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Physical performance aspects of an ACL-injury prevention program in adolescent female handball players – a cluster randomized controlled pilot study

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Abstract

Background High knee abduction moments (KAM) are a significant risk factor for anterior cruciate ligament (ACL) injury in CoD and sidestep cutting. However, the influence of training interventions on KAM during these tasks remains unclear. To promote the implementation of injury prevention programs (IPP) in athletes, a secondary aim of improving physical performance (PP) should be incorporated. **Purpose** The purpose of this cluster-randomized controlled pilot study was to investigate the effect of an ACL- injury prevention intervention on isometric strength and CoD performance in adolescent female handball players. Furthermore, we wanted to investigate the association between IS and CoD performance. **Methods** Forty-nine adolescent female handball players (age 16.73 ± 0.9 years) from three Norwegian high schools participated in the eight-week intervention study. The schools were randomized to an intervention group (IG) (*n=22*) or control group (CG) (*n=27*). The intervention consisted of three segments; (i) handball sidestep cutting-technique training, (ii) manual eccentric resistance training, and (iii) CoD technique training. Relative isometric force output (IFO) was measured to assess isometric strength in hip abduction (ABD), external hip rotation (EXT), and plantar flexion (PFL) was measured to assess pre-post change and IS-COD association. **Results** IG increased IFO significantly compared to the CG in PFL (*4.94%, p = 0.039*), but not ABD (*5.67%, p = 0.319*) or EXT (*3.78%, p = 0.448*). However, compared to the baseline measures, IG increased IS in all outcomes. IG did not improve CoD Total time (-*3.43%, p = 0.118*), but Phase 1 time was significantly reduced (-*3.47%, p= 0.015*). Moderate correlations for CoD Total time and all IS outcomes were observed pre-and post-intervention. Changes in IFO were not associated with changes in CoD total time. **Conclusion** Overall, the ACL- injury prevention intervention was unsuccessful in improving physical performance. IS was significantly associated with CoD performance at both time points. However, changes in IS were not associated with changes in CoD performance.

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1 Theoretical background and current knowledge

This master thesis is written in article form and adjusted to meet the requirements of The Journal of Strength and Conditioning Research. The first two chapters lay the theoretical and methodological foundation for the article. The first chapter will present the current knowledge of anterior cruciate ligament injuries in handball and how physical performance is affected by injury-preventing training programs. The second chapter reviews the research methods applied in this study.

1.1 ACL injuries

1.1.1 Introduction to ACL injuries

Knee injuries are common in numerous team ball sports (Chia et al., 2022). Particularly anterior cruciate ligament (ACL) injuries have a high incidence compared to other knee components, such as the meniscus and posterior cruciate ligament injuries (Majewski et al., 2006). With its origin at the medial wall of the lateral femoral condyle and insertion in the middle of the intercondylar area, the ACL greatly contributes to the stabilization and kinematics of the knee joint (Petersen & Tillmann, 2002). ACL injuries occur when the load applied exceeds the tolerance threshold, and are severe conditions with both short- and potential long-term consequences (Dos'Santos, Thomas, Comfort, et al., 2019). Alongside the acute physical, financial, and psychological consequences, an earlier and increased risk of developing early osteoarthritis is a concern. Furthermore, ACL injuries and osteoarthritis are often associated with subsequent physical activity limitations, thus contributing to the public health issue of physical inactivity (Farr et al., 2008; Raijmakers et al., 2015; Zebis et al., 2016). For individuals participating in team sports at a high level, the absence of key players can also negatively influence significant competition results, which in turn may result in a cascade of adverse outcomes for both the team and the individual athlete (Busfield et al., 2009; Erickson et al., 2013; Prodromos et al., 2007; Shah et al., 2010; Waldén et al., 2011). Therefore, understanding how to influence the risk factors of ACL injuries is a priority in sport science research.

1.1.2 Risk factors

Female adolescent handball players

Despite substantial efforts to prevent ACL injuries, a systematic review and meta-analysis by Bram et al. (2021) reported an ACL injury risk of nearly 1 per 10 000 athlete exposure for adolescent female athletes. The highest incidence is observed in sports involving athletes rotating and changing direction, and it has been reported that the majority of ACL injuries occur during non-contact situations, such as cutting, jumping, and single-leg landing maneuvers (Koga et al., 2010, 2011; Kristianslund et al., 2014; Olsen et al., 2004; Zebis et al., 2022). It should also be noted that non-contact ACL injuries are believed to mainly occur within the first 40 milliseconds after initial ground contact (Koga et al., 2010).

It is well-established that female athletes are at greater risk than their male counterparts (Gornitzky et al., 2016; Prodromos et al., 2007; Renstrom et al., 2008; Stanley et al., 2016; Waldén et al., 2011). For example, in their International Olympic Committee current concept statement, Renstrom et al. (2008) reported a female-to-male ACL-injury ratio of 4.5 for high school students and 3.63 for college students. However, it should be noted that the rate for professional athletes was 0.95, although these results are not representative of all populations or sports. For example, Renstrom et al. (2008) reference a retrospective study including elite-level handball players reporting female players having 0.82 ACL injuries pr. 1000 playing hours, compared with the male players having 0.31 ACL injuries pr. 1000 playing hours. This high incidence of ACL injuries among female elite handball players has also been confirmed by several prospective studies (Myklebust et al., 1997, 1998, 2003). Therefore, understanding how to reduce the incidence of ACL injuries in this subpopulation is of particular interest.

Biomechanical risk factors

While gender and participation in specific sports are established risk factors, it should be elaborated that the mechanisms and risk factors of ACL injuries are far more multifactorial. They may rely on external factors, e.g., environment, equipment, and protective gear, and internal factors, e.g., hormonal, anatomical, neuromuscular, and biomechanical factors (Bahr & Krosshaug, 2005; Dos’Santos, Thomas, Comfort, et al., 2019; Renstrom et al., 2008) While the external risk factors may be easily manipulated, the internal risk factor demands a greater effort. Considering the relative rarity of ACL injuries, longitudinal studies aiming to assess their incidence require significant resources and large sample sizes. Thus, establishing valid and reliable screening tests that can accurately predict ACL injuries through known risk factors has been an area of focus in sports science research (Hewett et al., 2005, 2016; Krosshaug et al., 2016; Myer et al., 2011; Mørtvedt et al., 2020; Steffen et al., 2016). Examples of this type of screening test are the vertical drop jump and single-leg squat. Although frequently used, these tests have been criticized, and alternative methods have been proposed (Kristianslund & Krosshaug, 2013; Krosshaug et al., 2016; Nilstad et al., 2021; Petushek et al., 2021).

Considering the significant differences in sport-specific movements, sport-specific screening tests are of interest. An example is the handball-specific sidestep cutting test previously used by Kristianslund & Krosshaug (2013). This controlled laboratory study included a sample of 120 female handball players from the elite series in Norway. The participants performed both a vertical drop jump test and a sport-specific sidestep cutting test, and kinematics and kinetics were analyzed. In addition to significantly lower knee flexion and significantly higher knee valgus, the sport-specific sidestep cutting test resulted in knee abduction moments (KAM) six times higher than the vertical drop jump test. Not only does this provide data to suggest sidestep cutting test might be preferential in ACL-injury risk assessment in handball players, but it elucidates the relatively high risk associated with the sport. The calculations of KAM are described by Kristianslund et al. (2014) and illustrated in handball-specific sidestep cuts in a study by Bill et al. (2022) (Figure 1). The findings of Kristianslund & Krosshaug (2013) are highly relevant in predicting ACL injuries, as high KAM has been reported as a significant risk factor by numerous studies (Hewett et al., 2005; Koga et al., 2010; Myer et al., 2015; Olsen et al., 2004; Quatman & Hewett, 2009). Furthermore, the Oslo Sports Trauma Research Center (OSTRC) has an ongoing prospective cohort study of 776 elite female handball and football players, with preliminary data supporting this further (Kristianslund et al., 2014; OSTRC). Therefore, there is a persuasive argument that researchers should deviate from non-sport-specific tests when aiming to predict ACL injuries in handball players.

Figure 1. Knee abduction moments during handball sidestep cuts. The arrows illustrate ground reaction force and knee abduction moment.

As the scientific literature investigating KAM grows, methods of influencing it have become a topic of interest. Even though the vertical drop jump test might not be the best screening test for predicting ACL injuries in handball players, interesting results have been published regarding what factors influence KAM when conducting the test. Among these is the strength of the gluteus medius, suggesting that interventions aiming to reduce KAM might benefit from including exercises aiming to strengthen it (Ueno et al., 2020). These findings might relate to the results of Kristianslund et al. (2014), which identified knee valgus as a significant contributor to KAM in handball sidestep cuts. Founded on the premise that the glutes medius stabilize the hip joint by abducting and externally rotating the femur (Beck et al., 2000), it is reasonable to hypothesize that improved strength and function might reduce KAM. Knee valgus was not the only identified significant influencer of KAM. Most importantly, forefoot landing was reported to reduce KAM significantly. Using the same premise of muscular function, this suggests that strengthening the ankle plantar flexors might be beneficial to promote forefoot landing and reduce KAM. Thus, strengthening the gastrocnemius and soleus muscles may have benefits related to a reduction in KAM.

1.2 Physical performance

1.2.1 Introduction to physical performance

While staying injury-free is important, athletes pursuing a career in sports will always want to maintain or improve their performance in their respective sports. Therefore, any injury-preventing training program should also have a secondary aim of improving physical abilities. This secondary aim might also positively influence compliance by motivating subjects to adhere to a suggested injury-preventing protocol, in which compliance is a significant concern (Myklebust et al., 2003; Noyes & Barber Westin, 2012). As performance in sports is multifactorial and consists of technical, tactical, and physical attributes, there are numerous ways to influence it (Smyth et al., 2023). While technical and tactical attributes primarily relate to specific sports, movements, or abilities, physical attributes have a broader, more general contribution to performance in sports. There are numerous physical attributes relevant to an athlete's performance, and several of these are components of an individual's physical fitness, which in turn relates to physical performance (PP). However, PP is a broad term, not clearly defined in the scientific literature. Thus, researchers seemingly use the term dependent on the methodology used in the assessment of it. Therefore, numerous independent tests and test batteries of PP exist in the scientific literature.

An example where this becomes very apparent is a recent systematic review investigating the effects of sleep loss on PP, which reported 227 different outcome measures (Craven et al., 2022). Depending on the resources, population, and the aim of the research or training, different measurements and test batteries may be preferred. For example, the assessment of PP in geriatric populations might involve a walking test or bodyweight squats (van Lummel et al., 2015), while the assessment of professional or recreational athletes benefits from more challenging tests. Furthermore, when considering potential measurements of PP for athletes participating in a particular sport, specificity to the sport's requirements should also be evaluated as the results might also be relatable to sport-specific performance. Therefore, researchers and practitioners should consider not only the reliability and validity of the device used for measuring their chosen outcome but also the potential influence of difficulty and technique variables.

1.2.2 Muscular strength and change of direction

Muscular strength is an immensely important physical attribute in almost any physical sport or activity (Suchomel et al., 2016). It is defined as the ability to exert force on an external object or resistance and can be a potential limiting physical factor in several sporting settings. For example, an athlete's ability to manipulate their body mass and exert force against gravity can be associated with important PP variables, such as sprinting or jumping performance. Furthermore, in sports involving physical contact with an external object, e.g., an opponent, a ball, or a barbell, muscular strength is also essential for the ability to manipulate them or it. These factors make muscular strength an important outcome measure when assessing physical capabilities, particularly in subjects competing in sports. Research investigating the association between muscular strength and other variables closely related to performance in specific sports supports this across various genres. For example, stronger athletes have reportedly produced faster 100-meter running times (Meckel et al., 1995) and faster 25-meter track cycling times (Stone et al., 2004) than their weaker peers. Furthermore, Gorostiaga et al. (2004) reported that stronger amateur- and elite male handball players had a greater velocity in both their stand-still and 3-step running throws. From a more general view, less specific to induvial sports, muscular strength is also reported to have a positive influence on other separate PP measures, such as the countermovement jump (Kraska et al., 2009; Wisløff et al., 2004), and stronger subjects outperforming their weaker peers is well-documented in the scientific literature (Hori et al., 2008; Keiner et al., 2022; Sheppard et al., 2008).

Another common PP measure is the ability to perform a change of direction (CoD). CoD has been defined as the ability to decelerate, reverse or change movement direction, and accelerate again (P. A. Jones et al., 2009). It is a fundamental physical attribute of many field-based sports, and its importance is well-documented across various sports (Paul et al., 2016; Sheppard & Young, 2006). In invasion sports, i.e., sports evolving opposing teams attempting to invade their opponent's territory and score goals (W. B. Young et al., 2015), the ability to rapidly change directions can contribute to penetrating defensive lines and creating goal-scoring opportunities(A. Fox et al., 2014; Zahidi & Ismail, 2018). As this genre of sport includes widely popular sports, e.g., soccer, handball, basketball, ice hockey, etc., a significant number of athletes can benefit from improving their CoD abilities. Moreover, it makes a good argument for why CoD assessments should be included in PP assessments. This is supported further by organizations like the National Football League including CoD-assessments in their combine (McGee & Burkett, 2003).

It has been postulated that CoD performance is influenced by numerous factors. Among these are 1) technique variables, such as stride length, foot placement, and posture and body lean; 2) linear sprinting ability; and 3) lower limb qualities, i.e., strength, power, rate of force development, and reactive strength (Dos'Santos et al., 2017; W. B. Young et al., 2002). Therefore, a significant association between muscular strength and CoD seems likely, not only through the direct connection to lower limb qualities, but also through the reported association between muscular strength and linear sprinting ability. This is made clear by a systematic review and meta-analysis by Seitz et al. (2014), who investigated the association between lower limb maximal strength and sprinting performance. The authors reported a statistically significant, very large correlation between squat strength and sprinting, with the effect being most considerable at <30-meter sprints. These findings are particularly interesting regarding CoD assessment, as CoD tests usually involve subjects running a relatively short distance. A direct relationship between CoD and muscular strength is also observed numerous times in the literature (Nimphius et al., 2010; Spiteri et al., 2014; Spiteri, Newton, Binetti, et al., 2015; Spiteri, Newton, & Nimphius, 2015). However, several studies have also observed a very varying, or even lack of association, thus leaving some uncertainty regarding the muscular strength-CoD relationship (Hori et al., 2008; Spiteri et al., 2013). There are, however, methodological considerations to be made, and it is suggested that these are the cause of the null findings (Suchomel et al., 2016). These will be presented in the following chapter.

1.2.3 Physical performance and ACL injury prevention programs

There exists a plethora of training programs aiming to prevent ACL injuries by positively influencing one or several known risk factors (Noyes & Barber Westin, 2012; Voskanian, 2013). As described in a previous chapter, there are numerous known risk factors, and therefore, various aims and training methodologies are found in the literature investigating ACL injury prevention. The programs usually aim to induce muscle strengthening, muscle recruitment patterns, landing- and deceleration patterns, proprioception, plyometrics, flexibility, and running technique (Vescovi & VanHeest, 2010; Voskanian, 2013). As muscular strength is an essential physical attribute related to a number of PP measures (Suchomel et al., 2016), it is reasonable to suggest that well-composted ACL injury prevention programs (ACL-IPP) incorporating muscle strengthening training might also positively influence PP.

While some ACL injury-preventing interventions have failed to improve relevant physical performance outcomes (Steffen et al., 2008; Vescovi et al., 2008), there are several that have shown potential as a means to improve it (Askling et al., 2003; Hewett et al., 1999; Mjølsnes et al., 2004; Reis et al., 2013). Several of these were included in a systematic review by Noyes & Barber Westin (2012), which sought to determine if ACL-IPP positively influences both injury rates and athletic performance tests in female athletes. Each of the respective 17 studies included in the review applied one of the following ACL injury prevention programs; Sportmetric, "Myklebust", "11", Knee Ligament Injury Prevention, and Prevent Injury and Enhance Performance (PEP). It should be noted that several other ACL-IPPs exist, such as "The Dynamic Neuromuscular Analysis Training" or "11+", and these were not included in the review due to a lack of PP assessment or failure to fulfill other inclusion criteria. Although the included ACL-IPP have similarities, there are important factors separating them. While all included agility exercises, only Sportmetrics, PEP, and the "11" included strength training in the program. Regarding other forms of exercise, plyometric training was included in all but the Myklebust program, flexibility was included in Sportmetrics and PEP, and balance training was included in Myklebust and "11". Furthermore, the duration of these training sessions was widely different, with "Myklebust" and "11" having the shortest sessions (~15 min) and Sportmetrics having the longest (90-120 min). Despite slight differences in age category and intervention timing, i.e., in-season or pre-season, these pronounced differences in program design are likely the cause of the differing intervention results.

