant of landing compared with landing at take-off (Linthorne, 2001). The ankle extension at landing does not replicate the ankle extension at take-off, resulting in a jump height overestimation of 0,5-2cm (Kibele, 1998). This resulted in some challenges in predicting maximal velocity in the skate jump, as planting the feet laterally would extend flight-time. When testing for peak impulse in the skate jump, each participant was instructed to push off and land with their feet in a vertical orientation. With this in mind, workload in the skate jump was roughly estimated. The peak impulse from single repetitions was multiplied with the number of repetitions and sets to calculate the workload in each muscle group and training program. There were no calculations of workload regarding hamstring-exercises, as a greater peak impulse in the Nordic hamstring exercise would be a result of an inability to reduce momentum. Hence, the exercise is not relevant to measure workload. However, the laying kick and Nordic hamstring exercise were matched upon maximal muscle activity in hamstring muscles based on work in van den Tillaar, Solheim & Bencke (2017).

The matching of the training programs is displayed in table 1. The matching and definition of stimulated muscles was based on which primary muscles the exercise was aimed at stimulating/overloading. It is worth noting that the values displayed in table 1 are similar across all training sessions for both strength and plyometric protocols, based on single measurements of nine participants. This workload is very likely to increase during the interventions, thus providing progressive overload over the period.

**Table 1.** Matching of exercises in strength and plyometric training.

| **Matched exercises** | | **Common aspects** | |
|---|---|---|---|
| **Strength exercises** | **Plyometric exercises** | **Targeted muscles** | **Workload per session** |
| Parallel squat, Unilateral squat & Calf Raise | Drop Jump, Unilateral CMJ & Hurdle jumps | Hip, knee and ankle extensor muscles | ≈4250 Ns |
| Lateral squat | Skate jump | Hip abductor muscles | ≈1650 Ns |
| Unilateral Nordic hamstring | Laying kick | Hamstring muscles | Peak EMG ≈75% of max voluntary contraction |

## Program and design

The training programs were based on principals of undulating periodization (Poliquin, 1988). The undulating model provides frequent changes in stimulus with rotating volume and intensity within a short period of time (Kraemer & Ratamess, 2004). This was achieved by varying the number of exercise repetitions on day 1 and 2 within a week of training and by altering the program after 3 weeks. This approach has shown to be more effective compared to the traditional linear periodization model at eliciting strength and power gains (Rhea, Alvar, Ball & Burkett, 2002). Both training groups performed a general warmup followed by dynamic stretching and submaximal lifts/jumps prior training, to provide optimal neuromuscular states, increased specific range of motions and to reduce the risk of injury (Bishop, 2003). The training programs are displayed in table 2 and 3, respectively.

**Table 2.** Periodized six week strength training program.

**Week 1-3 (Session 1-6)**

| **Day 1** | **Intensity** | **Rest (s)** | **Series** | **Reps per series** |
|---|---|---|---|---|
| Unilateral quarter squat | 85% of 1RM | 180 > | 2D & 2ND | 5 |
| Parallel squat | 85% of 1RM | 180 > | 3 | 5 |
| Lateral squat | 75% of 1RM | 180 > | 3D- & 3ND-start | 6 |
| Nordic hamstring | Max braking | 90 > | 2D- & 2ND-start | 5 |
| Unilateral plantar flexion | 70% of 1RM | 90 > | 3D- & 3ND-start | 8 |
| **Day 2** | | | | |
| Unilateral quarter squat | 80% of 1RM | 180 > | 2 D & 2ND | 6 |
| Parallel squat | 80% of 1RM | 180 > | 3 | 8 |
| Lateral squat | 75% of 1RM | 180 > | 3 D & 3ND | 6 |
| Nordic hamstring | Max braking | 90 > | 2 D & 2ND | 5 |
| Unilateral plantar flexion | 70% of 1RM | 90 > | 3 D & 3ND | 8 |

**Week 4-6 (Session 7-12)**

| **Day 1** | **Intensity** | **Rest (s)** | **Series** | **Reps per series** |
|---|---|---|---|---|
| Lateral squat | 80% of 1RM | 240 > | 4 D & 4ND | 4 |
| Unilateral quarter squat | 80% of 1RM | 240 > | 2 D & 2ND | 6 |
| Parallel squat | 80% of 1RM | 240 > | 3 | 6 |
| Nordic hamstring | Max braking | 90 > | 2 D & 2ND | 8 |
| Unilateral plantar flexion | 75% of 1RM | 90 > | 4 D & 4ND | 6 |
| **Day 2** | | | | |
| Unilateral quarter squat | 88% of 1RM | 240 > | 2 D & 2ND | 4 |
| Parallel squat | 85% of 1RM | 240 > | 3 | 6 |
| Lateral squat | 70% of 1RM | 240 > | 3 D & 3ND | 8 |
| Nordic hamstring | Max braking | 90 > | 3 D & 3ND | 8 |
| Unilateral plantar flexion | 75% of 1RM | 90 > | 4 D & 4ND | 6 |

1RM= 1 repetition maximum, D= dominant limb, ND= non-dominant limb.

**Table 3.** Periodized six week plyometric training program.

**Week 1-3 (Session 1-6)**

| **Day 1** | **Main focus** | **Rest (s)** | **Series** | **Reps per series** |
|---|---|---|---|---|
| Unilateral CMJ | Height | 90 | 5D & 5ND | 1 |
| Drop jump | Reactive strength | 60 | 10 | 1 |
| Unilateral hurdle jump | Contact time | 120 | 5D & 5ND | 3 |
| Bilateral hurdle jump | Contact time | 90 | 4 | 3 |
| Skate jump | Reactive strength | 90 | 3D- & 3ND-start | 6 |
| Laying kick | Reactive strength | 90 | 2D & 2ND | 5 |
| **Day 2** | | | | |
| Drop Jump | Reactive strength | 20 | 4 | 3 |
| Unilateral CMJ | Height | 60 | 6D & 6ND | 1 |
| Bilateral hurdle jump | Contact time | 60 | 6 | 3 |
| Unilateral hurdle jump | Contact time | 120 | 4D & 4ND | 3 |
| Skate jump | Reactive strength | 90 | 3D- & 3ND-start | 6 |
| Laying kick | Reactive strength | 90 | 2D & 2ND | 5 |

**Week 4-6 (Session 7-12)**

| **Day 1** | **Goal** | **Rest (s)** | **Series** | **Reps per series** |
|---|---|---|---|---|
| Skate jump | Reactive strength | 90 | 4D & 4ND | 4 |
| Bilateral hurdle jump | Contact time | 20 | 4 | 6 |
| Unilateral hurdle jump | Contact time | 120 | 4D & 4ND | 3 |
| Drop jump | Reactive strength | 60 | 8 | 1 |
| Unilateral CMJ | Height | 90 | 6D & 6ND | 6 |
| Laying kick | Reactive strength | 90 | 2D & 2ND | 8 |
| **Day 2** | | | | |
| Unilateral hurdle jump | Contact time | 90 | 4D & 4ND | 3 |
| Bilateral hurdle jump | Contact time | 60 | 4D & 4ND | 3 |
| Skate jump | Reactive strength | 120 | 3D & 3ND | 8 |
| Unilateral CMJ | Height | 90 | 6D & 6ND | 1 |
| Drop jump | Reactive strength | 60 | 8 | 1 |
| Laying kick | Reactive strength | 90 | 3D & 3ND | 8 |

CMJ= Countermovement jump, D= dominant limb, ND= non-dominant limb.

## 2.7 Motivational profile

To measure dispositional goal perspectives (motivational profile), a survey using the Norwegian version (Roberts & Ommundsen, 1996) of Perception of Success in Sport Questionnaire (POSQ) was completed (Roberts et al., 1998). The questionnaire encompasses six items measuring task-oriented goals and six items measuring ego-oriented goals. When completing the questionnaire, the participants responds on a Likert scale from 1 (strongly disagree) to 5 (strongly agree) on each item. They are responding in the context of what makes them feel most successful when practicing their sport. An example of an item measuring task orientation is: “I reach personal goals” and an example measuring ego orientation is: “I show other people I am the best”. The questionnaire has demonstrated satisfactory psychometric properties in Roberts & Ommundsen (1996) using Norwegian respondents.

To measure how goal perspectives related to performance, the sum of all COD conditions including split-times for 20m CODs was used to calculate percentage change from pre to post test.

## 2.8 Statistical analysis

Statistical analysis was carried out using SPSS statistics 25 program for windows (SPSS, Inc, Chicago., Illinois). For baseline measurements, a 4 (degrees: 45°, 90°, 135°, 180°) x 2 (side: left, right) analysis of variance (ANOVA) was used to identify statistical differences between left and right directional changes in CODs of 4m and 20m approach distances. One-way ANOVAs were used to identify differences between the different angles of directional change (4 degrees) in 4m and 20m CODs. Effect sizes (ES) were determined by eta squared (One-way ANOVA) and partial eta squared (Two-way ANOVA and repeated measures) and were abbreviated with $\eta^2$ and $\eta_p^2$ respectively (Lakens, 2013). Values of 0.01-0.059 were defined small ES, values of 0.06-0.139 were considered medium ES, and values of 0.14 or above were considered large ES (Cohen, 1988). When statistically significant differences occurred, post-hoc analysis using Bonferroni correction was conducted to identify comparisons that were statistically significant, these were marked with an α to remind the reader that the alpha level had been adjusted [α (0.05)/number of conditions in the ANOVA). Furthermore, paired sample t-tests were applied to compare CODs of equal angles between 4m and 20m approach distances.

Descriptive data was presented as mean ± SD after confirmation of the normal distribution using the Kolmogorov Smirnov test. In cases of deviation from normal distribution, non-parametric tests were used (i.e. Friedman's test for multiple comparisons and Wilcoxon signed rank test for pairwise comparisons). Mauchly's tests of sphericity was used to check for equality of variance between multiple conditions in ANOVA. If the assumption of sphericity had been violated, a correction was applied. Thus, if Greenhouse-Geiser epsilon exceeded 0.75, the Huynh Feldt correction was used, whereas a corresponding value less than <0.75 resulted in use of the Greenhouse Geisser correction (Girden, 1992; Vanrenterghem, Venables, Pataky & Robinson, 2012).

Pearson product moment correlation coefficient was used to investigate relationships between COD performance and measures of lower limb muscle qualities. This was also used to determine the relationship between motivational orientation and measures of overall COD performance, described in chapter 2.7. In cases of deviations from normal distribution, Spearman's rank-order correlation was applied to run non-parametric tests. The strength of the correlations (r) was based on following thresholds; (±0 -.10) = trivial, (±.10 -.30) = small, (±.30 -.50) = moderate, (±.50 -.70) = large, (±.70 -.90) = very large and (±.90 -1.0) = almost perfect (Hopkins, Marshall, Batterham & Hanin, 2009).

Training related effects were identified by Repeated Measures ANOVA with 2 (independent training groups) x 4 (degrees) x 2 occasions (pre, post) in both 4m and 20m CODs. Significant differences were followed by Post hoc analysis using Holm- Bonferroni correction. Cohen's d effect size was implemented to qualitatively determine the size of an effect in paired samples, as proposed by Cohen (1988). ES from 0.01-0.2 were defined as trivial, values of 0.2-0.49 were considered small ES, values 0.5-0.8 were considered medium ES, and values of 0.8 or above were considered large ES. Levene's test was used to check for equality of variance in independent samples; no unequal variance was found ($p < 0.05$), thus no corrections were applied.

