Comparison of performance and performance-related variables in different angles of changes of direction and effect of six weeks of strength- or plyometric training upon these performances.
Table of content:

Forord.................................................................................................................................3
Abstract ...............................................................................................................................4

1. Introduction.....................................................................................................................6
   1.1. Decisive factors for COD-performance .................................................................7
   1.2. Plyometric training for developing COD-performance ...........................................10
   1.3. Strength training for developing COD-performance ..............................................11
   1.4. Strength-dominant versus velocity-dominant CODs .............................................12

2. Method............................................................................................................................13
   2.1. Experimental approach to the problem .................................................................13
   2.2. Subjects ...............................................................................................................13
   2.3. Procedure............................................................................................................14
       2.3.1. Adaptions prior to testing ..............................................................................14

3. Equipment ......................................................................................................................15
   3.1. Electromyography (EMG) ....................................................................................15
   3.2. 3D-motion capture (Xsens) ................................................................................15
   3.3. Timing gates ........................................................................................................16
   3.4. Contact mats .......................................................................................................16

4. Description of the tests .................................................................................................17
   4.1. Testing protocol ...................................................................................................17
   4.2. COD-test ............................................................................................................17
   4.3. Plyometric tests ..................................................................................................20
       4.3.1. Unilateral vertical countermovement jump ...................................................20
       4.3.2. Drop jump ....................................................................................................21
       4.3.3. Bilateral Hurdle-jumps ................................................................................22
       4.3.4. Unilateral Hurdle jumps ............................................................................22
       4.3.5. Skate jump ....................................................................................................23
       4.3.5. Laying Hamstring-kick ................................................................................23
   4.4. Strength tests .......................................................................................................24
       4.4.1. Squat ............................................................................................................24
       4.4.2. Unilateral squat ............................................................................................25
       4.4.3. Lateral squat ................................................................................................25
       4.4.4. Unilateral Nordic hamstring .........................................................................26
       4.4.5. Unilateral calf-raises ....................................................................................26
5. Training program ................................................................................................................. 26
   5.1. Warm-up prior to training ................................................................................................. 28
   5.2. Strength training ............................................................................................................... 28
   5.3. Plyometric training .......................................................................................................... 30
6. Statistical analysis .................................................................................................................. 33
7. Results .................................................................................................................................. 34
   7.1. Comparison between the different CODs .......................................................................... 34
      7.1.1. Comparison of time to complete CODs, contact time, number of deceleration steps, and center of mass ........................................................................................................... 36
      7.1.2. Joint angles ................................................................................................................ 39
      7.1.3. Muscle-activation in the different COD-conditions ......................................................... 41
   7.2. Changes in performance and performance-related variables after six weeks of training ...... 43
      7.2.1 Changes in COD- and sprint performance .................................................................... 43
      7.2.2 Performance changes in the strength- and plyometric tests ............................................. 47
      7.2.3. Relationship between contact time, center of mass, and COD-performance .................... 48
      7.2.4. Changes in kinematics after the training intervention for both groups combined (n=20) ..... 51
8. Discussion ............................................................................................................................... 52
   8.1. Comparison of the different CODs ..................................................................................... 52
   8.2. Changes in performance and performance-related variables after completing the training intervention ........................................................................................................................................... 57
   8.3. Methodical considerations .................................................................................................. 61
   8.4. Practical applications ........................................................................................................... 62
9. Conclusion ............................................................................................................................... 64
References: .................................................................................................................................. 66
Forord
Jeg ønsker å takke min veileder Roland for veiledning både gjennom testingen og oppgaveskrivingen. En spesielt stor takk til min medstudent Håvard Guldteig som har tilbrakt utallige timer med meg på skolens laboratorium under både testing og datainnsamling. Ønsker også å takke alle som stilte opp som forsøksperson. Sist, men ikke minst, en stor takk til en veldig tålmodig samboer gjennom hele masterløpet.

Nord Universitet
Høst 2019
Hallvard Nygaard Falch
Abstract

The purpose of this study is separated into two main objectives. Firstly, comparing different changes of directions (COD), to see if it is reasonable to separate CODs as strength- or velocity dominant. Secondly, to investigate how strength- or plyometric training affects performance in strength- and velocity-dominant CODs. To answer the research questions, twenty-three young, male soccer players volunteered to participate in a pre-test. In the pre-test, the subjects were tested with a modified COD-test consisting of one turn at 45°, 90°, 135°, and 180° with both a 4m and 20m sprint approaching the COD-maneuver. The CODs were performed both with a left and a right turn, making the COD-test consist of sixteen CODs in total. Time, the performance variable in the COD-test, was measured with wireless photocells, and both total time and partial time to complete the test was noted. Afterwards, the subjects were tested in a randomized order for performance in five different strength- and six different plyometric tests. Performance in the strength tests were lifted external load. For the plyometric tests, the performance variable was contact-time and reactive strength index, which was identified using a contact-grid. After the pre-test, twenty of the subjects were paired based on their competition level and pre-test performance before randomly being recruited to a strength training program (n=9, age: 22.2±2.9 years, body-mass: 77.1±6.8 kg, height: 181.4±5.6 cm) or a plyometric training program (n=11, age: 22.5±2.5 years, body-mass: 82.5±6.9 kg, height: 182.3±5.4 cm). The strength- and plyometric training programs were matched in workload and all the subjects in both training groups completed the training program, which consisted of two training sessions a week, for a duration of six weeks (twelve sessions in total). The performance-related data sampled from testing days consisted of the number of deceleration steps prior to the step where the dominant foot performs the COD-maneuver (COD-step), center of mass in the COD-step, and angles of the ankle plantar flexion, knee flexion, hip abduction, and hip flexion in the COD-step. These variables were identified using a full-body motion capture system (Xsens). Xsens was also used to measure the time the foot was in contact with the ground (contact time) for the COD-step and the acceleration step (the first step with the dominant foot after the COD-step). In addition, muscle activation in the COD-step and acceleration step was measured using electromyography (EMG). The two-way analysis of variance (ANOVA) with repeated measures was conducted to compare performance and performance-related variables in the different CODs and to compare changes from pre- to post-test. The results of this study suggest that it is reasonable to separate the terms strength- and velocity dominant CODs in training terminology. 45° CODs are more velocity dominant and 180° CODs are more strength
dominant, while the 90° and 135° CODs are harder to categorize. 45° CODs are recognizable with a small displacement of center of mass, little deceleration prior to the COD step making velocity-maintenance possible, and a smaller knee- and ankle flexion in the COD-step compared to the other CODs. Also, muscle activation in adductor longus, gastrocnemius, and rectus femoris separates the 45° COD from the other CODs. The adductor longus was found to have significantly higher muscle activation in the COD-step when performing 45° CODs, because less innervation of the thigh is required prior to the COD-step. The 180° CODs are recognized with both feet in the ground when performing the COD-step, a low center of mass, and a full rotation of the body while changing momentum to the opposite direction. The flexion of the hip was found to be largest in the 180° CODs, compared to all other CODs.

There seems to be a linear relationship between the time to complete the COD-maneuver, center of mass, and contact time, which increase when the degree of the COD-maneuver increases. As such, the importance of the strength- and velocity qualities are dependent on the degree of the COD-turn. The approach distance seems to be the most important variable for determining the athletes’ need to decelerate prior to the COD-step. The findings from this study suggest that the physical qualities of the different CODs are determined by variations of the degrees and distance approaching the COD-maneuver and are an important consideration for sports and conditioning coaches. The training program was effective in developing strength of the strength-training group, and plyometric abilities of the plyometric-training group. No effect between the two groups was observed in COD-performance from pre- to post-test, but the results indicates that plyometric training is most efficient in developing the spectrum of qualities that the different CODs are dependent on. Plantar flexion of the ankle and flexion of the hip increase at post-test, suggesting that increased power in the plantar flexion and hip flexion movement are trainable factors positively influencing COD-performance. Also, the subjects were found to increase acceleration ability at post-test, a physical factor the COD-performance is dependent on. Strength- and plyometric training can therefore be used as tools for improving COD-performance. Plyometric training seems to be most effective, due to specificity in the velocity of muscle contractions. However, due to the study using a relatively small sample size and the complexity of the COD-maneuver, further research is warranted for more knowledge on the topic.

**Keywords:** COD, Strength-dominant, velocity-dominant, COD-step, acceleration-step, EMG
1. Introduction

Team sports that involve opponents require different abilities for success (Stølen, Chamari, Castagna, & Wisløff, 2005). One of those abilities is to move fast, because it helps to get a physical and tactical advantage by surpassing an opponent in sports such as soccer, handball, and rugby (Bourgeois, McGuigan, Gill, & Gamble, 2017; DeWeese, 2016). The ability to move fast is often characterized by the ability to perform fast changes of direction (COD), which is an important quality in field sports (Köklü, Alemdaroğlu, Özkan, Koz, & Ersöz, 2015). A study conducted in children soccer games found that only 3% of distance covered consisted of high-speed running (Castagna, D'ottavio, & Abt, 2003). Still, the athlete must be able to perform actions at maximum intensity, and repeat those actions throughout the game (Bangsbo, Mohr, & Krustrup, 2006; Bradley et al., 2009; Carling, Le Gall, & Dupont, 2012; Negra, Chaabene, Hammami, Hachana, & Granacher, 2016; Strøyer, Hansen, & Klausen, 2004). These maximum-intensity actions have a short duration and occur during the entire match, and are crucial for the match outcome as they could be the difference between scoring or conceding a goal (Castagna et al., 2003; Helgerud, Engen, Wisløff, & Hoff, 2001; Reilly, Bangsbo, & Franks, 2000). In fact, a study performed on German national-league soccer players showed that 83% of goals scored are preceded by a powerful action during the scoring or an assisting play (Faude, Koch, & Meyer, 2012). Field sports consist mostly of walking and jogging, but actions at maximum intensity are perhaps the key to success because surpassing an opponent and creating a surplus of players can enhance the chance of scoring in handball, rugby, and soccer. Such a powerful action could be a fast COD.

Brughelli, Cronin, Levin, and Chaouachi (2008) define COD as a preplanned whole-body movement into a new direction, without immediate reaction to a stimulus. Without reacting to a stimulus, the ability to rapidly change directions is only limited by the athlete’s physical abilities (DeWeese, 2016; Young, James, & Montgomery, 2002). CODs consist of an acceleration phase, deceleration-breaking phase and a re-acceleration into a new direction (DeWeese, 2016). The acceleration phase is similar to the acceleration phase in a sprint, where the athlete’s center of mass is first lowered to produce horizontal force to the ground. The turn in COD consists firstly of a breaking phase, caused by eccentric muscle work followed by a rapid concentric-propulsive force (Castillo-Rodríguez, Fernández-García, Chinchilla-Minguet, & Carnero, 2012). Analysis of soccer matches shows that soccer players perform about 700 turns per game at different intensities, where around 600 of these turns are 0° to 90°, turning
either right or left (Bloomfield, 2007). In a study, Withers, Maricic, Wasilewski, and Kelly (1982) found that around 50 of the CODs in a soccer match are performed at maximum intensity. Earlier research conducted on rugby players’ COD-ability at different levels reveals that professionals performed better on the COD-tests compared to sub-elite players (Baker & Newton, 2008). Another study conducted by Reilly, Williams, Nevill, and Franks (2000) found COD-performance to be a discriminating variable when comparing young elite and sub-elite soccer players. Since the ability to perform CODs is important for performance in many sports (Brughelli et al., 2008; Reilly, Williams, et al., 2000), knowledge of how to improve the physical aspects COD-performance is dependent on is of importance.

1.1. Decisive factors for COD-performance

![Flowchart](image)

Figure 1.1. Flowchart illustrating the different physical factors which are decisive for overall COD-performance. The different factors are technique, sprint-speed, and different muscle qualities. The figure is modified from Young et al. (2002).

CODs consist of a great acceleration of the athlete’s own bodyweight. As such, to optimize performance, athletes should minimize excessive body fat and increase strength in the lower extremities. Decrease in mass and increase in strength will improve the athlete’s relative strength (Peterson, Alvar, & Rhea, 2006) and could possibly increase COD-performance because the ability to move your own bodyweight is a result of mass and acceleration (Bourgeois, McGuigan, et al., 2017; DeWeese, 2016). In a study performed by Chaouachi et al. (2009), a high correlation was found between an athlete’s fat percentage and COD performance.
where the faster athletes had a lower percentage of body fat. Therefore, it would be ideal to increase strength in the lower extremities while not gaining unnecessary weight to better create a counterforce to the ground and increase COD-performance. In a review, Bourgeois, McGuigan, et al. (2017) used Newton’s laws of motion to explain the different factors COD-performance is dependent on.

**Newtons first law** of inertia and force: a body at constant velocity will remain at that velocity until acted upon by a force. There are also forces involved at a constant velocity, but the sum of forces equals 0. As such, an athlete must apply force to the ground to accelerate/decelerate and perform a COD. Required force to produce the COD will be dependent on the degree of the COD, the athlete’s mass, and speed when entering the COD-step according to Bourgeois, McGuigan, et al. (2017). Therefore, strength-dominant CODs would require a higher force to the ground during the COD, produced by either more forceful breaking steps, or a higher frequency of breaking steps (figure 1.2).

**Newtons second law** defines the relationship between mass, acceleration, and force (\(F=ma\)). Acceleration will occur according to the direction of net force (Bourgeois, McGuigan, et al., 2017). The greater the mass, the greater force is needed to accelerate and decelerate in a COD. As such, strength improvements can improve the athlete’s acceleration and therefore improve force (Lockie, Murphy, Schultz, Knight, & de Jonge, 2012; Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). **Newtons third law** states that for every force, there is an equal force in the opposite direction. While performing a COD, the athlete will produce force to the ground which will cause a propulsive force from the ground. To perform a COD, the athlete must therefore produce a net force to the ground in the appropriate direction during the COD (Bourgeois, McGuigan, et al., 2017). Appropriate breaking steps are dependent on the athlete’s ability to transmit the forces, rather than absorb them, to perform the COD in the desired direction (Young & Farrow, 2006). Considering Newtonian laws for COD-performance, the athlete’s strength and velocity qualities are of great importance. The review of Bourgeois, McGuigan, et al. (2017) proposed the principle of velocity- and strength-dominant CODs, to better understand the physical demands of the different types of CODs (figure 1.2).
Figure 1.2. Illustrates how the entering speed in the approach direction and angles of the COD-step make the COD velocity dominant or strength dominant (Bourgeois, McGuigan, et al., 2017).

The greater velocity an athlete approaches with a COD and the greater degrees of the COD-step, the more force is needed to perform the COD (figure 1.2). Hence, it is thought that strength-dominant CODs require a longer duration of time at the change of direction step as well as a longer breaking phase where steps for decelerating has longer contact time, which makes strength more vital compared to velocity-dominant CODs (figure 1.2). To effectively produce a great force to the ground while performing a COD, it is important to rapidly lower the center of mass while accelerating and decelerating, which gives the shorter athletes an anthropometrical advantage. A study by Chaouachi et al. (2012) found that shorter athletes performed significantly better in COD-tests compared to taller athletes.