Regarding ACL injury incidence, only the Sportmetrics and PEP programs significantly reduced the ACL injury rate. Nine different PP outcomes were utilized in the included studies, with some overlap between the respective studies. The outcomes included muscular strength, agility, speed, vertical jump, Vo_2-max, and sport-specific tests. The Sportmetrics program was reported to present the greatest increases in PP outcomes, with significant improvements in 9 of the 11 PP outcome measurements applied in the studies. The PEP was also reported to show potential to improve PP, with significant improvements in 4 of 7 PP outcome measures in female high school basketball players. However, in female high school soccer players, the PEP failed to induce significant improvements in any of the 7 PP outcome measures. Similarly, the “11” and the Knee Ligament Injury Prevention also failed to induce improvements in any of their respective 5 and 1 PP outcomes. Briefly summarized, the findings from this confirm that some IPP, like Sportsmetric and PEP, have the potential to reduce ACL injury rates while simultaneously improving PP. However, it also confirms that reducing the ACL- injury rate is challenging, especially when combined with the aims of improving PP, and requires careful consideration of variables associated with inducing training adaptions.

As the literature presents, there is a definite potential for injury-preventing interventions and programs to affect physical performance positively. On the other hand, it is also clear that not all interventions will provide the same benefits regarding IPP or PP. There might be several reasons for this; firstly, it seems that intervention duration and weekly volume have a significant influence, and secondly, intensity and exercise selection are suggested to be significant variables (Noyes & Barber Westin, 2012; Steffen et al., 2008). Therefore, researchers and practitioners developing interventions and training programs aiming to prevent ACL injuries and improve PP should consider these variables carefully.

1.3 Thesis aims

This thesis investigated the physical performance aspects of an eight-week training intervention aimed at reducing knee abduction moments during change of direction and handball-specific sidestep cuts in adolescent female handball players. The intervention consisted of handball sidestep cutting technique training, change of direction technique training, and manual eccentric resistance training. The H_0 were as follows;

i) Eight weeks of manual eccentric resistance- and CoD technique training does not significantly increase isometric strength.

ii) Eight weeks of manual eccentric resistance- and CoD technique training does not significantly improve CoD performance.

iii) Isometric strength is not significantly associated with CoD performance.

iv) Changes in isometric strength are not significantly associated with changes in CoD performance.

2. Methodological rationale and considerations

The study included in the present thesis was conducted as a cluster randomized controlled study. We aimed to investigate the PP-related outcomes of an 8-week training intervention aimed at reducing KAM in handball-specific sidestep cuts. The training intervention consisted of three segments, 1) MERT), 2) CoD technique training, and 3) team handball sidestep-cutting technique training. To assess PP, we measured CoD time and peak speed, in addition to peak relative isometric force output (IFO) in three single-joint exercises. This chapter will describe the rationale and considerations related to the methods used. This will consist of presenting research investigating the influence and efficacy of aspects of the intervention, as well as studies aiming to assess the validity and reliability of the measurement methods. However, a detailed description of the precise methods used in the study included in the present thesis will not be included in this chapter, as it will be included in the upcoming article.

2.1 Muscular strength assessment

2.1.1 Methods of assessing muscular strength

Strength tests are utilized by coaches and healthcare professionals to evaluate the current strength status of an individual or the effects of training interventions (Kraska et al., 2009). From a large perspective, two methods are generally used to assess muscular strength; isometric or dynamic force-generating capability (D. Lum et al., 2020). While dynamic strength tests have benefits, such as assessing a range of motion and having the potential to be specified to movements of interest (D. Baker et al., 1994), there are also some limitations. For example, the frequently utilized one repetition maximum (1RM) strength test, defined as a test establishing the heaviest load that can be lifted only once through a full range of motion (Picerno et al., 2016), is suggested to require levels of skill that inhibits an unskilled individual’s ability to generate maximal muscular force output, thus limiting its validity as a measurement of muscular strength (Buckner et al., 2017). Although small, there is also an injury risk associated with the 1RM strength test, along with potential fatigue and a temporary reduction in physical performance (Beckham et al., 2013; D. Lum et al., 2020). This can be problematic as strength assessments are frequently utilized in aspiring athletes, which might not have the capacity to recover in time for their scheduled training. In the present thesis, however, we used isometric force-generating capabilities, i.e., isometric strength (IS), as the general method of measurement for muscular strength.

While the general method of assessing strength isometrically has been utilized in research for decades (Bäcklund & Nordgren, 1968; Wilson & Murphy, 1996), it, too, has both benefits and limitations. Firstly, IS tests are simple to administer and do not require as much familiarization as dynamic tests (Brady et al., 2020; D. Lum et al., 2020). In comparison, and briefly mentioned in the previous section, dynamic tests, such as the 1RM strength test, however, are suggested to be dependent on individuals being skilled at the task at hand, and several studies have suggested including two or three familiarization sessions when investigating 1RM strength (Dias et al., 2005; Ritti-Dias et al., 2011). While this makes a case for the use of IS strength test when familiarization periods are inconvenient or impossible to administer, it should be noted that a recent systematic review by Grgic et al.(2020) investigated the test-retest reliability of the 1RM strength test and reported excellent reliability, independent of familiarization sessions, strength training experience, exercise, and age. However, even if the potential benefit regarding the number of familiarization sessions and skill requirements might be minor, IS strength tests are still considered reliable for strength assessments and have been reported to have a strong relationship with 1RM strength measurement, particularly as multi-joint movements (Bazyler et al., 2015; Drake et al., 2018). An example is the observation made by Blazevich et al. (2002), which investigated the relationship between isometric and dynamic strength testing in the squat and reported a correlation of (r = 0.77) at 90° knee flexion. Others have reported similar findings, and Mcguigan et al. (2010) reported a nearly perfect correlation between peak IFO and 1RM in the squat at 130° knee flexion (r= 0.97). Moreover, a systematic review by Lum et al. (2020), including 47 studies investigated the relationship between isometric and dynamic force output assessments of multi-joint exercises and concluded that the strength of the correlation was moderate to very strong for both upper-body and lower-body movements.

2.1.2 Isometric strength and physical performance outcomes

Based on the literature presented in the previous section, it is apparent that peak IFO provides insight into an individual’s dynamic muscular strength. However, some uncertainties remain regarding its relationship to other dynamic PP measures (Juneja et al., 2012; D. Lum et al., 2020). For example, in the widely utilized PP measure countermovement jump, the literature shows conflicting results. When investigating the association between relative peak IFO in the squat and countermovement jump height, a study by W. Young et al. (1999) reported no significant correlations. Similarly, both Khamoui et al. (2011) and West et al. (2011) reported no significant correlation between relative peak IFO in the isometric midthigh pull and countermovement jump height. On the other hand, several studies have reported significant associations. For example, D. W. Y. Lum & Joseph (2020) measured peak IFO in the squat and CMJ height pre- and post the 6-week training intervention included in their study and reported a significant correlation at both times of measurement.

Isometric strength is also reported to be significantly associated with other PP measures, such as CoD performance. Numerous studies have observed a significant inverse relationship between various CoD performance outcomes and IS tests in different populations, suggesting that higher isometric force output is associated with faster CoDs. When using the isometric midthigh pull to assess muscular strength, some examples of this are faster 505-agility test times in adolescent female netball players (Thomas et al., 2015), faster T-test, 505 agility test and modified 505-agility test times in adult female basketball players (Spiteri et al., 2014; Spiteri, Newton, Binetti, et al., 2015), and faster modified 505-agility test times in male collegiate athletes (Thomas et al., 2015). Furthermore, analysis by Spiteri, Newton, Binetti, et al. (2015) indicated that athletes with greater isometric strength achieved faster T-test and 505 agility test times. Collectively, the presented data suggest that conducting isometric strength tests to assess muscular strength is acceptable. Furthermore, the literature suggests that isometric strength may relate to other PP outcome measures, such as the CoD. However, it should be noted that most of the presented literature utilized multi-joint movements. As all the isometric strength measurements conducted in the study included in the present thesis involved singular joints, there is some uncertainty about whether all qualities and associations are transferrable.

2.1.3 Isometric strength assessment devices

In the study included in the present thesis, we used two different devices to assess IFO; the Vald Force Frame^{TM} (Vald Performance, Albion, Australia) for hip abduction and external hip rotation, and the HUR Labs FP4 (HUR lab Oy, Kokkola, Helsinki, Finland) for ankle plantar flexion. Hip IFO was measured bilaterally, while ankle plantar flexion was measured unilaterally.

HUR Labs FP4

The HUR Labs FP4 is a commercially available portable force platform measuring 61 x 61 x 6 cm, with industrial-grade force transducers attached at each corner, and is frequently used for research purposes (Davids et al., 2021; Myrholt et al., 2023; Norum et al., 2020; Sagelv et al., 2020; Wiig et al., 2019). However, it should be noted that the cited studies did not use the HUR Labs FP4 for IS measurement but rather jump tests, such as the CMJ and squat jump. Thus, there is limited background on its qualities as a device for assessing IFO in IS strength tests. There are, however, some relevant studies to be presented. For example, a criterion validation study by Dobbin et al. (2017) reported using the HUR Labs FP4 as the criterion for assessing IFO during the isometric midthigh pull in rugby players, thus giving the impression that HUR Labs FP4 provides valid IFO measurements. Moreover, regarding device qualities such as sampling frequency, the HUR Labs FP4 collects data at 1200 Hz, thus performing at a level far superior to the recommended lower threshold of 500 Hz for assessment of IFO in exercises such as the isometric midthigh pull (Dos'Santos, Jones, Kelly, McMahon, et al., 2019).

To the author's knowledge, any further studies have yet to be published investigating any validity or reliability regarding the use of the HUR Labs FP4 in any type of IS measurement. Although the presented literature indicates reasons for optimism in IFO measurement, the lack of data in the specific area of research should be kept in mind when interpreting the result. Lastly, an unexpected issue in investigating the use of the HUR Labs FP4 for IFO assessment, has been a lack of precision regarding device labeling. Regardless of the study aim, several published studies simply state using a portable force platform produced by HUR Labs to assess IFO (McPhail et al., 2021; Petrakos et al., 2019). As HUR Labs have produced numerous independent portable force platforms, collecting information on the precise portable force platform used has not been possible.

Vald Force Frame™

The Force Frame™ is the renewed portable force-measuring device produced by Vald Performance, replacing its predecessor, the GroinBar Hip Testing System. The GroinBar Testing System has been frequently utilized for research purposes and has been reported to have great re-test reliability for isometric hip strength testing (Desmyttere et al., 2019; Kadlec et al., 2021; Ryan et al., 2019). Moreover, O'Brien et al. (2019) investigated its concurrent validity in hip- and groin strength testing and reported moderate to good association with a hand-held dynamometer, which has been referenced as the best practice (Kemp et al., 2013; Thorborg et al., 2018). Hand-held dynamometers, however, present a challenge in a potential test bias, as the tester is required to provide support using external force when collecting data (Desmyttere et al., 2019). Moreover, Krause et al. (2014) reported that hand-held dynamometers were influenced not only by the tester's technique but also by the tester's strength. As athletes generally are stronger than the average person, it is suggested that this could induce a systematic error when testing athletes (Desmyttere et al., 2019).

Due to the Force Frame™ novelty as a device for IFO measurement in research, the literature regarding validity and reliability is relatively sparse. However, the chief executive officer of Vald Performance has stated that the hardware of the Force Frame™ is identical to GroinBar Hip Testing System, indicating the perseverance of the qualities laying the foundation for its use in research (Malone, 2019). While serious considerations have to be made in evaluating the potential bias of a statement by the chief executive officer of the manufacturing company, scientists regard the devices as comparable, and have adapted the use of the Force Frame™ in research measuring IFO in hip exercises (S. Jones et al., 2021; O' Connor et al., 2023). Furthermore, despite the novelty of the Force Frame™, studies investigating its reliability and validity are emerging. For example, a recent study by O' Connor et al. (2023) investigated the test-retest reliability of the Force Frame™ for measuring IFO in isometric hip abduction and isometric hip adduction. IFO was measured unilaterally and bilaterally in 50 adult males in two separate hip joint angles; 0° and 45° hip flexion. Summarized, the authors reported good-excellent reliability for all Force Frame™ measures. More specific to the methods used in the study included in the present thesis, in the bilateral measurements, the authors reported excellent reliability in hip abduction and good reliability for hip adduction. This is comparable to data on The GroinBar (Table 1), further supporting the notion that the Force Frame^{TM} provides the same qualities as its predecessor. Lastly, it may also be noted that in the same study, the authors investigated the concurrent and discriminant validity of the sphygmomanometer as a device to measure hip IFO. To conduct this investigation, the authors used the Force Frame^{TM} as the criterion method, suggesting that the authors trust its validity.

Table 1. ForceFrame and GroinBar test-retest reliability in isometric force output in hip exercises

Study Device	**Outcome measure**	**ICC (95% CI)**
(Desmyttere et al., 2019) GroinBar	Peak IFO 45° bilateral abduction	0.82 (0.67-0.90)
	Peak IFO 0° bilateral adduction	0.85 (0.74-0.92)
	Peak IFO 90° bilateral external rotation	0.88 (0.79-0.94)
	Peak IFO 90° bilateral internal rotation	0.77 (0.60-0.87)
O' Connor et al. (2023) ForceFrame^{TM}	Peak IFO 0° bilateral abduction	0.78 (0.63-0.87)
	Peak IFO 45° bilateral abduction	0.91 (0.84-0.95)
	Peak IFO 0° bilateral adduction	0.90 (0.82-0.94)
	Peak IFO 45° bilateral adduction	0.84 (0.74-0.91)

Abbreviations: 95%CI, confidence interval; ICC, intraclass correlation coefficient; IFO, isometric force output

2.2 Change of direction assessment

CoD performance has long been a topic of interest for researchers and performance coaches. Therefore, research aiming to determine the most reliable and valid methods is consistently published (Dos'Santos, Thomas, Jones, et al., 2019; Eriksrud et al., 2022; Nimphius et al., 2018). These methods often differ in notable variables that might influence the results and make comparing results difficult, as CoD is reported to be a task-specific skill (Dos'Santos, Thomas, Jones, et al., 2019; Eriksrud et al., 2022). This is apparent when evaluating and comparing tests like the Illinois agility test, 3-cone drill, and the T-test, and examples of significant variables are total test distance, the angle of the CoD, the number of CoDs, or external resistance (Nimphius et al., 2016). While all the referenced tests have benefits regarding specificity to a particular sport or situation, they also have significant shortcomings as CoD measures. Perhaps the most significant shortcoming is the extended duration of the tests, as these tests can last >10-14 s. This introduces a potential limitation in the participant's metabolic capacity, in addition to involving a significant amount of time where the participant is not changing direction (Nimphius et al., 2016; Vescovi & Mcguigan, 2008). The time not spent changing directions is often occupied by accelerating and sprinting, which makes them biased toward linear sprinting capabilities, thus, masking the participant's ability to change direction. As researchers have identified and reported these shortcomings, efforts to develop more valid tests have been made. An example is the 505 agility test, which limits these shortcomings significantly (Stewart et al., 2014).

2.2.1 The 505 agility test

The 505 agility test (505), described by Draper & Lancaster (1985), has a relatively short duration and involves a total of 20 m of running per trial. However, this includes a 10 m run-up, giving participants a "flying start" at the starting point of the measurement (Figure 2A) (Barber et al., 2016). The participant then sprints for an additional 5 m, performs a 180-degree turn, and sprints back to the measurement's starting point. While the 505 is superior to several other tests of CoD performance, it, too, has been criticized for the same shortcomings. For example, Nimphius et al. (2013) reported that a mere 31% of the total time of the 505 was spent changing directions. Because of these established limitations, researchers still aim to improve the tests for CoD assessment. For example, in the same article, Nimphius et al. (2013) propose the use of "Change of direction deficit", which can be described as the relationship between an individual's performance in a CoD test and a linear sprint test. Another example is the modified 505 agility test (m505). The m505 eliminates the 10 m flying start and has the participant standing still at the starting point but is otherwise identical to the original 505 agility test (Figure 2B) (Barber et al., 2016). However, it should be noted that several modified versions of 505 exist, and the same term has been used for differently designed tests in the literature (Baena-Raya et al., 2021; Eriksrud et al., 2022; Taylor et al., 2019). In the study included in the present thesis, however, only the described version of the m505 will be termed as such, as that was the test used for data collection.

A)

B)

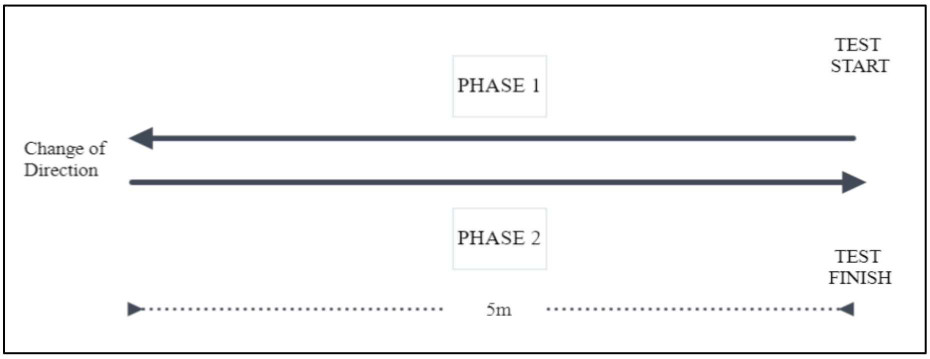

Figure 2. A) The original 505 agility test design **B)** A modified 505 agility test design.