**NB:** Appendix B presents statistics of left vs right COD conditions. No statistically significant differences were found, which suggest that left and right CODs share the same technical and physical qualities. Therefore, further analysis was conducted on left CODs only.

# 3. Results

## 3.1 Significance of force- and velocity-oriented COD tasks

### 3.1.1 Four-meters approaches to CODs

**Table 4** presents descriptive statistics and multiple comparisons of key variables in 4m COD conditions. For the sake of simplicity when reading ANOVA statistics, the degrees of freedom will not be displayed in text but can be found in tables. Ten one-way ANOVAs were completed, followed by post hoc testing. The ANOVA showed statistically significant differences in time to complete CODs between 4 conditions ($F = 375.01$, $p < 0.001$) with large effect size ($\eta_p^2 = 0.952$). Post hoc analysis revealed a statistically significant relationship with each instant of degree angle and all possible combination of 45°, 90°, 135° and 180° CODs ($\alpha < 0.05$). A significant difference in the number of deceleration steps applied before the COD step was found ($X = 47.3$, $p < 0.001$). Post hoc analysis found 45° and 90° COD to be statistically significantly different from all conditions ($\alpha < 0.05$), whereas no difference was found between 135° and 180° COD ($\alpha > 0.05$).

There was a statistically significant difference between COD angle and lowest COM displayed in the COD step for 4 conditions ($F = 71.93$, $p < 0.001$) and for CT ($F = 36.26$, $p < 0.001$) with large effect sizes ($\eta_p^2 = 0.80$ & 0.681). Post hoc analyses revealed all possible combinations of these two variables to be significant different ($\alpha < 0.05$). A significant difference was found for lowest COM displayed in the post step between for 4 conditions ($F = 8.92$, $p < 0.001$) and CT ($F= 4.06$, $p = 0.012$) with large effects sizes ($\eta_p^2 = 0.34$ & 0.20). Post hoc analysis revealed that all possible combinations were significantly different for the lowest COM in the post step ($\alpha < 0.05$), with the exception of 90° and 135° with 180° condition ($\alpha > 0.05$). Post hoc analysis for CT at the post-step revealed 45° to be significantly different from 90°, 135° and 180° conditions.

Statistically significant differences were found for all the respective joint angles measured at the lowest COM displayed in the COD step, except for the plantarflexion angle ($F = 1.24$, $p = 0.072$). Knee flexion angle displayed ($F = 6.60$), hip flexion angle displayed ($F= 7.84$) and abduction angle displayed ($F = 6.03$), all significant at the level of ($p < 0.001$) with large effect sizes ($\eta^2 = 0.28\text{-}0.32$). Post hoc found knee flexion angle for 45° conditions significantly different from 90° 135° and 180° ($\alpha > 0.05$). For the hip flexion angle, 45°, 90° and 135° were significantly different to 180° condition, whereas for hip abduction angle, the 90° and 135° conditions were significantly different from 180° ($\alpha > 0.05$).

**Table 4.** Four-meter COD tasks.

| **Variables** | **Conditions (M ± SD)** | | | | **ANOVAs** | | | | **Post hoc** |
|---|---|---|---|---|---|---|---|---|---|
| | **45° COD (A)** | **90° COD (B)** | **135° COD (C)** | **180° COD (D)** | ***df*** | ***F*** | *p* | $\eta^2$ | **Pairwise comparisons**$^{\alpha}$ |
| COD time (cs) | 172.9 ± 15.0† | 205.9 ± 15.6† | 237.5 ± 16.9† | 248.1 ± 16.4† | 3, 57 | 375.009 | < 0.001 | 0.952 | All combinations |
| Decelerations (n)$^{X}$ | 0.4 ± 0.8† | 2.7 ± 0.8† | 3.2 ± 0.5† | 3.2 ± 0.7† | 3 | 47.344 | < 0.001 | | A > BCD & B > CD |
| **COM** COD step (cm) | 17.6 ± 3.1† | 25.5 ± 6.0† | 30.7 ± 5.8† | 33.8 ± 7.0 | 3, 54 | 71.932 | < 0.001 | 0.800 | All combinations |
| **COM** post step (cm) | 12.7 ± 4.4 | 18.3 ± 4.5 | 18.5 ± 4.8 | 16.3 ± 3.2 | 3, 51 | 8.918 | < 0.001 | 0.344 | A > BCD |
| **CT** COD step (cs) | 151.5 ± 21.7 | 189.3 ± 42.5 | 234.5 ± 70.1 | 305.5 ± 89.8 | 1.832, 31.145 | 36.264 | < 0.001 | 0.681 | All combinations |
| **CT** post step (cs) | 158.6 ± 37.0 | 187.2 ± 66.2 | 194.8 ± 30.3 | 203.9 ± 36.8 | 3, 48 | 4.056 | 0.012 | 0.202 | A > BCD |
| Dorsiflexion (°) | 27.0 ± 9.4 | 25.6 ± 13.6 | 29.4 ± 17.8 | 34.0 ± 21.4 | 3, 48 | 1.236 | 0.307 | | |
| Knee flexion (°) | 48.0 ± 6.2 | 59.3 ± 12.0 | 59.2 ± 13.1 | 58.6 ± 15.6 | 3, 51 | 6.603 | < 0.001 | 0.280 | A > BCD |
| Hip flexion (°) | 11.5 ± 15.0 | 13.9 ± 12.3 | 14.8 ± 11.3 | 27.0 ± 13.6 | 3, 51 | 7.844 | < 0.001 | 0.316 | A > D & B > D & C > D |
| Hip abduction (°) | 7.6 ± 4.9 | 11.3 ± 6.0 | 8.8 ± 7.4 | 14.4 ± 7.7 | 3, 48 | 6.032 | < 0.001 | 0.274 | A > D & C > D |

COD time= time to complete COD with 4m approach distance + 4m exit distance, Deceleration= number of steps resulting in a negative change in velocity prior to the COD step, COM= largest center of mass displacement measured in the step, CT= ground contact time, X= Variable analyzed with Friedman's test for multiple comparisons (i.e. Friedman's ANOVA), † = A statistically significantly difference to COD tasks with a 20m approach distance ($p < 0.05$).

### 3.1.2 Twenty-meters approaches to CODs

**Table 5** presents descriptive statistics and multiple comparisons of key variables in 20m COD conditions. Twelve one-way ANOVAs were completed, followed by post hoc testing. The ANOVA showed statistically significant differences in time to complete CODs between 4 conditions ($F = 419.56$, $p < 0.001$) with a large effect size ($\eta^2 = 0.96$), and no significant difference for 16m split-time ($F = 1.33$. $p = 0.277$). Post hoc analysis revealed a statistically significant relationship between each instant of degree angle and all possible combinations of 45°, 90°, 135° and 180° CODs ($\alpha < 0.05$) with respect to total time. The same trend was displayed for total time ($F = 360.66$, $p = 0.001$) with a large effect size ($\eta^2 = 0.95$). A significant difference in the number of deceleration steps applied before the COD step was found ($X = 45.45$, $p < 0.001$). Post hoc analysis found 45° and 90° CODs to be statistically significantly different from all other conditions ($\alpha < 0.05$), whereas no difference was found between 135° and 180° CODs ($\alpha > 0.05$).

There was a significant difference for lowest COM displayed in the COD step for 4 conditions ($F = 79.13$, $p < 0.001$) and CT ($F = 37.16$, $p < 0.001$) with a large effect size ($\eta^2 = 0.82$ & $0.67$). Post hoc analyses revealed that 45° was significantly different to 90°, 135°, and 180° conditions and that 90° was different from 135° and 180° ($\alpha < 0.05$) for the lowest COM in the COD step. For CT displayed in the COD step, all combinations were significant ($\alpha < 0.05$), except 90° and 135° conditions ($\alpha > 0.05$). A significant difference was found for lowest COM displayed in the post step between 4 conditions ($F = 5.14$, $p < 0.003$) and CT ($F= 15.46$, $p < 0.001$) with large effects sizes ($\eta^2 = 0.26$ & $0.51$). Post hoc analysis revealed that 45° was significantly different from 90° conditions for lowest COM in the post step ($\alpha < 0.05$), whereas 45° was significantly different from 90°, 135°, and 180° conditions for CT at post step ($\alpha < 0.05$).

A significant difference was found for all the joint angles measured at the lowest COM displayed in the COD step in 4 conditions. This was evident for plantarflexion angle displayed ($F = 5.02$, $p = 0.004$), knee angle displayed ($F = 4.35$, $p = 0.008$), hip flexion angle displayed ($F = 15.51$, $p < 0.001$) and hip abduction angle displayed ($F = 4.72$, $p = 0.019$). Post hoc analysis found 45° conditions to be significantly different from 180° conditions for the plantarflexion angle and 45° significantly different from 135° for the knee flexion angle ($\alpha < 0.05$). For hip flexion angle, post hoc found 45° to be significantly different from 180° angle conditions, 90° significantly different from 135° and 180°, as well as 135° significantly different from 180° conditions ($\alpha < 0.05$). For hip abduction angle, the 90° and 135° was significantly different from 180° condition ($\alpha < 0.05$).

**Table 5.** Twenty-meter COD tasks.

| Variables | Conditions (M ± SD) | | | | ANOVAs | | | | Post hoc |
|---|---|---|---|---|---|---|---|---|---|
| | **45° COD (A)** | **90° COD (B)** | **135° COD (C)** | **180° COD (D)** | ***df*** | ***F*** | ***p*** | $\eta^2$ | **Pairwise comparisons**$^{\alpha}$ |
| COD time (cs) | 138.3 ± 10.6† | 183.6 ± 11.9† | 214.9 ± 14.1† | 230.2 ± 11.5† | 3, 57 | 419.558 | < 0.001 | 0.957 | All combinations |
| 16m Split-time (cs) | 269.9 ± 11.9 | 272.5 ± 13.3 | 172.8 ± 13.1 | 273.1 ± 14.9 | 1,962<br>37.285 | 1.329 | 0.277 | | |
| Decelerations (n)$^X$ | 2.9 ± 1.2† | 5.3 ± 0.9† | 6.2 ± 1.3† | 6.3 ± 1.1† | 3 | 45.446 | < 0.001 | | A > BCD & B > CD |
| **COM** COD step (cm) | 19.9 ± 3.7† | 28.4 ± 4.7† | 33.1 ± 5.7† | 35.6 ± 5.8 | 2.131,<br>38.359 | 79.129 | < 0.001 | 0.815 | A > BCD & B > CD |
| **COM** post step (cm) | 14.0 ± 3.5 | 19.6 ± 4.9 | 17.6 ± 4.2 | 16.6 ± 5.2 | 3, 45 | 5.138 | 0.003 | 0.262 | A > B |
| **CT** COD step (cs) | 150.1 ± 22.4 | 188.6 ± 41.5 | 220.5 ± 64.1 | 325.8 ± 107.2 | 1.599,<br>28.778 | 37.156 | < 0.001 | 0.674 | A > BCD & B > D & C > D |
| **CT** post step (cs) | 146.8 ± 18.7 | 179.4 ± 25.9 | 201.4 ± 36.8 | 211.5 ± 44.3 | 2.229,<br>33.433 | 15.456 | < 0.001 | 0.507 | A > BCD |
| Dorsiflexion (°) | 23.5 ± 13.2 | 30.2 ± 10.4 | 35.4 ± 15.9 | 37.6 ± 12.4 | 3, 48 | 5.015 | 0.004 | 0.239 | A > D |
| Knee flexion (°) | 50.6 ± 13.1 | 59.6 ± 15.6 | 65.5 ± 16.3 | 60.9 ± 10.5 | 3, 51 | 4.351 | 0.008 | 0.204 | A > C |
| Hip flexion (°) | 9.8 ± 16.1 | 9.0 ± 13.9 | 19.0 ± 11.7 | 32.0 ± 14.0 | 3, 51 | 15.514 | < 0.001 | 0.477 | A > D & B > CD & C > D |
| Hip abduction (°) | 9.7 ± 7.0 | 9.1 ± 6.6 | 10.7 ± 6.3 | 16.4 ± 8.8 | 1.812,<br>28.997 | 4.724 | 0.019 | 0.228 | A > D & B > D & C > D |

COD time = time to complete COD with 4m approach distance + 4m exit distance after performing a 16-meter approaching sprint (split-time). Deceleration= number of steps resulting in a negative change in velocity prior to the COD step, COM= largest center of mass displacement measured in the step, CT= ground contact time, X= Variable analyzed with Friedman's test for multiple comparisons (i.e. Friedman's ANOVA), † = A statistically significantly difference to COD tasks with a 20m approach distance ($p < 0.05$).