Earlier research conducted on COD shows no clear answer to what the optimal technique for COD-performance is, but it is thought that specific training can help the athlete find and develop their own optimal technique based on the athlete’s anthropometry (Young & Farrow, 2006). The body lean determines the direction of reaction forces produced to the ground and therefore also determines the efficacy of the COD (Young & Farrow, 2006; Young et al., 2002). Direction of forces produced to the ground should, alongside with the athlete’s muscular strength and velocity qualities, be considered when developing a training program to improve technique and overall COD-performance.
1.2. Plyometric training for developing COD-performance

Since the ability to perform CODs fast requires a great amount of force to the ground in a short duration of time, high rate of force development is needed (Young et al., 2002). Developing maximum force normally requires 0.6 to 0.8 seconds, but when performing functional movements such as a COD the time to produce force is shorter, depending on the COD-test (DeWeese, 2016). Reaction force is one of the variables that affect the COD-performance (figure 1.1) and concerns the ability to rapidly change the muscle work from eccentric to concentric. This is called the stretch-shortening cycle (SSC), and occurs in fast dynamic exercises like a countermovement-jump (CMJ) or a COD (Young & Farrow, 2006). Plyometric training often includes CMJs, and aims to improve the SSC-ability (Newton, 2011). It does this by producing as much force as possible in a short duration of time to increase movement power (Potach, 2016).

The SSC and the goal of producing power are the fundamentals underlying the thought that plyometric training can improve COD-performance (Young et al., 2002), and the most common approach quantifying the relationship has been through correlational analysis (Brughelli et al., 2008). Earlier studies have found moderate to high correlations between different jump- and COD-tests; \( r = -0.64 \) (Castillo-Rodríguez et al., 2012), \( r = 0.7 \) (Vescovi & Mcguigan, 2008) and \( r = 0.71 \) (Lockie, Schultz, Callaghan, Jeffriess, & Luczo, 2014). Several studies have utilized plyometric training to try to improve COD-performance; (Asadi, 2013; Chtara et al., 2017; Faigenbaum et al., 2007; Fernandez-Fernandez, De Villarreal, Sanz-Rivas, & Moya, 2016; Loturco et al., 2017; McCormick et al., 2016; Meylan & Malatesta, 2009; Negra et al., 2016; Ramírez-Campillo, Burgos, et al., 2015; Ramírez-Campillo, Gallardo, et al., 2015; Ramírez-Campillo et al., 2016; Ramírez-Campillo et al., 2014; Söhnlein, Müller, & Stöggl, 2014; Thomas, French, & Hayes, 2009; van den Tillaar, Waade, & Roas, 2015; Yanci, Castillo, Iturricastillo, Ayarra, & Nakamura, 2017), with varying results. The improvement in COD-performance after training intervention varied from 0% to 11.76%, with effect sizes ranging from small to huge (Sawilowsky, 2009). Several studies also investigated the effect of a plyometric training regime in combination with strength-, COD- or speed training; (Beato, Bianchi, Coratella, Merlini, & Drust, 2018; de Hoyo et al., 2016; Faigenbaum et al., 2007; Gil et al., 2018; Hammami, Negra, Shephard, & Chelly, 2017; Loturco et al., 2017). The improvement after training intervention varied from 0% to 6.2% with effect sizes ranging from small to huge.
Because of the complexity of the different sports and their demands, it can be problematic to develop a plyometric program to improve COD-performance. Earlier, it has been proposed that plyometric training should be conducted both bilaterally and unilaterally in the vertical, lateral, and horizontal plane (Brughelli et al., 2008).

1.3. Strength training for developing COD-performance

Strength training for maximum strength has been proposed by Cronin, Mcnair, and Marshall (2000) to be important in developing explosive actions, such as COD. Strength training is assumed to develop COD-performance (Brughelli et al., 2008) because the athlete has to overcome his own bodyweight to efficiently change momentum towards a new direction, according to Newton’s laws. Improved maximum strength in the lower extremities could therefore enhance COD-performance if the newly acquired strength improves the athlete’s relative strength (Bourgeois, McGuigan, et al., 2017; Meylan & Malatesta, 2009; Nimphius, Mcguigan, & Newton, 2010; Peterson et al., 2006). A common approach for quantifying the relationship between strength and COD-performance is conducting correlation analysis (Brughelli et al., 2008). Correlational studies measuring the relationship between strength training and COD have found low correlations ($r=0.03$ to $0.44$) (Markovic, 2007) and moderate to high correlations ($r=0.4$ to $0.8$) (Jones, Bampouras, & Marrin, 2009; Nimphius et al., 2010; Peterson et al., 2006). All studies that found moderate to high correlations used strength-dominant COD-tests as dependent variables to measure COD-performance (figure 1.2), where the COD-test had at minimum one turn at >90°. The varying size of the correlations could be a result of COD and strength tests used and degrees of the joints while performing the tests, which affects the muscles’ range of motion (Brughelli et al., 2008).

Strength training has been used in several studies to try to improve COD-performance (de Hoyo et al., 2016; Hammami et al., 2017; Negra et al., 2016; Torres-Torrelo, Rodríguez-Rosell, & González-Badillo, 2017; van den Tillaar et al., 2015), with improvements that varied from 0.4% to 7.1% (and effect sizes ranging from small to very large). Some studies also included strength training in their training intervention combined with plyometric-, speed- or COD-training (Faigenbaum et al., 2007; Hammami et al., 2017; Otero-Esquina, de Hoyo Lora, Gonzalo-Skok, Domínguez-Cobo, & Sánchez, 2017; Torres-Torrelo et al., 2017). The combined strength training resulted in an improvement ranging from 1.64% to 5.2% (and effect sizes ranging from small to very large).
1.4. Strength-dominant versus velocity-dominant CODs

As mentioned, Bourgeois, McGuigan, et al. (2017) proposed the principle of strength-dominant and velocity-dominant CODs (figure 1.2). Speed approaching the COD-step and the angle of the turn determines the athlete’s muscle strength and the velocity of the muscle contraction needed to perform the COD. Strength-dominant CODs are thought to take more time to perform because the athlete will lower the center of mass more in the breaking phase, and would therefore require more force than velocity-dominant CODs (Meylan & Malatesta, 2009). This could be explained by the theory of Hill (1938), which involves the relationship between force and velocity in a muscle contraction. A high amount of force results in a slower muscle contraction. On the other hand, muscle contraction at high velocity produces less force. The product of force and velocity is power (P=F x V). Figure 1.3 illustrates this relationship.

![Figure 1.3. Hills curve illustrating the relationship between force and velocity. A more forceful concentric muscle contraction equals a slower contraction velocity (Seow, 2013).](image)

Because of the required time to perform the COD-step, the varying improvements in COD-performance after training strength or plyometrics could be a result of varying specificity in the exercises included in the training program. Yet, to the author’s knowledge, no study has specifically studied the different qualities in the proposed velocity-dominant and strength-dominant CODs. Logically, no study has investigated the effect of plyometric- or strength training on strength- or velocity-dominant CODs either. As such, the objective of this study is to: 1) Compare different CODs with each other, to see if it is reasonable to separate them as strength- or velocity dominant CODs. 2) Investigate how strength- and plyometric training affects performance in strength- and velocity-dominant CODs after training two times a week for a duration of six weeks at the end of the season in semi-professional and amateur soccer players.
2. Method

2.1. Experimental approach to the problem
A repeated measures design with two groups (strength training vs. plyometric training) was used to determine the effect of six weeks of strength- or plyometric training on strength-dominant and velocity-dominant CODs, and to determine if it is possible to separate strength-dominant and velocity-dominant CODs based on kinematics and muscle activation. A randomized controlled study was conducted in which two groups of experienced soccer players, matched on competition level and performance in total time and partial time in the COD-tests at pre-test, received a strength- or plyometric training program and trained twice per week for six weeks. At pre-test, the players were tested in COD-performance plus different strength- and plyometric exercises to investigate similarities and differences between these exercises on the effect on the different CODs, in order to give more insight in how to develop the different physical qualities COD-performance is dependent on. The independent variables in this study are performance in the different strength- and plyometric tests plus a 30m sprint, where performance is measured in: External load (Kg), contact time (msec), Reactive strength index (RSI), jump height (cm), jump length (cm), and time (s). The dependent variable is performance in the COD-test (4m or 20m + COD + 4m) measured in seconds, at the different angles and different approaching velocities as a result of different lengths in the linear sprints before performing the COD maneuver.

2.2. Subjects
Twenty Norwegian, male soccer players participated in the training intervention of this study, and three extra subjects completed only the pre-test for extra data used for comparison of the CODs (table 2.1). The subjects in this study varied in competition level from Norwegian second to sixth division, and they differed in experience with strength- and plyometric training. They also differed in anthropometrical dispositions and physical abilities. The requirement for participation was a minimum of two soccer-training sessions a week. All subjects preferred the right foot as kicking foot. Preferred kicking foot is hereby defined as dominant foot. All subjects received in writing a detailed description of the testing procedure, approved by Nord University, which had to be signed by all the subjects. The benefits and risks of participation were also orally explained. The subjects were informed about the option to quit whenever they wanted, without having to give an explanation. They were also informed not to engage in heavy training
or consume alcohol twenty-four hours prior to testing and to eat a light meal two hours before the start of the test, but this was not controlled for. Because of the time spent to complete the test, subjects consumed nutrition rich in carbohydrates after the COD-tests for each test day. Also, pauses were included between the different tests, to ensure optimal recovery and performance.

Table 2.1. Descriptive statistics for the different training groups measured at pre-test. There were no significant changes measured at post-test. Body mass at post-test was 77.2±6.3 for the strength-training group and 82.8±8.6 for the plyometric-training group.

<table>
<thead>
<tr>
<th></th>
<th>Strength training (n=9)</th>
<th>Plyometric training (n=11)</th>
<th>Pre-test only (n=3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>22.2±2.9</td>
<td>22.5±2.5</td>
<td>22.3±1.2</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>77.1±6.8</td>
<td>82.5±6.9</td>
<td>76.3±10.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>181.4±5.6</td>
<td>182.3±5.4</td>
<td>178±9.4</td>
</tr>
</tbody>
</table>

2.3. Procedure

2.3.1. Adaptions prior to testing

All subjects participated in two familiarization days where they practiced the COD and strength- and plyometric tests to eliminate the chance that increases in post-test performance was a result of technical learning prior to the experimental treatment. Subjects were given performance feedback during the familiarization days and during both test days. They were encouraged to improve performance from each familiarization day and each test day. At the first of two familiarization days, the subjects came in groups and body height were taken using measuring tape, they were weighed on a standing-scale (Soehnle-professional 7830, stand scale), before finally answering a questionnaire. The questionnaire included questions about soccer trainings per week (minimum two trainings per week), dominant foot, and the division of their current club. During the familiarization days, the performances in different tests were noted and used to motivate and control for maximum effort during the test day. The warm-up protocol was the same for familiarization and test days, but the order of the different CODs and the order of exercises were always randomized. The 30m sprint was always tested first, followed by the COD-tests in a randomized order to prevent the results from being affected by
the test order. Afterwards, all strength- and plyometric exercises were performed in a randomized order.

3. Equipment

All the equipment used in all the tests, during the pre- and post-test, were synchronized in Musclelab version 10.5.69.4823 (Ergotest innovation A.S, Versikvegen 2, 3937, Porsgrund, Norway), except for Xsens. The data from Musclelab was collected by a data-synchronization unit with a 2,4 GHz radio host for connecting and synchronizing all the wireless equipment in time. Equipment used in Musclelab was also synchronized with a 3D motion-capture system (Xsens motion capture, MVN link, 240 Hz) using an IMU to control the validity of the study. IMU (Ergotest innovation, Porsgrund Norway, ML Gyros/ML6IMU01), a wireless accelerometer with a sampling rate of 200 Hz, was placed on the right upper leg. Placement of the IMU should be on top of the Xsens-acceleromer, located on the right upper leg.

3.1. Electromyography (EMG)

EMG (Ergotest innovation, Porsgrund Norway, ML Electromyography/ML6EMG01), with a sampling rate of 1000 Hz, was used to measure the dominant foot’s muscle activation in all the tests, sampled as root of mean square (RMS). The EMG sensors were attached to EMG pads (GS03 disposable sEMG electrodes, 38875 Harper Ave, Clinton Township, MI 48036, 2 inches per diameter). The electrodes were placed according to the guidelines of Day (2002) on the following muscles: gluteus maximus, gluteus medius, adductor longus, semitendinosus, biceps femoris, rectus femoris, vastus lateralis, vastus medialis, gastrocnemius, and soleus. Data affected by external noise was excluded from statistical analysis. Test contractions were also made prior to testing to secure good contact between the skin and EMG pads and a noise level of RMS less than 10 µV. If an electrode loosened during testing, the muscle activation for that specific muscle was also excluded for the rest of the tests.

3.2. 3D-motion capture (Xsens)

MVN, a product by Xsens (Xsens Technologies B.V. Enschede, Netherlands), is a full-body motion-capture system, based on inertial sensors with a sample rate of 240 Hz which creates a biomechanical model and hence makes biomechanical analysis possible. The Xsens suit was calibrated in Xsens V.19, the program also used for reprocessing the Xsens-files before
collecting data. During the pre- and post-test, Xsens was used as a visual feedback and technical control while performing the plyometric- and strength tests. During the post-test, performance at the pre-test was used to make sure the post-test results are comparable in technique, such as depth and joint angles.

3.3. Timing gates

The dependent variable of this study was time to perform COD where both total time and partial time were measured using timing gates. A wireless timer (Brower timing systems, Salt Lake Utah, USA, CM L5 MEM) registered total time and partial time, which was manually noted. The timing gates consist of two units: A sender (TC i-Photogate A) and a receiver (TC i-Photogate B) that transmit a laser between them. The time starts and stops when the laser is broken.

3.4. Contact mats

Infrared optical contact grid (Ergotest innovation, Porsgrun Norway, IR-contactmat-ML6TJP02) with a resolution of < 2msec was used to measure RSI, contact time, and jump height in the plyometric tests. The contact mats consist of two units, irSOURCE and irMIRROR, that send and reflect an infrared light a few millimeters above the floor. The two units record the time for when the subjects break the light beam, which makes recording of contact time and flight time possible.
4. Description of the tests

4.1. Testing protocol

At the day of testing, the subjects were tested one by one. Total time spent testing each subject varied due to the number of tests and equipment used, but in general it was approximately four hours. The day started with weight and height measurements, before placing EMG pads at the ten muscles on the subjects’ dominant foot. Afterwards, the warm-up for the COD-test started, followed by the COD-test in a randomized order. After the COD-test, the plyometric tests and strength tests were performed in a randomized order. The testing protocol was the same for both pre-test and post-test. Equipment and tests with the warm-up protocol are described more clearly in chapters 3 and 4.