Along with potential conflicting opinions regarding optimal tests to assess CoD, the heterogenicity in test design is likely due to differences in the measurement device. For example, both Baena-Raya et al. (2021) and Taylor et al. (2019) used photocell timing gates.

While photocells are commonly used when timing CoD, their sensitivity to movement makes it necessary for the participants to start a determined distance behind the starting position to avoid triggering them. Furthermore, using photocells only at the starting line and turning point provides limited information about performance within the different phases, i.e., acceleration, deceleration, and reacceleration, of a CoD- test. Considering the formerly mentioned masking effect of linear sprinting skills, this significantly compromises the strength of any conclusions regarding CoD-ability. These limitations can, however, be circumvented when using a motorized resistance device (MRD), which continuously collects data on position and velocity (Eriksrud et al., 2022).

2.2.2 The 1080 Sprint

In the study included in the present thesis, we used a portable MRD (1080 Sprint; 1080 Motion, Lidingö, Sweden), to collect data on distance and velocity during the CoD assessment. The 1080 sprint is a relatively novel device, with the first reports of application in research from 2018 (Derakhti, 2018; Rakovic et al., 2018). The 1080 sprint has been observed to have numerous areas of potential application, and it has been utilized as training equipment in intervention studies, and as a measurement device for sprint performance assessment (Lahti et al., 2020; Rakovic et al., 2018). This speaks to its versatility, as the 1080 Sprint may be used for both training, testing, and monitoring. Furthermore, a study by Rakovic et al. (2022), including 17 elite female handball players, recently investigated the criterion validity and within-session reliability of the 1080 Sprint for measuring sprints. Briefly summarized, the authors concluded that the 1080 Sprint provided both valid and reliable sprint performance measurements. Moreover, as a statement of its quality as a device to measure sprint performance, the 1080 Sprint has since been applied as the criterion in studies aiming to investigate the validity and reliability of other measurement devices (Gamble et al., 2023).

As for the use of the 1080 Sprint to assess CoD performance, the research literature is at an early stage of development. However, research is emerging (Eriksrud et al., 2022; Volk et al., 2023). For example, a recently published study by Eriksrud et al. (2022) investigated the validity of the 1080 Sprint in CoD assessment. The study used three-dimensional motion analysis data as their criterion method, using a complete body set of 63 reflective markers and 16 infrared cameras to collect the data. Moreover, the authors implemented the m505 test, making the results highly relevant to the present thesis. Briefly summarized, the study yielded very promising results, as excellent correlations and low coefficients of variation were reported between the velocity measured with the three-dimensional motion analysis data and the 1080 Sprint. Moreover, excellent correlations were reported in all assistance/resistance settings (3 kg, 6 kg, and 9 kg) investigated in the study, as well as for all phases of the m505.

Lastly, the application of externally assisted/resisted, i.e., externally loaded, CoD tasks, should be noted. External horizontal loading was also utilized in the study included in the present thesis and might have benefits related to its influence on the athlete's momentum. As CoD performance is highly dependent on an athlete's ability to create and change their momentum (Fernandes et al., 2020; Nimphius et al., 2018), externally loading specific phases have the potential to influence difficulty level or illuminate phase-specific weaknesses. With the m505 test design implemented in the study included in the present thesis, the athlete was facing the MRD during phase 1 and moving away from it during phase 2. Thus, the MRD provided the subjects with 3 kg external horizontal loading, facilitating greater velocity and momentum in phase 1, while making the reacceleration in phase 2 more challenging. Although the external loading makes time- and velocity data non-comparable to non-loaded test designs, the continuous data collection of the MRD might provide new insight into an athlete's CoD capabilities. Thus, the use of MRDs in CoD assessment shows great potential as a tool to better understand the determinants of CoD performance.

2.3 The training intervention

The intervention design is perhaps the most important methodological consideration in any training intervention study, as it lays the foundation for promoting the desirable physiological adaptations. Therefore, careful consideration should be given to coordinate intervention design and study aim when selecting or developing a training intervention. As the present thesis was part of a larger project, the primary aim of the intervention was that of the larger project. As previously stated, the aim was to investigate training methods for reducing KAM during handball-specific sidestep cuts and CoD in adolescent female handball players. However, as mentioned in the previous chapter, any IPP should have a secondary aim of improving performance. To support this secondary goal, many variables were considered when developing the intervention applied in the present study.

The intervention consisted of three segments, i) handball-specific sidestep cutting training, ii) MERT, and iii) CoD technique training. The upcoming article included in the present thesis contains a complete description of the CoD- and MERT programs; therefore, they will not be described in this chapter. Furthermore, as the present thesis did not use any data related to the handball-specific sidestep cuts, this part of the intervention will not be further mentioned. However, a comprehensive description elaborating on the details of the included exercises and the entirety of the intervention is included in Appendix 2 of the following article. Therefore, this subchapter will present research investigating the effects of the training methods utilized in the intervention, as well as the necessary consideration in using them.

2.3.1 Manual resistance training intervention

An important consideration in developing a resistance training intervention is the practical implementation. To facilitate this and promote adherence, the resistance training was implemented in the scheduled school curriculum handball training sessions. Therefore, the training had to be feasible on a handball field, as this was the location of most scheduled training sessions. Thus, traditional gym equipment was not available, and external resistance was provided by training partners. This method of applying external load to a movement is referred to as manual resistance training (MRT) (Dorgo et al., 2009). While it is common knowledge that traditional resistance training using barbells, dumbbells, or machines can induce increases in muscular strength, there are several further considerations to be made when incorporating MRT. Firstly, the external loading is of relevance. It should be noted that MRT presents obvious issues regarding registering and analyzing data on the precise external force applied. Thus, incorporating periodization and progression is difficult. Furthermore, the requirement of an additional individual may be challenging for some individuals. Moreover, communication between training partners is essential to optimize the training stimuli and provide accommodating resistance. In addition, large discrepancies in body weight between training partners might provide further considerations necessary. However, there are also notable benefits and research reporting its efficacy as a resistance training method.

For example, Kraemer et al. (2001) investigated the effects of six independent training programs performed over six months in untrained females. One included training program was exclusively exercises completed in the field, i.e., partner-based training and plyometrics. The authors reported several significant improvements in the field-based training group. Among these were significant increases in 1RM in the squat and bench press, bench throw, and 1RM box lift, as well as several strength-endurance- and aerobic measurements. These significant increases in a variety of strength measurements make the muscle-strengthening effect of the specific program apparent. However, the inclusion of exercises not based on manually induced resistance leaves significant uncertainty regarding the effects of partner-based exercises in isolation.

A study by Dorgo et al. (2009) provides insight into this. The study was conducted in college students, allocated into two separate intervention groups. Both groups were assigned a 14-week resistance training intervention, either a traditional weight resisted program or an MRT program. Apart from the method of external loading, the programs were structured identically. The programs consisted of full-body training sessions with exercises involving all large muscle groups. The training was organized as tri-sets, i.e., three exercises organized in a circuit with short rest intervals (20-30s) between each exercise. The study reported several findings relevant to the intervention used in the article included in the present thesis. For maximal muscle strength, 1RM was assessed in the bench press and squat at baseline and post-intervention. A significant increase was reported both for RT programs, independent of assessing relative or absolute strength. The same findings were reported in all muscular endurance outcomes. Moreover, no significant differences were reported between the groups in any strength outcome. These results suggest that an MRT program can induce the same physiological adaptations as a traditional weight resisted program.

However, the training status of the samples included in the two studies invites discussion. Kraemer et al. (2001) reported subjects to be untrained, while Dorgo et al. (2009) reported a variety of training experiences among the subjects. As the initial increases in strength are thought to be relatively easily achievable and a consequence of early neural adaptations (Carroll et al., 2001; Folland & Williams, 2007), resistance-trained subjects might be preferred, to provide insight beyond the initial months of resistance training. Furthermore, the lack of a control group is a methodological weakness observed in Dorgo et al. (2009) and Kraemer et al. (2001). Without it, the level of certainty related to the effect of the intervention is weakened, and stated or residual confounding factors may significantly influence the results (Ruble, 2017).

While there is no abundance of experimental research including a control group in investigation of the effects of MRT, there are some. Due to several relevant design similarities to the study included in the present thesis, a particularly interesting example is Dorgo, King, Candelaria, et al. (2009). The study was conducted as a cluster randomized control trial in adolescents, and the intervention was implemented in the high school's physical education curriculum. The study randomized and assigned classes to either a control group (school curriculum physical education classes), a MRT group, or a MRT combined with cardiovascular endurance group. The main objective was to assess the effect of the intervention programs on the student's fitness. The intervention period was 18 weeks, with a steady increase in training volume throughout the intervention, from 12 to 28 sets per training session. Similarly to Dorgo et al. (2009), the MRT was performed in full-body sessions using tri-sets and 20-30s rest intervals. The study included eight outcome measures to assess fitness, five of which included muscular strength; curl-up, trunk lift, push-up, flexed-arm hang, and modified pull-up. The MRT group was reported to significantly improve all measurements related to muscular strength. Apart from the flexed-arm hang, MRT combined with cardiovascular endurance group was reported to produce similar improvements. However, compared to the control group, both MRT groups failed to induce significantly different improvements in all test exercises except for the curl-up and push-up. The relatively large sample of 222 adolescents with complete datasets and the inclusion of a control group makes these findings highly relevant to the present thesis. Furthermore, as the training was conducted in very similar conditions, i.e., in a class setting on a field or gymnasium as a part of the high school curriculum, the results provide insight into what can be expected of an MRT intervention. However, it should be noted that the MRT interventions conducted by Dorgo, King, Candelaria, et al. (2009) had a duration more than twice that of the present thesis (8 weeks). Thus, the midway (9-week) results should also be mentioned. Interestingly, in terms of statistically significant differences, the findings were close to identical to the post-intervention findings. The only difference being that the MRT + cardiovascular endurance group was reported to have a significantly larger improvement in trunk lift than the control group. This further supports the question of the long-term efficacy of MRT, yet also suggest an effect on muscular strength, particularly short term.

Eccentric resistance training

Dynamic muscle activity is divided into two phases; eccentric and concentric (Roig et al., 2009). Eccentric muscle contractions (EMC) refers to the muscle contraction occurring when the force applied to the muscle exceeds the momentary force produced by the working muscle, resulting in a lengthening of the working muscle (Douglas et al., 2017b; Lindstedt et al., 2001). As mentioned in the previous chapter, most ACL injuries occur in the first 40 milliseconds after landing. This is during the deceleration phase, where athletes attempt to reduce or change their momentum, thus conducting the eccentric phase of the movement. Therefore, the resistance training program included in the present thesis was composed of exercises only utilizing the eccentric phase of the movement, i.e., eccentric resistance training (ERT). This is a well-established method of resistance training, first introduced in physiological studies in 1953 (Lindstedt et al., 2001). Thus, there is an abundance of research investigating its mechanisms and effect.

Resistance training is traditionally performed utilizing both EMC and concentric muscle contractions (CMC), with one eccentric and one concentric phase constituting one repetition (Suchomel et al., 2019). However, researchers are still interested in the effects of ERT, and new studies are published frequently (Douglas et al., 2017b, 2017a; Roig et al., 2009; Suchomel et al., 2019). Perhaps the most referenced quality of EMC is the early observed increased force output compared to CMC (Levin et al., 1927). This is important, as force output is thought to be crucial to stimulate muscular strength increases and is suggested to have a proportional relationship (Goldberg et al., 1975). While many mechanisms are involved in the physiological adaptation of ERT, the observations of intervention studies are more relevant to the present thesis. For example, a recent study by Hakkinen et al. (2022) investigated the effects of upper body ERT compared to upper body concentric resistance training (CRT) on hypertrophy, and dynamic- and IS in a sample of resistance-trained women. The duration of the intervention was ten weeks, and in addition to the baseline- and post-intervention- assessments, the subjects performed all tests one week before the baseline data collection and five weeks after the post-intervention assessment. The pre-baseline assessment was utilized as data for a control group, i.e., the participants acted as their control group, while the assessment five weeks after the post-intervention assessment was to evaluate the detraining effect. Regardless of group allocation, the intervention consisted of two supervised training sessions per week, with the weekly training volume increasing throughout the intervention. The program consisted of high-intensity isokinetic bench press using a device constructed specifically for the research purpose, and the remainder of the training was designed only to impede atrophy of leg and trunk muscles. The subjects performed 1RM and maximal IFO in the bench press at all four assessment time points, and several relevant findings were reported. While both the CRT and ERT group significantly increased their 1RM, only the ERT produced significant increases in IFO post-intervention. Furthermore, both CRT and ERT significantly increased the muscle mass in upper body extremities. However, the ERT group showed a significantly greater increase in muscle mass in the pectoralis major and triceps brachii, i.e., the primary agonist muscle groups, compared to the CRT group. Moreover, during detraining, only the ERT group was reported to maintain upper body extremity muscle mass significantly larger than at baseline.

Summarized, the study by Hakkinen et al. (2022) provides a rationale for including ERT in interventions aiming to increase muscular strength. However, considering that the different muscle groups are thought to respond differently to resistance training (American College of Sports Medicine, 2009; Roig et al., 2009), caution should be used when interpreting the results of this single study. Therefore, it should also be noted that similar findings have been reported in other upper-body (Sato et al., 2022; Valdes et al., 2021), and lower body muscle groups (Baroni et al., 2015). There are also several systematic reviews published on the effects of ERT (Douglas et al., 2017a; Roig et al., 2009). For example, a systematic review and meta-analysis by Roig et al. (2009) investigated the effect of ERT versus CRT on muscle mass and strength in healthy adults. The analysis included a total of 678 participants, and the results were in line with the previously mentioned experimental studies. The authors concluded that compared to CRT, ERT was associated with greater increases, not only in eccentric strength but also total strength, i.e., averaged concentric-, eccentric-, and isometric torque. While the findings further support the use of ERT to promote increases in muscular strength, some limitations have to be considered. Heterogeneity was reported in 16 of the 18 subgroup analyses, and the authors highlight differences in training intensity and intervention duration as potential reasons. As briefly mentioned in the MRT subchapter, initial increases in strength are thought to be easily achievable and a consequence of early neural adaptations (Carroll et al., 2001; Folland & Williams, 2007). Therefore, a considerable variation in intervention duration (4-25 weeks) limits the conclusions that can be drawn regarding if the mechanisms behind the increases in muscular strength were central, i.e., neural, or peripheral (Roig et al., 2009). Thus, uncertainty remains regarding the long-term effects. As for the influence of differences in resistance training intensity, a significant influence on physiological adaptations is reported (Schoenfeld, Grgic, et al., 2017). These will be presented further in the following subchapter.

Periodization and resistance training variables

When developing a resistance training intervention, several aspects and training variables should be considered and manipulated to induce the desirable outcome (Bird et al., 2005; Figueiredo et al., 2018). Examples of suggested relevant variables are repetitions per set (Carvalho et al., 2022; Schoenfeld et al., 2021; Schoenfeld, Grgic, et al., 2017), sets per exercise (Krieger, 2009; Ralston et al., 2017), sets per exercise or muscle group per week (Androulakis-Korakakis et al., 2020; Heaselgrave et al., 2019; Ralston et al., 2017), training frequency (Grgic et al., 2018; Heaselgrave et al., 2019) and proximity to failure (Refalo et al., 2022). Training periodization, i.e., the strategic manipulation of training over time (Moesgaard et al., 2022), is useful to provide a framework for the different phases included in the training plan (Bell et al., 2022; DeWeese et al., 2015b, 2015a). Dependent on the duration of the plan, the number and scope of these phases might vary.

The phases, or "cycles", can be categorized into microcycles, mesocycles, and macrocycles (V. Issurin, 2008). A microcycle is a short and repeatable phase, often 1-4 weeks, and is commonly referred to as a training block. Mesocycles are comprised of several microcycles, typically last 4-16 weeks, and allow for greater accumulation and realization of training stimuli. Macrocycles are long-term training plans comprised of subsequent mesocycles. The resistance training intervention in the article included in the present study lasted eight weeks; thus, a single mesocycle aiming to increase muscular strength was developed. The mesocycle was comprised of 3 microcycles, and block periodization was utilized. Traditionally, block periodization divides a mesocycle into distinct microcycles, with each microcycle aiming to promote a specific training goal. The effectiveness of this type of periodization is well established across several training goals in the scientific literature (V. B. Issurin, 2016; Stone et al., 2021). The intervention included a two-week microcycle aiming to familiarize the subjects with the exercises, followed by two independent blocks aiming to induce increases in muscular strength. This periodization framework provided the foundation for the MERT program. However, careful consideration of training variables was made in the further programming.

A very influential resistance training variable is training volume. However, training volume can be defined in different ways. Traditionally, total training load is perhaps the most utilized method and is calculated *weight * repetitions * set* for each exercise (Figueiredo et al., 2018). The method is observed to be useful in tracking training volume and providing data with a strong correlation to muscular hypertrophy. In recent decades, however, a new method has received significant attention from sports scientists. This method is the assessment of training volume by counting the weekly number of sets per muscle group or exercise. With a fast-growing literature, the field has, in the recent decade, generated sufficient data to complete more extensive reviews and analyses. An example is the recent systematic review that pointed out just how significant the influence of training volume is in inducing muscle hypertrophy (Schoenfeld, Ogborn, et al., 2017). The authors suggested a graded dose-response relationship, where muscle hypertrophy increases with the number of weekly sets (Schoenfeld, Ogborn, et al., 2017). However, other research suggests that differences in agonist muscle groups and the subjects' training status might influence the ideal number of weekly sets to maximize muscle hypertrophy (Baz-Valle et al., 2022; Heaselgrave et al., 2019).