### 3.1.3 Four- vs twenty-meter approaches to CODs

The variables that are statistically significantly different with respect to 4m vs 20m conditions are marked with a cross sign (†) in table 4 and 5. Forty-two paired sample t-tests were completed in total.

A statistically significantly difference was found between 4m time (M=172.9±15.0) and 20m time (M=138.3±10.6) performed in 45° condition; t (19) = -13.53 and for 90° between 4m (M=205.9±15.6) and 20m (M=183.6.9±11.9) condition; t (19) = -7.60 and for 135° between 4m (M=237.5±16.9) and 20m (M=214.9±14.1) condition; t (19) = .6.35 and for 180° between 4m (M=248.1±16.4) and 20m (M=230.2±11.5) condition; t (19) = -6.35, where all conditions were significant at the level of (p < 0.001).

A statistically significantly difference in the number of deceleration steps applied before the COD step was found between 4m (M=0.4±0.8) and 20m (2.9±1.2) performed in 45° condition; t (17) = 3.75 and for 90° between 4m (2.7±0.8) and 20m (5.3±0.9) condition; t (17) = 3.82 and for 135° between 4m (3.2±0.5) and 20m (6.2±1.3) condition; t (17) = 3.77 and for 180° between 4m (3.2±0.7) and 20m (6.3±1.1) condition; t (17) 3.77= , all significant at the level of (p < 0.001).

A statistically significant difference was found for lowest COM in COD step for 45° between 4m (M=17.6±3.1) and 20m (M=19.9±3.7) condition; t (17) = 3.34, p = 0.01 and for 90° between 4m (M=25.5±6.0) and 20m (28.4±4.7) condition; t (17) = 2.32, p = 0.033 and for 135° between 4m (M=30.7±5.8) and 20m (M= 33.1±5.7); t (17) 3.34, p =0.004. No significant difference was found for 180° between 4m (M=33.4±7.0) and 20m (35.6±5.8) condition; t (17) = 0.86, p = 0.403. No significant difference was found for lowest COM between 4 and 20m conditions for any variable at the post step and likewise for all steps measuring CT (p > 0.05).

No statistically significantly difference was found for any variable measuring joint angle at lowest COM displayed in the COD step for plantar flexion, knee flexion, hip-flexion and hip abduction (p > 0.05). See appendix C for a better view of the exact statistics of the mean difference and pairwise comparisons between all variables for 4m vs 20m COD conditions.

*NB: The most key variables within actual COD tasks are added in chapter 3.1.4 for the purpose of granting more knowledge to data displayed in table 4 and 5. These are referred to as subcomponents and should not be confused with lower limb muscle qualities.*

### 3.1.4 The relationship between muscle qualities and performance in COD tasks.

Dynamic lower limb muscle qualities (strength, power, and reactive strength) represent different exercises which each demand force exertion in different directions. A non-statistically significant relationship was found between COD time and bilateral and unilateral measures of strength in all conditions with mostly trivial and small effects, with the exception of the relationship between bilateral strength in 20m 135° condition (r=.32, ES= moderate). Nevertheless, these effects are uncertain ($p > 0.05$).

A negative statistically significant relationship was found between COD time bilateral power for 90° and 135° condition (r= -.54 to -.67, ES= large) and for unilateral power in 135° condition (r= .52, ES= large), indicating that greater power output decreases time to finish COD tasks for these respective conditions. Bilateral measures of RSI indicate no statistically significantly relationships between COD times for conditions with trivial to moderate effect sizes ($p > 0.05$). A negative statistically significant relationship between COD time and lateral strength 20m 135° (r=.52, ES= large) and for lateral power for all 4m conditions (r=.47 to .69, ES= moderate to large) and for lateral power in 45° condition (r=.56, ES= large) was found.

**Table 6.** Correlations between time to complete COD tasks with lower limb strength, power and reactive strength qualities.

| | **4m COD tasks** | | | | **20m COD tasks** | | | |
|---|---|---|---|---|---|---|---|---|
| **Variable** | **45°** | **90°** | **135°** | **180°** | **45°** | **90°** | **135°** | **180°** |
| Bilateral strength | -.11 | -.13 | -.13 | -.20 | -0.8 | -.25 | -.32 | -.26 |
| Bilateral power | -.52 | **-.67**** | **-.54*** | -.50$^{\#}$ | -.37 | -.27 | -.36 | .09 |
| Bilateral reactive strength | -.37 | -.35 | -.37 | -.44$^{\#}$ | -.30 | -.06 | -.6 | -.14 |
| Unilateral strength | -.05 | .05 | .04 | 0.10 | .00 | -.07 | .04 | -.10 |
| Unilateral power | -.45$^{\#}$ | -.44$^{\#}$ | **-.52*** | -.35 | -.27 | .14 | .02 | .37 |
| Lateral strength | -.22 | -.11 | -.14 | -.22 | -.24 | -.40$^{\#}$ | **-.52*** | -.39$^{\#}$ |
| Lateral power | **-.66**** | **-.47*** | **-.51*** | **-.69**** | **-.56*** | -0.05 | -.31 | -.06 |

*$p < 0.05$, **$p < 0.01$, # = non-significant correlations at the level of ($p < 0.10$).

## 3.2 Effects of strength vs plyometric training on different CODs

Paired sample t-tests revealed no significant difference in CODs + part-times between the two groups at pre-test. As such, baseline data for CODs + 20m part-time previously presented in table 4 and 5 is representative descriptive data for COD performances at pre-test. The exact pre- and post-test means ± SD, and p-values for each training group can be found in appendix D. These performance changes are therefore illustrated in figures in the text.

A two-way ANOVA (Group x time) found no difference between the strength training group and the plyometric training group when comparing CODs of equal angles from both 4m and 20m approach distances ($p = 0.37$). A one-way ANOVA for 20m part-time found no significant effect between groups in 16m sprints performed prior to CODs of different angles.

A group-specific ANOVA for the strength training group revealed a significant main effect of time from pre- to post-test when comparing CODs of equal angle in 4m- and 20m CODs ($F = 6.555$; $p = 0.034$, $\eta_p^2 = 0.450$), although no statistically significant effects were found when conducting post hoc test ($p \geq 0.067$). A group-specific ANOVA for the plyometric training group revealed a significant main effect of time from pre- to post-test when comparing CODs of equal degree angle from 4m- and 20m COD respectively ($F = 11.862$; $p = 0.006$, $\eta_p^2 = 0.543$). Post hoc testing revealed that the plyometric group had significantly improved their performance from pre- to post-test in 4m 135°-4m 180° and 20m 180° COD ($p \leq 0.046$). Figure 5 illustrates training induced effects of the two training programs in both groups, presented with both percentage of change (figure 5a) and effect sizes (figure 5b) on time to complete different CODs.

A one-way ANOVA within the strength training group showed a significant effect from pre- to post-test with respect to 20m part-times ($F = 5.946$; $p = 0.041$, $\eta_p^2 = 0.426$). However, no significant effects were found after conducting post hoc testing ($p \geq 0.056$). Non-significant 20m part-times in 45°, 90°, 135°, and 180° CODs displayed percentages of change at 0.5%, 1%, 1.7% and 0.9% respectively, with no ES (0.09), trivial ES (0.18), small ES (0.32) and trivial ES (0.16). A one-way ANOVA for the plyometric training group revealed a significant effect from pre- to post-test with respect to 20m part-times ($F = 7.678$; $p = 0.020$, $\eta_p^2 = 0.434$). Post hoc testing showed a significant improvement in 180° part-time ($p = 0.026$) with medium ES (0.77) and a percentage change of -3.8%. The non-significant part-times ($p > 0.05$) in 45°, 90° and 135° displayed percentages of change at -2.1%, -2.7% and -2.1% respectively, with no ES (0.03), medium ES (0.62) and small ES (0.47) respectively.