4.2. COD-test

![Diagram of the Change of direction (COD) test](image)

**Figure 4.1.** Illustration of the Change of direction (COD) test. X=turning zone, marked by lines of 2m, placed 1m apart. Turning cone is placed in the middle of the first line. A marks the start of the CODs with a 4m sprint approaching the COD. B marks the CODs with a 20m sprint approaching the COD. The start line was 2m long. Arrows shows the direction of the sprint. The cones marking the angles of the turn (end cones) were placed 1m from each other, and the center point between them was 4m from the turning cone (X).
To measure COD-performance in soccer players according to figure 1.2, the COD-test should be short (<10 seconds) in order to avoid contribution of the aerobic energy systems (Gastin, 2001). A complex COD-test with many turns and a long duration of time will measure the athletes energy systems rather than their muscular and technical ability to accelerate, decelerate, and re-accelerate (Brughelli et al., 2008). As such, COD-performance was tested with one COD at different angles and different lengths approaching the turning point (figure 1.4), to separate strength- and velocity-dominant CODs, based on Bourgeois, McGuigan, et al. (2017). Prior to testing, a pilot study with a group of six persons that were not included in this study performed the COD-test with different lengths approaching the COD. The subjects were found to reach a higher velocity the longer the sprint before the turning point. Therefore, the COD-test consisted of a length of both 4 and 20 m to separate the extremities of velocities in the sprint when approaching the COD, followed by a 4 m re-acceleration towards a new direction to complete the test. The athletes were instructed to complete the test within the shortest total time possible. They were not informed about partial time, in order to prevent them from entering the COD with a low velocity, making the COD more match-like (Alves, Rebelo, Abrantes, & Sampaio, 2010). The COD-test was performed on an indoor court surface.

Warm-up for COD consisted firstly of a five-minute jog to increase body temperature. The warm-up was then followed up by a test-specific warm-up, with three runs at different intensities (60%, 70%, and 80% of max speed) based on a protocol by van den Tillaar, Lerberg, and von Heimburg (2016). Then four sprints of 15 m, with a 60° and 120° right and left turn, were performed at 80% of max, before the warm-up was completed with a 30 m sprint at 80% of max. The specific warm-up was included for the subjects to repeat the test, without favoring any CODs, before performing the test at maximum intensity. Resting periods of 1-2 minutes were included between all runs during the warm-up, to avoid fatigue. The first test was a 30 m sprint, with two attempts, followed by the COD-test performed in a randomized order. The COD-test was performed with a three to five minute resting period between each run, with the COD-test at varying lengths, to avoid limited access to ATP and CrP (Raastad, 2007). Since there were in total 16 CODs, results from familiarization day were used to control performance and to avoid several attempts and unnecessary fatigue.

All CODs were performed from 20 m and 4 m, with both a right and left turn, where the angle of the turn was 45°, 90°, 135°, or 180°. Each COD started with a standing start and the front foot placed 20 cm behind the timing gates, which was placed on each side of a 2 m long line
On the signal from a researcher, the subject decided when to start the test. This was done in order to avoid reacting to a stimulus, which was possible since COD-times were measured with timing gates. The subject ran from A or B and around the turning cone (X) to perform a COD, and finished the test by running through the end cones. The times to complete the different COD-tests from 4m were measured from start A to X and completed by passing the end cones. From 20m, the total time was measured from Start B to X and completed by passing of the end cones, while partial time was measured from A to the passing of the end cones. Only when performing 180° CODs were the turning cones removed. The test was then performed with a sprint from Start A or B, performing a 180° COD in the turning zone to either right or left, and a sprint back through Start A to complete the test. For all the CODs performed, except the 45°, the subject had to cross the first line of the turning zone with both feet, but not the second. Attempts that violated these requirements were excluded.

The dependent variables measured in the COD-test is performance, consisting of total time to complete the COD-test and partial time. The independent variables were the number of breaking steps, muscle activation, joint angles, center of mass (COM), and contact time in the COD-step, plus contact time in the first acceleration step after performing the COD-maneuver. With the use of Xsens and the velocity of pelvis and the reduction in height of the COM, the number of breaking steps when performing a COD was counted. This was possible since the subjects reduced their speed and lowered the COM during the breaking phase of the COD. In the COD-step and first re-acceleration step, while performing a COD, contact time was measured from the first frame with the dominant foot in contact with the ground, to the last frame where the dominant foot was still in contact with the ground. COM in the COD-step was defined as lowest COM with the dominant foot still in contact with the ground. Angles in the dominant foot’s hip, knee, and ankle joints were measured from the lowest COM in the turning step, while the dominant foot was still in contact with the ground. The highest muscle activation in all the ten mentioned muscles was measured in the COD-step and acceleration step, and was used in statistical analysis. Equipment used in the COD-test was EMG, IMU, Xsens, and wireless timing gates.
4.3. Plyometric tests

Warm-up for plyometric tests consisted of performing the exercise at sub-maximum intensities, in order to avoid fatigue since the subject is already warm and to get a rehearsal of the test (Shellock & Prentice, 1985). A contact mat was used for measuring the performance variables: jump height, RSI, and contact time. The subject had three attempts at each jump, with a rest period of two to five minutes between each attempt. All plyometric tests were performed on an indoor athletic surface, except laying hamstring kick, which was performed on a soft rubber gym mat. The laying hamstring kick was tested at both pre- and post-test, but since the only performance variable is muscle activation, it was excluded from the analysis of this study. A description is included in this chapter for all the exercises, including those excluded from analysis, to visually illustrate the exercises included in the training program (chapter 5).

4.3.1. Unilateral vertical countermovement jump

In the unilateral vertical countermovement jump, the performance variable was jump height. The test was performed with the dominant foot and a contact mat measured jump height. When jumping, the contact mats registered the time from when the feet of the subject were in the air to impact with the ground (flight time). The contact mats used flight time to calculate jump height with the equation: 

\[ d = V_i t + \frac{1}{2} at^2 \]

where \( d \) = jump displacement, \( V_i \) = initial velocity, \( t \) = flight-time and \( a \) is acceleration due to gravity (9.81 m/s²). The subjects had their hands placed on their hip during the entire jump and avoided contributing to the jump performance by leaning their upper body forward. Subjects were instructed to jump as high as possible, with a fast countermovement, to make use of the stretch-shortening cycle (Komi, 1984). The non-dominant foot should be passive, to prevent it from creating momentum during the jump. These constraints were made to ensure power in the lower extremities was responsible for performance, not the contribution of momentum (Markovic, Dizdar, Jukic, & Cardinale, 2004). Technique was controlled for using Xsens at both the pre- and post-test and was helpful as visual feedback. The subjects performed a minimum of three CMJs, depending on whether the height increased or decreased, with two minutes of rest between each attempt to avoid fatigue. The highest jump that met the requirements of the study was used for statistical analysis.
4.3.2. Drop jump

Research shows that there is no single optimal drop height when performing drop jumps (DJ), but optimal drop height varies between individuals (Ramirez-Campillo et al., 2018). In this study, DJ-performance was measured using reactive strength index (RSI). The subjects were instructed to perform the DJ with the shortest contact time possible, while jumping as high as possible to optimize the RSI-value (Thomas et al., 2009). The RSI-value is jump height divided by contact time (Flanagan & Comyns, 2008), and is often used to measure reaction force. During adaption day, the subjects performed DJ from a height of 15cm, 30cm, 45cm, and 60cm, where RSI was noted to individualize optimal drop height at the day of testing and during training. The subjects were instructed to perform DJ with their hands on their hips during the entire jump and avoid contributing to the jump height with a forward lean of the upper body. The DJ with the highest RSI-score, which met the requirements of the study was used for further statistical analysis.

Figure 4.3. Illustration of the DJ-test. 1) Shows the “walk out”, 2) is at impact with the ground, and 3) is post the push-off phase.
4.3.3. Bilateral Hurdle-jumps

Bilateral hurdle jumps were performed on an athletic field surface, were the athletes jumped over four hurdles, using both feet, from a standing start. The objective was to obtain the shortest contact time possible, since the sprint in COD demands fast development of force (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). To ensure a short contact time, a group of six subjects not included in this study performed bilateral hurdle jumps prior to the adaption day. It was found that when the hurdles were placed at a 170cm distance, the athletes were able to produce fast horizontal forces and get a short contact time (<250 msec). The height of the hurdles was individualized at the day of testing, using the result from the adaption days to find the optimal hurdle height. Optimal hurdle height for each individual was tested at heights varying from 30 cm to 60 cm. At the day of testing, subjects performed three series of three repeated jumps, where the jump with shortest contact time was used for analysis.

Figure 4.4. Illustration of the bilateral hurdle jumps which were performed over ropes. 1) Is the starting position, 2) is in the air, 3) landing on the toe-balls before immediately 4) jumping over the next rope.

4.3.4. Unilateral Hurdle jumps

The unilateral hurdle jumps were performed using the dominant foot. The procedure was the same as for the bilateral hurdle jump, with the only difference being reduced distance between the hurdles (100cm). Since the heights of hurdles were individualized, the height of the hurdles was lower (20 cm to 30 cm) compared to when performing bilateral hurdle jumps.

Figure 4.5. Illustration of the unilateral hurdle jump over ropes. 1) The starting position followed by 2) the jump and 3) impact on the toe-balls.
4.3.5. Skate jump

Skate- jumps were performed laterally. The subject performed a lateral jump for maximum distance using their dominant foot, where jump distance was the performance variable, marked with tape. The only requirement was to stand at landing when landing on the non-dominant foot. Technique was controlled for by using Xsens.

![Skate jump illustration](image)

**Figure 4.6.** Illustration of skate-jump. 1) Starting position, 2) push-off phase, 3) eccentric landing while trying to overcome inertia and jump back.

4.3.5. Laying Hamstring-kick

![Laying hamstring-kick illustration](image)

**Figure 4.7.** Illustration of the laying hamstring-kick. 1) Shows starting position, before 2) the right heel is kicked to the ground to move the body upwards.
4.4. Strength tests

Warm-up prior to the strength exercises consisted of performing the exercise at sub-maximum intensities, in order to avoid fatigue since the subject is already warm and to get a rehearsal of the test (Shellock & Prentice, 1985). All strength exercises were performed close to 1RM at the second familiarization day in order to estimate the subjects 1RM and avoid multiple attempts, which can cause fatigue on the test day. Each strength exercise was performed with one to maximum three attempts, which was possible because of the 1RM-estimate from familiarization day two. The performance variable in the strength tests was external load. All strength tests were performed on an indoor athletic surface. Unilateral Nordic hamstring and unilateral calf raises were also tested but excluded from the analysis of this study since the angle of the joints were not standardized and the performance variable was muscle activation only. As such, only illustrations of these two exercises are included in this chapter to get a visual presentation, of all the exercises in the training program (chapter 5).

4.4.1. Squat

The squat test was a traditional parallel squat, where 1RM was measured. The requirement for depth was that a visualized line between patella and trochanter major should be parallel to the ground. According to Schoenfeld (2010), the parallel squat may vary from 70-100° in the knee joint, depending on the athlete’s mobility. Therefore, the angle of the knee-joint at pre-test was used as a control at the post-test. Attempts at post-test were approved with a variation from pre-test at ± 3° in the knee joint. The attempt with the highest external load with an approved knee angle were used in the analysis.

![Figure 4.8. Illustration of the parallel squats 1) starting position and 2) parallel depth.](image)
4.4.2. Unilateral squat

The unilateral squat was performed with the dominant foot in a smith machine. The performance variable was 1RM. The test was performed with bending the knee to a degree varying from 40 to 60° (Schoenfeld, 2010). With the use of Xsens, the knee angle was controlled during pre-test and matched during post-test with a variation of ± 3°. The attempt with the highest external load with an approved technique was used for analysis.

![Figure 4.9. Illustration of the unilateral squats 1) starting position and 2) lowest depth.](image)

4.4.3. Lateral squat

Lateral squat was performed with a barbell placed on trapezius and a starting position with both feet parallel. The dominant foot was then moved out to the side, and extension of the hip initiated the movement before the knee joint was bended to approximately 90°. To finish off the test, the dominant foot then pushed against the floor to get back to the starting position. The performance variable was 1RM. Technical requirements were: a straight non-dominant foot with no knee bend and the dominant foot’s heel should not be placed any further forward than the toes of the non-dominant foot. With the use of Xsens, the knee angle in the dominant foot was controlled during pre-test and matched during post-test with a variation allowing ± 3°. The attempt with the highest external load with approved technique was used in statistical analysis.

![Figure 4.10. Illustration of the lateral squat. 1) Starting position, 2) lowest depth, 3) and the lowest depth, seen from the side.](image)
4.4.4. Unilateral Nordic hamstring

Figure 4.11. Illustration of the unilateral Nordic hamstring. 1) Starting position and 2) lowest position.

4.4.5. Unilateral calf-raises

Figure 4.12. Illustration of the unilateral calf-raise. 1) Lowest and, 2) the highest position while extending the ankle as much as possible.

5. Training program

After the pre-test, subjects were randomly assigned to either a strength- or plyometric training program, where everyone completed two training sessions per week for a total of six weeks. To make sure the strength- and plyometric training programs were comparable, data from a sample of nine subjects was collected from the strength- and plyometric tests. This was done in order to calculate workload, since the test exercises are the same as the training exercises. Workload was measured by impulse (∫Fdt) generated per test attempt, according to the methods of Ettema, Gløsen, and van den Tillaar (2008). Peak impulse generated by the subjects for each test exercise was then used to calculate workload for the different test exercises, and afterwards used to match the two different training programs. Peak impulse in the strength exercises were
calculated with the use of a linear encoder from Musclelab with a sampling rate of 200 Hz, which measured maximum velocity. Linear regression estimated peak impulses of the strength tests at different loads of estimated 1RM. In the plyometric tests, maximum velocity occurs prior to take-off, and with the use of a contact grid measuring flight time an estimation of impulse was possible. The exception from this approach of normalizing the two training programs was the laying hamstring kick which was matched by the unilateral Nordic hamstring, after a study performed by van den Tillaar, Solheim, and Bencke (2017) found non-significant differences in the hamstrings muscle activation between the two exercises. Both training programs were periodized for the first and the second half of the training intervention (six first and six last training sessions), where the workload was ≈6000Ns. Both the first and second half of the training intervention consisted of a training day one and a training day two, which the subjects switched between to make the periodization non-linear. Non-linear periodization has been shown in earlier studies to be effective in developing strength and power abilities in soccer players (Barbalho et al., 2018). The plyometric- and strength exercises were matched in targeting work towards the same muscles, where both programs obtained exercises with a unilateral and bilateral force production in both the vertical and lateral direction. Subjects were followed up on each training day to ensure maximum effort and correct technique while performing the exercises. They were also strongly encouraged to avoid any training with the lower extremities prior to the strength- or plyometric sessions, to maximize the effect of the training sessions (Fernandez-Fernandez et al., 2018). The duration of one strength- or plyometric session was approximately an hour and a half. The training exercises are the same as the test exercises and are illustrated in chapter 4.