The influence of training volume on muscular strength is also well-researched, and systematic reviews and meta-analyses have been published (Krieger, 2009; Ralston et al., 2017; Rhea et al., 2003). For example, Ralston et al. (2017) investigated the differences in muscular strength increase between low, medium, and high volume of weekly sets. Low, medium, and high training volumes were defined as <5, 5–9, and ≥10 sets per exercise per week, respectively. Separate analyses were done for exercise complexity, i.e., single and multi-joint exercises, and the influence of training status, e.g., novice, intermediate, advanced, was also investigated. Summarized, the results were in-line with the reports from the earlier systematic reviews and meta-analyses referenced above. However, their analysis provided useful insight into to nuances of the influence of resistance training volume. Not surprisingly, low volume was reported to be less effective than medium or high volume for increasing muscular strength, regardless of training status or exercise complexity. The results suggest that medium volume is sufficient for novice trainees. For intermediate or advanced trainees, medium and high volume is suggested to be preferable. Furthermore, examination of exercise-specific 1RM differences further supports the graded dose-response relationship. However, it should be noted that there are conflicting studies (J. S. Baker et al., 2013; Schoenfeld et al., 2019). Nevertheless, the literature suggests that there are benefits to performing medium and high volume (>5 sets per exercise per week) resistance training to induce muscular strength gains. However, there are indications of diminishing returns at very high volumes. As training volume is closely related to training frequency, it too, should be briefly mentioned. While training a specific muscle group or exercise more than once per week is often recommended (Bull et al., 2020), research mostly fails to observe the benefit when equating for training volume. This claim is supported by a recent systematic review and meta-analysis researching the topic (Grgic et al., 2018). The authors reported a dose-response relationship between training frequency and muscular strength gains, but when equating for weekly training volume, no association was observed. There should, however, be noted that incorporating an excessive number set for a single exercise or muscle group in a single training session might be detrimental to performance (Ribeiro et al., 2015). Therefore, increasing the training frequency might be beneficial at high training volumes.

Repetitions performed per set is considered an important variable when attempting to induce specific physiological adaptations from resistance training. A “repetition continuum” model has been postulated, suggesting that the number of repetitions performed per set is highly influential to specific adaptations (Schoenfeld et al., 2021). Specifically, the model suggests performing <5 repetitions for strength goals, 8-12 repetitions for hypertrophy, and >15 repetitions for muscular endurance goals. While the model has been criticized, particularly regarding the repetition range of hypertrophy, the results of several systematic reviews and meta-analyses suggest it to be accurate regarding the repetition range for increasing muscular strength across different populations (Carvalho et al., 2022; Csapo & Alegre, 2016; Schoenfeld, Grgic, et al., 2017). Thus, there seems to be no uncertainty as to whether low-repetition resistance training sets are effective in increasing muscular strength. However, it should be noted that the number of repetitions performed in the studies mentioned in the present paragraph are mostly stated as *repetition maximum*. In other words, the sets were performed with the highest load possible while achieving the prescribed number of repetitions or until muscular- or volitional failure was reached. Thus, the prescribed number of repetitions is closely related to the load being used in an inverse relationship, as the ability to perform repetitions decreases with an increasing load (Kraemer & Ratamess, 2004). This makes the subject of training intensity necessary to mention.

Within the field of resistance training, training intensity has often been prescribed as a percentage of 1RM (Harris et al., 2004; Nuzzo et al., 2023; Zourdos et al., 2016, 2021). The measure of intensity provides the athletes with an exact load and is usually prescribed accompanied by a number of repetitions and sets, for example, 3 sets of 10 repetitions at 70% of 1RM. While the method has been utilized in successful interventions, recent research suggests that the measure might have significant limitations. These limitations are related to the individual variance reported in achievable repetitions at a given % of 1RM. An example of this is observed in the study by Cooke et al. (2019). The fifty-eight subjects performed the back squat at 70% of 1RM and were instructed to complete as many repetitions as possible. The authors reported the mean number of repetitions ranging from 6-26, suggesting a very significant individual variation. Similar findings have also been reported by others, further suggesting that intensity estimated by the percentage of 1RM might be flawed (Hoeger et al., 1990; Richens & Cleather, 2014).

As the objective measure of intensity seemingly has significant shortcomings, subjective measures have been proposed. The Borg scale (Borg, 1970) is such a measure, involving the athlete rating their perceived level of exertion (RPE) on a scale ranging from 6-20. The Borg scale is reported to be a great assessment tool in endurance activities and is significantly correlated with heart rate (Morishita et al., 2018; Pfeiffer et al., 2002; Robertson & Noble, 1997; Scherr et al., 2013). However, as the fatigue induced by resistance training is local to the working muscles, other scales assessing subjective RPE have been suggested (Hackett et al., 2012; Helms et al., 2018; Lagally et al., 2002; Robertson et al., 2003). An example of this is *repetitions in reserve* (RIR), which was used to prescribe training intensity in the article included in the present thesis. RIR-based load prescription assigns the athlete with a target number of repetitions, but in addition, provides the number of repetitions the athletes should be removed from completing their repetition maximum (Zourdos et al., 2016). For example, if a trainee is capable of performing a maximum of 8 repetitions with a specific weight but concludes the set at 6 repetitions, this would be 2 RIR, as the athlete had two repetitions in reserve. If they performed 5, it would be 3 RIR, and so on. While studies are supportive of utilizing RIR to assess intensity (Graham & Cleather, 2021; Helms et al., 2018; Zourdos et al., 2016), it should be noted that it has some limitations. These are mostly related to inaccuracy in intra-set assessment, as most individuals are reported to underestimate RIR (Halperin et al., 2022; Pelland et al., 2022; Zourdos et al., 2021). This provides researchers and practitioners with a challenge, as some studies have suggested that proximity to failure has a significant influence on inducing muscular strength increases and hypertrophy when training volume is equated (Grgic et al., 2022). However, studies observe that RIR is significantly easier to estimate with heavier loads and lower RIR (Zourdos et al., 2021), suggesting that RIR is still an effective intensity prescription for interventions aiming to increase muscular strength. It should also be noted that some studies have failed to observe a difference in training to failure or non-failure, thus further research is needed (Vieira et al., 2021).

To summarize, numerous variables significantly influence the strengthening effect of a resistance training intervention. To facilitate increases in muscular strength, the current literature suggests using periodization to create a framework for programming training variables. Furthermore, sufficient weekly training volume (>5 sets per exercise per week) should be assigned. In programs and interventions assigning very high training volume, an increased training frequency might be beneficial to intra-session performance, which in turn might induce greater increases in muscular strength. Lastly, the sets should be performed at a low RIR, with a heavy external load, and consequently, in sets of relatively few repetitions.

2.3.2 Change of direction intervention

As briefly mentioned, the study included in the present thesis was part of a larger project. Thus, the aim of the CoD intervention was that of the larger project. Therefore, the main aim was to reduce KAM, not prioritizing the improvement of PP. However, the primary technical cues implemented in the intervention should be briefly mentioned. The CoD intervention was included in the intervention group's handball training warm-up protocol. Throughout the eight-week intervention, three CoD exercises were performed, gradually increasing exercise complexity and intensity. However, the primary technical cues were the same. The purpose of the cues was to influence factors reported to be associated with low KAM during CoD and cutting (A. S. Fox, 2018; Kristianslund et al., 2014; Leppänen et al., 2021). The cues were: (i) to keep the majority of their body weight over their non-turning leg, i.e., keep a neutral torso, and (ii) avoid knee valgus on the turning leg. While maintaining a neutral torso and avoiding knee valgus are reported to have benefits in reducing KAM, the influence on CoD performance has to be elaborated.

The study included in the present thesis was a pilot study aiming to provide insight into a specific and relatively narrow field of research. Consequently, there is limited previous research to provide a rationale for expectations. Indeed, to the best of the author's knowledge, no previous studies have incorporated the mentioned cues in a study aiming to assess CoD performance. However, intervention studies aiming to improve CoD- and cutting performance through technique training have been successful (Dos'Santos et al., 2021; Dos'Santos, McBurnie, Comfort, & Jones, 2019). Thus, there is evidence to support the notion that CoD technique and performance have the potential to be significantly influenced by short-term training interventions. Furthermore, the six-week intervention in the study by Dos'Santos et al. (2021) does have similarities to the CoD intervention used in the article in the present thesis. For example, the training principles of progression and specificity are apparent. Furthermore, there are relevant overlaps of the exercises utilized in the respective studies. However, it should not be ignored that the cues and training by Dos'Santos et al. (2021) aimed to improve performance. Therefore, similar efficacy in CoD performance improvement might not be reasonable to expect. Furthermore, Dos'Santos et al. (2021) a large volume of CoD training in their intervention, assigning the intervention group 260-330 meters of specific CoD training, including 19-30 deceleration and 24-36 CoDs every week throughout the intervention. Nevertheless, despite significant uncertainty, reports of significant CoD performance improvements from short-duration CoD training interventions suggest a potential for the CoD technique intervention included in the following article to improve PP.

2.4 Ethics

The Regional Committee for Medical and Health Research Ethics, South Eastern Norway Regional Health Authority, was not responsible for the ethical evaluation of this study as it did not fall under the Health Research Act. Therefore, the study was submitted to and approved by the ethical committee of the Norwegian School of Sport Sciences (Appendix 1). It also conformed to the latest revision of the Declaration of Helsinki. All participants signed a written informed consent form prior to inclusion, which emphasized the rights of the participants, including voluntary participation and the right to withdraw from the study at any time (Appendix 2). In addition, participants below the age of 16 years old were required to have their parents or guardians sign an additional written consent form. The study was also approved by the Norwegian Social Science Data Services to adhere to data privacy regulations (Appendix 3). All personal data were non-identifiable during data collection and anonymized after data collection. Co-authorship was regulated according to the Vancouver Convention, and a complete list of project contributors is in Appendix 4.

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3 Article

3.1 Title page

Manuscript title: Physical performance aspects of an ACL-injury prevention program in adolescent female handball players – a cluster randomized controlled pilot study

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Physical performance aspects of an ACL-injury prevention program in adolescent female handball players – a cluster randomized controlled pilot study

3.2 Abstract

Background High knee abduction moments (KAM) is a significant risk factor for anterior cruciate ligament (ACL) injury for both in CoD and sidestep cutting. However, the influence of training interventions on KAM remains unclear. To promote the implementation of injury prevention programs (IPP) in athletes, a secondary aim of improving physical performance (PP) should be incorporated. **Purpose** The purpose of this cluster-randomized controlled pilot study was to investigate the effect of an ACL- injury prevention intervention on isometric strength and CoD performance in adolescent female handball players. Furthermore, we wanted to investigate the association between IS and CoD performance. **Methods** Forty-nine adolescent female handball players (age 16.73 ± 0.9 years) from three Norwegian high schools participated in the eight-week intervention study. The schools were randomized to an intervention group (IG) (*n=22*) or control group (CG) (*n=27*). The intervention consisted of three segments; (i) handball sidestep cutting-technique training, (ii) manual eccentric resistance training, and (iii) CoD technique training. Relative isometric force output was measured to assess isometric strength in hip abduction (ABD), external hip rotation (EXT), and plantar flexion (PFL). were measured to assess pre-post change and IS-COD association. **Results** IG increased IFO significantly compared to the CG in PFL (*4.94%, p = 0.039*), but not ABD (*5.67%, p = 0.319*) or EXT (*3.78%, p = 0.448*). However, compared to baseline, IG increased IS in all outcomes. IG did not improve CoD Total time (*-3.43%, p = 0.118*), but Phase 1 time was significantly reduced (*-3.47%, p= 0.015*). Moderate correlations for CoD Total time and all IS outcomes were observed pre- and post intervention. Changes in IFO was not associated with changes in CoD total time. **Conclusion** Overall, the ACL- injury prevention intervention was unsuccessful in improving physical performance. IS was significantly associated with CoD performance at both time points. However, changes in IS were not associated with changes in CoD performance.

Keywords: injury prevention, resistance training, change of direction, manual resistance

3.3 Introduction

Anterior cruciate ligament (ACL) injuries are common among athletes but have significant consequences (Montalvo et al., 2019). Short-term, pain and debilitation may cause an absence physical activity and sports, which can result in may result in a cascade of negative outcomes (Busfield et al., 2009; Prodromos et al., 2007; Shah et al., 2010; Waldén et al., 2011). Long-term, ACL injuries are associated with an earlier and increased risk of developing osteoarthritis (Lohmander et al., 2007; van Yperen et al., 2018), which is associated with reduced physical activity (Farr et al., 2008; Raijmakers et al., 2015). Thus, ACL injuries contribute to the public health threat of physical inactivity (Zebis et al., 2016). Furthermore, for aspiring adolescent athletes, absence from their sport may cause lost career opportunities and anxiety toward a return to sports (Shah et al., 2010).

Despite substantial efforts to prevent ACL injuries, a systematic review and meta-analysis by Bram et al. (2021) reported an ACL injury risk of nearly 1 per 10 000 athlete-exposure in adolescent female athletes. The highest incidence is observed in sports involving athletes rotating and changing direction, and the majority of ACL injuries occur during non-contact situations, such as cutting, jumping, and single-leg landing maneuvers (Koga et al., 2010, 2011; Kristianslund et al., 2014; Olsen et al., 2004; Zebis et al., 2022). Dynamic valgus and knee abduction moments (KAM) are identified risk factors (Hewett et al., 2005). Measured in in drop jump screening test, KAM can predict ACL injury; however, the test has been criticized (Kristianslund & Krosshaug, 2013; Krosshaug et al., 2016). Therefore, sport specific screening methods have been proposed. A study by Kristianslund & Krosshaug (2013) compared drop jumps to a handball specific sidestep cutting test and reported six times higher KAM during the sport specific test. Subsequent studies have identified biomechanical variables of influence, and are reported to explain 62% of KAM (Kristianslund et al., 2014). Particularly, high knee valgus and heel landing predicted high KAM. Thus, methods of promoting forefoot landing and avoid knee valgus during sidestep cutting is highly relevant from an injury-preventing perspective. Knee valgus has also been reported to increase KAM during change of direction (CoD) tasks not related a specific sport (Dos'Santos et al., 2019). Furthermore, lateral trunk flexion over the plant, i.e., turning foot, is associated with higher KAM (Dempsey et al., 2007; Jones et al., 2015). Therefore, to reduce KAM, and thus ACL injury risk, coaches and athletes should implement strategies to influence these biomechanical factors.

However, aspiring athletes will always want to improve their physical performance (PP). Therefore, ACL injury prevention programs should aim to improve it. In addition to its association with ACL injury risk, CoD is also attribute related to PP. It is a fundamental physical attribute of many field-based sports, and its importance is well-documented across various sports (Paul et al., 2016; Sheppard & Young, 2006). In invasion sports, i.e., sports evolving opposing teams attempting to invade their opponent's territory and score goals (Young et al., 2015), the ability to rapidly change directions can contribute to penetrating defensive lines and creating goal-scoring opportunities (A. Fox et al., 2014; Zahidi & Ismail, 2018). Another important physical attribute is muscular strength (Chaabene et al., 2020; Suchomel et al., 2016). In sports involving physical contact with an external object, e.g., an opponent, a ball, or a barbell, muscular strength is also essential for the ability to manipulate them or it. Furthermore, an individual's ability to manipulate their body mass and exert force against gravity can be associated with important PP variables, such as sprinting, jumping, and CoD. Manual resistance training (MRT) is resistance training performed with training partners providing the external resistance, and has been reported as effective for increasing muscular strength (Dorgo, King, & Rice, 2009) However, there is limited knowledge about its efficacy in adolescent athletes.

Therefore, the purpose of the present study was to assess PP aspects of a ACL- injury prevention pilot intervention. The aims were two-fold, (i) to investigate the effect of a combined CoD technique- and MERT intervention on isometric strength and CoD performance, and (ii) investigate the association between IS and CoD performance.

3.4 Methods

3.4.1 Study design and subjects

The study was designed as a cluster randomized controlled trial. Three Norwegian high school sports schools were contacted, and fifty-one adolescent female team handball players were recruited. All the participants attended their respective school's team handball specialization course, in addition to playing in various team handball clubs (elite division, 1st, 2nd, or 3rd division). Furthermore, all subjects reported conducting resistance training weekly. The schools were randomized and allocated to a group; two in the control group (CG) and one in the intervention group (IG).