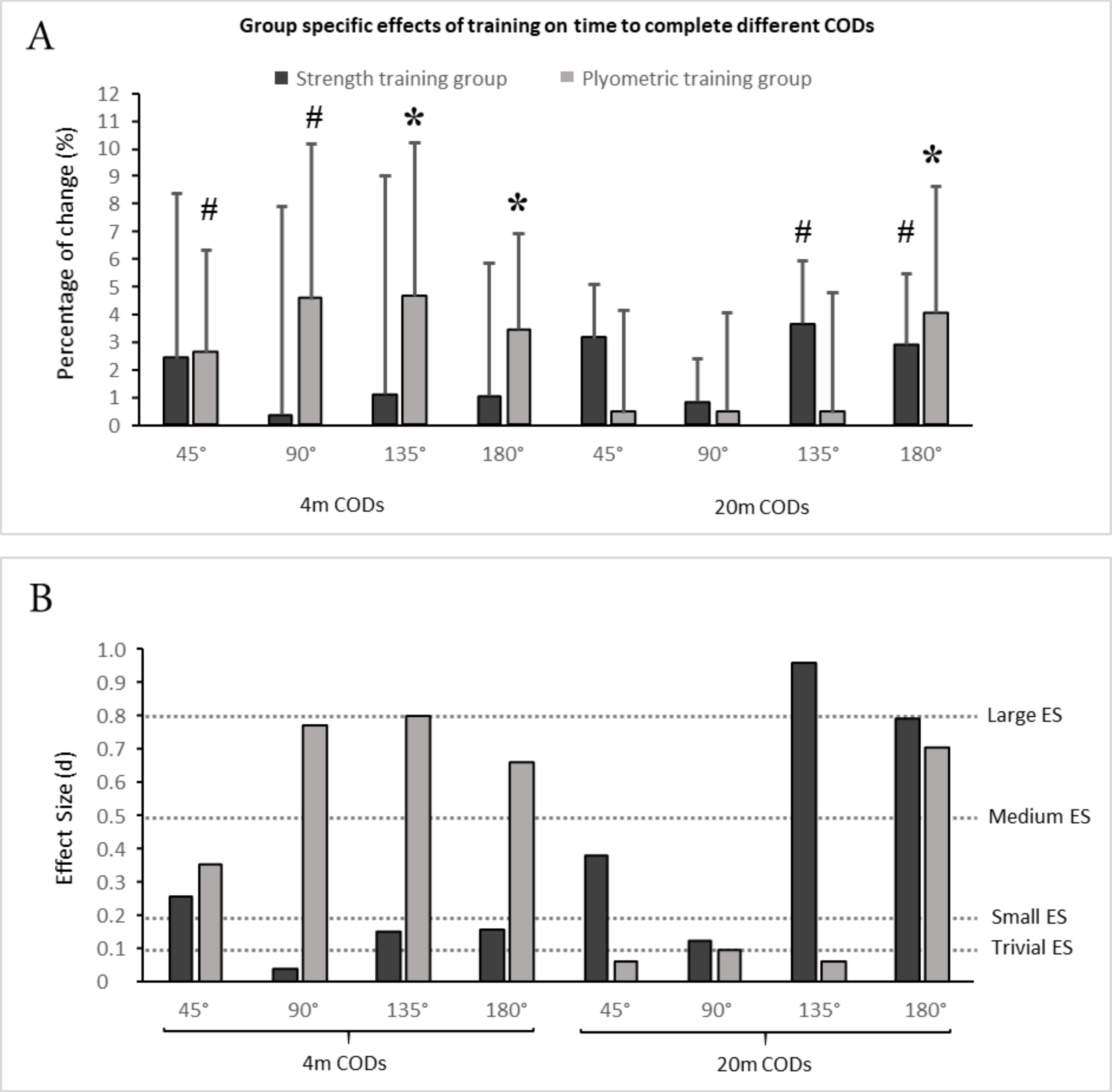

**Figure 5.** A) Percentage of change (±SD) after 6 weeks of training upon time to complete COD tasks of 4m and 20m approach distances and four different COD angles in each group. B) Effect sizes after training intervention in each group and the respective COD tasks. $*p < 0.05$, $\#p < 0.10$

All strength and plyometric exercises trained improved from pre- to post-testing ($F \geq 3.214$, $p \leq 0.05$, $\eta_p^2 \geq 0.167$). However, a significant effect from pre- to post-testing (group x time interaction) was found in only 7 out of 8 strength and plyometric exercises ($F \geq 4.776$; $p \leq 0.045$, $\eta_p^2 \geq 0.230$), the exception being the bilateral hurdle jump ($F = 0.435$; $p = 0.519$, $\eta_p^2 = 0.028$). The strength training group improved more in all strength exercises (bilateral, unilateral, and lateral squats) compared to plyometric training groups, while the plyometric training group improved more in all plyometric exercises (except the bilateral hurdle jump, Table 7).

**Table 7.** Mean (±SD) of the different strength and plyometric exercise performances at pre- and post-test for each group and between group comparisons.

| | **Strength training group** | | | | **Plyometric training group** | | | | **ANOVA effect:** |
|---|---|---|---|---|---|---|---|---|---|
| **Exercise variable** | **Pre** | **Post** | **Δ (d)** | **Δ (%)** | **Pre** | **Post** | **Δ (d)** | **Δ (%)** | **group x time (p)** |
| Bilateral squat (kg) | 113.6±22.5 | 127.8±19.5 | 0.68 | 12.5* | 130.0±21.6 | 132.5±13.0 | 0.14 | 1.9 | 0.021* |
| Unilateral squat (kg) | 88.3±11.8 | 104.7±11.3 | 1.42 | 18.6* | 98.7±10.7 | 103.4±12.0 | 0.41 | 4.8* | 0.023* |
| Lateral squat (kg) | 90.6±15.4 | 106.3±16.0 | 1.00 | 17.3* | 106.1±15.4 | 104.3±12.4 | 0.13 | -1.7 | 0.001** |
| Drop jump (RSI) | 1.35±0.27 | 1.31±0.29 | 0.14 | -3.0 | 1.27±0.31 | 1.48±0.29 | 0.70 | 16.5* | 0.015* |
| Unilateral CMJ (cm) | 17.3±3.9 | 18.5±4.1 | 0.30 | 6.9 | 16.5±2.9 | 19.6±2.4 | 1.17 | 18.8* | 0.045* |
| Bilateral hurdle jump (ms) | 172.7±18.5 | 151.8±22.0 | 1.03 | -12.1* | 168.3±22.7 | 152.4±12.1 | 0.91 | -9.4* | 0.435 |
| Unilateral hurdle jump (ms) | 193.1±9.2 | 187.9±19.0 | 0.37 | -2.7 | 196.8±21.2 | 175.9±17.0 | 1.09 | -10.6* | 0.044* |
| Skate-jump (cm) | 201.5±15.0 | 204.4±16.3 | 0.19 | 1.4 | 192.0±18.6 | 202.4±20.3 | 0.53 | 5.4* | 0.022* |

*p < 0.05, d = Cohen's d effect size.

## 3.3 The relationship between motivation and the effects of the intervention.

The strength training group displayed task- and ego-orientation scores of (M=4.15±0.41) and (M=3.70±0.82) respectively. The overall performance in the strength training group in the COD tests from pre-test (M=2725±117) to post-test (M=2682±118) corresponded to a percentage change of -1,60%. With respect to the intercorrelations, medium ES were displayed between task and ego (r=0.45), medium ES between ego-orientation and changes in COD performance (r=0.48). Nonetheless, these effects are unclear ($p > 0.05$).

The plyometric training group displayed task- and ego-orientation scores of (M=4.05±0.69) and (M=3.98±0.68) respectively. The overall performance in the strength training group in the COD tests from Pre-test (M=2720±127) to post-test (M=2658±78) corresponded to a percentage change of -2,20%. A statistically significant relationship was found between task-orientation and changes in COD performance with very large ES (r=0.71, p = < 0.05), while no statistically significant intercorrelations were observed between task- and ego-orientation ($p > 0.05$). The correlations are displayed in table 8.

**Table 8.** Correlations: strength training group (below diagonal) and plyometric training group (above diagonal).

| | **Task-orientation score** | **Ego-orientation score** | **Change (%) in COD performance** |
|---|---|---|---|
| **Task-orientation score** | 1 | 0.05<br>0.89 | **-0.71**<br>**0.01*** |
| **Ego-orientation score** | 0.45<br>0.23 | 1 | 0.09<br>0.80 |
| **Change in COD performance** | -0.16<br>0.68 | -0.48<br>0.20 | 1 |

# 4 Discussion

The main objective was as follows: (1) to investigate the significance of force- and velocity-oriented COD tasks, specified trough the following research question: What characterizes strength- and velocity-oriented change of direction tasks, with respect to descriptive kinetic and kinematic measures in COD, and how does lower limb muscle qualities relate to faster COD performance?; 2) can 6 weeks of strength or plyometric training influence performance in strength- and velocity-oriented change of direction tasks in soccer athletes?; (3) how do individual characteristics, with respect to motivational profile, influence performance in soccer athletes prior to strength or plyometric training?

The main findings were that there is a linear effect of time to complete CODs with an increase in angle of directional change. The 4m 45°, 20m 45° and 4m 90° CODs displayed limited braking requirements, which made it possible to maintain momentum throughout the COD maneuver and these CODs can therefore be regarded as velocity-oriented. The 20m 90° COD and 135° + 180° COD from both the 4m and 20m approach distance can be considered force-oriented as these were characterized by substantial braking requirements, greater ground contact time, and lowering of COM in the COD step. Lower limb joint mechanics in the COD step are not dependent on the approach distance, but rather on the angle of directional change, which can be attributed to momentum lost prior to turning in 20m CODs. These findings were accompanied by greater plantar flexion and hip flexion angles when cutting from smaller to larger angle CODs, whereas the knee joint stabilized when cutting from 90° to 180° that may be seen in context of an injury/performance conflict (Dos'Santos et al., 2018). In the training intervention, both groups displayed promising results that were accompanied by improvements in strength and plyometric performances. However, only the plyometric training group revealed statistically significant results in 4m 135° and 180° CODs and the 20m 180° COD with percentages of -3.4% to 4.7% and medium to large ES. These effects were probably due to fact that the rate of force development in COD is more similar to plyometric training than maximal strength training is, which may hinder participants from expressing their maximum force capacity (Suchomel, Nimphius & Stone, 2016). The strength training group displayed their greatest improvements in 20m 135° COD with large ES, but these findings require further investigation ($p > 0.05$) as this task may be more dependent on maximal strength than any other task assessed in this research. Finally, task-orientation was related to an increase in overall COD performance in the plyometric group, which is in line with the biomechanical analysis and the effects of training intervention will have practical applications when organizing training.

## 4.1 Significance of force- and velocity-oriented COD tasks

### 4.1.1 Time to complete different COD tasks

Results show that there is an equally large and linear effect of time to complete CODs with an increase in angle of directional change for both 4m and 20m COD ($\eta^2 \approx 0.95$). When comparing CODs of equal angles, the time to complete the task was significantly greater for all 20m CODs, which is in accordance with Bourgeois and colleagues (2018), although Bourgeois and colleagues only compared a 45° and 180° COD task from a set distance. This means that participants will benefit from an increased approach velocity 4m prior to turning in 20m CODs, resulting in shorter COD time, which is logical given the way the tests are designed. When comparing 20m CODs, there were no differences in 16m split-time as shown by the ANOVA. This indicates that participants make no early contextual adjustment in approach speed four meters prior to turning based on the angle of directional change. Furthermore, a decrease in approach velocity is expected before turning in COD. As such, explanatory data with measurements closer to the COD turn can provide more knowledge of the current objective.

### 4.1.2 Deceleration phase

One of the most important findings was the number of deceleration steps performed before the COD step. This study shows that smaller angle CODs (45°) are less determined by the ability to decelerate as there are barely any participants applying any steps resulting in a decrease in velocity in 4m 45° COD (0.4 steps) and relatively few in 20m 45° COD (2.9 steps). These results are consistent with Hader, Palazzi & Buchheit (2015), who reported faster cutting speed during a 45° COD compared to a 90° COD from a 10m approach distance. As such, the goal will be to maintain velocity during the COD, with reducing the braking force from the steps prior to the COD turn (Dos'Santos et al., 2019). Previous research by Condello et al. (2013) shows that athletes are rounding the turn in small angle of directional change. This can explain why there are relatively few deceleration steps in 45° COD as braking forces are typically distributed over multiple steps (Havens & Sigward, 2015b), but it also implies the use of a crossover cut associated with faster performance in 45° CODs (Dos'Santos et al., 2019). As velocity maintenance is also key in high velocity sprinting, superior performance in 45° CODs may be accomplished by maintaining a higher center of mass and reducing ground contact time, such as in high velocity sprinting (Morin et al., 2012; Young & Farrow, 2006).

In moderate angle CODs (90°), there were relatively few deceleration steps from the 4m approach distance (2.7 steps) and a more substantial amount in the 20m approach distance (5.3 steps). The low number of deceleration steps applied in 4m 90° implies that velocity maintenance may be possible in 90° CODs if the approach distance is short enough. This is supported by Spiteri and colleagues (2015) who stated that the braking requirements during a T test (involving a 90° turn) are less determined by braking force to shift momentum and run in a new direction, as the task required a relatively short distance approaching the COD turn. Thus, the 4m 90° COD may be relatively velocity-oriented, whereas 20m 90° COD may be more force-oriented.