Table 5.1. Showing the exercises matched in targeted muscles and workload in Newton second (Ns).

<table>
<thead>
<tr>
<th>Strength-exercises</th>
<th>Plyometric exercises</th>
<th>Targeted muscles</th>
<th>Workload per session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squat, unilateral squat and calf raise</td>
<td>Drop jump, unilateral countermovement-jumps and hurdle jumps</td>
<td>Hip, knee and ankle extensor muscles</td>
<td>≈4250 Ns</td>
</tr>
<tr>
<td>Lateral squat</td>
<td>Skate jump</td>
<td>Hip abductor muscles</td>
<td>≈1650 Ns</td>
</tr>
<tr>
<td>Unilateral Nordic hamstring</td>
<td>Laying hamstring kick</td>
<td>Hamstring muscles</td>
<td></td>
</tr>
</tbody>
</table>
5.1. Warm-up prior to training
The start of the warm-up was a general sub-maximum jog to increase core and muscle temperature, which increases neuromuscular performance (Young & Behm, 2002). Afterwards, the subjects performed dynamic stretching of the muscles in the lower extremities, since dynamic stretching are preferable in short-term explosive activities compared to static stretching (Faigenbaum, Bellucci, Bernieri, Bakker, & Hoorens, 2005; McMillian, Moore, Hatler, & Taylor, 2006). Dynamic stretching is also useful in increasing range of motion of the joints while reducing the chance of muscular injuries (Amiri-Khorasani, Osman, & Yusof, 2011). The last part of the warm-up was performing the exercise at increasing intensities to recruit the specific muscle fibers and neural pathways for optimal performance (Young & Behm, 2002). The specific warm-up helped the subjects repeat the exercise before their training sets (Shellock & Prentice, 1985). The warm-up protocol was the same for both the strength-training group and the plyometric-training group. Because of mobility problems, some of the subjects performed extra stretching prior to the training sets of the strength exercises. For example, subjects who lifted the heel up in the eccentric phase of the squat, stretched to improve flexibility around the talocrural and subtalar joints (Schoenfeld, 2010).

5.2. Strength training
Each of the subjects trained at different external loads, based on the percentage of their 1RM from the pre-test. The applied external loads used at the training sessions was noted during each training to progress in external load for the next training session. The amount of sets, reps, the percentage of 1RM, and different exercises are shown in table 5.2. The resting period between each set was three to five minutes, depending on several factors such as the exercise, amount of reps, the subjects form, etc. Strength-training sessions were performed twice a week, in accordance to the meta-analysis conducted by Peterson, Rhea, and Alvar (2004) on dosage-response in strength training.

During the intervention, the parallel squat was trained at a parallel depth as described in the test description, where subjects were instructed to obtain the same depth. Earlier studies have shown that the deeper squats have a transfer to squats performed with shorter ROM, but not the other way around (Rhea et al., 2016). As such, the subjects performed the squat at a large ROM with instructions to have an emphasis on a controlled eccentric phase to minimize stress on the knee joints (Schoenfeld, 2010), while still moving upwards as fast as possible. The exercise
was incorporated because the acceleration phase of a COD is dependent on concentric strength in the knee flexors to produce great horizontal force to the ground (Jones et al., 2009).

The **unilateral squat** was trained with the same technique as described at the pre-test, with a depth keeping the knee-joint at 40-60° and was incorporated as a more sport-specific exercise (Rhea et al., 2016; Schoenfeld, 2010). The exercise was performed unilaterally in a smith machine in order to avoid excessive amount of weight on the back. As such, back strength would not be a limiting factor for external load (Eliassen, Saeterbakken, & van den Tillaar, 2018), while at the same time reducing injury risks. The subjects were instructed to keep the eccentric phase of the lift controlled and move upwards as fast as possible in the concentric push-off phase to simulate the propulsive force in a COD. The COD-step is unilateral; therefore, unilateral strength-exercises should not be neglected. Unilateral movement patterns in the strength exercises are more equal to the COD-step, compared to bilateral strength exercises (Bourgeois, McGuigan, et al., 2017).

The **lateral squat** was performed with a knee angle at approximately 90°, with the hip initiating the movement. To accomplish this, the lateral step must be placed at such a distance that the supporting foot is completely stretched out, without a bend in the knee, in accordance to Keogh (1999). Subjects were instructed to push off as fast as possible in the concentric phase while performing the exercise.

The **unilateral Nordic hamstring** was trained repeatedly in an apparatus locking and putting pressure on the ankles of the subjects. The subjects lowered their torso while resisting the effect of gravity using their hamstring muscles, without extending the hip, and bumping up to the starting position with a return to the bottom after their body was fully lowered (Solheim, 2015). The exercise was included because earlier studies have pointed out the importance of eccentric hamstring strength during the breaking phase of a COD (Chaouachi et al., 2012).

**Unilateral calf raises** were trained unilaterally in a smith machine with focus on correct toe placement. The subjects were instructed to maintain medium speed in the eccentric phase and a high concentric speed while extending the ankles as much as possible. The exercise was included since maximum power development in the ankle extensors has previously shown to be of importance for COD-performance (Marshall et al., 2014).
Table 5.2. Shows the exercises, sets, repetitions, and percentage of one repetition maximum (1RM), for each strength training-session. Training session 1-6 = first half of the intervention, session 7-12 = second half of the intervention.

<table>
<thead>
<tr>
<th>Day 1 – Session 1, 3 and 5</th>
<th>Exercise</th>
<th>Sett</th>
<th>Reps</th>
<th>Percentage of 1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unilateral squat</td>
<td>2 (per leg)</td>
<td>5</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>Parallel squat</td>
<td>3</td>
<td>5</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>Lateral squat</td>
<td>3 (per leg)</td>
<td>6</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>Unilateral Nordic hamstring</td>
<td>2 (per leg)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unilateral calf raises</td>
<td>3 (per leg)</td>
<td>8</td>
<td>70%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 2 – Session 2, 4 and 6</th>
<th>Exercise</th>
<th>Sett</th>
<th>Reps</th>
<th>Percentage of 1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unilateral squat</td>
<td>2 (per leg)</td>
<td>6</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Parallel squat</td>
<td>3</td>
<td>8</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Lateral squat</td>
<td>3 (per leg)</td>
<td>6</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>Unilateral Nordic hamstring</td>
<td>2 (per leg)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calve raises</td>
<td>3 (per leg)</td>
<td>8</td>
<td>70%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 1 – Session 7, 9 and 11</th>
<th>Exercise</th>
<th>Sett</th>
<th>Reps</th>
<th>Percentage of 1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lateral squat</td>
<td>4 (per leg)</td>
<td>4</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Unilateral squat</td>
<td>2 (per leg)</td>
<td>6</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Parallel squat</td>
<td>3</td>
<td>6</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Unilateral Nordic hamstring</td>
<td>2 (per leg)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unilateral calf raises</td>
<td>4 (per leg)</td>
<td>6</td>
<td>75%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 2 – Session 8, 10 and 12</th>
<th>Exercise</th>
<th>Sett</th>
<th>Reps</th>
<th>Percentage of 1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unilateral squat</td>
<td>2 (per leg)</td>
<td>4</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td>Parallel squat</td>
<td>3</td>
<td>6</td>
<td>85%</td>
</tr>
<tr>
<td></td>
<td>Lateral squat</td>
<td>3 (per leg)</td>
<td>8</td>
<td>70%</td>
</tr>
<tr>
<td></td>
<td>Unilateral Nordic hamstring</td>
<td>3 (per leg)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unilateral calf raises</td>
<td>4 (per leg)</td>
<td>6</td>
<td>75%</td>
</tr>
</tbody>
</table>

5.3. Plyometric training

The plyometric-training program was individualized based on performance on the pre-test. Drop jumps were performed from the height at which each of the subjects obtained the highest RSI score, and the height of the hurdles when performing hurdle jumps was dependent on the height the subject obtained the shortest ground contact time. Both the hurdle height and drop height were found at the second adaption day prior to the pre-test. Skate jumps were performed at 90% of the length of their maximum jump length at pre-test and trained repeatedly. After six training sessions, a new maximum jump length for skate jump was performed, to keep progressing in the exercise. Exercise, sets, reps, and pause time are shown in table 5.3. When performing hurdle jumps, drop jumps and countermovement jumps, a contact mat was used to give the subjects feedback on performance and worked as a motivational tool (Flanagan & Comyns, 2008). If the athletes cannot manage to get their contact time below 250 msec in hurdle jumps or drop jumps, adjustments in the exercise has to be made to avoid lack of specificity (Flanagan & Comyns, 2008). Such adjustments were not required. The frequency of plyometric training was moderate (2 sessions a week) in accordance to de Villarreal, González-Badillo,
and Izquierdo (2008), who found that 2 or less plyometric trainings a week is more beneficial in developing power abilities compared to >2 sessions a week.

**Countermovement jumps** were trained unilaterally, with hands on the hips and the instruction to jump as high as possible vertically without the back contributing to the jump height. Their passive foot should also remain passive during the jump. No further constraints were given, though the subjects were informed about the possible advantages of a fast countermovement to optimize SSC-contribution (Thomas et al., 2009), and the advantage of fully extending their ankles for jump height.

**Drop jumps** were performed with the subjects dropping from their optimal height, and immediately after impact with their toe balls to the ground, they performed a vertical jump. The subjects were instructed to gain as high an RSI-score as possible, and therefore obtain maximum height while minimizing ground contact time (Thomas et al., 2009). The RSI-score has in earlier studies been recommended as a tool to improve athletes’ fast SSC (<250 msec) (Flanagan & Comyns, 2008), which is of importance for the transfer to high-speed abilities such as COD (Aagaard et al., 2002). Extension of their back should not contribute to increased jump height. To prevent injuries, the subjects avoided locking their knees upon impact with the ground. During the concentric movement after impact, they were instructed to fully extend their ankles to obtain maximum height. Progression during training was made by changing the drop height to gain a higher level of pre-activation prior to impact, but not at the cost of a fast SSC, neither so high that the athletes failed to jump on the toe balls and touched the ground with the heel during impact (Flanagan & Comyns, 2008). When dropping from the height, they were instructed to “walk out” instead of jumping out, in order to avoid a higher drop height.

The **unilateral hurdle jump** was trained by jumping over four hurdles on one leg at the time, from a standing-still start position. Hurdles were placed 1m apart. Subjects were instructed to obtain as short ground contact time as possible to use the fast SSC. Progression was made during the training intervention by increasing the height of the hurdles to increase power output, but not at the cost of a fast SSC (Flanagan & Comyns, 2008).

The **bilateral hurdle jump** was trained the same way and with the same instructions as the unilateral hurdle jumps. The only differences were that the jumps were performed with both
legs instead of one at a time, higher hurdles, and a longer distance between the hurdles (170 cm).

The *skate jump* was trained repeatedly, jumping between two lines where the distance between them was 90% of the subjects maximum jump length, which was found at the pre-test. Subjects were instructed to obtain a knee angle of approximately 90° and at the same time minimize ground contact time (Reyment, Bonis, Lundquist, & Tice, 2006).

The *laying hamstring kick* was trained repeatedly with a low ROM and with a high frequency while maximizing force. The subject laid on the back with shoulders and hip to the ground, and then kicked the heel to the ground to lift the lower body up (van den Tillaar et al., 2017).

**Table 5.3.** Shows the exercises, sets, repetitions, and pause time in seconds (S), for each plyometric training-session. Training session 1-6 = first half of the intervention, session 7-12 = second half of the intervention. D= dominant foot. ND= non-dominant foot.

<table>
<thead>
<tr>
<th>Day 1 – Session 1, 3 and 5</th>
<th>Exercise</th>
<th>Sett</th>
<th>Reps</th>
<th>Pause time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Countermovement jump</td>
<td>5-D &amp; 5-ND</td>
<td>1</td>
<td></td>
<td>90s</td>
</tr>
<tr>
<td>Drop jump</td>
<td>10</td>
<td>1</td>
<td></td>
<td>60s</td>
</tr>
<tr>
<td>Unilateral hurdle jump</td>
<td>5-D &amp; 5-ND (exclusion of the first jump)</td>
<td>3</td>
<td></td>
<td>120s</td>
</tr>
<tr>
<td>Bilateral hurdle jump</td>
<td>4 (exclusion of the first jump)</td>
<td>3</td>
<td></td>
<td>90s</td>
</tr>
<tr>
<td>Skate jump</td>
<td>3-D start &amp; 3-ND start</td>
<td>6</td>
<td></td>
<td>90s</td>
</tr>
<tr>
<td>Laying Hamstring kick</td>
<td>2-D &amp; 2-ND</td>
<td>5</td>
<td></td>
<td>90s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 2 – Session 2, 4 and 6</th>
<th>Exercise</th>
<th>Sett</th>
<th>Reps</th>
<th>Pause time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drop jump</td>
<td>4</td>
<td>3</td>
<td></td>
<td>20s each rep, 120s each sett</td>
</tr>
<tr>
<td>Countermovement jump</td>
<td>6-D &amp; 6-ND</td>
<td>1</td>
<td></td>
<td>60s</td>
</tr>
<tr>
<td>Bilateral hurdle jump</td>
<td>6 (exclusion of the first jump)</td>
<td>3</td>
<td></td>
<td>60s</td>
</tr>
<tr>
<td>Unilateral hurdle jump</td>
<td>4-D &amp; 4-ND (exclusion of the first jump)</td>
<td>3</td>
<td></td>
<td>120s</td>
</tr>
<tr>
<td>Skate jump</td>
<td>3-D start &amp; 3-ND start</td>
<td>6</td>
<td></td>
<td>90s</td>
</tr>
<tr>
<td>Laying Hamstring kick</td>
<td>2-D start &amp; 2-ND start</td>
<td>5</td>
<td></td>
<td>90s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 1 - Session 7, 9 and 11</th>
<th>Exercise</th>
<th>Sett</th>
<th>Reps</th>
<th>Pause time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skate jump</td>
<td>4-D start &amp; 4-ND start</td>
<td>4</td>
<td></td>
<td>90s</td>
</tr>
<tr>
<td>Bilateral hurdle jump</td>
<td>4 (exclusion of the first jump)</td>
<td>6</td>
<td></td>
<td>20s each rep, 120s each sett</td>
</tr>
<tr>
<td>Unilateral hurdle jump</td>
<td>4-D start &amp; 4-ND start</td>
<td>3 (exclusion of the first jump)</td>
<td>120s</td>
<td></td>
</tr>
<tr>
<td>Drop jump</td>
<td>8</td>
<td>1</td>
<td></td>
<td>60s</td>
</tr>
<tr>
<td>Countermovement jump</td>
<td>6-D start &amp; 6- ND start</td>
<td>6</td>
<td></td>
<td>90s</td>
</tr>
<tr>
<td>Laying Hamstring kick</td>
<td>2-D start &amp; 2-ND start</td>
<td>8</td>
<td></td>
<td>90s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Day 2 - Session 8, 10 and 12</th>
<th>Exercise</th>
<th>Sett</th>
<th>Reps</th>
<th>Pause time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilateral hurdle jump</td>
<td>4-D start &amp; 4-ND start</td>
<td>3</td>
<td></td>
<td>90s</td>
</tr>
<tr>
<td>Bilateral hurdle jump</td>
<td>4-D</td>
<td>3</td>
<td></td>
<td>60s</td>
</tr>
<tr>
<td>Skate jump</td>
<td>3-D start &amp; 3-ND start</td>
<td>8</td>
<td></td>
<td>120s</td>
</tr>
<tr>
<td>Countermovement jump</td>
<td>6-D start &amp; 6-ND start</td>
<td>1</td>
<td></td>
<td>90s</td>
</tr>
<tr>
<td>Drop jump</td>
<td>8</td>
<td>1</td>
<td></td>
<td>60s</td>
</tr>
<tr>
<td>Laying Hamstring kick</td>
<td>3-D start &amp; 3-ND start</td>
<td>8</td>
<td></td>
<td>90s</td>
</tr>
</tbody>
</table>
6. Statistical analysis

All subjects from the strength training group and the plyometric training group completed all training sessions. After testing, data from the pre- and post-tests were manually collected from both Musclelab and Xsens to secure the validity of the data. Afterwards, the collected data was exported to SPSS 25 (SPSS, Inc., Chicago, IL, USA) for further analysis. Data processed in SPSS was also used in Microsoft Excel Version 16.23 for creation of figures.