3.4.3 Physical performance assessment

Isometric strength assessment

IS testing took place at the school's scheduled curriculum handball training at two times PRE and POST. Isometric hip abduction (ABD) and external hip rotation (EXT) strength were assessed bilaterally using Force Frame^{TM} (Vald Performance, Albion, Australia) at a sampling frequency of 50 Hz. Isometric plantar flexion (PFL) was assessed unilaterally using the HUR Labs FP4 (HUR lab Oy, Kokkola, Helsinki, Finland) at a sampling frequency of 1200 Hz. Upon arrival at the laboratory, the participants received a verbal description of the procedures and were instructed to perform a 5-10 min warm-up of their choice. The participants initiated the testing protocol with the ABD strength test, followed by the EXT strength test, and lastly, the PFL strength test. For all tests, the participants were instructed to familiarize themselves with the test through two trials at 60 and 80% of maximum effort before completing a 5-second maximum effort trial.

The hip abduction assessment was conducted with the participants in the supine position facing the ceiling with fully extended hip- and knee joints. The participants were instructed to keep their hands on their shoulders, arms crossing over the chest. Furthermore, the participants were instructed to avoid bending their knees, elevating their hips, and externally rotating their legs as they applied maximum lateral force. The force sensors were placed at hip-width at their lateral malleolus. For the external hip rotation assessment, the subjects remained in the supine position. The knee joint was at 90° flexion, and the soles of the feet were flat on the ground as they applied maximum lateral force to the sensors placed at hip-width at the lateral epicondyle of the femur. A goniometer was used to set the joint angle. For the ankle plantar flexion assessment, the participants stood upright in the center of the force plate. They were instructed to maintain an extended knee on the working leg throughout each test trial, while applying maximum vertical force to a fixed barbell.

Change of direction performance assessment

The CoD testing took place in the biomechanics laboratory at the Norwegian School of Sport Sciences. CoD performance was assessed at baseline (PRE) and 1-3 weeks after the completion of the intervention (POST). A portable motorized resistance device (MRD) (1080 Sprint; 1080 Motion, Lidingö, Sweden) was used to assess time and position at a sampling frequency of 333 Hz. The MRD was connected an external portable computer using the 1080Motion (Version 6.0.9.0) software. The settings were: load, 3kg resistance/3kg assistance; mode, no flying weight; gear, first; and speed limit, 14 m/s resistance/14 m/s assistance.

The warm-up consisted of a general and a specific part. The general warm-up consisted of ~5 min of low-intensity cycling on a stationary bike, ~5 min of low-intensity running and side shuffling, and bodyweight exercises. Preceding the specific CoD warm-up, the subjects conducted ~30 min handball-specific sidestep-cutting tests (Appendix 1). Finally, before initiating the specific warm-up, the subject watched a video of the CoD test procedure and received a verbal explanation of the test. The specific warm-up consisted of familiarization trials. The subjects were instructed to perform as many sub-maximal trials as necessary and to inform the test conductor when they were ready to initiate the recording of maximum-effort trials. The subjects completed four successful repetitions of the m505 test, performing two turns off each leg. The test course was measured at 5 meters and marked with cones (Figure 1). The subjects were instructed to start with the front of their lead foot as close to the starting line as possible and aim to place their turning foot in line with the cones marking the turning point. For a valid test, some part of the subjects turning foot had to be in line with the cones. Two laboratory assistants controlled this, overlooking the tests from two separate angles.

During phase 1 of the m505, the subjects ran towards the MRD. Phase 2 involved reaccelerating away from the MRD. Thus, the MRD applied 3 kg of assistance during Phase 1 and 3 kg of resistance during Phase 2. The fiber cord from the MRD was attached to the subject using a carabiner onto a freely rotating pulley (Cyclone 52; Purmotion, United States), which in turn was attached to a belt with two carabiners (1080 Vest; 1080 MAP AS, Oslo, Norway). When turning off the left foot, the carabiners were attached over the right hip and vice versa. This was to ensure that the fiber cord from the MRD was not in conflict with the CoD movement.

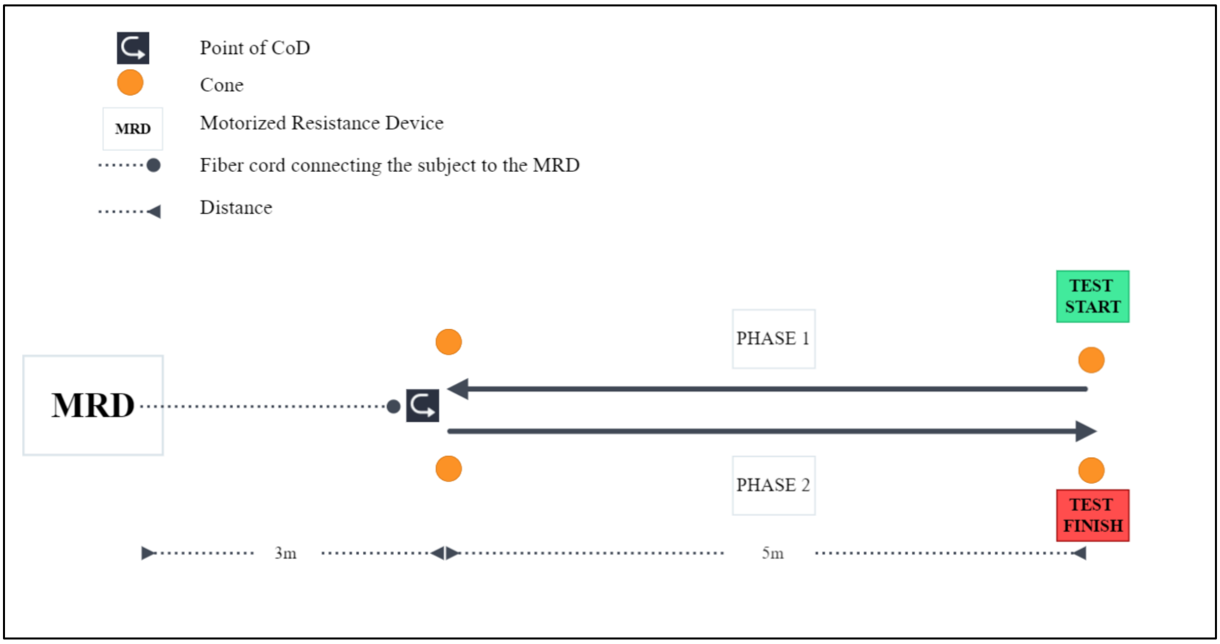

Figure 1. Modified 505 test design.

3.4.4 Training intervention

Following the baseline data collection, the intervention group was assigned an 8-week training intervention. The intervention consisted of three segments; (i) handball sidestep cutting-technique training, (ii) manual eccentric resistance training, and (iii) CoD technique training. The present study did not use data related to team handball sidestep cutting. Therefore, only the CoD technique and MERT training programs will be described. However, a detailed description of the complete intervention is found in Appendix 2.

The subjects were instructed to perform the CoD and MERT at least twice per week throughout the intervention, i.e., 16 CoD technique training sessions and 16 MERT sessions, with additional sessions being permitted. The training sessions were part of the subject’s high school team handball curriculum, and the sessions were supervised by the handball team’s coaches. The coaches had been instructed by the authors on the execution of the separate exercises and the entirety of the program. If unable to attend scheduled training, subjects were instructed to ensure completion in their leisure time. As the intervention period encompassed the subjects mid-term break, a reminder was communicated the preceding week. Furthermore, the subjects were offered coaching by the researchers on their normally scheduled training days. To assess compliance, the subjects answered a questionnaire at intervention completion.

The MERT program consisted of three bodyweight exercises. The exercises were clamshells, dynamic side planks, and unilateral calf raises (Figure 2). The training program was periodized, and each session was performed twice a week (Table 1). For all exercises, the subjects were instructed to emphasize a controlled eccentric phase, utilizing the full range of motion. Furthermore, the participants were instructed to communicate throughout sets to achieve the target RIR and ensure sufficient resistance throughout full range of each repetition. The training duration was estimated at ~15-20 min.

Table 1. Manual eccentric resistance training intervention.

	Week 1-2			Week 3-5			Week 6-8		
Exercise	**Reps**	**Sets**	**RIR**	**Reps**	**Sets**	**RIR**	**Reps**	**Sets**	**RIR**
Dynamic side plank	8	1	2-3	6	2	1	4	3	0
Clamshell	8	1	2-3	6	2	1	4	3	0
Standing unilateral calf raise	8	1	2-3	6	2	1	4	3	0

Abbreviations: Reps, repetitions; RIR, repetitions in reserve.

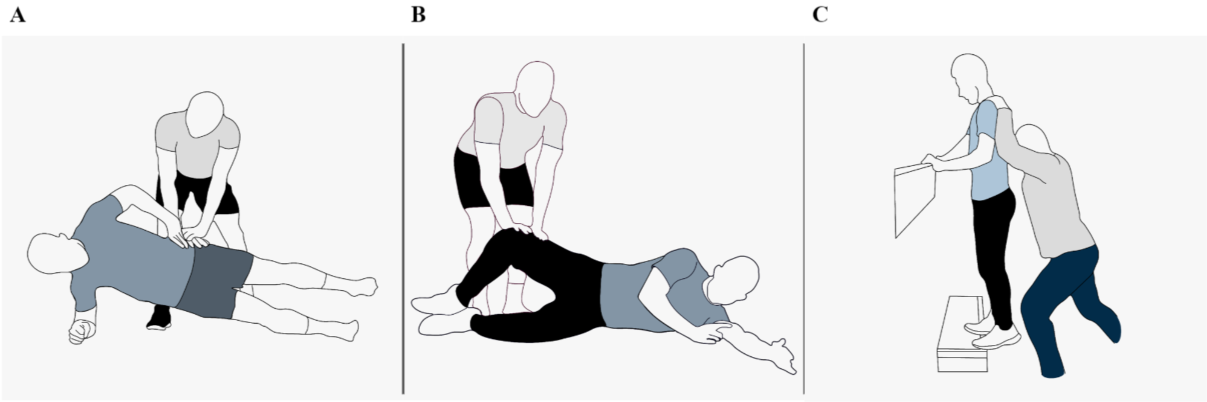

Figure 2. Manual eccentric resistance training exercises. **A)** Dynamic side planks **B)** Clamshells **C)** Standing unilateral calf raise

The CoD training intervention consisted of three training blocks, weeks 1-2, 3-5, and 6-8, with one block consisting of one exercise (Table 2). Each session was performed twice per week and incorporated to the warm-up for a handball training session. The exercises were step-downs, side shuffle CoD, and sprint CoD. For all CoD exercises, the participants were instructed to avoid leaning their trunk over the outer leg, i.e., turning leg, thus, keeping most of their body weight on their inner leg. In addition, the subjects were instructed to avoid valgus collapse on the turning leg. Furthermore, the subjects were instructed to prioritize the technique, and increase the speed as they familiarized and improved their skills in the exercise. The step-downs were performed on a ~15 cm step-box (Figure 3A). Subjects stepped down and back with alternating legs, with the leg on the box defined as the inner leg. The side-shuffle was conducted on a track marked by cones measured at 5m apart (Figure 3B). The subject conducted moderate intensity sideway shuffles between the cones, changing direction at each cone. The sprint CoD was conducted on the same track as the side shuffle. However, the subjects were instructed to perform the exercise running forward at maximal intensity.

Table 2. Change of direction training intervention overview.

	Week 1-2			Week 3-5			Week 6-8		
	Time (s)	Sets	Intensity	Time (s)	Sets	Intensity	Reps*	Sets	Intensity
Step-downs	30	3	Moderate	-	-	-	-	-	-
Side shuffle CoD	-	-	-	30	3	Moderate	-	-	-
Sprint CoD	-	-	-	-	-	-	2*	2	High

*Change of directions per leg.

Abbreviations: CoD, change of direction

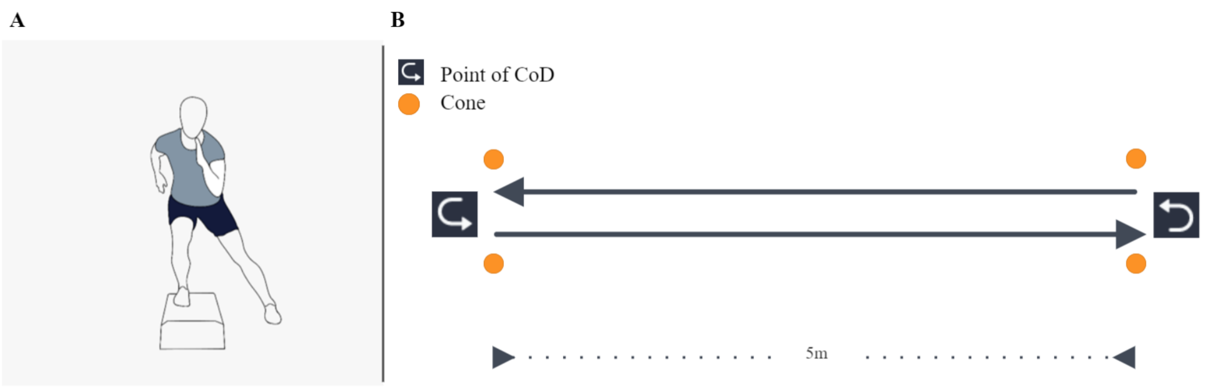

Figure 3. The change of direction technique exercises **A)** Step down **B)** The track used for side-shuffle and spint change of direction.

3.4.5 Statistical analysis

For all IS outcomes, left and right leg average was calculated, and relative peak IFO was used in the analysis. CoD Total time was defined as the main CoD performance outcome. Therefore, all COD data was extracted from each subject's fastest m505 trial. All statistical analyses were performed using IBM SPSS Statistics 29.0.1.0. Alpha (α) levels for testing statistical significance were set at .05. All variables were assessed for normality using the Shapiro- Wilks test. Dependent on parametric data and normal distribution, data were described using mean ± SD. Paired samples T-tests were performed to examine within group changes. Independent T-tests were performed to examine between group differences. Levene's test for equality of variances was used to assess intergroup variance. The relationship between IS and CoD was assessed using bivariate Pearson correlation coefficient. For inclusion, a compliance of 80% was required in the CoD technique sessions and MERT training sessions, respectively.

3.5 Results

Forty-two subjects completed all tests. Two subjects did not fulfill the compliance criteria; thus, forty subjects were included in the analysis, (Table 3). There were no significant differences in characteristic between the groups, except for height (*3.9 cm, p = 0.036*). At baseline, no differences were observed in any IS measure. However, significant differences were observed in CoD total time, Phase 1 speed, and Phase 2 speed (Table 4). All included IG participants completed ≥16 *(100%)* CoD and MERT sessions, respectively.

Intra-group, no significant pre- post changes were observed in any exercise for the CG (Table 5). The IG significantly increased IFO in ABD *(0.11 N/kg, p = 0.002)* and PFL *(1.33 N/kg, p =0.004)*, but not EXT (*0.16 N/kg, p =0.054*). There was a significant inter-group differences in change in IFO in PFL (*p = 0.039*), but not ABD (*p = 0.319*) or EXT (*p = 0.448*). There were no intra-group differences in CoD peak speed in either phase for either group. For trial duration, intra-group pre- post differences were observed in CG for Phase 2 (-*0.6 s, p = <0.001*). For the IG, pre- post differences were observed in Total time (-*0.11 s, p = 0.004*), Phase 1 (-*0.06 s, p = 0.032*), and Phase 2 (-*0.05 s, p = 0.002*). No inter-group difference was observed in change of Total time (*p = 0.118*) or Phase 2 (*p = 0.374*). However, a significant reduction in Phase 1 duration was observed for the IG compared to CG (*p = 0.015*). There were no between-group differences in CoD peak speed. At baseline, significant moderate correlations between CoD Total time and all IS outcomes was observed for all participants pooled, and CG and IG respectively (Table 6). Post intervention, significant correlations was observed in CG and all participants pooled. No significant correlation was observed between change in CoD Total time and change in any outcome.

Table 3. Subject characteristics.

	Control (n=21) (mean ± SD)	**Intervention (n=19)** (mean ± SD)
Age (years)	16.6 ± 0.7	16.7 ± 1.1
Height (cm)	170.5 ± 5.8	174.4 ± 5.7*
Bodyweight (kg)	69.0 ± 10.4	68.9 ± 8.0
Weekly training (hours)		
Total weekly training	10.9 ± 3.3	12.0 ± 1.8
Resistance training	3.3 ± 1.2	3.9 ± 0.8
Team handball training	7.5 ± 2.5	8.1 ± 1.4
Player position (n)		
Line	6	3
Center back	2	0
Left/right back	10	13
Left/right wing	3	3

* Significantly different from control, $P < 0.05$.

Abbreviations: cm, centimeters; kg, kilograms; SD, standard deviation.

Table 4. Change of direction performance outcomes.

	Baseline		**Post intervention**	
	Control (n=27) (mean ± SD)	**Intervention (n=22)** (mean ± SD)	**Control (n=21)** (mean ± SD)	**Intervention (n=19)** (mean ± SD)
Trial duration (s) (mean ± SD)				
Total time	3.38 ± 0.20	3.21 ± 0.15*	3.31 ± 0.22 (-2.07)	3.10 ± 0.15 (-3.43) **
Phase 1	1.78 ± 0.12	1.73 ± 0.12	1.81 ± 0.14 (1.69)	1.67 ± 0.11 (-3.47) **,***
Phase 2	1.55 ± 0.11	1.48 ± 0.05	1.49 ± 0.10 (-3.87) *	1.43 ± 0.07 (-3.38) **
Peak speed (m/s) (mean ± SD)				
Phase 1	4.68 ± 0.28	5.03 ± 0.47 *	4.59 ± 0.29 (1.92)	4.83 ± 0.49 (-3.98)
Phase 2	4.60 ± 0.34	4.84 ± 0.28 *	4.64 ± 0.32 (0.87)	4.93 ± 0.43 (1.86)

* Significantly different from control at baseline, P <0.05

** Significantly different from baseline, P < 0.05.

*** Significantly different from control, P < 0.05.

Abbreviations: m/s, meters per second; s, seconds; SD, standard deviation; 95%CI, confidence interval; ; SD, standard deviation; 95%CI, confidence interval.