In larger angle CODs (135° and 180°), there was a relatively large number of deceleration steps from 4m approach distance (3.2) and 20m approach distance (6.2 - 6.3 steps). Early research within this field has shown that nearly all momentum will be lost in CODs requiring > 90° turn (Andrews, McLeod, Ward & Howard, 1977). Although this is mostly consistent with the present study, the data show that deceleration requirements reach a certain threshold in CODs of ≥ 135° angle, which implies that deceleration requirements are similar between these two angles of directional change. The braking requirements of these two angles are substantial and seem crucial for performance. This is supported by Nedergaard et al. (2014) who found peak deceleration velocity to be greater in the two preceding steps compared to the COD step in a 135° COD. This finding suggests that not only the quantity of deceleration requirements in 135° and 180° CODs are evident, but also the quality, as much of the total net force required for braking and changing direction must be applied in the preceding steps prior to turning.

In general, it must be mentioned that deceleration requirements will be greater with an increase in approach distance, as more deceleration steps were found in all 20m CODs compared to 4m CODs when comparing the same angle of directional change. The present findings are of great relevance considering that previous research investigating mechanical aspects of COD performance have primarily focused on the final COD step (Dos' Santos et al., 2017), and few studies have addressed the deceleration phase (Besier, Lloyd, Ackland & Cochrane, 2001; McLean, Neal, Myers & Walters, 1999; Sigward & Powers, 2006). Data from this study proves that this is not enough, as there are multiple steps resulting in a decrease in velocity prior to most COD turns.

### 4.1.3 Change of direction step

**Centre of mass and ground contact time**

Sheppard & Young (2006) suggested that lowering COM is essential in optimizing acceleration and deceleration during COD. This study revealed a large effect of vertical COM displacement with an increase in COD angle for 4m ($\eta^2 = 0.80$) and 20m COD ($\eta^2 = 0.81$) in the COD step. Greater lowering of COM was also achieved in 20m approach distance in angles of 45°, 90° and 135° in comparison to 4m approach distance.

The deceleration component in the COD step can be seen as an extension of the deceleration phase whereby high net braking force is produced trough a greater range of motion in larger angle CODs (Bourgeois, Gamble, Gill & McGuigan, 2018) and with greater approach distance. However, with lowering the COM, it also set up the participant in a prime position to create propulsive force toward the new direction of travel. The reason why no difference was observed between 180° CODs may be explained by the fact that a bilateral COD step is typically adopted in directional changes sharper than 135° angle (Dos'Santos et al., 2019). This is supported by the greater hip abduction found in 180° CODs in comparison to all other angles, implying a wider stance associated with bilateral COD step (Dos'Santos et al., 2019). As such, associated loads in the COD step are possibly distributed on two-foot contacts, seen more often in 180° CODs. This will most likely compensate for the increased COD angle, making it possible to brake and apply propulsive force over a shorter range of motion, as found in 180° CODs. A bilateral COD will inarguably enable greater friction on the floor, thus providing a favorable technique in a push-off without the risk of slipping. Hence, the influence of approach speed may regulate the COM between 180° CODs, thereby no differences in this variable were observed.

Another aspect of great interest is that the adoption and possibly more frequent use of a bilateral COD step in 180° CODs implies that 135° and 180° are two very distinctive tasks, despite both being regarded as force-oriented (Bourgeois et al., 2017). The ground contact data in the COD step provides further support for this argument, as relatively large and statistically significant differences are displayed in ground contact time between 135° and 180° COD from 4m- (23cs vs 31cs) and 20m (22cs vs 33cs) respectively.

Previous research has reported longer ground contact time when adopting the split-step technique in comparison to other techniques (Bradshaw et al., 2011; Trewartha, Munro & Steele, 2008). The technical differences between the two proposed force-oriented tasks raise a series of complex questions, leading to the formulation of three aspects regarding this issue:

1) If a side step technique is adopted consistently for the 135° COD tasks, the unilateral ground impact associated with the split-step would probably require greater force exertion in the dominant leg in comparison to the 180° CODs where the impact and the forthcoming forces are shared bilaterally.
2) There are no differences regarding COM between the 135° and 180° COD from 20m approach distance. Considering that contact times differ significantly between these two conditions, there would be limited time to develop force to the ground in 135° condition. This will most likely require higher ground peak forces to be exerted as forces are distributed over a shorter range of motion.
3) If these statements are correct, assuming the peak force is determined by force capacity in contrast to force tolerance (Dos'Santos et al., 2019), how does this contribute to the understanding of bilateral force deficit? (Henry & Smith, 1961), and should training aimed at developing 135° COD tasks be different than 180° CODs in terms of unilateral of bilateral training when considering the principal of specificity? (Henry, 1958).

Further investigation of the COD step shows that COM displacement is velocity dependent for all angles except 180° COD, while the contact time remains unchanged. Nedergaard et al. (2014) compared five different approach velocities in 135° COD. Their results showed that approach velocity did not influence peak ground reaction force during the COD step. Contrastingly, Vanrenterghem et al. (2012) found that peak ground reaction force increases with increases in approach speed in more severe direction change of 45° angle. Thus, there is a trend that suggests that the more force-oriented CODs may represent a threshold for the maximum amount of peak propulsive force the athletes are able to exert in the COD step. This could be explained by the fact that sharper angle CODs require greater rotation of both upper and lower limb when cutting, thus demanding greater transverse mechanics of joints, as opposed to sagittal plane mechanics in smaller angle CODs (Sigward, Cesar & Havens, 2015). Consequently, this leads to an unequal distribution of loads across joints in larger angle CODs, resulting in greater loading on the knee joint, which is associated with anterior cruciate ligament injury (Havens & Sigward, 2015b) as the knee joint is sensitive to rotation. This leads to a performance-injury conflict when cutting to larger angles (Dos'Santos et al., 2019), and performance cannot be entirely explained by physical capacities.

## Lower limb joint mechanics

Kinematic data shows that lower limb joint angles in COD are not velocity dependent. The ANOVA suggests that lower limb joints angles are largely angle dependent ($\eta^2 = 0.204 - 0.477$), with the exception of plantarflexion angles observed in the 4m COD tasks. Despite post hoc displaying examples of differences in joint angles between different angle CODs, the data does not necessarily imply a clear linear pattern. Data shows that greater hip flexion is achieved in 4m 180° COD compared to all other 4m COD angles, and greater hip flexion angle is achieved in 20m 135° and 20m 180° COD compared to all other 20m CODs. Havens & Sigward (2015a) found differing hip joint angles between a 45° and a 90° COD task in soccer players. It is worth noting that they defined joint angles at initial ground contact, which could explain why the result are contrasting to this study, where no differences are displayed between 45° and 90° CODs. Nevertheless, the author concluded that the hip joint plays a larger part in smaller to sharper angles of directional change, which is partly supported by data in this study. These differences in hip joint angles where also found between 20m 135° and 20m 180° COD. Furthermore, it is worth mentioning the relatively large differences in terms of numbers when comparing hip angles in 20m 135° and 20m 180° COD to the same angles from the from 4m approach distance. However, the results were not statistically significant and further research is needed to conclude whether hip angles are velocity dependent or not.

Previous research suggest that the 90° COD requires larger knee braking force in comparison to a 45° COD, but when changing direction towards angles sharper than 90° the associated forces on the knee seems to stabilize (Havens & Sigward, 2015a; Schreurs, Benjaminse & Lemmink, 2017). This could explain why the knee flexion does not differ across tasks that are 90° and over, while the knee angle is significantly less for 45° CODs, independent of approach distance. Nevertheless, Schreurs et al. (2017) argued that participants may subconsciously restrain compressive forces to the lateral sides of the knee to prevent injury which must be seen in context of the performance injury conflict previously mentioned (Dos'Santos et al., 2019). Hence, the minimal knee joint angles may be compensated by increased hip flexion angles. This suggests that hip flexors play a vital role of distributing forces evenly across joints, as Cramer, Darby & Cramer (2014) have shown that the hip joint is integral to the transfer of forces between lower and upper extremities. As such, players may rely more on the relatively greater strength by the hip and trunk muscles rather on the weaker and more distally located muscles in the lower extremities during COD (Mornieux, Gehring, Fürst & Gollhofer, 2014).

Current findings enlightened with previous research imply that athletes may not fulfill their true strength potential in larger angle CODs, and more training towards stabilization in the knee joint specifically may be required to excel in COD.

As indicated by ANOVA, larger dorsiflexion was found in 20m CODs. However, the post hoc displays that 20m 180° COD is significantly different from 45° COD only, even though there are relatively large differences between other COD angles in terms of absolute values for both approach distances (implying that dorsiflexion is larger for sharper CODs), but the observed effect remains unknown. However, increased dorsiflexion contributes to shift the center of pressure further away from COM, thus allowing greater horizontal forces to be produced (Schreurs et al., 2017). The larger hip flexion angles observed in larger angle CODs in addition to increased dorsiflexion will setup the hip extensor muscles in prime position to contract and produce propulsive force to the ground and increase momentum in the new direction (Hewit, Cronin & Hume, 2012).

The ability to dorsiflex may be limited by participants Achilles tendon stiffness or tightness, reported to be limited in Soccer players compared to non-players (Ekstrand & Gillquist, 1982). Achilles tendon stiffness has been reported to be an important mechanical function to dissipate energy (Fouré, Nordez & Cornu, 2010). It is generally considered to be crucial in stabilizing the ankle joint, but it also adds a risk when flexing the joint beyond its limit (Hattori & Ohta, 1986). Therefore, the ability to dorsiflex the ankle may be crucial for performance in 20m 180° COD and the lack of ability to dorsiflex the ankle in this task may impact performance. Considering that ankle joint stiffness is important in other aspect of the game, practitioners must evaluate whether training to increase ankle dorsiflexion mobility conflicts with other aspects of the game, and the training on this mechanical aspect should be based on which COD the player performs the most during competition.

### 4.1.4 Transition and acceleration in new direction

Data from the post step shows no difference in ground contact time and COM displacement between CODs of 90°, 135° and 180° angle. However, in 45° CODs, including both 4m and 20m approach distances, it was shown that both contact time and COM displacement differed from other angles, except COM displacement between 20m 45° with 20m 135° and 20m 180° COD. This is hard to understand as 20m 45° and 20m 90° significantly differed in COM displacement in the acceleration step. It is possible that more compressive/decompressive forces will be accumulated in the lateral sides of the knee during the COD step of 20m 90° COD and perhaps the participants compensate with lowering the COM in the acceleration step to enable greater propulsion towards the exit point. Contrastingly, in both 135° and 180° COD, it is possible to rotate the trunk towards the new direction of travel prior to and during the COD step (Sasaki et al., 2011). This can enable the force to be distributed more anteriorly and posteriorly on the knee, enabling greater grater force application at push off. This make sense as we previously discussed that when cutting from an angle of 90° or larger, the knee seems to stabilize (Havens & Sigward, 2015a; Schreurs et al., 2017). The same trend was not evident in 4m 135° COD, possibly due to lower deceleration requirements.

A previous section in this study described how the deceleration prior to turning affected the CODs of > 90° angle. The present data shows that velocity maintenance is possible for 45° CODs. Less COM displacement and contact time in the acceleration step compared to other COD angles are made possibly by the benefit participants receive from velocity established in previous steps. This is consistent by data from Hader et al. (2015) who reported an exit velocity after COD of approximately 7.4m/s in a 45° task and 4.9m/s in a 90° task, which was measured approximately 2m after the subsequent turn.