When comparing time to complete the different CODs at pre-test, the paired samples t-test revealed no significant difference in time for the CODs with a right turn and the CODs with a left turn. There were no significant differences in number of breaking steps prior to the COD-step when comparing CODs with a left and a right turn either. As such, it is reasonable to assume that CODs with a left turn and CODs with a right turn are dependent on the same physical qualities. Straightforwardly, the CODs with a left turn were used for analyzing the performance-related variables. The average performance of the CODs with a right and left turn were used for analysis of COD-performance only. Performance in each COD-condition is analyzed independently, plus combined for the degrees hypothesized to be more velocity dominant (45°+90°) and strength dominant (135°+180°).

Descriptive statistics is expressed as mean ± standard deviation. The data was tested for normal distribution using the Kolmogorov-Smirnov test. A two-way analysis of variance (ANOVA) with repeated measures was used to analyze the effect of degrees and distance on the performance-related variables center of mass, contact time, and joint angles when performing the different CODs (2 distances*4 different degrees). A two-way ANOVA with repeated measures was also used to investigate the effect of the two training interventions on performance in the COD-test, plus the performance-related variables center of mass and angle of the joints (4 CODs*2 pre- and post-measurements). A one-way ANOVA was only conducted to analyze sprint times prior the 20m CODs (4 sprints). Finally, a two-way ANOVA with repeated measures was conducted to investigate the effect of the training program on the strength tests (3 tests*2 pre-to post-measurements) and plyometric tests (5 tests*pre-to post-measurements). When significant differences occurred, Holm—Bonferroni post-hoc tests were conducted. The EMG-data violated the assumption of a normal distribution, and as such, the Wilcoxon signed ranks were used post-hoc to investigate differences in muscle activation for the different COD-conditions. The assumption of sphericity was controlled for by Mauchlys
test of sphericity. If $p$-values for sphericity were $p < 0.05$, the Greenhouse-Geisser correction was reported. The relationship between changes in center of mass, contact-time, and changes in COD-performance was assessed by the Pearson correlation coefficient ($r$). The alpha-level was set at $p < 0.05$.

7. Results
At baseline, the independent samples $t$-test revealed no statistically significant differences between the two groups anthropometrics, nor between pre-test performance in the strength-, plyometric- or COD-tests. Comparison of the performance-related variables in the different COD-conditions are presented in chapter 7.1. Changes in performance and performance-related variables after completing six weeks of strength- and plyometric training are presented in chapter 7.2.

7.1. Comparison between the different CODs
For analysis of the performance-related variables, the CODs with a left turn were used, which is non-problematic since CODs with a right turn and CODs with a left turn share the same physical qualities, as explained in chapter 6. Also, EMG data was only collected from the dominant foot of the subjects, and the dominant foot performed the COD-step in COD-maneuvers with a left turn (since all the subjects are right-foot dominant). For comparison between the different CODs, both training-groups results were combined since the objective was to compare the different CODs, not the two training groups. Data was sampled from the pre-test, except for the EMG data where methodological problems induced a low $n$. As such, EMG comparisons are made using data from both pre- and post-test results.

The main findings presented in chapter 7.1 are: 1. the time for the subjects to complete the CODs takes significantly longer when the angle of the COD-turn is increased in both 4m and 20m CODs (figure 7.1 A). 2. With increased degrees in the COD-step, the subjects contact time in the COD-step increases, but contact time remains statistically non-significant when comparing 4m CODs with 20m CODs (figure 7.1 B). 3. The subjects’ number of breaking steps during the COD-maneuver increases at 20m CODs compared to 4m CODs, and when the degrees of the COD-turn increase (figure 7.2 A). 4. The subjects’ center of mass in the COD-step is significantly lower when the degrees of the COD-turn increase. The center of mass is also significantly lowered when performing 20m CODs compared to the 4m CODs, except for
the 180° CODs (figure 7.2 B). 5. The greatest difference in joint kinematics between the different CODs were found to be in the flexion of the hip, which increases at CODs with larger degrees. The knee flexion is significantly lower at 45° CODs compared to all the other CODs (figure 7.3). 6. Differences in joint angles were observed when comparing CODs at different degrees, but there was no statistically significant difference in joint angles when comparing 4m and 20m CODs (figure 7.3). 7. When comparing muscle activation in the different COD-conditions, a significant difference was only observed in adductor longus, rectus femoris, and gastrocnemius for the different COD-conditions (figure 7.4).

Table 7.1. Baseline values in change of direction- (COD) time and performance-related variables when performing 4m and 20m CODs for both training groups combined (n=23)

<table>
<thead>
<tr>
<th></th>
<th>45°</th>
<th>90°</th>
<th>135°</th>
<th>180°</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4m COD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD-time (s)</td>
<td>1.73±0.15</td>
<td>2.06±0.15</td>
<td>2.38±0.17</td>
<td>2.48±0.16</td>
</tr>
<tr>
<td>Deceleration steps (n)</td>
<td>0.4±0.8</td>
<td>2.8±0.8</td>
<td>3.2±0.5</td>
<td>3.3±0.7</td>
</tr>
<tr>
<td>COM (cm) COD-step</td>
<td>17.7±3</td>
<td>25.3±5.7</td>
<td>30.7±5.6</td>
<td>33.7±6.7</td>
</tr>
<tr>
<td><strong>CT (ms)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- COD-step</td>
<td>149.9±17.4</td>
<td>188.3±39.6</td>
<td>224.4±40.5</td>
<td>300±84.9</td>
</tr>
<tr>
<td>- Acceleration step</td>
<td>154.4±39.2</td>
<td>181.1±73.5</td>
<td>198.5±27.8</td>
<td>204.6±35.9</td>
</tr>
<tr>
<td><strong>Joint angle at COD-step</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Ankle flexion</td>
<td>27.5±9.1</td>
<td>26.9±13.2</td>
<td>29.9±16.5</td>
<td>33.6±19.3</td>
</tr>
<tr>
<td>- Knee flexion</td>
<td>47.5±6.3</td>
<td>58.3±11.4</td>
<td>59.2±9.6</td>
<td>57.2±15.5</td>
</tr>
<tr>
<td>- Hip abduction</td>
<td>8.4±4.8</td>
<td>11.3±5.4</td>
<td>9.6±7.1</td>
<td>13.3±8.8</td>
</tr>
<tr>
<td>- Hip flexion</td>
<td>12±14</td>
<td>13.5±11.4</td>
<td>14.8±10.7</td>
<td>25.4±13.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>45°</th>
<th>90°</th>
<th>135°</th>
<th>180°</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>20m COD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD-time (s)</td>
<td>4.08±0.18</td>
<td>4.56±0.19</td>
<td>4.88±0.23</td>
<td>5.03±0.21</td>
</tr>
<tr>
<td>Deceleration steps (n)</td>
<td>2.9±1.2</td>
<td>5.3±0.8</td>
<td>6.2±1.3</td>
<td>6.3±1</td>
</tr>
<tr>
<td>COM (cm) COD-step</td>
<td>19.9±3.6</td>
<td>28.3±4.5</td>
<td>32.9±5.5</td>
<td>35.5±5.5</td>
</tr>
<tr>
<td><strong>CT (ms)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- COD-step</td>
<td>152.1±22.3</td>
<td>182.8±32.5</td>
<td>209.7±64.9</td>
<td>320.9±109.8</td>
</tr>
<tr>
<td>- Acceleration step</td>
<td>144.6±16.3</td>
<td>188.1±31.1</td>
<td>200.2±36.2</td>
<td>212.6±44.2</td>
</tr>
<tr>
<td><strong>Joint angle at COD-step</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Ankle flexion</td>
<td>22.4±13.3</td>
<td>28.4±12.6</td>
<td>35.1±17.2</td>
<td>35.2±18.7</td>
</tr>
<tr>
<td>- Knee flexion</td>
<td>49.7±13</td>
<td>59.2±17</td>
<td>63.3±16.4</td>
<td>58.4±13.1</td>
</tr>
<tr>
<td>- Hip abduction</td>
<td>13.6±16.6</td>
<td>13.7±20</td>
<td>10.8±5.8</td>
<td>15.1±9</td>
</tr>
<tr>
<td>- Hip flexion</td>
<td>8.8±14</td>
<td>9.2±12.9</td>
<td>18.9±10.8</td>
<td>30.4±13.9</td>
</tr>
</tbody>
</table>
Mean ± standard deviation of absolute values measured at pre-test. The higher the value, the lower displacement of center of mass (COM) in the COD-step. A higher value for the joints equals more flexion or abduction of the joint. CT= contact time.

7.1.1. Comparison of time to complete CODs, contact time, number of deceleration steps, and center of mass

A significant effect of degree of COD ($F>21.8$; $p<0.01$, $\eta^2_p=0.67$) and between approach distance (4m vs 20m) on total, partial and contact times in the COD-step were found when both training groups were combined at the pre-test (figure 7.1). No significant effect was found between distance for contact-time in the COD-step or acceleration-step, or of degrees with a 4m approach and contact time in the acceleration step ($F<2.2$; $p=0.11$, $\eta^2_p=0.15$). An effect for degrees was observed in the acceleration step when performing 20m CODs, and for the COD-step in both 4m and 20m CODs ($F>11.2$; $p<0.01$, $\eta^2_p=0.5$). Post-hoc tests revealed that the total time to complete the COD-condition and contact time in the COD-step increases when the degree of the COD-maneuver increases. Also, contact time in the acceleration step was found to be significantly lower in the 20m 45° COD when compared to the acceleration-step in all the other 20m CODs (figure 7.1). A significant effect of the degree of COD and between approach distance was observed for number of deceleration steps and center of mass ($F>64$ $p<0.01$, $\eta^2_p=0.78$). Post-hoc tests revealed that when the degree of the COD-maneuver increases, the number of deceleration steps and displacement of the center of mass increases. The exceptions were number of deceleration steps for the 4m and 20m 135° which were $\approx 180°$ CODs and the center of mass in the 4m 180° COD was $\approx$ center of mass in the 20m 180° COD (figure 7.2).
Figure 7.1. Mean ± standard deviation of A) change of direction - (COD) time, B) Contact time at the COD-step and C) acceleration step measured at pre-test. † Significant difference compared to the 20m COD with the same degrees ($p<0.05$). # Significantly different compared to all CODs at the different degrees from the same distance ($p<0.05$).
Figure 7.2. Mean ± standard deviation of A) deceleration steps when performing the different change of directions (CODs) and B) center of mass in the COD-step, measured at pre-test. # Significantly different compared to all CODs at the different degrees from the same distance ($p < 0.05$). † Significant differences between the 4m and 20m COD at this degree ($p < 0.05$). * Significant difference between these two conditions ($p < 0.05$).
7.1.2. Joint angles

Joint angles comparisons are sampled from the lowest center of mass in the COD-step. No significant effects of approach distance (4m vs 20m COD) were observed for any of the joints ($F < 2.3; p = 0.15, \eta_p^2 = 0.12$). An effect of degrees of the COD-maneuver was observed for both hip- and knee flexion ($F > 4.4; p < 0.01, \eta_p^2 = 0.19$), where flexion of the joint increased at CODs with larger degrees. Post-hoc tests revealed that the angle of the knee joint was significantly smaller at the 4m 45° COD compared to the other CODs from 4m, and when comparing the 45° with the 135° and 180° CODs from 20m. Hip flexion was found to be significantly larger in the 180° CODs compared to the other CODs, both in a 4m and 20m approach. Hip flexion in the 20m 135° COD was also significantly larger when compared to 20m 45° and 90° CODs. No effect of degrees was observed for hip abduction in the 20m or 4m CODs, or for ankle flexion in the 4m CODs ($F < 2.4; p = 0.09, \eta_p^2 = 0.11$). But an effect of degrees was observed for the ankles in the 20m COD ($F = 3.5; p = 0.02, \eta_p^2 = 0.17$), where the angle was found to be smaller in the 45° COD compared to the 135° and 180° COD (figure 7.3).
Figure 7.3. Mean ± standard deviation of joint angles measured at pre-test for the A) ankles plantar flexion, B) knee flexion, C) hip flexion and d) hip abduction when performing change of directions (CODs) with a 4m and 20m sprint approach. # Significantly different compared to all CODs at the different degrees from the same distance. (p< 0.05). † Significant differences between two CODs from the same distance (p< 0.05).
7.1.3. Muscle-activation in the different COD-conditions

A significant effect of degree was observed for the adductor longus and gastrocnemius ($F > 5.2$; $p < 0.01$, $\eta^2_p = 0.3$) in the 4m COD-step, and for the adductor longus and rectus femoris in the 4m acceleration-step ($F > 3.2$; $p = 0.04$, $\eta^2_p = 0.23$). A significant effect of distance was observed in the acceleration step of rectus femoris in ($F = 7.7$; $p = 0.02$, $\eta^2_p = 0.39$). For the rest of the muscles, no effect of distance ($F < 2.3$; $p = 0.17$, $\eta^2_p = 0.25$) or degrees ($F < 2.7$; $p = 0.06$, $\eta^2_p = 0.23$) was found in either the COD-step nor acceleration step. Post-hoc tests revealed that the muscle activation in adductor longus is significantly higher in the 4m 45° COD-step and acceleration step compared to muscle activation in all the other 4m COD-conditions. The gastrocnemius also revealed significantly higher muscle activation in the 4m 45° COD-step, while the 135° showed significantly lower muscle activation compared to the other 4m COD-conditions. For the rectus femoris, a significant lower muscle activation was found in the 4m 45° acceleration step, compared to the other 4m acceleration steps. In addition, the acceleration step in the 4m 135° and 180° COD showed significantly higher muscle activation compared to their 20m counterpart (figure 7.4).
Figure 7.4. Mean ± standard deviation of muscle activation measured for all the ten muscles for each change of direction (COD). COD-step= Dominant foot performing the COD-maneuver. ACC-step= first acceleration step of the dominant foot after performing the COD-maneuver. * Significant difference compared to all CODs at the different degrees from the same distance (p< 0.05). # Significant differences between CODs of different degrees (p< 0.05). † Significant differences between 4m and 20m CODs with the same degrees of the COD-step (p< 0.05).