Table 5. Relative peak force output in all isometric strength outcomes.

	Baseline		Post-intervention	
	Control (n=27)	**Intervention (n=22)**	**Control (n=21)**	**Intervention (n=19)**
	Mean ± SD	Mean ± SD	Mean ± SD (% change)	Mean ± SD (% change)
Hip abduction (N/kg)	1.89 ± 0.38	1.94 ± 0.37	1.96 ± 0.40 (3.70)	2.05 ± 0.36 (5.67) *
90° external rotation (N/kg)	4.25 ± 0.85	4.23 ± 0.61	4.34 ± 0.88 (2.12)	4.39 ± 0.62 (3.78)
Unilateral plantar flexion (N/kg)	25.14 ± 4.64	26.90 ± 2.71	24.26 ± 4.60 (-3.51)	28.23 ± 2.66 (4.94) *,**

* Significantly different from baseline, P < 0.05.

** Significantly different from control, P < 0.05.

Abbreviations: N/kg, Newton per kilogram; SD, standard deviation; 95%CI, confidence interval.

Table 6. Pearson correlation coefficients of CoD total time and IS outcomes.

	Baseline CoD total time		
	Control	Intervention	All
	n=27	*n=22*	*n=49*
Baseline hip abduction	-0.516**	-0.590**	-0.530**
Baseline 90° external rotation	-0.396*	-0.662**	-0.432**
Baseline unilateral plantar flexion	-0.535**	-0.420	-0.537**
	Post-intervention CoD total time		
	Control	**Intervention**	**All**
	n=21	*n=19*	*n=40*
Post-intervention hip abduction	-0.455*	-0.421	-0.441**
Post-intervention 90° external rotation	-0.441*	-0.244	-0.346*
Post-intervention unilateral plantar flexion	-0.433*	-0.142	-0.507**
	Change in CoD total time		
	Control	**Intervention**	**All**
	n=21	*n=19*	*n=40*
Change in hip abduction	-0.204	0.387	-0.294
Change in 90° external rotation	0.435	0.137	-0.267
Change in unilateral plantar flexion	-0.009	0.146	-0.119

* Significant at the 0.05 level

** Significant at the 0.01 level

3.6 Discussion

The present study implemented an intervention comprised of three separate segments, all having a primary aim of reducing KAM in handball specific sidestep cuts and CoD. However, the aim of the present study was to (i) to investigate the effect of an eight-week CoD technique- and MERT intervention on IS and CoD performance; and (ii) to investigate the association between IS and CoD performance. For IS, we observed significant improvements in PFL, but not ABD or EXT. For CoD performance, the main outcome was not improved; however, significant improvements were observed in Phase 1 Time. A significant negative correlation was observed between IS outcomes and CoD at baseline, but for the IG, the correlation was absent post intervention. Furthermore, no significant correlation was observed between change in IS and change in CoD performance.

3.6.1 Muscular strength

The MERT aimed to reduce KAM mediated by muscular strength improvements in the ankle plantar flexors, hip abductors, and hip external rotators. However, significant improvements were only found in PFL. No previous studies have investigated the efficacy of a MERT program in strengthening these muscle groups. Furthermore, the literature investigating the effects of MRT mostly utilizes both the concentric and eccentric phase of the exercises. Thus, methodological comparable research is relatively sparse. To the best of the authors knowledge, only Katsura et al. (2019) has investigated the effect of MERT on muscular strength. Katsura et al. (2019) investigated the effect of MERT on knee extensor maximal voluntary isometric contraction strength in older adults and reported significant increases in knee extensor maximal voluntary isometric contraction strength. However, the significant discrepancy in age and training status compared to the subjects included in the present study provides uncertainty regarding transferability of findings (Lemmer et al., 2000).

While there is a lack of research investigating the effect of MERT on muscular strength, there are several studies investigating MRT using combined concentric and eccentric training. As the eccentric phase is frequently emphasized in these studies, some are relevant. Overall, MRT is suggested to be effective to increase muscular strength. Most studies have found significant improvement from a MRT intervention (Boede et al., 2017; Dorgo, King, Candelaria, et al., 2009; Dorgo, King, & Rice, 2009; Tokumaru et al., 2011), and almost no studies have reported null findings (Chulvi-Medrano et al., 2017). However, as the participants of Boede et al. (2017) and Tokumaru et al. (2011) were elderly, the issues of age-discrepancy remains. However, in a 14-week intervention study, Dorgo et al. (2009) compared a MRT program to a traditional weight-resisted resistance training program in healthy college students. Some subjects reported having resistance training experience, and 45% reported engaging in ≥2 hours of weekly resistance training prior to the start of the study. A significant increase in muscular strength was observed in both groups. Furthermore, no difference was observed in muscular strength improvements between the training groups, indicating that MRT can provide similar improvements as traditional resistance training. However, incomplete information about the resistance training status of the subjects influences the interpretation of the findings.

Generally, resistance trained individuals are more dependent on the long term hypertrophy to increase muscular strength, while untrained individuals might increase muscular strength significantly through early neurological adaptations (Moritani & deVries, 1979). While muscular strength improvements generated by early neurological adaptations are valuable, they provide no insight into long term effects of an intervention. Interestingly, this might be observed in another study reporting significant improvements in muscular strength after a MRT intervention (Dorgo, King, Candelaria, et al., 2009). The participants were high school students (15-16 years), naturally clustered by their school classes, with the intervention integrated in their scheduled physical education curriculum. The training status of the participants was not stated; however, the low age of the participants suggests limited resistance training experience. There were two intervention groups, separated only by additional cardiovascular training in one of them. For the intervention groups, the MRT complimented the scheduled physical education curriculum, while the control group attended regular physical education classes. Muscular strength was assessed through five different tests. Compared to the control group, significantly greater improvements were reported for both intervention groups in two outcomes at the end of the 18-week intervention. However, in reference to early neural adaptations, all these improvements were already significant after 9 weeks of the intervention. Moreover, at 9 weeks, significant improvements were observed in two additional strength outcomes in one intervention group, and one in the other. Thus, it appears that the strength improving effects at some point plateaued, and even diminished. As the present study only assessed strength before and after the eight-week intervention, have no data to suggest performance stagnation or unrealized potential.

Interestingly, both is Dorgo, King, Candelaria, et al. (2009) and Dorgo et al. (2009) implemented tri-sets, i.e., three exercises performed in succession with short rest intervals. While tri-set are thought to be effective in increasing muscular strength (Weakley et al., 2017), there is a lack intervention studies investigating the subject. However, there is an abundance of literature reporting the effectiveness of similar methods, such as supersets, i.e., performing two exercises in succession with short rest intervals (Robbins et al., 2010). Nevertheless, the short rest intervals implemented in tri-sets decrease neuromuscular performance and force generating capacity during training compared to traditional strength training utilizing longer rest intervals (Iversen et al., 2021). Considering that the magnitude of force developed is associated with increases in muscular strength (Goldberg et al., 1975), tri-sets might be suboptimal for increasing strength. Therefore, the contrasting findings in the present study are likely a consequence of variation other training variables, such as exercises selection and training volume. Regarding the MERT exercises implemented in the present study, studies using electromyography has reported significant neuromuscular activity in the relevant hip and calf muscles when performing similar movements, even without an external resistance (Jeong et al., 2019; Kinugasa & Akima, 2005; McBeth et al., 2012; Sidorkewicz et al., 2014). As for training volume, the MERT intervention assigned 2-6 weekly sets for plantar flexion, hip abduction, and external hip rotation, respectively. A systematic review and meta-analysis by (Ralston et al., 2017) observed that intermediate athletes benefit from >5 set per week. This threshold was only reached in the last 3 weeks of the intervention, suggesting that the training volume might have been insufficient in the first five weeks. Higher training volume was also observed in the successful interventions of Dorgo, King, Candelaria, et al. (2009) and Dorgo, King, & Rice (2009), indicating its influence in MRT interventions. Summarized, the findings of the present study are not in line with the literature investigating MRT. However, the uncharted research area of MERT in resistance-trained athletes, provide sparse grounds for comparison. The contrasting findings compared to studies using MRT are likely due insufficient stimuli to produce a significant increase in muscle strength.

3.6.2 CoD performance

The primary aim of the CoD technique segment of the intervention was to reduce KAM during CoD by influencing biomechanical factors. However, in the present study we wanted to assess the effect on CoD performance, using m505 trial duration as the main outcome. While we observed no improvements in CoD total time, the IG significantly reduced Phase 1 Time by 3.47%. Although not significantly different to baseline, Phase 1 Speed was reduced by 3.98% in the IG. It is reasonable to suggest that taken together, this indicates more effective CoD technique.

Other ACL-injury prevention interventions have produced varying results on CoD performance; however, significant improvements have been reported in females participating in multidirectional sports (Mohammadi & Fakhraei Rad, 2022; Noyes et al., 2013; Roso-Moliner et al., 2023). In the present study, we did not prescribe a specific training session duration. However, we estimated a total duration of ~30-40 min for all three intervention segments. Furthermore, to facilitate the implementation of the intervention, the handball specific sidestep cutting technique training and the CoD technique training was incorporated in the IG scheduled warm-up during handball training. Therefore, it should be noted that the interventions assigned by Mohammadi & Fakhraei Rad (2022) and Noyes et al., (2013) were large and time-consuming, requiring 60-90 min of training three times per week. Consequently, convincing coaches and athletes to implement the programs long-term might be challenging. However, a study by Roso-Moliner et al. (2023) observed significant improvements in CoD performance when implementing a 24 min training protocol three times per week, suggesting potential for less time-requiring injury prevention programs.

ACL-injury prevention studies have also failed to improve CoD (Lindblom et al., 2012; Vescovi et al., 2008). When investigating the Prevent Injury Enhance Performance program in adolescent female soccer players, Vescovi et al. (2008) observed no significant improvement in CoD performance. Similarly, Lindblom et al. (2012) reported no improvement in CoD performance from a neuromuscular training program in youth female football players. However, the method of CoD assessment should be noted. Both Vescovi et al. (2008) and Lindblom et al. (2012) assessed CoD performance using the Illinois Agility test. The Illinois Agility test includes ~60 meters of running and 11 CoDs at 90-180 degrees. Contrastingly, the m505 utilized in the present study involves ~10 meters of running and a single 180-degree CoD. This difference in methodology might significantly influence the results, as CoD performance is dependent on numerous physical qualities, such as metabolic capacity, technique variables, linear sprinting ability, and lower body qualities (Dos'Santos et al., 2017; Vescovi et al., 2008; Young et al., 2002). It is likely that results from the Illinois Agility test might be more influenced by metabolic capacity, and less by lower body muscular strength, than shorter test. This suggest that comparison of results from studies using different tests should be done cautiously. Indeed, even tests more similar in design indicate the potential influence on CoD performance results. A study by Lindblom et al. (2020) investigated the effect of two injury prevention programs on CoD performance in youth football players and conducted both the 505 Agility test (~20m, 1 CoDs at 180 degrees) and the Agility T-test (~37m, 4 CoDs at 90-180 degrees). While both intervention groups produced significant improvements in 505 Agility test, neither improved the Agility T-test, further suggesting caution when comparing results of different CoD test.

Similar to the present study, the implementation of a variety of training methods is observed in frequently utilized ACL injury prevention programs (Noyes & Barber Westin, 2012; Voskanian, 2013). This complicates identifying significant training factors in the interventions. For example, studies by Mohammadi & Fakhraei Rad (2022) and Noyes et al., (2013) implemented strength, speed, agility, balance, plyometric training, and Roso-Moliner et al. (2023) implemented neuromuscular training involving stretching, stability, and bodyweight strength training. In the present study we implemented three segments; handball specific sidestep cutting technique training, CoD technique training, and MERT. Therefore, the contribution of the respective intervention segments on CoD performance remains uncertain. However, previous studies investigating solely CoD technique interventions have been successful. A study by Dos'Santos et al. (2021) implemented a six-week CoD speed and technique intervention in men participating in multidirectional sports, and significant improvements in a modified 505 was reported. The contrasting findings compared to the present study might be related to the CoD training volume, as Dos'Santos et al. (2021) implemented far more CoD training. Specifically, during the last three weeks of the interventions, we included 48 CoDs with no additional CoD training, while Dos'Santos et al. (2021) included 88 CoDs and an additional 73 decelerations. Furthermore, the technical cues of Dos'Santos et al. (2021) aimed at improving CoD performance. There is data suggesting biomechanical overlap between reducing ACL-injury risk and improving CoD performance (A. S. Fox, 2018). However, our result suggest that attempting to avoid trunk lean over the turning leg, combined with avoiding leg knee valgus, does not improve CoD performance.

3.6.3 Change of direction and isometric strength relationship

For the CG and all participants pooled, moderate negative correlations were observed between CoD Total time and all IS outcomes, suggesting that the stronger subjects produced faster CoDs. This is in line with previous research investigating the relationship (Spiteri et al., 2014, 2015; Thomas et al., 2015). However, we found no correlation between IS pre-post change and CoD pre-post change. This is likely explained by the limited changes in both IS and CoD performance. Interestingly, for the IG, CoD Total time only correlated with IS outcomes at baseline. Thus, it appears that the intervention significantly influenced the IS-CoD relationship. While the reasons for this are uncertain, a possible explanation is the greater intra-group improvements in IS outcomes (3.78 – 5.67 %) compared to CoD Total time (-3.43%).

The inter-study variation in CoD- assessment previously discussed must be considered when interpreting our findings. We assessed CoD using a m505 with a MRD providing assistance/resistance. This method is novel in research. However, the non-MRD m505 is frequently used to assess CoD performance, and significant relationships to IS have been reported (Thomas et al., 2015, 2017). The short distance and single CoD included in the test suggest that our findings are not significantly influence by metabolic capacity (Vescovi & Mcguigan, 2008). Furthermore, the assistance in Phase 1 facilitates increased horizontal velocity, and the resistance in Phase 2 inhibits it. Thus, in reference to Newton's laws of motion, the redirection of the momentum at the point of CoD requires a larger force production than un-assisted/resisted. Thus, greater muscular strength is required.

However, it has been postulated that different strength qualities are important at different phases of a CoD (Spiteri et al., 2014). During the deceleration, sufficient eccentric strength is necessary to reduce and stop the momentum (Harper et al., 2019, 2022). During the amortization, isometric strength is utilized, and concentric strength contribute to reaccelerating (Jones et al., 2017). Although the present study failed to improve the main CoD performance outcome, significant improvement was observed in Phase 1. As we implemented an eccentric resistance training intervention, it might appear reasonable to suggest that this improvement was mediated by increased eccentric strength. However, this is speculative, and we provide no data to support this. Furthermore, eccentric resistance training is suggested to induce significant improvements in both eccentric and isometric strength (Douglas et al., 2017). Therefore, we suggest that our IS outcomes are representative of overall strength.

3.6.4 Strengths and limitations

The purpose of a pilot study is to provide the first insights into a specific novel field of research. To that end, the present study has provided new insight into performance aspects of an ACL injury-preventing CoD technique- and MERT. The study has significant strengths in the utilization of validated and reliable measurement devices, both for CoD assessment (Eriksrud et al., 2022) and IS (O' Connor et al., 2023; O'Brien et al., 2019). In addition, supervision of the intervention facilitated correct execution of exercises, and might have benefited the IG in increasing muscular strength (Mazzetti et al., 2000). The 100% compliance rate among all IG subjects should also be noted as a significant strength, and consequently, we are confident that the results are not influenced by lack of adherence to the intervention protocol. However, the findings from this study cannot be fully interpreted without accounting for its limitations. The small sample size prevented analysis of the influence of player position. As different handball positions have different physical demands, there might exist a relationship between position and intervention effect (Karcher & Buchheit, 2014). Furthermore, we did not control for additional training stimuli. The subjects were aspiring handball players playing for separate handball teams in their leisure time, thus, there might have been significant inter-subject differences in total training volume and match frequency during the intervention. Training and handball matches in the days preceding testing might also have influenced the subject's recovery, and consequently their laboratory performance, as we did not standardize the interim between their last match or training session and time of testing. Finally, we note that the interpretation of the results should not be extended past adolescent female handball players.