When analyzing the different phases of COD in conjunction with established theory, there is no doubt that COD ability requires different skills and capacities. COD ability can be considered as a multistep action, as introduced by (Andrews et al., 1977). Based on this research it was evident that different CODs were determined by different mechanical functions. 45° CODs can be considered velocity-oriented while 135° and 180° COD are considered force-oriented as suggested by (Bourgeois et al., 2017). The 90° COD cannot be categorized as either force or velocity-oriented based solely on the angle of directional change. However, the 4m 90° COD can be considered velocity-oriented, as results indicate that it is possible to maintain momentum throughout the turn, whereas 20m 90° COD can be considered force-oriented as the approach distance hinders participants from successfully applying enough propulsive force in the COD step to maintain momentum throughout the COD maneuver.

### 4.1.5 The relationship between muscle qualities and performance in COD tasks.

The primary findings from the correlation analysis show that the relationships between different lower limb muscle qualities and COD differ based on the direction of motion and the rate of force development, and that these aspects vary with the angle of directional change and approach distance. Both bilateral maximal strength and unilateral maximal strength correlated poorly (r= .05 to -.32) with different CODs. In part, this is down to the fact that these motions are not specific enough to mediate the movement in COD which typically involves an anterior/lateral foot plant (Dos'Santos et al., 2018) with high reliance on rate of force development (Suchomel et al., 2016). The only statistically significant relationship with respect to maximal strength was found in the lateral motion. However, this was only found in 20m 135° CODs, argued to be the COD task most reliant on maximal force production out of all COD tasks in this study. In an early literature review in the COD research domain, Sheppard & Young (2006) concluded that concentric strength is not a predictor of change of direction speed. Since the maximal strength tests only included variations of the squat, there was no specific testing of eccentric strength capacity and may therefore explain the poor relationships of these measures with time to complete CODs. This is down to the fact that many CODs were found to be highly determined by braking capacity, where eccentric strength is deemed important (Spiteri et al., 2014). Different measures of power correlated greatly with the 4m approach distance. The measurement of power did not seem to be as reliant on the direction of motion but rather on approach distance (Table 6), as found in tests of 4m approach distance where Small to medium ES (r =. -35 to. -67) were displayed in bilateral and unilateral power qualities. However, only 4m 90° and 135° COD was found significant in these motions.

The greatest relationship of power with time to complete COD were observed in laterally directed motion, where all 4m CODs + 20m 45° COD significantly correlated with time to complete COD, with small to medium ES (r = -.47 to -.69). The exercise used to represent this quality was the skate jump, which may be particularly relevant as it allows participants to develop their own optimal technique based on their anthropometrics (i.e. lower limb length) and better mediate their technique used in COD. Furthermore, no statistically significant relationship was found between reactive strength and time to complete COD, which is contrasting to Young et al. (2002) who suggested this quality to be important in COD.

It is worth mentioning that correlation analysis does not evidence causation, meaning that an increase in one variable through training (muscle quality) might not reliably result in an increase in the dependent variable (COD time) over time. This was investigated by Nimphius, Mcguigan & Newton (2010), who found some strength and power variables to vary with time and came to the conclusion that these variables are better suited to address training if investigated longitudinally, as these relationship are not consistent and are dependent on the individual athlete.

## 4.2 Effects of strength vs plyometric training on different CODs

The aim of the training intervention was to examine the effect of strength versus plyometric training on CODs with different angles of directional change and approach distance (now suggested to be either force or velocity-oriented) when workload and exercise direction of motion between each modality are matched. The main findings suggest that both training approaches can improve most CODs as an increase in performance was evident in all CODs (Figure 5). However, no significant difference between groups was found. Increases in performance for both groups are accompanied with an increase in strength performance in the strength group and an increase in plyometric performance in the plyometric group. However, further research with a greater sample size is required to validate the results as results from several CODs lacked statistical significance, and these effects are unlikely due to chance.

In 4m 135° and 180°, and 20m 180° CODs, only the plyometric group showed statistically significant improvements in performance, with percentages of -3.4% to -4.7%. These significant results were greater than previous studies implementing plyometric training in similar CODs of similar duration in matured soccer players (Loturco et al., 2017; Yanci et al., 2017). The results in this study show that a plyometric training program can improve some force-oriented CODs. This is in line with previous research by Falch et al. (2019) and Bourgeois et al. (2017). However, in these studies, plyometric training was also deemed effective for improving velocity-oriented CODs, which was not as clear in this study. It is possible that the lack of improvement in velocity-oriented CODs can be explained by the fact that most turns in soccer are performed at 0° to 90° angles (Bloomfield et al., 2007). As such, it is possible that participants have acquired a greater skill in these CODs. Greater training stimulus and training over a longer period of time may be required for considerable improvement to take place.

Nevertheless, the improvement in the proposed force-oriented task of 4m 135° and 180° CODs and 20m 180° COD indicates that plyometric training develops sufficient amount of force in rates required to facilitate these performance improvements. Drawing the focus towards the strength training program, this training approach is arguably suboptimal as Suchomel et al. (2016) mentioned that the rate of force development in COD limits the participants' ability to express their maximal force capacity. Previous research by Loturco et al. (2017) demonstrated how training with different loads affects the ability to produce power at different loads. The researchers divided players into two groups, each training the squat jump. One group trained with loads below optimal power load; the other group trained with loads higher than optimal power load. The group training with loads lower than their optimal power load increased performance in the entire range used to express power (-20%, 0% and 20%). The group training with optimal power load only increased their power at 0 and 20% loaded conditions. Considering the fact that plyometric training is highly associated with the ability to express power (Brughelli et al., 2008), performance in this style of training can be highly determined by the ability to produce a great amount of force in limited time (i.e. force and velocity adaptive). This can explain the why the group training with loads below optimal power load were able to stimulate adaptation in a greater range of the force velocity spectrum, which is expected to vary in COD. This claim has however been subject to criticism and disagreement in the literature.

Nonetheless, this style of training seems to reach a certain limit, as no improvement was revealed in 20m 135° COD. This is of major importance, considering the 135° represent a threshold from where a unilateral to bilateral COD step is typically adopted (Dos'Santos et al., 2019), previously argued in this study to have major implications for force requirements in these tasks. Contrastingly, the strength training group displayed their greatest effect in 20m 135° COD with percentage change of -3.6% and a large effect size (also found in 20m 180° COD), which must be accounted for even if no significant differences were found. The effect in 20m 135° COD was substantially better in terms of absolute effects compared to the plyometric group (figure 5). As such, it is possible that participants from the strength training group approached 20m 135° COD with greater confidence to accommodate to the increased force requirements associated with this task, thus being more likely to express their maximal force capacity. However, this effect requires further investigation ($p > 0.05$).

The effect of the plyometric training program and the less clear effect of the strength training program on improving different CODs could be explained by the fact that both groups improved their strength and plyometric qualities. The results show that the strength training group improved their performance in 3 out of 3 strength exercises and in 1 out 5 plyometric exercises. The plyometric training group increased their performance in 5 out of 5 plyometric exercises and improved in 1 out of 3 strength exercises (unilateral squat). The improvement in the unilateral squat in the plyometric group was unexpected. It is possible that this improvement was a result of the shortened knee range of motion in the unilateral squat, an angle similar to those displayed in most plyometric exercises, as this exercise was performed with a shortened range of motion in the knee joint. Theory suggests that this would result in more substantial improvements as the greatest adaptation occurs at the specific joint angle trained (Rhea et al., 2016), thereby more similar to the knee angle displayed in different plyometric exercises (Marcovic, 2007). Despite this fact, only medium ES (4.8% improvement) were found at post-test in the plyometric group, and large ES (18.6% improvement) were found in the strength training group, shown in the ANOVA to be significantly better. Despite these improvements in both groups, the strength training group was substantially better at improving maximal strength, which was also true for both the bilateral and the lateral squat (table 7). This may explain why the strength training displayed considerable improvements ($p > 0.05$) in both 20m 135° COD and 180° COD, as well as why the plyometric group displayed great improvements in most force-oriented CODs, with the exception of 20m 135° COD which as argues requires greater adaptations in the ability to express maximal force.

With respect to plyometric performances, it was also unexpected that the strength training group would increase their performance in the bilateral hurdle jump (ES= Large, -12.1% improvement). It is possible that the strength training group increased performance in the bilateral hurdle jump as a result of increased strength in the Calf raise exercises, as earlier research has shown that the hurdle jump induces high muscle activation in the same muscle groups (Cappa & Behm, 2013). Unfortunately, improvements in the calf raise exercises was not included as it was hard to standardize and isolate the effect of a lift loaded by the plantar flexors since it would be easy to apply momentum to the ankle as a consequence of extension from more proximal limbs. Contrastingly, no significant effect was found in the unilateral hurdle jump in the strength training group, where the plyometric group significantly improved (ES= large, -9.4% improvement), and this effect was significantly better in comparison. These substantial differences in improvement between bilateral and unilateral hurdle jumps in the strength training group may be explained by the fact that a one leg push-off will require greater stability and balance, and plyometric training has been shown to be highly effective in achieving this (Ramírez-Campillo et al., 2015).

With the exception of the bilateral hurdle jump, performance increase was significantly greater in all plyometric exercises in the plyometric group compared to the strength training group. These increases in plyometric qualities may have contributed to greater 16m approach speeds in the plyometric group which varied from 2.1% to 3.8% compared to 0.5% to 1.7% in the strength training group. However, a significant change was only found in the 180° part-time, which could explain the improvement in 20m 180° COD in the plyometric group. This effect may be down to the fact that plyometric exercises are characterized by fast stretch shortening cycles < 250ms (Flanagan & Comyns, 2008), which is more similar to sprinting, where ground contact times have been reported be around 100ms at maximal velocity (Mero & Komi, 1985). As such, the increased approach speed found in 20m 180° COD may have contributed to better performance in the subsequent COD, and other part-time may have facilitated performance in other CODs as well.

## 4.3 The relationship between motivation and the effects of the intervention.

The purpose of this part of the study was to investigate how motivation is related to the effectiveness of this intervention. A very large and statistically significant relationship was found between task orientation and change in overall COD performance in the plyometric training group. Previous research on young soccer players has shown that elite players score higher in task orientation compared to non-elite players (Kavussanu, White, Jowett & England, 2011; Reilly et al., 2000) and that in a similar group, task orientation has also shown to be a predictor of future performance (Höner & Feichtinger, 2016). Although this study was conducted with fully matured soccer players of differing ability, which makes it hard to draw parallels to other studies, it does support the notion that task orientation can be an important dispositional tendency, and that is related to short term development in an important soccer specific skill. This is supported by van Yperen & Duda (1999) who found task orientation to be linked to increases in soccer specific skills in young soccer players over the course of a single season.

Unfortunately, this study did not measure the motivational climate, which is important considering that goal involvement is determined both by goal orientation and perception of motivational climate (Gershgoren et al., 2011). The organization into training groups arguably made it possible for social comparisons to take place, considering that ego-oriented players tend to place more emphasis on competitive edge, self-esteem and social status (Rebelo-Gonçalves, Coelho-e-Silva, Severino, Tessitore & Figueiredo, 2015) while task-oriented individuals tend to attribute success to effort, learning and demonstrating mastery (Kavussanu & Roberts, 2001). It is possible that ego-oriented players did not exceed performance of others in the plyometric group due to a shift in focus towards trying to avoid demonstrating incompetence (Lemyre et al., 2002), a possible explanation for why ego orientation was not related to increase in COD performance.

An alternative explanation is that in this research, contact mats were used to measure performance in plyometric exercises. From the experience of Flanagan & Comyns (2008) they suggested that the quality of plyometric exercises is enhanced by using contact mats. However, the authors also mentioned that dependency on regular feedback from contact mats is possible. In training contexts, this mean that participants can be more focused at displaying great numbers in plyometric scores shown by the monitor, and hence develop or adapt a technique in training situations which is better suited to show greater scores rather than a technique that has transferability to the skill the participants are trying to develop. As such, it is reasonable to assume that task-oriented individuals used the monitor displaying plyometric scores to compare performance with themselves, within session and from session to session, with the primary goal of developing COD ability. These tenets have empirical support, considering that task-oriented individuals tend to use effective strategies in training to aid their achievement goals (Lochbaum & Roberts, 1993).

On the other hand, ego-oriented players may define success in terms of displaying greater numbers than task-oriented players within the session, thus adapting a more disadvantageous technique at the expense of the overall scope. During observation, some players seemed to be more focused on exceeding the performance of others, rather than attributing improvement to the increase in individual performance. There is arguably a dearth of data to confirm these statements, but these are behaviors that support basic tenets of AGT theory (Duda, 1989; Nicholls, 1984, 1989; Roberts, 2012) and that are worth considering when organizing training.

With respect to strength training group, one would expect that this type of training would allow for social comparison as the weight lifted demonstrates a very clear and definitive measure of capacity, which can be motivating for ego-oriented individuals if they are able to demonstrate better performance than co-trainers and negative if when they perform worse. In the strength training group, there was a minor relationship between task-orientation and improvement in COD performance, and moderate relationship between ego-orientation and improvement in COD, which may have facilitated motivation for ego-oriented individuals. These results were not statistically significant but should be of interest for future researchers as no conclusion can be drawn from this study alone.

## Strengths & limitations of the study & future research

This study had several strengths and limitations. First of all, the strength of this study must be attributed to the relatively large sample size and its depth with respect to the biomechanical analysis of COD. Based on the Authors knowledge, only Schreurs et al. (2017) have previously investigated a continuum of different angles (45°, 90°, 135°, 180°) within one study, and that study only did so from one set of approach distance. It merits mention that Dos’Santos et al. (2018) investigated the influence of both angle and velocity on COD in a literature review. However, results will be drawn across different populations, which is not the case in this study. This can be considered a great strength, as comparisons can be drawn between more comparable terms. Secondly, the present study collected no kinetic data. Future research should employ force plates measuring ground reaction force in different planes (Z, X, Y) to quantify the exact force requirements during COD and which phases of COD the different training programs are influencing.

Moreover, the focus on different phases of COD have already garnered much attention in newer research where a great deal of focus has been placed on the “penultimate step” (the step prior to COD) with respect to deceleration requirements (Dos' Santos, Thomas, Comfort & Jones, 2019). Although this is a step in the right direction in the COD domain, this study showed that there are multiple important steps in COD, which calls for greater depth of analysis of multiple variables in future research.

This study was not without its weaknesses, for the purpose of readability, no traditional correlation matrix was interpreted with respect to research question 1, and thus valuable information in terms of interrelationships were not measured. This could have granted more information regarding whether or not a performance increase in one exercise explains an increase in another, thus demonstrating whether they exhibit unique features.

Additionally, there was a limited number of participants in the training intervention, rendering the strength training prone to displaying less statistically significant results. As such, there was a greater emphasis on effect sizes. Although these were discussed and no conclusions can be drawn from non-significant effect sizes, these measurements are still be of interest for future research to see the trends regarding training. However, the low sample size means that results should only be generalized to the population of this study.

Perhaps most importantly, the strength training group reported their training to be physically demanding, and fatigue toward the last two weeks of the training program was reported to be substantial for some individuals. As such, it is possible that some players were still recovering or being subject to supercompensation from the intervention, and better improvements may have been evident if changes had been measured longitudinally.

Furthermore, the study was conducted in a controlled lab environment that may not reflect participants ability to perform CODs in soccer specific match situations. The test days were also long and both physically and mentally challenging which might have influenced the results of this study. In addition, primarily one trial was performed for each COD which can be considered a weakness as some inter-variability in performance is expected for each COD task. Finally, the training groups in this study functioned as control groups for each other. A control group outside this study could better have determined if changes within groups are due to the intervention or as a consequence of improvements in their regular soccer practice.

## Practical application

The development of COD ability has become more specific. This means that training agents or athletes themselves must carefully evaluate which CODs are most important in competitive situations, not just in frequency but in terms of which CODs typically determine match related outcomes and which CODs are important with respect to individual player positions. The velocity-oriented CODs should be assessed by training which aims to produce maximum power in exercises stimulating fast muscle contraction velocities. Force-oriented COD should be adopted for modalities that aim to express maximum power in exercises stimulating slower muscle contraction velocities. It is also important that exercises used to develop COD ability replicate the motion in COD; exercises such as the skate jump and the lateral squat are recommended.

Based on the contact time in the COD step, the rate of force development in the COD step was shown to be less than 310ms in this research. This will favor plyometric training for developing performance in most CODs. Velocity-oriented CODs seem to hinder the expression of maximal force capacity, and strength training may be suboptimal to develop these CODs. The current strength training program showed signs of great improvement in CODs with a greater approach distance in angles of > 135° directional change and may be effective at developing these CODs. Force-oriented CODs also includes substantial braking requirements. This calls for specific deceleration training that can enable soccer players to brake over fewer steps by planting their feet anteriorly of their COM, thus performing the COD both safely and more effectively. By decelerating over fewer steps with reduced contact time this will enable greater storage of elastic energy, which can be utilized concentrically at push-off and resulting in increased exit velocity (Spiteri et al., 2015).

Regardless of the COD performed, training should be carefully adapted based on the individual athlete, as previous work has shown that a minimum level of maximal strength is necessary for plyometric training to have an effect on the ability to develop COD (Falch et al., 2019). Technical ques should also be adopted when assessing maximal intensity COD, such as keeping an upright torso and reducing contact time in 45° CODs and gradually lowering COM with increased angle of directional change with a specific focus on flexing the hip and ankle in the largest angle CODs.

When organizing training, training should be planned according to the players individual psychological dispositions and the strength and conditioning coach should arrange the motivational climate accordingly. The use of contact times was useful for developing COD ability in the plyometric training group, and by using portable devices such as a smartphone it is possible to track measurements such as jump height, contact time and reactive strength. However, when implementing these devices, strength and conditioning coaches must avoid developing a dependency on such external equipment.

## Conclusion

In conclusion, a COD is a multidimensional ability that cannot be fully examined trough the COD step alone, but also on a preceding deceleration phase, which affects the momentum throughout the COD turn and the transition into the new direction of travel. These biomechanical aspects also differ depending on the angle of directional change and approach distance. As such, these different CODs require specific approaches to physical training in order to develop the physical aspects required to facilitate performance and preventing injury. In general, the ability to express power is of great importance, in addition to expressing power at shorter contraction velocities with greater range of motion with an increase in angle and approach distance when turning.

These requirements may explain why plyometric training seems superior at developing overall COD performance, but more research with larger sample sizes is needed to confirm these trends. Increases in performances can also be explained by the fact that task-oriented individuals in the plyometric training group saw better increases in overall COD performance after 6 weeks, and attention toward dispositional tendencies should be accounted for when organizing training.

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# Appendices

## **Appendix A.** Basis behind the selection of exercises and exercise order.

The three different back squat variations were implemented in the strength training program based on several factors, one of these being that the squat is well established as an exercise that improved lower limb strength and power (Chelly et al., 2009; Comfort, Haigh & Matthews, 2012; Schoenfeld, 2010). Exercises stressing multiple joints simultaneously have proven to elicit greater metabolic and acute hormonal responses (Ballor, Becque & Katch, 1987; Kraemer, Ratamess & Komi, 2003). As such, primary exercises such as squat can facilitate the effect of secondary exercises at developing muscle strength adaptations when they are performed immediately after squatting (Rønnestad, Nygaard & Raastad, 2011).

Consequently, performing larger body part exercises before smaller body part exercises allows for the completion of greater total training volume (Sforzo & Touey, 1996). Longitudinal studies have shown that the use of larger and more demanding body part exercises results in greater strength improvements when they are performed first in a session (Spineti et al., 2010). With respect to previous research, the sequencing order of exercises carries implications for training. The different variations of squat exercises were based on the recommendations that exercises should be performed both bilaterally and unilaterally and in multiple directions with varying load (Bourgeois, McGuigan, Gill & Gamble, 2017). Considering that squats performed both bilaterally and unilaterally have displayed similar effects (McCurdy, Langford, Doscher, Wiley & Mallard, 2005; Speirs, Bennett, Finn & Turner, 2016), these were implemented in the strength-training program and were performed early within each session.

The unilateral quarter squat was always performed before the bilateral squat. Unlike bilateral actions, this exercise enables greater force production, due to the bilateral force deficit (Howard & Enoka, 1991). The bilateral deficit posits that the total amount of force produced during two unilateral actions is greater than the force produced during a single bilateral contraction (Nijem & Galpin, 2014). Hence, more muscle stimulation is expected to occur in the leg extensor muscles during unilateral squat, as the smith machine does not require as much stabilization and lessens spinal loading (Kraemer & Ratamess, 2004; Schoenfeld, 2010). As the unilateral squat is more specific to the movement pattern during COD, this exercise was prioritized to be performed with shortened ROM as this has been shown to be effective at enhancing performance in many athletic movements (Rhea et al., 2016)

On the other hand, squats performed with increased ROM has proven to enhance performance in other squats performed with shorter ROM over time (Rhea et al., 2016). Thus, squats performed with a greater range of motion exhibit greater stimulus for muscle growth and strength in the exercises suggested to have transfer to athletic performance. As a result, the bilateral parallel squat was included as a fundamental exercise, always performed after the unilateral squat with increased ROM. Lateral squats were implemented with the specific purpose of mediating the lateral push-off apparent in COD tasks (Bourgeois et al., 2017). This exercise was chosen to be performed first in some sessions, resulting in a trade-off between specificity and training volume.

Eccentric hamstring strength has been suggested to be particularly important when decelerating prior to a COD-maneuver (Chaouachi et al., 2009). A study by Mjølsnes, Arnason, Østhagen, Raastad & Bahr (2004) found 10 weeks of Nordic hamstring exercise to be more effective compared to the leg curl exercise. As the decelerations prior to a COD maneuvers are performed in a unilateral fashion, it was decided to implement the unilateral Nordic hamstring in the training program. Finally, unilateral plantarflexion performed in a smith-machine was implemented to provide a complete and balanced lower-body program.

As with strength training, it has been suggested that plyometric training aimed at developing COD-ability should be performed bilaterally and unilaterally, where force is exerted in multiple directions (Brughelli, Cronin, Levin & Chaouachi, 2008). It is worth noting that plyometric exercises performed with few repetitions will arguably not be limited by metabolic demands to the same extent as many strength-exercises, due to shorter time under tension. As different COD-task represent different demands of motor control and muscle qualities, it was deemed appropriate to include some variation with respect to the sequencing order of the plyometric exercises, with the aim of maintaining the natural applicability this form of training allows.