7.2. Changes in performance and performance-related variables after six weeks of training

7.2.1 Changes in COD- and sprint performance

A two-way ANOVA revealed an effect from pre- to post-test in 4m and 20m CODs, plus partial time (F> 5.3; p= 0.03, $\eta^2_p= 0.22$), but no effect between the two training groups (F< 1.7; p= <0.18, $\eta^2_p= 0.08$). Both the strength-training group and plyometric-training group improved their COD-performance in each COD-condition from pre- to post-test (table 7.2). Post-hoc tests revealed that the strength-training group improved significantly in the strength-dominant CODs from 20m (135°, 180° and 135°+180°) plus partial time in the 180° and 135°+180° COD. The strength-training group improved on average the most in partial time (except 20m 180°). The plyometric-training group improved on average the most in all the COD-conditions (except 4m 45° and 20m 135°). Plyometric training resulted in significant improvements in several of the 4m CODs (135°, 180°, 45°+90° and 135°+180°) but only two 20m CODs (20m 180° and 20m 45°+90°) (figure 7.5). Sprint time prior to the 20m COD (total time ÷ partial time), revealed non-significant differences in sprint times approaching the COD at the different degrees. Both groups experienced improvements in all the sprint times prior to the COD-maneuver after the training intervention, and statistically significant improvements in sprint times prior to the 20m 90° and 135° COD (Table 7.3).
Table 7.2. Changes in change of direction performance (COD) after a six-week training-intervention in the strength-training group and the plyometric-training group

<table>
<thead>
<tr>
<th>4m COD, Mean pair</th>
<th>Strength-training group (n=9)</th>
<th>Plyometric-training group (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(s)</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>45° + 90° (velocity)</td>
<td>1.89±0.22</td>
<td>1.85±0.23</td>
</tr>
<tr>
<td>135° + 180° (strength)</td>
<td>2.43±0.15</td>
<td>2.39±0.14</td>
</tr>
<tr>
<td>45°</td>
<td>1.74±0.13</td>
<td>1.68±0.13</td>
</tr>
<tr>
<td>90°</td>
<td>2.05±0.17</td>
<td>2.03±0.16</td>
</tr>
<tr>
<td>135°</td>
<td>2.39±0.14</td>
<td>2.35±0.14</td>
</tr>
<tr>
<td>180°</td>
<td>2.47±0.16</td>
<td>2.43±0.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>20m COD, Mean pair</th>
<th>Strength-training group (n=9)</th>
<th>Plyometric-training group (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(s)</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>45° + 90° (velocity)</td>
<td>4.33±0.30</td>
<td>4.29±0.32</td>
</tr>
<tr>
<td>135° + 180° (strength)</td>
<td>4.97±0.17</td>
<td>4.88±0.17</td>
</tr>
<tr>
<td>45°</td>
<td>4.08±0.20</td>
<td>4.03±0.20</td>
</tr>
<tr>
<td>90°</td>
<td>4.59±0.14</td>
<td>4.54±0.19</td>
</tr>
<tr>
<td>135°</td>
<td>4.89±0.17</td>
<td>4.78±0.16</td>
</tr>
<tr>
<td>180°</td>
<td>5.05±0.14</td>
<td>4.98±0.13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Partial time, Mean pair</th>
<th>Strength-training group (n=9)</th>
<th>Plyometric-training group (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(s)</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>45° + 90° (velocity)</td>
<td>1.60±25</td>
<td>1.59±27</td>
</tr>
<tr>
<td>135° + 180° (strength)</td>
<td>2.24±10</td>
<td>2.19±10</td>
</tr>
<tr>
<td>45°</td>
<td>1.37±0.09</td>
<td>1.34±0.11</td>
</tr>
<tr>
<td>90°</td>
<td>1.84±0.09</td>
<td>1.83±0.10</td>
</tr>
<tr>
<td>135°</td>
<td>2.16±0.06</td>
<td>2.11±0.06</td>
</tr>
<tr>
<td>180°</td>
<td>2.31±0.07</td>
<td>2.27±0.06</td>
</tr>
</tbody>
</table>

Mean ± standard deviation of change of direction- (COD) performance. Pre- and post-test results are the average of CODs with a left and right turn (mean pair). Changes from pre- to post is presented in percentage (Diff%). 45° + 90° = Average performance in the velocity-dominant CODs. 135° + 180° = Average performance in the strength-dominant CODs. * Significant changes from pre- to post-test within the group (p< 0.05).
A) Subjects

Changes in time (s)

4m 45° COD

4m 90° COD

4m 135° COD

4m 180° COD

B) Subjects

Changes in time (s)

20m 45° COD

20m 90° COD

20m 135° COD

20m 180° COD
Figure 7.5. Individual changes in change of direction- (COD) time after a six-week training-intervention for the strength-training group and the plyometric-training group; (A) 4m COD, (B) 20m COD and (C) 20m partial time. The horizontally dotted line displays the average difference in COD-time for the two groups.

Table 7.3. Changes in sprint time prior to the COD after a six-week training-intervention in the strength-training group and the plyometric training group

<table>
<thead>
<tr>
<th>Sprint time (s)</th>
<th>Strength training (n=9)</th>
<th>Plyometric training (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>20m COD 45°</td>
<td>2.72±0.14</td>
<td>2.69±0.13</td>
</tr>
<tr>
<td></td>
<td>2.74±0.12</td>
<td>2.71±0.13</td>
</tr>
<tr>
<td></td>
<td>2.73±0.13</td>
<td>2.67±0.18</td>
</tr>
<tr>
<td></td>
<td>2.73±0.16</td>
<td>2.71±0.14</td>
</tr>
<tr>
<td>30m sprint</td>
<td>4.37±0.21</td>
<td>4.35±0.2</td>
</tr>
</tbody>
</table>

Mean ± standard deviation in sprint times measured at pre- and post-test. Sprint time prior to the 20m change of direction (COD) = total time ÷ partial time. Changes in time from pre- to post-test is presented in percentages. Pre- and post-test results is the average of CODs with a left and right turn (mean pair). * Significant changes from pre- to post-test within the group (p< 0.05).
7.2.2 Performance changes in the strength- and plyometric tests

The two-way ANOVA revealed an effect of pre- to post-test in the strength tests for the strength-training group and in the plyometric tests for the plyometric-training group ($F > 5.3; p = 0.05, \eta^2 = 0.4$). A group effect between the two groups was found in the strength tests ($F = 768; p < 0.01, \eta^2 = 0.99$), where the strength-training group was found to increase performance significantly better in all the strength tests compared to the plyometric-training group. A group effect between the two groups was also found in the plyometric tests ($F = 3852; p < 0.01, \eta^2 > 0.99$), in which the plyometric-training group increased performance significantly better than the strength-training group in all the plyometric tests, except bilateral hurdle jump (table 7.4).

Table 7.4. Pre- and post-test performance in the strength- and plyometric tests with performance changes after the training intervention

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Strength training (n=9)</th>
<th>Plyometric training (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Squat (kg)</td>
<td>113.6±21.2</td>
<td>127.8±18.4</td>
</tr>
<tr>
<td>Unilateral Squat (kg)</td>
<td>89±10.4</td>
<td>104±10</td>
</tr>
<tr>
<td>Lateral Squat (kg)</td>
<td>89.4±14</td>
<td>106.3±14.9</td>
</tr>
<tr>
<td>Drop-jump (RSI)</td>
<td>1±0.3</td>
<td>1.3±0.3</td>
</tr>
<tr>
<td>Unilateral squat jump (cm)</td>
<td>17±3.7</td>
<td>18.5±3.9</td>
</tr>
<tr>
<td>Bilateral hurdle jump (ms)</td>
<td>169±18.6</td>
<td>154±19.7</td>
</tr>
<tr>
<td>Unilateral hurdle jump (ms)</td>
<td>192±9.1</td>
<td>188±17.6</td>
</tr>
<tr>
<td>Skate-jump distance (cm)</td>
<td>202±14</td>
<td>204±15.2</td>
</tr>
</tbody>
</table>

Mean ± standard deviation of pre- and post-test performance in the strength- and plyometric tests. Changes in performance from pre-test to post-test are presented in percentages (Diff%). * Significant changes from pre- to post-test within the group ($p < 0.05$). # Significant changes from pre- to post-test between the groups ($p < 0.05$).
7.2.3. Relationship between contact time, center of mass, and COD-performance

The strength-training groups’ changes in contact time (CT) in the COD-step correlated significantly with changes in time for partial time in the 20m 90° COD ($r=0.76$) and in the 20m 180° COD ($r=-0.76$). The plyometric-training groups changes in CT in the COD-step and changes in time for the 20m 180° COD partial time were significantly correlated ($r=-0.66$). Also, correlations for the plyometric-training groups’ change in CT in the acceleration step and changes in time for the 4m 135° COD ($r=-0.75$), 20m 90° COD partial time ($r=-0.59$) and 20m 180° COD partial time ($r=0.64$) were significant (Table 7.5).

Table 7.5. Relationship between changes in contact time in the COD-step, acceleration step, and changes in COD-time after the six-week training-intervention for the strength-training group and plyometric-training group

<table>
<thead>
<tr>
<th>COD 4m</th>
<th>Strength training (n=9)</th>
<th>Plyometric training (n=11)</th>
<th>Both groups combined (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COD 45°</td>
<td>ACC 0.46</td>
<td>COD 0.43</td>
</tr>
<tr>
<td>90°</td>
<td>0.46</td>
<td>0.72</td>
<td>-0.62</td>
</tr>
<tr>
<td>135°</td>
<td>0.18</td>
<td>0.17</td>
<td>0.02</td>
</tr>
<tr>
<td>180°</td>
<td>-0.14</td>
<td>-0.51</td>
<td>0.23</td>
</tr>
<tr>
<td>COD partial time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45°</td>
<td>-0.58</td>
<td>0.52</td>
<td>-0.44</td>
</tr>
<tr>
<td>90°</td>
<td>0.76*</td>
<td>-0.16</td>
<td>-0.23</td>
</tr>
<tr>
<td>135°</td>
<td>-0.32</td>
<td>-0.27</td>
<td>-0.5</td>
</tr>
<tr>
<td>180°</td>
<td>-0.75*</td>
<td>-0.15</td>
<td>-0.66*</td>
</tr>
</tbody>
</table>

Correlations between changes from pre- to post-test in contact time for the COD-step, acceleration step, and changes in 4m change of direction- (COD) times, and changes in COD-partial time. The data is sampled from CODs with a left turn. * Significant correlations ($p<0.05$). $r =$ Pearson correlation coefficient. COD= change of direction-step. ACC= first acceleration step with the dominant foot, after the COD-step.
An effect for both training groups were found for the pre- to post measurements in center of mass (COM) in the 4m and 20m CODs with a significantly lower COM measured at post-test ($F> 34; p< 0.01, \eta^2 = 0.83$). Strength-training group changes in COM and changes in time for 4m 90° COD ($r= -0.8$) and 20m 180° COD partial time ($r= -0.75$) were significantly correlated. The plyometric-training group changes in COM and changes in time for the 4m 135° COD ($r= -0.74$) were significantly correlated (table 7.6). The correlation of changes in COD-time with changes in CT and COM are visually illustrated in figure 7.6.

### Table 7.6. Changes in center of mass and its relationship with changes in COD-time, after a six-week training intervention

<table>
<thead>
<tr>
<th>4m COD</th>
<th>Strength training (n=9)</th>
<th>Plyometric training (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>45°</td>
<td>18.5±2.4</td>
<td>18.1±3.1</td>
</tr>
<tr>
<td>90°</td>
<td>25.2±4.1</td>
<td>27.8±5.4</td>
</tr>
<tr>
<td>135°</td>
<td>31.4±4.3</td>
<td>31.7±5.8</td>
</tr>
<tr>
<td>180°</td>
<td>32±6.4</td>
<td>37.2±6.9</td>
</tr>
<tr>
<td>20m PT</td>
<td>45°</td>
<td>20.3±3.3</td>
</tr>
<tr>
<td>90°</td>
<td>28.4±3.6</td>
<td>30±3.9</td>
</tr>
<tr>
<td>135°</td>
<td>33.9±3.9</td>
<td>34.1±5.6</td>
</tr>
<tr>
<td>180°</td>
<td>36.5±3.9</td>
<td>36.6±5.4</td>
</tr>
</tbody>
</table>

Correlations between changes in time for 4m change of directions, 20m partial time, and changes in center of mass. $r= $ Pearson correlation coefficient. Center of mass measured at pre-test and post-test is presented as means ± standard deviation of absolute values, with changes (Diff) presented as mean of absolute values. PT= Partial time. * Significant correlations ($p< 0.05$). # Significant change from pre- to post ($p< 0.05$).
Figure 7.6. Correlations of changes in change of direction- (COD) time and center of mass (A and B). Figure C displays the correlation between changes in COD-time and changes in contact time in the COD-step. COM= Center of mass measured in the COD-step. CT COD= Contact time in the COD-step. Changes is measured from pre- to post-test.
7.2.4. Changes in kinematics after the training intervention for both groups combined (n=20)

No effect of the training intervention was observed in the angle of the hip abduction nor in hip and knee flexion for the 20m CODs ($F< 3.9; p= 0.07, \eta^2_p = 0.22$). A significant effect of the training intervention was observed in the 4m CODs for knee- and hip flexion ($F> 8.8; p= 0.01, \eta^2_p = 0.37$), where post-hoc results revealed the flexion of the hip to significantly increase at post-test for the 4m 90° and 135° COD. An effect of the training program was also observed for the ankle in both 4 and 20m CODs ($F> 5.2; p= 0.04, \eta^2_p = 0.29$), where post-hoc results revealed a significant increase in flexion for the 4m 45° COD only (Figure 7.7).