3.6.5 Perspectives

Ultimately, the intervention in the present study aimed to reduce ACL-injury risk by reducing KAM in handball specific sidestep cuts and CoD, not improve PP. However, to promote implementation among practitioners, injury-prevention programs should have a secondary aim of improving physical performance. While some biomechanical factors are associated with both preventing ACL-injury and improving PP (A. S. Fox, 2018), the result of the present study provides no clarity as to whether strategies of avoiding knee valgus and trunk lean over the turning leg improves PP. While we observed few significant improvements in PP compared to the CG, the IG significantly improved compared to their baseline measurements. This should not be ignored, as it indicates that the intervention might have future potential. However, interpretation of paired-samples data in an independent samples study can contribute to misleading conclusions (Bland & Altman, 2011). Thus, we emphasize the necessity to consider the paired samples findings with caution. Finally, researchers should continue to investigate the physical performance aspects of injury-preventing interventions. The tendencies observed in the present study may be further investigated, and future research should investigate if a greater training volume is beneficial for PP outcomes. Furthermore, in studies investigating CoD performance, incorporating eccentric strength test can provide further insight into the relationship between different muscular strength qualities and CoD phases.

3.7 Conclusion

Overall, we conclude that the CoD technique and MERT intervention did not significantly improve IS or CoD performance in adolescent female handball players. At baseline, IS was significantly associated to CoD performance. However, changes in IS was not associated with changes in CoD performance.

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List of Common Abbreviations

1RM: one repletion maximum

505: 505 agility test

ACL: anterior cruciate ligament

CMC: concentric muscle contraction

CMJ: countermovement jump

CoD: change of direction

CRT: concentric resistance training

EMC: eccentric muscle contraction

ERT: eccentric resistance training

ICC: intraclass correlation coefficient

IF: isometric force

IFO: isometric force output

IS: isometric strength

KAM: knee abduction moments

kg: kilograms

m505: modified 505 agility test

MERT: manual eccentric resistance training

MRD: motorized resistance device

MRT: manual resistance training

N: Newton

N/kg: Newton per kilogram

PP: physical performance

RIR: repetitions in reserve

RPE: rate of perceived exertion

RT: resistance training

TRT: traditional resistance training

Appendix Part I

Appendix 1

Tron Krosshaug

Institutt for idrettsmedisinske fag OSLO 21. juni 2022

Søknad 233 – 160622 - Redusere risikofaktorer for korsbåndskader hos unge kvinnelige håndballspillere

Vi viser til søknad, prosjektbeskrivelse, informasjonsskriv og innsendt melding til NSD.

I henhold til retningslinjer for behandling av søknad til etisk komite for idrettsvitenskapelig forskning på mennesker har komiteen i møte 16.juni 2022 konkludert med følgende:

Vurdering

I søknaden opplyses det om en viss risiko for skade under testene, herunder fremre korsbåndskade: Risikoen er imidlertid lav (1-2 ganger per 1000 spilletimer). I søknaden oppgis at skaderisikoen er vesentlig høyere i kamp enn på trening. Risikoen for skade som ledd i studien oppgis derfor som lavere i enn i reelle kampsituasjoner. Når det gjelder spillere med eksisterende korsbånd skade oppgis imidlertid risikoen for skade under planlagte studietester for å være tre ganger høyere, men at inklusjon av denne gruppen kan forsvares grunnet høy nytteverdi med tanke på ny kunnskap om sammenhengen mellom belastning og skaderisiko – også for deltakere med tidligere kjent kneskade som er klarert som kampklare. Komiteen støtter prosjektleders vurdering, men ber om at den særskilte risikoen gruppen med tidligere kjent kneskade utsettes for, er godt beskrevet i informasjonsskrivet.

Deltakere skal rekrutteres fra videregående skoler med toppidrett. Treningen vil gjennomføres på utøvernes respektive skoler. Dersom denne treningen inngår i ordinær undervisning må det påses at skolen har et alternativt opplegg for de om ikke ønsker å delta i prosjektet. Det bør opplyse om et ev alternativt opplegg i informasjonsskrivet. Komiteen ber videre om at det rettes opp i begrepene knyttet til anonyme og avidentifiserte data i informasjonsskrivet.

Vedtak

På bakgrunn av forelagte dokumentasjon finner komiteen at prosjektet er forsvarlig og at det kan gjennomføres innenfor rammene av anerkjente etiske forskningsetiske normer nedfelt i NIHs retningslinjer. Til vedtaket har komiteen lagt følgende forutsetning til grunn:

- *Vilkår fra NSD følges*
- *Informasjonsskrivet justeres i tråd med komiteens merknader*
- *Dersom testene/treningen inngår i ordinær undervisning må det påses at skolen har et alternativ opplegg for elever som ikke ønsker å delta*

Komiteen gjør oppmerksom på at vedtaket er avgrenset i tråd med fremlagte dokumentasjon. Dersom det gjøres vesentlige endringer i prosjektet som kan ha betydning for deltakernes helse og sikkerhet, skal dette legges fram for komiteen før eventuelle endringer kan iverksettes.

Med vennlig hilsen

Anne Marte Pensgaard

Professor Anne Marte Pensgaard
Leder, Etisk komite, Norges idrettshøgskole

Appendix 2

NORGES IDRETTSHØGSKOLE

Vil du delta i forskningsprosjektet

"Redusere risikofaktorer for korsbåndskader hos unge kvinnelige håndballspillere"?

Dette er en invitasjon til deg om å delta i et forskningsprosjekt, hvor formålet er å undersøke om man kan påvirke risikofaktorer for fremre korsbåndsskader ved å gjennomføre et 8 uker langt styrke- og teknikktreningsprogram. I dette skrivet ønsker vi å gi deg informasjon om målene for prosjektet, samt hva deltakelse vil innebære for deg.

Formål

Tidligere studier viser at finteteknikk påvirker risiko for å få en fremre korsbåndskade hos kvinnelige håndballspillere på elitenivå. Vi ønsker nå å undersøke om vi kan påvirke denne risikoen ved å gjennomføre målrettet styrke- og teknikktrening over 8 uker. Da den samme risikofaktoren som er tilstede under både finter også er tilstede under en generell retningsendring, ønsker vi i tillegg å gjennomføre en retningsforandringstest (505-test). I tillegg til å belyse risiko for fremre korsbåndskader vil denne testen også gi informasjon om deltakeres fysisk prestasjon. Sekundært ønsker vi å undersøke hvilken effekt det samme treningsprogrammet har på fysisk prestasjon. Dataene fra studien vil benyttes i master-og doktorgradsprosjekter.

Hvem er ansvarlig for forskningsprosjektet?

Norges Idrettshøgskole er ansvarlig for prosjektet.

Hvorfor får du spørsmål om å delta?

Vi søker 75 kvinnelige håndballspillere fra norske toppidrettsgymnas. Du må ha fylt 16 år for å kunne delta. Kvinnelige håndballspillere på høyt nivå er spesielt utsatt for fremre korsbåndsskader, og dette prosjektet er viktig for å kunne forstå hvordan vi skal redusere skaderisikoen.

Hva innebærer det for deg å delta?

Dette er et biomekanisk eksperiment, der vi vil feste refleksmarkører på kroppen din. Refleksmarkører filmes av infrarøde kamera når du gjennomfører de ulike testene. Etter oppvarming vil du kunne gjennomføre flere prøveforsøk for å bli kjent med testene. Du må ha på deg en kort shorts, sports-BH og skoene du bruker når du spiller håndball. Vi vil i tillegg måle høyde, kroppsvekt og samle inn informasjon om spillerposisjon og skadehistorikk. Du må påregne å være i laboratoriet i ca 1,5 time.

Etter testing vil alle skolene som deltar bli tilfeldig plassert i enten en treningsgruppe eller kontrollgruppe. Skolene som havner i treningsgruppen vil gjennomføre et teknikk- og styrketreningsopplegg i 8 uker. Treningen vil gjennomføres på utøvernes respektive skoler. Målet med treningsopplegget er å redusere korsbåndskader og øke prestasjon. Dersom man ikke ønsker å delta i prosjektet vil et alternativt treningsopplegg kunne gjennomføres i stedet for det som benyttes i prosjektet. Skolen som havner i kontrollgruppen vil ikke gjennomføre noe spesifikt treningsopplegg, men beholde deres planlagte treningsprogram.

Etter 8-uker vil alle utøverne bli testet med de samme testene som ble gjort tidligere for å se etter endringer i resultatene.
Testingen vil være svært lik den fysiske aktiviteten som bedrives i deltakernes vanlige håndballtrening, og det er dermed en svært liten risiko for skade. Det presiseres dog at risikoen for korsbåndskade er større for spillere med tidligere korsbåndsskader.

Det er frivillig å delta

Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger

Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket. Det er kun masterstudenter, veileder og prosjektmedarbeidere som vi ha tilgang til opplysningene om deg. I tillegg vil prosjektet gjøres i samarbeid med German Sport University Cologne, som dermed også vil ha tilgang til data. Navnet og kontaktopplysningene dine vil gjøres avidentifiserbare og vi vil kun benytte forsøkspersonnummer i databehandlingen.
Individuelle deltakere vil ikke kunne gjenkjennes i publikasjoner. Personopplysninger vil bli tatt vare på frem til post-testing er gjennomført, sannsynligvis innen julen 2022.

PC'er som benyttes i prosjektet vil være passordbeskyttet. Datamaterialet vil bli lagret på forskningsserver.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?

Prosjektet skal etter planen avsluttes 15.08.2023. Alle persondata vil være avidentifiserbare, men all data vil oppbevares i 5 år etter prosjektslutt pga etterprøvbarhet av forskningsdata.

Dine rettigheter

Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke personopplysninger som er registrert om deg
- å få rettet personopplysninger om deg
- få slettet personopplysninger om deg
- få utlevert en kopi av dine personopplysninger (dataportabilitet)
- å sende klage til personvernombudet eller Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?

Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra *Norges Idrettshøgskole* har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverketHvor kan jeg finne ut mer?

Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- *Norges Idrettshøgskole* ved masterstudenter Patrik Thun *(patrik_thun@hotmail.com), Sigurd Solbakken (sigsolba@hotmail.com) eller eller veileder/prosjektleder Tron Krosshaug (tronk@nih.no, tlf: 456 60 046)*
- Vårt personvernombud: Rolf Haavik *(personvernombud@nih.no)*

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen

Tron Krosshaug	*Patrik Thun*	*Sigurd Solbakken*
(Forsker/veileder)	(Masterstudent)	(Masterstudent)

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet «*Redusere risikofaktorer for korsbåndskader hos unge kvinnelige håndballspillere*», og har fått anledning til å stille spørsmål. Jeg samtykker til å delta i prosjektet.

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet.

(Signert av prosjektdeltaker, dato)

Appendix 3

20.05.2023, 13:21 Meldeskjema for behandling av personopplysninger

Sikt

Meldeskjema / Can a strength and technique intervention reduce knee abduction m... / Vurdering

Vurdering av behandling av personopplysninger

Referansenummer	Vurderingstype	Dato
263122	Standard	16.08.2022

Prosjekttittel
Can a strength and technique intervention reduce knee abduction moment in young female handball players?

Behandlingsansvarlig institusjon
Norges idrettshøgskole / Institutt for idrettsmedisinske fag

Felles behandlingsansvarlige institusjoner
German Sport University Cologne

Prosjektansvarlig
Tron Krosshaug

Prosjektperiode
15.08.2022 - 31.12.2023

Kategorier personopplysninger
Alminnelige
Særlige

Lovlig grunnlag
Samtykke (Personvernforordningen art. 6 nr. 1 bokstav a)
Uttrykkelig samtykke (Personvernforordningen art. 9 nr. 2 bokstav a)

Behandlingen av personopplysningene er lovlig så fremt den gjennomføres som oppgitt i meldeskjemaet. Det lovlige grunnlaget gjelder til 31.12.2023.

Meldeskjema

Kommentar
Personverntjenester har vurdert endringen registrert i meldeskjemaet.

Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet med vedlegg. Behandlingen kan fortsette.

OPPFØLGING AV PROSJEKTET
Vi vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Kontaktperson: Simon Gogl
Lykke til videre med prosjektet!

Appendix Part II

Appendix 1

Warm-up protocol

1. 5 min low intensity cycling on a stationary bike
2. 5 repetitions of 10 m forward jogging, immediately followed by 10 m backward jogging.
3. 5 repetitions of 10 m forward shuffling, immediately followed by 10 m backward shuffling.
4. 10 bodyweight squats
5. 10 bodyweight standing calf raises
6. 10 jump squats

The subjects then completed the testing protocol related to the larger project investigating knee abduction moments during handball-specific sidestep cuts. This involved a minimum of 6 repetitions of Task 2 implemented by Bill et al., (2022), before initiating the familiarization with the m505 test protocol.

References

Bill, K., Mai, P., Willwacher, S., Krosshaug, T., & Kersting, U. G. (2022). Athletes with high knee abduction moments show increased vertical center of mass excursions and knee valgus angles across sport-specific fake-and-cut tasks of different complexities. *Frontiers in Sports and Active Living*, *4*. https://www.frontiersin.org/articles/10.3389/fspor.2022.983889

Appendix 2

Øvelser for styrke- og oppvarmingsintervensjon

Håndballfinteprosjekt

Oversikt: Styrketrening

Styrkeøvelser	Uke 1-2 Tilvenning			Uke 3-5 Middels Hardt			Uke 6-8 Hardt		
Treningssenterøkt	Rep	Set	RIR	Rep	Set	RIR	Rep	Set	RIR
Sideplanke	8	1-2	2-3	6	2	1	4	3	0
Clam Shell	8	1-2	2-3	6	2	1	4	3	0
Tåhev (Beinpress eller Smithmaskin)	8	1-2	2-3	6	2	1	4	3	0
Håndballbaneøkt									
Sideplanke	8	1-2	2-3	6	2	1	4	3	0
Clam shell	8	1-2	2-3	6	2	1	4	3	0
Tåhev m/partner	8	1-2	2-3	6	2	1	4	3	0

RIR: Repetisjoner i reserve. Antallet ytterligere repetisjoner utøveren hadde vært i stand til å gjennomføre når et sett avsluttes. Skulle man f.eks. være i stand til å kjøre 10 repetisjoner med en gitt motstand, men RIR er satt til å være 1 betyr dette at kun 9 repetisjoner skal gjennomføres.

0 RIR: Settet gjennomføres til utmattelse. Motstanden er så høy at utøveren ikke vil være i stand til å gjennomføre en ekstra repetisjon.

Styrketreningsøvelser

Sideplanke Progresjon 1 (Uke 1-2)

Start sideliggende på bakken. Sett nedre albue og underarm mot underlaget og plasser øvre ben på toppen av det nedre.

Løft deretter kroppen fra bakken ved å stramme muskulaturen på siden av hoften og overkroppen, slik at kun underarmen og foten på nedre side av kroppen har kontakt med underlaget.

Den eksentriske fasen starter med at hoften senkes til den får kontakt med gulvet. Deretter løftes hoften opp igjen til startposisjon.

Sideplanke Progresjon 2 (Uke 3-8)

Start sideliggende på bakken. Sett nedre albue og underarm mot underlaget og plasser øvre ben på toppen av det nedre. Bena skal være strake.

Løft deretter kroppen fra bakken ved å stramme muskulaturen på siden av hoften og overkroppen, slik at kun underarmen og foten på nedre side av kroppen har kontakt med underlaget. Øvre ben løftes også opp fra det nedre.

En partner presser aktivt ned på utøverens hofte og utøveren bruker muskulaturen på siden av hoften og overkroppen for å motvirke at hoften synker mot gulvet. Når hoften er blitt presset ned til bakken løfter utøver den opp til startposisjon. Det er viktig at partnere styrer motstanden i forhold til det gitte antall repetisjonen. Dvs. at partnere må gi mye motstand på 4 repetisjoner og lite eller ingen motstand på 6 og 8 repetisjoner.

Clam shell (Uke 1-8)

Start sideliggende på bakken. Ha omtrent 45 graders fleksjon i hoften og 90 graders fleksjon i knærne, med det øvre benet plassert på toppen av det nedre.

Løft og utoverroter deretter øvre kne så mye som mulig uten føttene mister kontakten. Partner legger press ned på utøverens øvre kne for å påføre ytre motstand. Det er viktig at partnere styrer motstanden i forhold til det gitte antall repetisjonen.

Ettbens eksentrisk tåhev (Uke 1-8)

Utøveren starter stående på kanten av et trappetrinn eller en annen kant. Kun forfoten er på kanten, bakre del av foten er ikke i kontakt med underlaget.

Øvelsen starter med at utøver løfter den ene foten fullstendig fra underlaget, slik at kun det ene benet belastes. Deretter brukes muskulaturen i leggen til å gjennomføre en tåhev. I senkefasen av øvelsen bruker partner egen kroppsvekt til å henge på utøver sine skuldre for å gi ekstra motstand. Utøver og parter må kommunisere for å sikre riktig motstand.

Når utøver har senket seg selv rolig ned til bunnposisjonen slipper partner skuldrene til utøveren og utøveren gjennomfører en tåhev opp til topposisjonen uten ekstra motstand. Deretter gjentas dette i oppgitte antall repetisjoner.

Gjennomføres treningsøkten på et treningssenter kan smith-maskin, benpress eller stående tåhev-maskin benyttes med samme utførelse som beskrevet over.

Oversikt: Oppvarmingsøvelser

Fullstendig plan:

Mobilitet og stabilitet
Squat to stand med brystrygg rotasjon
Utfall matrise °90, °135, 180
Ett beins markløft med strake armer

Løp & teknikk
Løp forlengs, baklengs og sidelengs
Monster walks med eller uten strikk
Diagonalhopp (3H, 3V) med landing – fokus: forfotlanding (2-3 serier)
Diagonalhopp (3H, 3V) med landing – fokus: unngå valgus (2-3 serier)
Finte – fokus: forfotlanding + unngå valgus (3H, 3V), gradvis økende intensitet

180° retningsforandring Fokus på innoverlening av overkropp, og vekt på begge bein		
Uke 1-2	Uke 3-5	Uke 5-8
Vektoverføring (på kasse) (2-3 serier)	Shuffle, 5m avstand, moderat innsats (2-3 serier)	

Skulder		
Uke 1-2	Uke 3-5	Uke 5-8
Stående Y med partner	Face pulls med partner	Stående T med partner
En hånds roing med partner	Band pull apart tommel ut	Utover rotasjon med partner
Skulderpushups	Yoga pushups	Pushups med en hånd på ball

Dueller - Finteinngang en mot en Fokus på forfotlanding og kneposisjon		
Uke 1-2	Uke 3-5	Uke 5-8
HV + VH finte (med motspiller, men ingen kontakt) (3 serier hver vei)	HV + VH finte (noe motstand) (3 serier hver vei)	

Kast
Valgfritt
Målvakt
Valgfritt

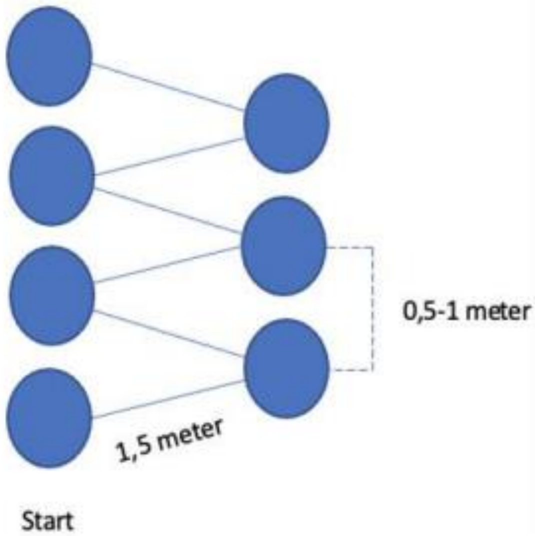
180° retningsforandring Fokus på innoverlening av overkropp, og vekt på begge bein		
Uke 1-2	Uke 3-5	Uke 5-8
		Løp, full innsats 5m avstand (2H + 2V) (2 runder)

Dueller - Finteinngang en mot en Fokus på forfotlanding og kneposisjon		
Uke 1-2	Uke 3-5	Uke 5-8
		HV + VH finte (full motstand) (3 serier hver vei)

Oppvarmingsøvelser: Finteprosjekt

Øvelsene beskrevet under er kun delen av oppvarmingen som relatert til finteprosjektet. De resterende øvelsene i oppvarmingen er ikke inkludert her.

Diagonalhopp (3H, 3V) med landing – fokus: forfotlanding (3 serier)

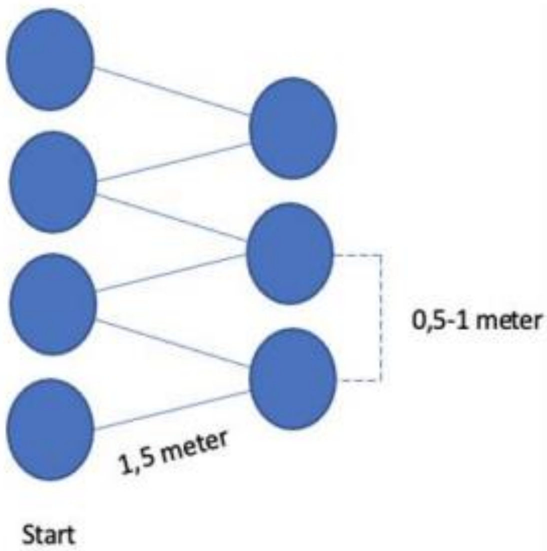


Kjegler er plassert med omtrent 1,5 meter mellomrom på omtrent 45 grader vinkel fremover. Den første kjeglen ligger til venstre og det plasseres totalt 6 kjegler (Se bilde).

Utøveren starter stående på sitt venstre bein ved den første kjeglen. Utøveren hopper mot høyre og lander med sitt høyre bein ved neste kjegle. Målet med øvelsen er at landingen skal skje med forfoten først, deretter bakre del av foten. Utøveren forsøker å lande i balanse uten flytte foten for mye. Når utøveren har full kontroll, kan utøveren hoppe videre mot venstre og lande på sitt venstre bein.

6 hopp gjennomføres per runde.

Diagonalhopp (3H, 3V) med landing – fokus: kneposisjon (3 serier)



Kjegler er plassert med omtrent 1,5 meter mellomrom på omtrent 45 grader vinkel fremover. Den første kjeglen ligger til venstre og det plasseres totalt 6 kjegler (Se bilde).

Utøveren starter stående på sitt venstre bein ved den første kjeglen. Utøveren hopper mot høyre og lander med sitt høyre bein ved den neste kjegle. Målet med øvelsen er å holde kontroll på kneet og unngå at det faller innover ved landing. Når utøveren har full kontroll, kan utøveren hoppe videre mot venstre og lande på sitt venstre bein.

6 hopp gjennomføres per runde.

Finte – fokus: forfotlanding + kneposisjon (3H, 3V), gradvis økende intensitet

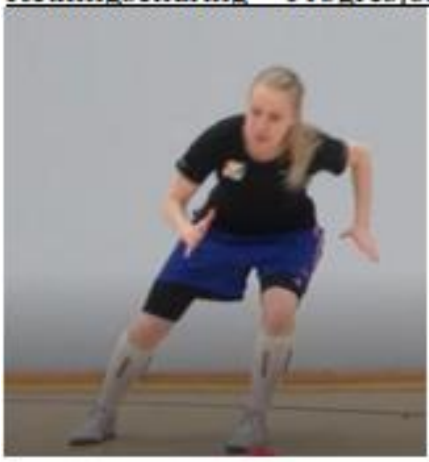
Det plasseres 7 kjegler i skiksakformasjon. Det skal være 5 meter mellom hver kjegle i lengde og 3 meter i bredde (Se bilde).

Spilleren starter ved første kjegle. Øvelsen starter med at utøveren løper mot neste kjegle i løypen og utfører en finte med retningsforandring, hvor utgangen er i retning av den neste kjegle. Dette gjentas videre ved hver kjegle og utøveren gjennomfører dermed 6 finter per runde. Det tekniske fokuset skal være forfotlanding og knekontroll (unngå at knærne faller inn).

Retningsendring – Progresjon 1 (Uke 1-2): 3 serier – 30 sek

Utøveren starter øvelsen stående på en step-kasse. Øvelsen går ut på å sette ett og ett bein ned på bakken til siden for step-kassen. Beinet som står igjen på step-kassen skal ha en bøy i både kne og hofte, og fokuset er på å holde overkroppen stabil over dette beinet. Tyngdepunktet skal altså holdes over step-kassen. I tillegg skal utøver unngå at knærne faller inn. Når utøverens venstre fot er på kassen vil høyre arm være fremme, og omvendt. Start rolig og øk tempo når man er trygg på teknikken.

Retningsendring – Progresjon 2 (Uke 3-5) 3 serier – 30 sek



Det er plassert 2 kjegler med 5 meters mellomrom. Utøveren starter ved den ene kjeglen og skal gjennomføre en «side shuffle» fra kjegle til kjegle i moderat tempo. Når utøveren kommer til en kjegle gjøres det en retningsendring, hvor målet er at mesteparten av utøverens vekt skal holdes over det innerste beinet ved at overkroppen holdes over dette benet. I tillegg bør utøverne unngå at kneet på det ytterste beinet faller inn.

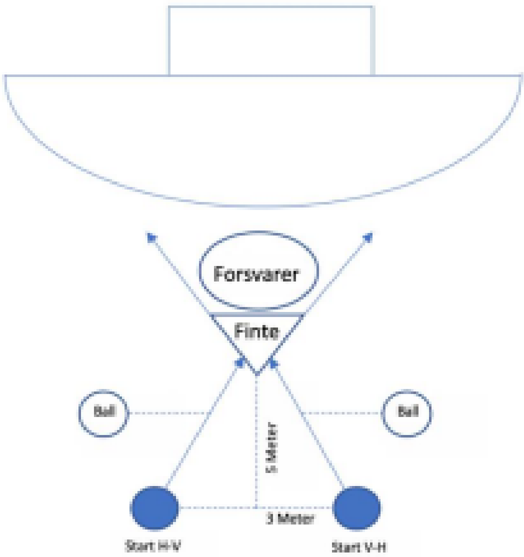
Retningsendring – Progresjon 3 (Uke 6-8) (2H + 2V) (2 runder)

Det er plassert 2 kjegler med 5 meters mellomrom. Utøveren startet ved en kjegle og løper i full hastighet mot den andre kjeglen (Se video). Ved denne kjeglen skal utøveren gjøre en 180-graders vending. Når utøveren kommer til en kjegle gjøres det en retningsendring, hvor målet er at mesteparten av utøverens vekt skal holdes over det innerste beinet ved at overkroppen holdes over dette benet. I tillegg bør utøverne unngå at kneet på det ytterste beinet faller inn.

Dueller – Progresjon 1 (Uke 1-2)

HV + VH finte (med motspiller, men ingen kontakt) - 3 serier hver vei

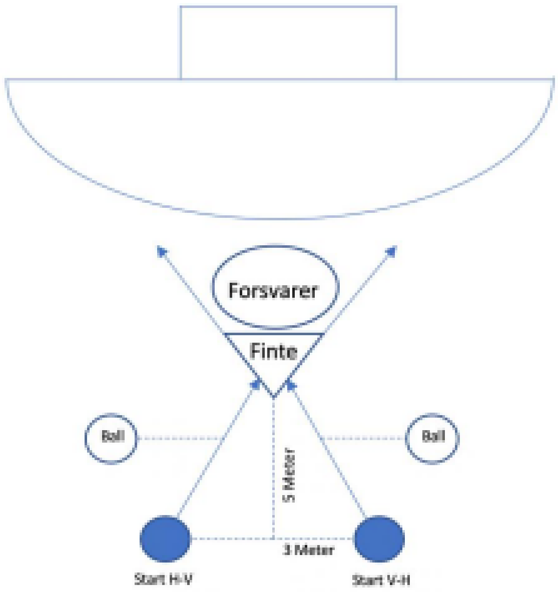
Utøverens oppgave er å utføre en fintebevegelse med en høyre-venstre eller venstre-høyre retningsendring. Utøveren starter fem meter tilbake og tre meter til siden i forhold der finten utføres (Se bilde). Forsvarspilleren står ved straffemerket. Angrepspiller løper skrått mot forsvarspilleren, mottar ballen og utfører en finte som ligner på den de ville utført i kampsituasjon. Målet er å finte en bevegelse én retning, med en rask retningsendring mot motsatt side. Om angrepspilleren starter fra sin venstre side vil hun motta ballen fra venstre og finte høyre-venstre. Starter angrepspilleren fra høyre, vil ballen da også komme fra høyre, og finten blir venstre-høyre. Spilleren vil avslutte på mål etter finten. Utøveren finter fra annenhver side.



Fokuset under finten er forfotlanding og unngå at kneet faller inn.
Forsvarspilleren vil være passiv, og ikke ha noe kontakt med angrepspilleren. Hvem som kaster pasningen og hvem som forsvarer kan variere.

<u>Dueller – Progresjon 2 (Uke 3-5)</u>
HV + VH finte (med motspiller, noe motstand/kontakt) – 3 serier hver vei

Utøverens oppgave er å utføre en fintebevegelse med en høyre-venstre eller venstre-høyre retningsendring. Utøveren starter fem meter tilbake og tre meter til siden i forhold der finten utføres (Se bilde). Forsvarspilleren står ved straffemerket. Angrepspiller løper skrått mot forsvarspilleren, mottar ballen og utfører en finte som ligner på den de ville utført i kampsituasjon. Målet er å finte en bevegelse én retning, med en rask retningsendring mot motsatt side. Om angrepspilleren starter fra sin venstre side vil hun motta ballen fra venstre og finte høyre-venstre. Starter angrepspilleren fra høyre, vil ballen da også komme fra høyre, og finten blir venstre-høyre. Spilleren vil avslutte på mål etter finten. Utøveren finter fra annenhver side.



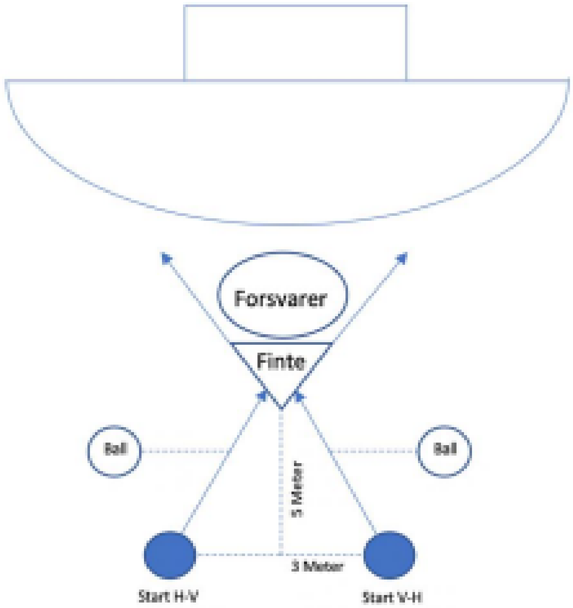
Fokuset under finten er forfotlanding og unngå at kneet faller inn.

Forsvarspilleren vil gi moderat motstand og ha kontakt med angrepspilleren. Hvem som kaster pasningen og hvem som forsvarer kan variere.

Dueller – Progresjon 3 (Uke 6-8)

HV + VH finte (med motspiller, full motstand/kontakt) – 3 serier hver vei

Utøverens oppgave er å utføre en fintebevegelse med en høyre-venstre eller venstre-høyre retningsendring. Utøveren starter fem meter tilbake og tre meter til siden i forhold der finten utføres (Se bilde). Forsvarspilleren står ved straffemerket. Angrepspiller løper skrått mot forsvarspilleren, mottar ballen og utfører en finte som ligner på den de ville utført i kampsituasjon. Målet er å finte en bevegelse én retning, med en rask retningsendring mot motsatt side. Om angrepspilleren starter fra sin venstre side vil hun motta ballen fra venstre og finte høyre-venstre. Starter angrepspilleren fra høyre, vil ballen da også komme fra høyre, og finten blir venstre-høyre. Spilleren vil avslutte på mål etter finten. Utøveren finter fra annenhver side.



Fokuset under finten er forfotlanding og unngå at kneet faller inn.

Forsvarspilleren vil gi full motstand og ha full kontakt med angrepspilleren. Hvem som kaster pasningen og hvem som forsvarer kan variere.

Appendix 3

Project contributors

Name	Job title	Institution	Akademic degree	Role
Tron Krosshaug	Professor	Norges Idrettshøgskole	Ph.D	Project supervisor
Sigurd Solbakken	Master student	Norges Idrettshøgskole	Bachelors deg.	Contributor
Patrik Thun	Master student	Norges Idrettshøgskole	Bachelors deg.	Contributor
Lasse Mausehund	Ph.D candidate	Norges Idrettshøgskole	Masters deg.	Contributor
Patrick Mai	Ph.D candidate	DSHS, Cologne	Masters deg.	Contributor
Kevin Bill	Ph.D candidate	DSHS, Cologne	Masters deg.	Contributor
Julian Müller-Kühnle	Ph.D candidate	Univ. Klinkum Stuttgart	Dr. Med.	Contributor
Markus Kurz	Ph.D candidate	Mid-Sweden University	Masters deg.	Contributor
Manpreet Singh	Master student	Internship NIH	Bachelors deg.	Contributor
Stefan Hildebrandt	Bachelor student	Internship NIH		Contributor
Kati Pasanen	Associate professor	University of Calgary	Ph.D	Contributor
Uwe Kersting	Professor	DSHS, Cologne	Ph.D	Contributor
Hege Grindem	Associate professor	Norges Idrettshøgskole	Ph.D	Contributor
Grethe Myklebust	Professor	Norges Idrettshøgskole	Ph.D	Contributor
Merete Møller	Researcher	Norges Idrettshøgskole	Ph.D	Contributor
Seikai Toyooka	Orthopedist	Research fellow NIH	Ph.D	Contributor
Yusuke Kamatsuki	Orthopedist	Research fellow NIH	Ph.D	Contributor
Ola Eriksrud	Associate professor	Norges Idrettshøgskole	Ph.D	Contributor
Vigdis Holmeset	Trainer	WANG Oslo		Trainer
Gitte Madsen	Trainer	WANG Romerriket		Intervention trainer
Stian Olimb	Trainer	Otto Treider		Trainer
Kyrre Vegard Johannesen	Trainer	WANG Oslo		Intervention Trainer
Emil Carlsen	Bachelor student	Norges Idrettshøgskole		Data collection
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