Drop jump (DJ) was implemented because it is commonly used to enhance athletic performance (Young, Wilson & Byrne, 1999) and has been used in many training-programs designed to develop COD-performance (Ramirez-Campillo et al., 2018; Ramírez-Campillo et al., 2014; Thomas, French & Hayes, 2009). The drop jump allows for easy individualization by adjusting the drop height, making it well suited for optimizing the effect of training (Ramirez-Campillo et al., 2018). The exercises were to be performed bilaterally due to the injury risk associated with unilateral DJ (Bates, Ford, Myer & Hewett, 2013; Pappas, Hagins, Sheikhzadeh, Nordin & Rose, 2007).

The unilateral countermovement-jump (CMJ) was chosen as the second exercise performed in vertically direction. It is characterized by a slower stretch shortening cycle (SSC) in comparison to the drop jump (Cronin & Hansen, 2005), thus training different aspects of the force velocity spectrum that are expected to vary in different COD tasks (Bourgeois et al., 2017). Studies combining these two exercises have displayed large effects on COD performance (Hernández et al., 2018; Ramirez-Campillo et al., 2018; Ramírez-Campillo et al., 2014).

Horizontal hurdle jumps performed both bilaterally and unilaterally were chosen to mediate the specific demands of propulsion force that occur during acceleration and during COD maneuvers (Dos'Santos, McBurnie, Thomas, Comfort & Jones, 2019). A project prior the intervention aimed at finding a universal length (% of max length) that athletes of different anthropometrics and capacities could perform. The goal was to maximize rapid horizontal force exertion and at the same time allow for smooth jump-transitions between hurdles. Furthermore, skate jumps were implemented as a response to lateral squats. Two studies that have implemented lateral jumping in their programs have displayed large effects upon COD performance (Meylan & Malatesta, 2009; Yanci, Castillo, Iturricastillo, Ayarra & Nakamura, 2017). Testing prior to intervention revealed that participants differing in lower limb-length have displayed quite different techniques when performing repeated jumps at a specific value of a single max skate jump length. After extensive testing, a good all-round approach with respect to length performed in skate-jump was set. It is worth noting that the specific approaches with respect to hurdle- and skate jumps were completed because it is difficult to base this on previous literature, since distances set in these exercises vary across age, sex, individual qualities and anthropometrics.

Finally, the laying kick was implemented as a response to the Nordic hamstring. Both exercises have displayed high levels of EMG-activation in comparison to other popular hamstring-exercises (van den Tillaar, Solheim & Bencke, 2017). In the plyometric training program, there was no specific isolation exercise stimulating the calves because plyometric are generally well suited for developing maximal strength in the ankle extensor muscles (Marshall et al., 2014). In particular, the use of hurdle jumps has resulted in high EMG-activation in the ankle extensor muscles (Cappa & Behm, 2013).

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**Appendix B.** Descriptive statistics with pairwise comparisons for 4m and 20m COD tasks. (N=20)

| | **45° COD** | | **90° COD** | | **135° COD** | | **180° COD** | | **ANOVA (degree x side)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Left** | **Right** | **Left** | **Right** | **Left** | **Right** | **Left** | **Right** | ***df*** | ***F*** | ***p*** | $\eta_p^2$ |
| **4m COD** | | | | | | | | | | | | |
| COD time (cs) | 172.9 ± 15.0 | 174.4 ± 14.6 | 205.9 ± 15.6 | 206.2 ± 15.5 | 237.5 ± 16.9 | 240.5 ± 13.0 | 248.1 ± 16.4 | 249.7 ± 15.1 | 3, 57 | 0.202 | 0.894 | 0.011 |
| Lowest COM (cm) | 18.1 ± 2.5 | 18.4 ± 2.9 | 26.7 ± 4.8 | 25.7 ± 2.8 | 30.4 ± 6.0 | 29.9 ± 4.6 | 33.9 ± 7.1 | 34.8 ± 5.5 | 3, 48 | 0.994 | 0.404 | 0.058 |
| Decel. steps (n) | 0.4 ± 0.8 | 0.1 ± 0.4 | 2.8 ± 0.9 | 2.7 ± 0.7 | 3.2 ± 0.5 | 3.6 ± 0.94 | 3.3 ± 0.7 | 3.7 ± 0.7 | | | | |
| **20m COD** | | | | | | | | | | | | |
| COD time (cs) | 138.3 ± 10.6 | 138.2 ± 11.0 | 183.6 ± 11.9 | 183.8 ± 9.0 | 214.9 ± 14.1 | 214.5 ± 8.4 | 230.2 ± 11.5 | 230.7 ± 10.2 | 2.171, 41.249 | 41.249 | 0.975 | 0.002 |
| 16m split-time (cs) | 269.9 ± 11.9 | 272.0 ± 17.2 | 272.5 ± 13.3 | 273.3 ± 12.2 | 272.8 ± 13.1 | 271.4 ± 14.3 | 273.1 ± 14.9 | 271.2 ± 13.9 | 2.645, 50.257 | 1.092 | 0.356 | 0.054 |
| Total time (cs) | 408.2 ± 18.2 | 410.1 ± 15.6 | 456.1 ± 19.7 | 457.1 ± 17.7 | 487.6 ± 23.9 | 485.9 ± 17.2 | 503.3 ± 22.0 | 501.9 ± 17.5 | 3, 57 | 0.426 | 0.735 | 0.022 |
| Lowest COM (cm) | 20.0 ± 3.9 | 20.5 ± 3.3 | 29.0 ± 4.8 | 26.6 ± 3.6 | 33.3 ± 6.3 | 32.2 ± 6.2 | 35.6 ± 6.5 | 35.4 ± 6.9 | 1.197. 24.926 | 1.210 | 0.314 | 0.085 |
| Decel. steps (n) | 2.9 ± 1.2 | 2.6 ± 1.3 | 5.3 ± 0.9 | 5.3 ± 0.8 | 6.2 ± 1.3 | 6.3 ± 1.2 | 6.3 ± 1.1 | 6.2 ± 0.6 | | | | |

## **Appendix C.** Characteristics and distinctions of different COD tasks (4vs20m comparisons)

| **Variables** | | **45° COD** | | | **90° COD** | | | **135° COD** | | | **180° COD** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***n*** | ***MD*** | ***t*** | ***p*** | ***MD*** | ***t*** | ***p*** | ***MD*** | ***t*** | ***p*** | ***MD*** | ***t*** | ***p*** |
| COD time (cs) | 20 | -34.7 ± 11.5 | -13.529 | .001 | -22.3 ± 13.1 | 7.606 | .001 | -22.6 ± 15.9 | -6.345 | .001 | 17.9 ± 18.8 | 4.207 | .001 |
| Decelerations (n)$^Z$ | 18 | 2.5 ± 1.2 | 3.750 | .001 | 2.6 ± 0.7 | 3.816 | .001 | 2.8 ±1.1 | 3.772 | .001 | 3.1 ± 1.1 | 3.768 | .001 |
| **COM** COD step (cm) | 18 | 2.2 ± 2.8 | 3.336 | .004 | 2.7 ± 5.0 | 2.316 | .033 | 2.1 ± 2.7 | 3.340 | .004 | 0.8 ± 3.7 | 0.858 | .403 |
| **COM** post step (cm) | 15 | 1.5 ± 3.5 | 1.710 | .109 | 1.0 ± 6.1 | 0.614 | 0.549 | -1.0 ± 4.6 | -0.882 | .393 | 0.1 ± 6.0 | 5.1 | .914 |
| **CT** COD step (cs) | 17 | 0.7 ± 27.6 | 0.106 | .917 | -4.5 ± 33.1 | -0.558 | .585 | 5.8 ± 67.8 | 0.351 | .730 | -16.1 ± 97.4 | -0.682 | .505 |
| **CT** post step (cs) | 14 | 13.3 ± 39.4 | 1.263 | .229 | 1.1 ± 41.3 | 0.097 | .924 | -5.8 ± 42.9 | -0.504 | .622 | -2.9 ± 55.7 | -0.197 | .847 |
| Plantarflexion (°) | 17 | 3.5 ± 10.8 | -1.323 | .204 | 4.6 ± 13.7 | 1.373 | .189 | 6.0 ± 21.7 | 1.137 | .272 | 3.6 ± 19.0 | .784 | .444 |
| Knee flexion (°) | 18 | -2.6 ± 12.5 | -0.878 | .392 | -0.3 ± 16.1 | -0.090 | .929 | -6.3 ± 16.4 | -1.629 | .122 | -2.3 ± 15.6 | -0.624 | .541 |
| Hip flexion (°) | 18 | -1.8 ± 16.0 | -0.465 | .648 | -4.9 ± 11.4 | -1.469 | .160 | 4.2 ± 11.4 | 1.573 | .134 | 5.0 ± 16.4 | 1.298 | .212 |
| Hip abduction (°) | 17 | 2.2 ± 7.8 | 1.134 | .274 | -2.1 ± 5.4 | -1.644 | .120 | 1.8 ± 5.9 | 1.258 | .226 | 2.0 ± 7.4 | 1.095 | .290 |

Note: Degrees of freedom (n-1) remains equal between conditions due to listwise exclusion of cases. Z= Variable analysed with Wilcoxon signed rank test.

## Appendix D. Mean (±SD) COD times (cs) at pre- and post-test with p-values for strength and plyometric training groups.

| | **Strength training group** | | | **Plyometric training group** | | |
|---|---|---|---|---|---|---|
| **Variables** | **Pre** | **Post** | **Effect (p)** | **Pre** | **Post** | **Effect (p)** |
| **COD-time** | | | | | | |
| 4m 45° | 171.3±16.6 | 167.2±15.0 | 0.27 | 174.2±14.3 | 169.6±11.7 | 0.07 |
| 4m 90° | 203.2±18.8 | 204.0±19.3 | 0.87 | 208.0±13.0 | 198.5±11.6 | 0.06 |
| 4m 135° | 237.4±20.0 | 234.8±15.0 | 0.67 | 237.5±15.0 | 226.4±12.8 | 0.04* |
| 4m 180° | 244.0±17.5 | 241.4±15.3 | 0.53 | 251.4±15.4 | 242.7±11.1 | 0.01* |
| 20m 45° | 138.0±9.5 | 133.7±13.0 | 0.29 | 138.5±11.9 | 137.8±10.9 | 0.80 |
| 20m 90° | 184.3±13.2 | 182.8±10.7 | 0.68 | 183.0±11.4 | 182.1±8.0 | 0.79 |
| 20m 135° | 216.7±7.7 | 208.8±8.7 | 0.09 | 213.4±18.0 | 212.4±14.2 | 0.85 |
| 20m 180° | 231.9±6.7 | 225.1±10.4 | 0.07 | 228.8±14.6 | 219.5±11.8 | 0.01* |
| **16m Part-time** | | | | | | |
| 20m 45° | 271.6±14.0 | 270.3±14.1 | 0.52 | 268.5±10.3 | 268.2±12.1 | 0.08 |
| 20m 90° | 273.2±13.1 | 270.6±15.6 | 0.09 | 271.8±14.1 | 265.5±9.3 | 0.08 |
| 20m 135° | 273.7±13.7 | 269.0±15.9 | 0.06 | 272.0±13.3 | 266.3±10.8 | 0.14 |
| 20m 180° | 273.6±16.2 | 271.0±15.6 | 0.31 | 272.7±14.6 | 262.4±12.0 | 0.03* |

*$p < 0.05$

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