Figure 7.7. Changes in kinematics from pre- to post-test for both the training groups combined. * Significant change from pre- to post ($p< 0.05$).
8. Discussion

This study had two primary aims: 1) Compare different CODs with each other to see if it is reasonable to separate them as strength- or velocity dominant CODs. 2) Investigate how strength- and plyometric training affects semi-professional and amateur soccer players’ performance in strength- and velocity-dominant CODs after training two times a week for a duration of six weeks at the end of the season. The main findings when comparing the different CODs were that time to complete the COD, center of mass, number of deceleration steps, and contact time in the COD-step increases when the degree of the COD-maneuver increases. The 45° COD seems to be possible to categorize as a velocity-dominant COD while the 180° CODs are strength dominant. The 45° COD is found to induce a smaller flexion of the ankle and knee in the COD-step and higher muscle activation in adductor longus, gastrocnemius, and rectus femoris compared to the other CODs. The 180° COD is the only COD-maneuver not dependent on a fast SSC (>250 msec) in the COD-step and requires more flexion of the hip compared to other CODs. The 90° and 135° CODs are harder to categorize. No differences were observed when comparing 4m and 20m CODs except for number of deceleration steps, suggesting that distance approaching the COD affects the deceleration required, while the technique of the COD-step is only dependent on the degree of the COD-maneuver. Both the strength training and plyometric-training group improved their COD-performance after the training intervention. No differences were observed in increased performance between the two training groups, maybe due to a relatively low number of subjects, although plyometric training seems to be most effective for developing the spectrum of qualities COD-performance is dependent on.

8.1. Comparison of the different CODs

The time to complete the CODs increases significantly when the degree of the COD-turn increases (figure 7.1 A) for the different 4m CODs, 20m CODs, and 20m partial time. With increased degrees of the turn in the COD-step, the subjects’ contact time in the COD-step increases, but no differences were observed for contact time when comparing 4m CODs with 20m CODs (figure 7.1). The results of comparing contact time in the 4m COD-step with the 20m COD-step might suggest that the velocity approaching the CODs does not affect the contact time in the COD-step; the degrees of the COD-maneuver does. This is supported by the kinematic data, where no differences in joint angles were observed when comparing CODs at different lengths approaching the COD-step (figure 7.3). As such, when comparing 4m and 20m
CODs, the difference might be found in the deceleration steps prior to the COD-step, since deceleration occurs over a limited number of strides prior to the COD-step, where the body absorbs high eccentric forces (Hewit, Cronin, Button, & Hume, 2011). Thus, making the COD-maneuver a multiple-step action (Dos’Santos, Thomas, Comfort, & Jones, 2018), where the required deceleration increases for CODs with larger degrees and higher velocities prior to the COD-step. When comparing contact time in the acceleration step, the only differences observed were that the 20m 45° COD was significantly shorter compared to contact time in the other 20m CODs. This could be because the 20m 45° shows most similarities with straight-line sprinting (Dos’Santos et al., 2018) and the importance of short contact times for performance in straight-line sprinting speed has been established in earlier studies (Morin et al., 2012). The kinematic data supports this finding, where the COD-step in 45° CODs was found to have a significantly lower flexion of the knee (4m COD), while the ankle joint was less plantar flexed (20m COD) compared to the other COD-steps. This is perhaps because the 45° COD requires less breaking and as such requires less flexion of the hip and shorter contact time prior to the COD-step for velocity maintenance, demanding more breaking of the ankles when performing the COD-step (figure 7.3).

When decelerating, the ankle plantar flexes to absorb forces and decrease momentum of the body (Dos’Santos et al., 2018). As such, the gastrocnemius, which plantar flexes the ankle joint (Hewit et al., 2011), seems to be of great importance when decelerating in a COD-maneuver, especially in the COD-step of the 45° CODs. The muscle activation in the gastrocnemius shows a tendency to decrease the larger the turn of the 4m COD-becomes. A possible explanation is that the COD-maneuvers at larger degrees require greater forces for deceleration prior to the COD-step, while the smaller degrees require less breaking prior to the COD-step. As such, more breaking is required of the ankles prior to the COD-step at larger degrees resulting in lower muscle activation in the COD-step (figure 7.4). The increase in muscle activation in gastrocnemius in CODs with smaller turns is supported by earlier research where only two CODs were compared (Rand & Ohtsuki, 2000). The findings in this study of muscle activation in adductor longus also supports separating the qualities needed to perform the 45° from the other CODs. In the 4m 45° COD, muscle activation in the adductor longus were found to be significantly higher compared to the other 4m CODs in the COD-step and acceleration step. It is possible that the subjects rotated more towards the desired direction when the degree of the COD-turn increased, since it is more optimal for COD-performance (Dos’Santos et al., 2018), but this was not measured. However, if so, it might explain why the adductor longus showed a
tendency of reduced muscle activation in CODs with larger degrees. When the subject is more rotated towards the desired direction in the COD-step, less work is required of the adductor longus to innervate the thigh, resulting in lower muscle activation. In the acceleration step for the rectus femoris, the muscle activation was found to be smaller at 4m 45° CODs. One of the main objectives for rectus femoris is to extend the leg and has previously been proposed to be one of the most important muscles for deceleration (Hewit et al., 2011). The flexion of the knee was found to be smaller at CODs with smaller degrees (figure 7.3), which means that less extension of the leg is required in the acceleration steps of the 45° CODs (figure 7.4), causing less muscle activation in the rectus femoris. Although differences were found for muscle activation of the acceleration step, contact time does not seem to be affected by the COD-condition (except 20m 45°), which the subjects seem to perform as fast as possible on their own accord. A reduced contact time will increase step frequency in the acceleration phase (Murphy, Lockie, & Coutts, 2003) and could therefore be beneficial for a fast COD-performance (Cronin, McNair, & Marshall, 2002; Dos’ Santos, Thomas, Jones, & Comfort, 2017). The subjects did significantly increase the number of breaking steps when the degrees of the CODs increased and when comparing 4m and 20m CODs (figure 7.2 A), supporting the finding that velocity approaching the COD affects deceleration prior to the COD-step.

The importance of deceleration is well supported by earlier studies (Dos’ Santos et al., 2017; Spiteri, Cochrane, Hart, Haff, & Nimphius, 2013; Spiteri et al., 2015). The findings of this study is in accordance to the theory of Bourgeois, McGuigan, et al. (2017), which is based on Newtonian laws, suggesting that increases in the degrees of the COD-turn and velocity approaching the COD-step would require larger forces to change momentum. The number of deceleration steps increases when the distance approaching the CODs and degrees of the COD increases, while contact time in the COD-step is only affected by the degrees of the COD. Hewit et al. (2011) argues for maximizing the contact time during the deceleration phase in order to create a greater negative impulse towards the surface, which will cause a decrease in the momentum of the body prior to the COD-step. A decrease in momentum prior to the COD-step will make velocity maintenance possible in the COD-step (Hader, Palazzi, & Buchheit, 2015) and it will be easier to overcome inertia and re-accelerate with a fast acceleration step towards the desired direction. The findings of this study supports that applying great force during the breaking steps prior to the COD-step is advantageous for COD-performance (Dos' Santos et al., 2017; Dos’Santos et al., 2018) and is of greater importance in CODs performed with a higher velocity approaching the COD. As such, training for COD-performance should aim to improve
the qualities of the different steps performed in the COD-maneuver, not only the COD-step. Since there were no significant differences in contact time observed when comparing 4m and 20m CODs, the recommendation for a fast COD would be effective deceleration prior to the COD-step with long contact time of the deceleration steps and then performing the COD-step without decreasing velocity of the momentum or increasing contact time in the acceleration step (Spiteri et al., 2015). To avoid misunderstandings, long contact time while decelerating means short flight time, to maximize contact with the ground in accordance to Newtons first law. This is accomplished by applying forces towards the ground over a minimal amount of time to decrease the momentum of the body prior to the COD-step while rotating the trunk, transmitting the forces towards the appropriate direction (Hewit et al., 2011). In addition, a large breaking force in the eccentric breaking of the COD could potentially increase the concentric acceleration velocity post the COD-step, due to elastic energy of the lengthened muscle (Green, Blake, & Caulfield, 2011). As mentioned, a reduction in contact time is suggested to enhance sprinting ability (Morin et al., 2012), a physical factor determining COD-performance (Young et al., 2002). But an increase in velocities approaching the COD-step would require greater force (more deceleration steps or longer contact time in deceleration steps) to decelerate prior to the COD-step (Spiteri et al., 2014). Since the sprint velocity prior to the COD and the degrees of the COD is thought to determine the force required for deceleration (Dos’Santos et al., 2018), it was assumed that sprint time approaching each of the 20m CODs (total time ÷ partial time) would differ. However, they were found to be similar for each 20m COD at the different degrees (table 7.3).

Since a difference in sprint times not were observed between the 20m CODs, the subjects did: 1) not make contextual approaches dependent on the degree of the different CODs, or 2) the subjects did not start to decelerate their velocity before crossing the timing gates which measured partial time. If premature measurement of the partial time is the reason for this nullfinding, and it most likely is because it contradicts other studies (Hader et al., 2015; Schreurs, Benjaminse, & Lemmink, 2017), future research should measure partial time either with a closer distance to the COD-step or make several measurements of partial time for comparisons. Too long of a straight-line sprint distance when measuring COD-performance is known as the COD-deficit (Nimphius, Callaghan, Spiteri, & Lockie, 2016) and is problematic since a fast sprint will increase performance in total time while decreasing performance in partial time due to the larger forces needed to decelerate when performing the COD-maneuver (Dos’Santos et al., 2018).
As mentioned, time to complete the COD, contact time in the COD-step, and center of mass increases when the degrees of the COD increases. The subjects’ center of mass in the COD-step is significantly lower when the degrees of the COD-turn increase in both the 4m CODs and 20m CODs. When comparing 4m and 20m CODs, the center of mass was found to be significantly lower in the 20m CODs, except for 180° CODs (figure 7.2 B). For the 20m CODs, a greater sprint approaching the COD-step requires the athlete to move through a greater eccentric load and greater breaking capacity is required to decelerate and transfer the momentum towards a new direction (Spiteri et al., 2015). As such, when performing 20m CODs, the subject will due to momentum get a greater forward lean of the upper body compared to the 4m CODs, resulting in a lower center of mass. Increased degree of the COD-maneuver was also found to induce a lower center of mass. A lower center of mass will be advantageous in applying horizontal forces in a short duration of time (Brughelli et al., 2008; Sheppard & Young, 2006) and could therefore be beneficial in more strength-dominant CODs.

These findings are logical, as the 180° CODs demand the longest contact time in the COD-step (figure 7.1) and more horizontal force in the COD-step is required to change momentum, thus making the subject lower their center of mass for optimal force production during the COD-step. A low center of mass with a great flexion of the hip in the COD-step can allow the athlete to extend the hip and increase propulsive ability (Spiteri et al., 2015), although a forward lean of the trunk will increase the time spent to change momentum towards a new direction because of the time spent rotating (Dos’Santos et al., 2018). When decelerating, the foot causing the breaking is placed in front of center of mass to absorb force. To avoid a forward momentum, flexion of the hip and the ankles’ plantar flexion increases while the knee extends, distributing forces over a greater eccentric range of motion, with impact forces over as many joints as possible and reduced stress towards the joints (Hewit et al., 2011). Prior to and during the COD-step, velocity of the body decreases and the subject will need to re-accelerate towards the new direction, which is done by powerfully extending the hip, knee, and ankles (Delecluse, 1997). This study indicates that the hip flexion required increases when the degrees of the COD-maneuver increases.
8.2. Changes in performance and performance-related variables after completing the training intervention

The main finding of the training intervention in this study is that the strength-training and plyometric-training group improved significantly in COD-performance from pre- to post-test. Although the strength-training group reduced their time to complete all the COD-conditions, only improvements in the 20m 135° and 180° COD (table 7.2) were found to be significant, the two CODs in this study hypothesized to be the most strength dominant, based on the review of Bourgeois, McGuigan, et al. (2017). The plyometric-training group experienced significant improvements in COD-performance for 4m 135°, 4m 180°, and 20m 180° COD (table 7.2). Sprint time prior to the 20m COD (total time ÷ partial time) was also reduced for each 20m COD-condition for both the strength- and plyometric-training group from pre- to post-test, while partial time was not significantly changed for any 20m COD-condition (table 7.2), except for the strength-training group in 20m 180° COD.

The tendency of improvements of sprint time prior the COD and small improvements in partial time might indicate that both the strength- and the plyometric-training groups have improved their acceleration ability after the training intervention due to the previously mentioned COD-deficit. As a result of improved acceleration ability, when performing 4m CODs the subjects will produce greater force in the acceleration phase, and as such need more force to decelerate and change momentum during the breaking phase of the COD. This is supported by the principle of strength-dominant and velocity-dominant CODs (Bourgeois, McGuigan, et al., 2017). When performing the 4m COD, the first acceleration step was not limited by time, which will cause a production of large forces towards the ground, at a low velocity. Such forces will be larger after a strength-training intervention (Delecluse et al., 1995) due to increased muscle strength and will thus increase the ability to accelerate the body (Wisløff et al., 2004). As a result, greater propulsive forces in the COD-maneuver are required to decelerate. The fact that increased strength increasing the ability to accelerate requires more deceleration prior the COD-step could explain why the strength-training group did not significantly increase their 4m COD-performance. It would also explain why the strength training group improved more in only the 4m 45° COD compared to the plyometric-training group, since the 4m 45° COD does not include deceleration steps for many of the subjects and is largely dependent on acceleration. In the 4m 45° COD, the most important acceleration step occurs at the start of the test with no time constraints, which allows the subjects to perform it with a large force at a low velocity. In
hindsight, the 4m CODs should have included either a measure of partial time closer to the COD-step or a standardized velocity approaching the COD as in the study of Hader et al. (2015). These findings raise criticisms of how earlier studies have measured COD-ability and concluded that the training resulted in increased COD-performance, when increased COD-performance could be a result of increased acceleration performance. In accordance to the previously mentioned findings, when the subjects linear sprint prior to the COD is improved, greater force is required to decelerate (hence longer contact time in the breaking steps) resulting in an increased partial time, even though total time to complete the COD might have improved.

In a study, Spiteri et al. (2015) observed no differences between the velocity of the faster and slower athletes approaching the COD-turn, and suggested that differences in eccentric breaking strength is a distinguishing factor for COD-performance. As such, it might be hypothesized that if the subjects of this study did not make contextual approaches on the different COD-turns, the increased COD-performance could be a result of improved ability to better handle the eccentric forces and decelerate from the improved acceleration ability. Greater eccentric strength shortens the time to decelerate and rapidly make a transition into the propulsive phase of the COD (Spiteri et al., 2015), which is of importance when performing CODs (Dos' Santos et al., 2017). The current study found a significant correlation with reduced contact time in the COD-step and reduced partial time in the 20m 180° COD (figure 7.6), which suggests that performance in partial time is negatively affected by performance in the total time spent to complete 20m CODs. Still, the findings of the current study did not show a clear enough trend to make any conclusion about the importance of a reduction or increase in contact time in the COD-step for improved COD-performance. It is worth mentioning that earlier research has found significant correlations between a short contact time in the COD-step and a fast COD-performance (Sasaki, Nagano, Kaneko, Sakurai, & Fukubayashi, 2011). The study of Sasaki et al. (2011) who observed this relationship used the 505-test, which actually measures partial time when performing a 180° COD and is as such in accordance with the findings of this study. Spiteri et al. (2015) on the other hand, found longer contact time in the COD-step to be beneficial for a more effective COD (when total time is measured), by producing more force when changing momentum. Therefore, the results of this study are not in conflict with earlier research when the findings suggest that a reduction or increase in contact time for the COD-step is beneficial depending on the COD-maneuver; a reduction in contact time in the COD-step is of importance if partial time is the dependent variable, while an increase in contact time is useful if total time is measured in a COD-test which includes straight-line sprinting.
A reduction in contact time can be accomplished by improved peak plantar flexor power, which is thought to improve COD-performance (Marshall et al., 2014). After the training intervention, significant increases were found in plantar flexion of the ankle when performing the 4m COD in the COD-step (figure 7.7). Plyometric training is thought to produce great ankle plantar flexor movements and short contact time (Marshall & Moran, 2013), which could explain why the plyometric-training group increased significantly in their 4m COD-performance, while the strength-training group did not. The study of Cappa and Behm (2013) points out that unilateral hurdle jumps seem to be effective for development of muscular power and sport-specific use of the fast SSC. They also pointed out high muscle activation in the gastrocnemius when performing the exercise, which is found in this study to display high muscle activation in the 4m 45° COD (figure 7.4). The plyometric-training group did improve their plyometric abilities after the training intervention, while the strength-training group did not improve as much. It is worth noting that the plyometric-training group significantly reduced their contact time in bilateral and unilateral hurdle jumps, which means they reached the force needed to jump over the hurdles faster.

Hurdle jumps and drop jumps are similar in their ability to perform a plantar flexion of the ankles to impact the ground with the toe balls. The drop jump puts a large load of work on the ankles (Hammami, Negra, Aouadi, Shephard, & Chelly, 2016) and requires eccentric strength of the gastrocnemius (Hewit et al., 2011), which is important for COD-performance. The strength-training group did improve in the plyometric exercise bilateral hurdle jumps, which also put a lot of stress on the ankles. It could be hypothesized that the improvements the strength-training group experienced in bilateral hurdle jumps is a result of training unilateral calf raises and a quality which positively affected the COD-maneuvers after the training intervention. Based on this study’s findings it is reasonable to say that plyometric training can be used to improve COD-performance. If the aim was to improve 45° CODs only, two of the exercises (skate jump and unilateral countermovement jump) that the plyometric training group trained during the training intervention should have been replaced with more velocity-dominant exercises that enables a fast SSC (<250 msec) to increase specificity towards velocity-dominant (45°) CODs (Dos’Santos et al., 2018). The current study suggests that contact time and center of mass are variables dependent on the degree of the COD-turn (table 7.1). The strength-training group was found to have a significant correlation between a lower center of mass and a reduction in 20m 180° partial time after the training intervention, which is in line with earlier studies that suggest that a lower center of mass is advantageous in more forceful COD-
movements which require a greater amount of horizontal force production (Sheppard & Young, 2006) (table 7.6). The strength-training group also showed significant correlations between changes in center of mass and reduction in the time to complete the 4m 90° COD (Table 7.6). For the plyometric-training group, significant correlations for changes in center of mass in the COD-step and changes in time were only observed for the 4m 135° COD. The strength-training group showed results in improved time for the 20m 135° and 20m 180° CODs, the CODs found to have the lowest center of mass. Thus, the longest contact time during the COD-step (table 7.1). And as mentioned, longer contact time means the possibility of generating more force during the concentric movement of the COD-step (Cronin & Hansen, 2006).

Earlier research has pointed out that stronger athletes are able to produce a faster horizontal propulsive force to change momentum in the COD-step (Spiteri et al., 2013). The contact time when performing the COD-step in the 180° COD was in this study found to be >250 msec, which means it is not dependent on a fast SSC. All the other COD-steps, plus the acceleration steps were <250 msec and hence defined as fast SSC movements (Aagaard et al., 2002; Flanagan & Comyns, 2008). Except for the COD-step in the 180° COD, the results suggest based on contact time only that the plyometric training was more COD-specific. This is supported by Young (2006), who highlights the importance of movement pattern and specificity of the contraction velocity in the muscles. Also, the COD-performance is dependent on multiple steps (Dos’Santos et al., 2018) with short contact time (for deceleration and acceleration), not only the COD-step, which could explain why the plyometric-training group also significantly improved their 180° COD-performance after completing the training intervention. The current study did not measure contact time for the steps in the sprint approaching the 20m COD, which may have been reduced and as such be the cause of the increased sprint performance (Morin et al., 2012). Even though the strength-training group increased performance in the strength test, the complexity of the training exercises might limit the specificity in the movement of the strength exercises. For example, a fast push-off phase in the lateral squat with correct technique might be complex when the exercise is newly learned. This is problematic, since muscular coordination is important for achieving transfer to the sport-specific task (Young, 2006). Another problem with the strength exercises is that the acute effects on COD-performance might change in the long term. Newly acquired strength needs to be used in a sport-specific context for the new strength to be beneficial and such adaptions take time (Bourgeois, Gamble, Gill, & McGuigan, 2017; Bourgeois, McGuigan, et al., 2017). Still, results from this study suggest that strength training can be used as a tool for developing strength-dominant CODs.
(135° and 180°) after six weeks of training. The velocity of the strength exercises used to improve performance in strength-dominant CODs is recommended to be >250 msec (Dos’Santos et al., 2018), which this study found to be specific for the 180° COD. This study found an increased flexion of the hip in the strength-dominant CODs, compared to the other CODs, a consideration to be made when planning a sport-specific training program.

Exercises such as the parallel squat performed with a load of a high percentage of 1RM will produce forces with a low velocity, increasing the specificity towards strength-dominant CODs. The parallel squat also induces a great flexion of the hip, which the results of this study found to be beneficial when performing strength-dominant CODs. The subjects were also found to increase their hip-flexion in the CODs at the post-test. Increases in hip flexion might be beneficial, according to Havens and Sigward (2015), who found a relationship between hip extensor moment to be important for COD-performance. However, other explanations should not be neglected when trying to explain the change in hip flexion. As mentioned, the subjects improved their sprint time prior to the COD-step, which will require more force to change momentum. When approaching the COD-step in a larger velocity, stabilization of the trunk and overcoming inertia will be more demanding, causing a greater forward lean of the trunk when decelerating which could be causing a larger flexion of the hip.

8.3. Methodical considerations

This study consists of two main research questions, and methodical considerations is addressed for both. Firstly, subjects participating for comparisons of the different COD-maneuvers to answer research question one are soccer players, and might not represent other field sports. A relatively low number of subjects induces a problem for research question number two, which was to investigate changes in performance of the COD-test, for a strength-training (n=9) and plyometric-training (n=11) group. Despite the strength-training group functioning as a control group for the plyometric-training group and vice versa, a control group could have given more insight into the isolated effect of the program in comparison to the overall population. Another consideration for research-question number two is that only the acute effects of the training intervention were measured. The training program was reported by the subjects to be very demanding, which could complicate measuring post-test results shortly after the training intervention. The training program was thought to be a supplement to the regular soccer trainings, which is the specific training. The load of the training program could have negatively
affect the sport-specific trainings during the training intervention. The days of testing were long and demanded a lot of concentration from the subjects. This is mainly a consideration for research question number one, since the procedure at the pre-test and post-test were identical.

Due to the length of the test-days, battery-time of the EMG pieces caused complications. Also, EMG data was sampled from many muscles, making collection of data more demanding as the data was collected with one data synchronization unit. As such, to secure subjects for comparisons of muscle activation, results from both pre- and post-test were used for the analysis in this study. Due to the size of this study, measurements were limited to the dominant foot only. This is non-problematic since right and left CODs share the same physical qualities. However, data from the non-dominant foot during the COD-maneuver would bring more insight to research question number one, since the subjects with a long contact time in the COD-step could potentially show less contact time in deceleration steps prior to the COD-step. Vice versa, flight time in each step during the COD-maneuver and velocity approaching the COD, which may better enlighten the ability to decelerate in a COD, were not measured. Taking this into consideration, the underlying mechanism behind an effective COD-performance may be linked just as much to the steps prior to the maneuver itself, thus making room for future research to improve, as most of the empirical evidence and conclusions stem from COD-step data. The most important consideration, although obvious, is that the tests in this study were performed in a controlled lab environment. As such, the improvements in COD-performance is only theoretically thought to have a transfer to competition settings.

8.4. Practical applications

Due to the complexity of the COD-maneuver, strength- and condition coaches should address the types of CODs that occur most frequently in the given sport and is of most importance to the athlete. Then, the aim should be to improve the physical components the specific COD-performance is dependent on. Since the COD-maneuver is complex, further research is warranted for more specific guidelines. General advisement would consist of developing eccentric strength in the lower extremities to effectively produce force to the ground when decelerating, and also to tolerate the propulsive forces from the ground. The eccentric strength will be of more importance when the degrees of the COD-maneuver and velocities approaching the COD-step increase. Eccentric strength training is very demanding. Therefore, research has struggled to find great methods for overcoming this aspect, since there are few studies
addressing this issue with respect to COD-performance. Future research should put more emphasis on this aspect with respect to evidence in this study, since this study found an increase in deceleration steps in 20m CODs compared to 4m CODs and when the degree of the COD-maneuver increased. Due to a lack of a clear empirical way of measuring COD-performance after the implications of the COD-deficit was addressed (Nimphius et al., 2016), it is hard to conclude if the athletes should emphasize short or long contact time in the COD-step. Although, the findings of this study suggest short contact time to be beneficial to reduce partial time, while a long contact time is beneficial for total time allowing the subject to approach the COD-step with a higher velocity. Such technical cues for an effective COD seem to be a sport-specific consideration.

The results of contact time in the acceleration step for the different CODs indicate that the acceleration step could be encouraged to be as short as possible, to rapidly produce horizontal force (Cronin et al., 2002; Dos’ Santos et al., 2017; Murphy et al., 2003). To accomplish this, strengthening the rectus femoris, which this study found to be important in the acceleration-step post 20m CODs, could be ideal. Apart from the joint angles found in the hip joint, knee and ankle joint angles were found not to be influenced by degree and distance approaching the COD, except for the 45° COD, where the knee and ankle joint were found to have a smaller flexion. With this in mind, training of the muscles surrounding the knee and ankle joint should be trained with a minimized range of motion for specific movements to increase performance in the 45° COD. Also, strengthening the gastrocnemius seems ideal for deceleration ability. Furthermore, an increased ability to perform a plantar flexion of the ankle joint to minimize contact times seems appropriate for optimizing COD-performance. Plantar flexion of the ankle joint and short contact times are key factors for a rapid acceleration (Dos’ Santos et al., 2017), and were also found to be of most importance in the 45° CODs COD-step. Training the hurdle jumps were found to decrease the contact time while the drop jumps increased power output, two training exercises that require plantar flexion of the ankle with minimized range of motion and could thus be useful for increasing COD-performance in the 45° CODs. Short contact-times might be beneficial for improving the other steps a COD-maneuver requires since a COD consists of multiple steps (Dos’ Santos et al., 2018). However, the current study focused mainly on the COD-step and first acceleration step. For the CODs performed with a larger degree of the COD-step, this study indicates that a low center of mass and flexion of the hip are beneficial in more strength-dominant CODs. An increase in hip flexion in the COD-step and increased strength in the hip flexors are beneficial for an effective COD by producing greater propulsive
force in the COD-step. The results of this study suggest that the hip flexors should be trained with a large range of motion for great hip angles, which could be accomplished with exercises such as the parallel squat. For a study that compares the strength- and velocity-dominant CODs with a standardized velocity approaching the COD, several measurements of partial time and measurements of the performance-related variables in both feet is warranted.

9. Conclusion

1) The results of this study suggest that it is reasonable to separate CODs in the term of strength- and velocity dominant, indicating that 45° CODs are more velocity dominant and 180° CODs are more strength dominant, while the 90° and 135° CODs are harder to categorize. 45° CODs are recognizable by little deceleration prior the COD step, making velocity-maintenance possible, smaller knee- and ankle flexion in the COD-step, and higher muscle activation for the adductor longus in the COD-step. This is because less innervation of the thigh is required prior to the COD-step. Higher muscle activation was also found in gastrocnemius for the 45° CODs, since less deceleration is required prior to the COD-step. The 180° CODs are recognized by both feet being on the ground when performing the COD-step and a full rotation of the body while changing momentum to the opposite direction, caused by a large and powerful flexion of the hip. Even though the 90° and 135° COD were not categorized as either strength- or velocity dominant, there seems to be a linear relationship between the time to complete the COD-maneuver, displacement of the center of mass, and contact time which increase when the degree of the COD-maneuver increases. As such, the importance of the strength- and velocity qualities are dependent on the degree of the COD-turn, while approach distance seems to be the important variable for determining the athletes’ need to decelerate prior to the COD-step. The kinematics in the COD-step is similar when comparing 4m and 20m CODs, but the 20m CODs require more steps prior to the COD-step for breaking. Since the different CODs seem to be dependent on specific qualities, optimizing individual physical training programs to improve COD-performance should be based on the distinctiveness of the different field-sports concerning occurrence of different sprints and degrees of directional changes.

2) The training programs were effective in developing strength in the strength-training group, and plyometric abilities in the plyometric-training group. The findings of the current study are in accordance with earlier studies, suggesting that the physical qualities of the COD-maneuver can be developed by both strength- and plyometric training. Although no difference in COD-
performance was observed between the strength- and plyometric-training group, the results indicate that plyometric training is most efficient in developing the spectrum of qualities the different CODs are dependent on. The increased COD-performance in this study is suggested to be a result of increased power in the plantar flexion of the ankle and hip flexion movement. Based on the plyometric tests, contact times in the different steps of the COD-maneuvers might have been reduced, however, such analysis goes beyond this study. The subjects were also found to increase their performance in sprints prior the 20m CODs, suggesting increased acceleration ability. How to perform an optimal measurement of COD-performance is still a topic relevant for future studies. Since the time to complete all the CODs were reduced from pre- to post-test for both training groups, a study performed with a larger number of subjects and a control group is warranted.
References:


