NORWEGIAN SCHOOL
OF SPORT SCIENCES

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Muscle activation of thigh muscles in predetermined and randomized cutting directions during side-cut faking tasks among female handball athletes

A cross-sectional study

Master thesis in Sport Sciences
Department of Sports Medicine
Norwegian School of Sport Sciences, 2022

Abstract

Purpose: Muscle activity is an important factor contributing to knee joint stability during side-cut faking maneuvers. The side-cut faking maneuver is one of the most common non-contact anterior cruciate ligament (ACL) injury situations in female handball. Being a highly dynamic maneuver, the timeframe to plan an appropriate muscle activation strategy might decrease when faced with randomized events, putting the ACL at risk. However, research on muscle activation during side-cutting maneuvers has failed to recreate a realistic side-cut faking maneuver mimicking in-game scenarios. The purpose of this study was to investigate the effect of anticipation on muscle activity in female handball athletes under game-like scenarios during side-cut faking maneuvers.

Methods: Fifty-one female handball players from the Norwegian Premier, 1st, 2nd and 3rd divisions were recruited to the study. The muscle activity of biceps femoris (BF), semitendinosus (ST), vastus lateralis (VL), and vastus medialis (VM) was measured 50 milliseconds (ms) before and after initial contact (IC) by electromyography (EMG) during three side-cut faking maneuvers. For Task 1 the athletes did a side-cut in a predetermined direction. For Task 2 the athletes received a pass prior to executing a side-cut in a predetermined direction to fake a static defender. In Task 3 the athletes received a pass. When the ball was caught, two out of three defenders approached the athlete. The athlete would then be forced to cut away from the approaching defenders, resulting in a randomized cutting direction.

Results: In ST and VM there was a statistically significantly higher average muscle activation in Task 2 compared to Task 1, 50 ms before IC. In VL there was statistically significantly lower average muscle activation in Task 3 compared to Task 2, 50 ms before IC. No significant differences were detected 50 ms after IC.

Conclusion: No differences were detected between the simplest tasks with a predetermined cutting direction compared to the randomized cutting direction. The only exception was a reduced VL pre-activity between Task 2 and Task 3. Implying that the pre-activity, which is crucial to knee stability is not affected by the task complexity. Significant, yet small differences were detected within the predetermined side-cuts. Therefore, a simple task seems to be sufficient for EMG-screening when simulating in-game scenarios. There were no indications towards muscle activation patterns associated with increased ACL injury risk across tasks.

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Preface

This master’s thesis marks the end of a six-year period of higher education and my time at Norwegian School of Sport Sciences. The process of writing this thesis has been both challenging, educational and exciting. I have gained insight into the world of sport science research and I have gained massive respect for researchers and all the hard work that goes along with data collection, analysis, and writing.

The learning curve has been steep, but I am both happy and proud to finally have submitted my master's thesis. Admittedly, it would not have been possible without the help and support of others.

First of all, I would like to thank my main supervisor, Professor Tron Krosshaug, for all the feedback and the hours you have put in for me to submit an independent and well-completed master's thesis. Your knowledge and work ethic seems endless and I am proud to have been working with you. A special thanks also goes to Mr. Patrick Mai for helping me with the dataset, statistical analysis, and motivating words. Your ability to make complex data understandable is admirable. Thanks also to the rest of the research team and participants for a well-conducted data collection. This would not have been possible without any of you.

Thanks to my fellow students, friends, family, and last but not least my lovely partner for help with proofreading and motivational words when things have been tough.

On to a new chapter and challenges!

Mathias Midthjell Eggerud
Norwegian School of Sport Sciences, June 2022

Abbreviations

ACL	Anterior cruciate ligament
PCL	Posterior cruciate ligament
MCL	Medial collateral ligament
LCL	Lateral collateral ligament
VM	Vastus medialis
VL	Vastus lateralis
RF	Rectus femoris
VIM	Vastus intermedius
BF	Biceps femoris
ST	Semitendinosus
SM	Semimembranosus
IC	Initial contact
VDJ	Vertical drop jump
EMG	Electromyography
RMS	Root mean square
KAM	Knee abduction moment
GRF	Ground reaction forces
MVIC	Maximal voluntary isometric contraction
Ms	Milliseconds
Hz	Hertz
V	Volt
N	Newton
SENIAM	Surface Electromyography for the Non-Invasive Assessment of Muscles
RR	Relative risk
CI	Confidence interval
SD	Standard deviation

Introduction

Anterior cruciate ligament (ACL) injuries are both dreaded and common in sports in general, and handball especially. The reason for this is because of the long-term consequences of the injury such as the development of knee osteoarthritis and an extensive rehabilitation period (Lohmander et al., 2007). Additionally, an ACL injury can potentially threaten the athlete’s future participation in sports (Cohen et al., 2007; Lohmander et al., 2007). Several athletes end their careers or return to their sports, but at a lower level as a result of ACL injury because of the fear of re-injury, knee instability, or knee-related pain or stiffness (Lindanger et al., 2019). Furthermore, an ACL injury can have a massive impact on athletes’ performance (Cohen et al., 2007; Lohmander et al., 2007).

ACL injuries are among the most common knee injuries in handball. The injury usually occurs among players playing different back player positions (e.g., left, middle, right) (Myklebust et al., 1997). Like most ACL injuries, the majority of injuries occur in non-contact situations in female handball (Myklebust et al., 1997). Characteristic for injury situations in female handball is that they occur during games (75%) and during cutting movements (82%), typically left-right or right-left, trying to feint an opponent, or when landing after a jump (Myklebust et al., 1998; Olsen et al., 2004). Additionally, the injury most often occurs when the player handles a ball and is focusing on the opposing goal or defenders (Myklebust et al., 1997). Also, the frequency of ACL injuries is higher for female athletes compared to males. In the study by Myklebust et al. (1998) the incidence of ACL injuries was 5 times higher among females compared to males, and 30 times higher during competition than in training. One of the reasons for this might be explained by the difference in neuromuscular activation patterns (Ireland, 2016).

During dynamic and rapid movements, like side-cutting, the relative orientation of the thigh to the shank is a factor contributing to ACL injury because of an increased anterior tibial shear force and increased knee valgus (Boden et al., 2000; Ford et al; 2003; McLean et al., 2004; Olsen et al., 2004; Koga et al., 2010; Withrow et al., 2006). To stabilize the knee joint during such movements, the muscles work concurrently with ligaments to provide stability to the knee, known as neuromuscular control.

The quadriceps muscles are often associated with ACL injury because of the shear force created by the muscle group, contributing to anterior tibial translation. Female athletes demonstrate increased activation of the quadriceps relative to the hamstring muscles, during cutting maneuvers, resulting in increased anterior tibial shear force (Besier et al., 2001; Malinzak et al., 2001). This is a result of the disproportional agonist-antagonist relationship between quadriceps and hamstring muscles, which often appears during cutting and landing movements in combination with low knee flexion angles (Myer et al., 2005). The role of the hamstring muscles during such movements is to decrease the anterior tibial shear force induced by the quadriceps (Aagaard et al., 2000; Colby et al., 2000). However, female athletes show a decreased muscle activation of the hamstring muscles, relative to the quadriceps muscles. Additionally, female athletes show a disproportionated medial to lateral hamstring muscle activation, associated with a more open medial knee joint space, leading to further valgus of the knee during side-cutting movement (Rozzi et al, 1999; Zebis et al., 2008, Zebis et al., 2009; Zebis et al., 2021).

In recent times, neuromuscular activation patterns during dynamic sport-specific movements have been used to identify athletes at future risk of ACL injury (Zebis et al., 2009; Zebis et al., 2021), and to investigate the movements itself (Sell et al., 2006; Kim et al., 2014; Meinerz et al., 2015; Donnelly et al., 2015; Kim et al., 2016). In handball, the nature of the sport and the time of injury include external factors such as environment and equipment, and other stimuli like ball handling and opponents (Myklebust et al., 1997; Olsen et al., 2004; Bahr & Krosshaug; 2005). In these situations, the athletes are given a limited timeframe to identify the stimulus and do the neurocognitive processing which is required to perform a motor plan. Research shows that ACL injuries occur approximately 40 milliseconds (ms) after initial contact (IC), leaving sparse time for feedback to sufficiently activate the muscle surrounding the knee (Koga et al., 2010).

When the movement is anticipated (e.g., predetermined side-cutting maneuver) the muscles can be activated to stabilize the knee joint prior to IC. Though, when external factors and stimulus cannot be anticipated the central nervous system's time to plan a muscle activation strategy decrease (Besier et al., 2001). Ineffectual timing and muscular deficits may therefore potentially lead to undesirable joint angulations that put the ACL under strain and risk of injury (Koga et al., 2010; Myer et al., 2005).

However, external factors and stimuli are often overlooked when researching sport specific movements (Bahr & Krosshaug, 2005; Sell et al., 2006). Additionally, there is a limited amount of research on the effect of anticipation and stimulus on muscle activity during the most prominent non-contact injury situation in handball, the side-cutting maneuver, especially in female athletes.

Although accurate measurements of sport-specific movements are provided in a laboratory setting it is important that both the movements executed, surroundings, and stimulus are as close to a realistic situation as possible (Bolt et al., 2021). Thus, factors and stimuli such as anticipation, the behaviour of opponents and ballhandling are all playing an important role when researching on game-like scenarios (Besier et al., 2005; Bahr & Krosshaug, 2005; Bolt et al., 2021). Accordingly, electromyography (EMG) measurements during side-cutting tasks in combination with anticipation under game-like scenarios, can provide great insight into the neuromuscular activation strategies in female athletes.

Purpose of the study

Based on the previous research, discussed factors and the prevalence of ACL injuries, the purpose of the study is to investigate the effect of anticipation on muscle activity in female handball athletes under game-like scenarios during side-cut faking maneuvers.

Specifically, we want to investigate how the muscle activity change 50 ms before and after initial contact (IC) during two side-cut faking maneuvers in a predetermined direction and one side - cut faking maneuver in a randomized direction. For Task 1, athletes were instructed to perform a fake-cut in a predetermined direction without catching a ball or faking a defender. For Task 2, athletes performed a fake-cut in a predetermined direction after catching a ball to fake one static defender. In Task 3 the athletes received a pass. When the ball was caught, two out of three defenders approached the athlete. The athlete would then be forced to cut away from the approaching defenders, resulting in a randomized cutting direction.

1. Theoretical background

1.1 Dynamic knee stability

The majority of athletes heavily depend on the ability to run fast, jump high and change direction at high speeds, to be able to succeed. During such movements the knee joint is exposed to high moments and forces because of its location. Tibia and fibula, the two longest bones in the body, offers freedom in range of motion in six degrees (extension, flexion, internal rotation, external rotation, varus and valgus stress) and three planes (sagittal, transverse and frontal) (Abdulhasan & Grey, 2017). Additionally, these bony structures are surrounded by some of the most powerful muscles in the lower extremities.

The knee joint's ability to remain stable when exposed to movements such as cutting and rapid change of load, is referred to as dynamic knee stability (Williams et al., 2001). Stability of the knee joint is primarily achieved through knee ligaments and muscle activation of the muscles surrounding the knee joint (Abdulhasan & Grey, 2017).

1.2 Knee stability: ligaments

Knee ligaments consist of fibrous bands of tissue. These are connected to the fibula and tibia and provide stability to the knee. There are primarily four ligaments that provide stability to the knee joint. These ligaments provide different forms of stability based on their location. Which of the ligaments that are recruited depends on the angle of the joint and the plane of the loaded knee. However, the stability of the knee is often a result of several ligaments synergistically recruited (Abdulhasan & Grey, 2017).

These are the ACL, posterior cruciate ligament (PCL), medial collateral ligament (MCL) and the lateral collateral ligament (LCL) (Kakarlapudi & Bickerstaff, 2001; Williams et al., 2001). The ACL's primary role is resisting anterior and rotational displacements of the tibia relative to the femur, e.g., hyperextension and anterior tibial translation. Secondly, it prevents varus and valgus movements (Kakarlapudi & Bickerstaff, 2001; Acevedo et al., 2014). Further, the PCL prevents posterior displacements, MCL provides stability to the medial portion of the knee, and LCL prevents varus and external rotation of the knee (Abdulhasan & Grey, 2017).

(a) Sagittal section through the right knee joint

(b) Superior view of the right tibia in the knee joint, showing the menisci and cruciate ligaments

(c) Anterior view of right knee

Figure 1: *Sagittal (a), superior (b) and anterior (c) view of knee anatomy. Adopted from OpenStax College (CC BY 3.0) (https://creativecommons.org/licenses/by/3.0/).*

The ACL contributes up to 85% of the stability of the knee and is therefore considered as the main stabilizer of the knee. The ACL consists of two bundles, the anteromedial and the posterolateral. The anteromedial bundle, which is the shortest band, is taut in flexion and slack in extension. On the other hand, the posterolateral bundle is tense in extension and lax in flexion (Abdulhasan & Grey, 2017). The ACL is an intraarticular, but extracapsular structure consisting of collagen. It originates from the medial wall of the lateral femoral condyle, to the insertion anteriorly of the tibial articular surface (Acevedo et al., 2014).

The ligaments can only provide adequate stability to the knee when the loads applied are moderate. During dynamic movements e.g., cutting, landing and deceleration, the ligaments are exposed to a greater load and can exceed the strength of the ligament itself, possibly resulting in an injury (Williams et al., 2001). Therefore, the knee joint is dependent on other stabilizing forces besides ligaments, such as muscle activity, to keep the ligaments strain within a safe range.

1.3 Knee stability: muscle activation

The muscles surrounding the knee have a secondary role in knee stability. Although the muscles play a secondary role, both ligaments and muscles work concurrently to provide good function and stability to the knee. Producing a controlled movement via coordinated muscle activity is commonly referred to as neuromuscular control. This is one of the key factors to stabilizing the knee joint, and therefore ACL injury prevention (Williams et al., 2001).

Further, it can be divided into three basic components: sensory organs, neural pathways and muscles. To function, the system relies on feedback to be able to feed-forward, so that the muscles can do the contractions, which in turn leads to movement (Williams et al., 2001).

When a load sufficient enough to challenge the stability of the knee is applied, the sensory organs provide feedback from the golgi tendon organs and muscle spindles. In turn, this will produce a neuromuscular response that activates the muscle and acts as a stabilizer to the knee joint. This phenomenon is called joint stiffness and is regulated by the muscles that are activated, surrounding the knee (Williams et al., 2001). This occurs in situations when the ligaments are exposed to forces that put the ligaments at risk, and are in need of assistance, which is provided through muscular force (Abdulhasan & Grey, 2017).

The ligaments are typically at risk during dynamic and rapid movements. During these movements the orientation of the thigh, relative to the shank, is believed to contribute to ACL injury because of knee joint valgus and increased anterior tibial translation (Ireland, 1999; Olsen et al., 2004; Hewett et al., 2005). The increased valgus loading and anterior tibial translation is thought to increase the strain on the ACL, and may so cause an injury (McLean et al., 2004).

Consequently, efforts on minimizing knee valgus in such movements, may reduce the risk of ACL injury. The ability to control the orientation of the shank relative to the thigh during such movements are dependent on muscle activation of the muscles surrounding the knee joint (Palmieri-Smith et al., 2008). Additionally, the tensile stiffness and damping of the muscles are, according to Blanpied et al. (1995), linearly proportional to the active tension developed by the muscles. Hence, the activation of muscles surrounding the knee joint could contribute to more desirable joint angulations during rapid and dynamic movements (Dietz et al., 1981).

1.3.1 Hamstring anatomy and function

The hamstring muscle is a complex consisting of three different muscles, that all play an important role in human movement in different ways, such as walking, to more explosive movements e.g., running and jumping (Rodgers & Raja, 2021)

The muscle complex consists of the semitendinosus (ST), semimembranosus (SM) and biceps femoris (BF). The ST and SM and the long head of BF run posteriorly along the length of the femur, and cross both the femoroacetabular and tibiofemoral joints. However, the BF's short head is an exception. The short head of the BF originates from the lip of the femoral line aspera, which is distal to the femoroacetabular joint. Therefore, it is argued that the short head of the BF is not a true hamstring muscle (Rodgers & Raja, 2021). Additionally, the BF is inserted to the fibular head and the lateral condyle of the tibia. ST and SM are inserted to medial tibia and medial tibial condyle, respectively.

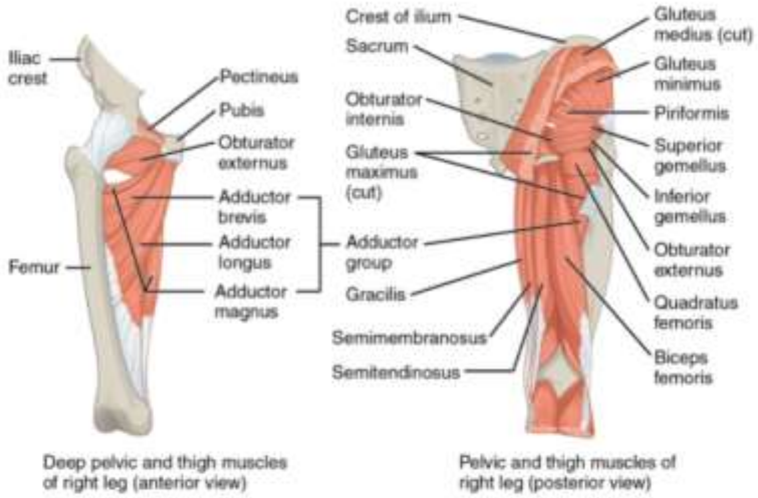


Figure 2: *Anterior and posterior view of the hamstring muscles. Adopted from OpenStax College (CC BY 3.0) (https://creativecommons.org/licenses/by/3.0/).*

In contrast to the short head of the BF, all hamstring muscles originate from the ischial tuberosity. The long head of the BF and ST are linked together by an aponeurosis, which extends from the ischial tuberosity. Respectively, BF, ST, and SM form the superolateral and superomedial borders of the popliteal fossa (Rodgers & Raja, 2021). The hamstring muscles allow for both hip extension and knee flexion. The muscles also play an important role in knee joint stabilization. The hamstring muscles operate simultaneously with the ACL by resisting anterior tibial translation (Rodgers & Raja, 2021).

1.3.2 Quadriceps anatomy and function

The quadriceps muscles are among the most extensive muscle groups in the human body and play a vital role in sports and daily living. The quadriceps muscles enable movements such as knee extension and hip flexion. Further, it provides proper gait cycles and maintenance of patellar stability (Bordoni & Varacallo, 2021).

The quadriceps muscles consist of the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), and vastus intermedius (VIM). The RF originates from the anterior inferior iliac spine with direct tendon, the upper rim of the acetabulum with indirect tendon, and the hip joint capsule with reflected tendon. VL originates from the lateral side of the great trochanter, from the lip of linea aspera and gluteal tuberosity. The VM originates from the neck of the femur and lateral linea aspera. The VIM originates laterally and anteriorly from three-fourths of the femur, and the lateral lip of linea aspera (Bordoni & Varacallo, 2021).

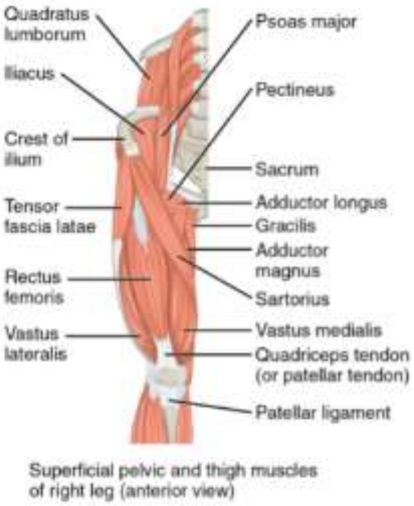


Figure 3: *Anterior view of the quadriceps muscles. Adopted from OpenStax College (CC BY 3.0) (https://creativecommons.org/licenses/by/3.0/).*

The four heads of the quadriceps muscles run downwards and form a single tendon, called quadriceps muscle tendon, which is located on the patella. Most fibers from the quadriceps muscle heads are inserted to the patella. However, the most superficial tendon fibers cover the patella by running over the patella and inserting on the patellar ligament (Bordoni & Varacallo, 2021).

1.4 ACL injury causation

If the ultimate goal is to prevent injuries, a thorough understanding of injury mechanisms is necessary. However, this might be challenging as the key components leading to injury are often overlooked. Research on injury mechanisms is often limited to identifying the exclusive relationship between risk factors and injury situations, leaving out the information leading up to the event of an injury (Bahr & Krosshaug, 2005).

If schematically presented, the time interval leading to the injury, is called an injury mechanism, and is the result of both internal (e.g., age sex, body composition, anatomy) and external risk factors (e.g., environment, sports factors, equipment). External and internal risk factors make the athlete susceptible to injury, but risk factors alone do not cause injury. There is a continuous debate on which risk factors are relevant for ACL injury, as researchers have found multiple external and internal factors associated with it (Bahr & Krosshaug, 2005).

1.4.1 ACL injury mechanisms

The mechanism of ACL injury is separated into two categories, non-contact and contact situations. Injuries that occur as a result of contact situations account for approximately 30% of all ACL injuries (Cimino et al., 2010). The remaining 70% of ACL injuries occur in non-contact situations. In a study by Olsen et al. (2004), twenty video analyses were made of situations where the ACL was injured. The purpose of the study was to uncover injury mechanisms for ACL injuries among female handball players in the top divisions in Norway (Olsen et al., 2004).

The results refer to two different injury mechanisms. The first and most common injury mechanism occurred when the player planted the foot in the ground, followed by a cutting movement. A side-cutting maneuver is done at high speeds with the purpose of making the opposing player think that you are going in one direction, then going in the opposite direction (Zebis et al., 2009). The side-cut is performed by translating the body to the side over the planted leg and then moving explosively in the opposite direction (Bencke et al., 2018). The efficiency of the side-cut is not so much dependent on the speed of the movement, but more on the translation of the body. Simultaneously, there was a strong valgus angle of the knee joint, and an external or internal rotation with the knee joint close to full extension (Olsen et al., 2004).

The second injury mechanism was also characterized by a valgus position of the knee joint with an internal or external rotation, with the knee close to full extension. The injury, on the other hand, occurred in situations where the player landed after a one-legged jump shot (Olsen et al., 2004).

In a study by Koga et al. (2010) ten non-contact ACL injury situations in handball and basketball were investigated using an advanced model-based image-matching method. In seven of the cases, the injury occurred during a cutting maneuver. In the three remaining cases, the injury occurred in a 1-legged landing, referring to two of the most common ACL injury situations identified by Olsen et al (2004).

The kinematic results show that the knee was relatively straight at IC (24° flexion angle), but drastically increased only 40 ms later (47° flexion angle). Similar to the knee flexion angle, the knee abduction angle was low at IC (0°) and increased 40 ms after IC (12°). In terms of knee rotation angle, an externally rotated knee (5°) was observed at IC, but then internally rotated by 8° during the first 40 ms. From 40 ms to 300 ms an external rotation of 17° was observed. The knee kinematics were consistent across all cases. (Koga et al., 2010).

Based on these results and previous research on injury mechanisms, Koga et al. (2010) propose the following hypothesis for non-contact ACL injury mechanisms. 1) Valgus loading applies tension to MCL which makes it taut and lateral compression occurs. 2) In addition to the lateral compression, the force created by the quadricep muscle activation causes a displacement where the lateral femoral condyle moves posteriorly and the tibia translates anteriorly and rotates internally. Resulting in an ACL tear. 3)

When the primary restraint to anterior translation is gone, the medial femoral condyle shifts posteriorly, resulting in an external rotation of the tibia.

1.4.2 Non-contact ACL injury in women's handball

ACL injuries are among the most common knee injuries in European handball. The injury usually occurs among players playing different back player positions (e.g., left, middle, right) (Myklebust et al., 1997). The injury most often occurs when the player is in the attacking phase of the game. The player usually handles the ball and is focusing on the opposing goal or defenders when the injury occurs (Olsen et al., 2004).

Handball players also report that the injury occurs in situations that they have been involved in several times before, without injuring the ACL. Characteristic for injury situations in women's handball is that they occur during games (75%) and during cutting maneuvers, typically left-right or right-left, trying to fake an opponent, and when landing after a jump (Olsen et al., 2004).

Like most ACL injuries, the majority of injuries occur in non-contact situations in women's handball (Myklebust et al., 1997). A study by Myklebust et al. (1998) reported that 82% of non-contact injury situations occurred during a cutting maneuver, independent of sex. However, the frequency of ACL injuries is higher for female athletes compared to males. In the study by Myklebust et al. (1998) the incidence of ACL injuries was 5 times higher among women compared to men and 30 times higher during competition than in training.

Myklebust et al. (1997) did a study reporting that 1.8% of the women in the top three handball divisions in Norway suffered an ACL injury during the course of two seasons. In addition, players in the upper-division had the greatest risk of suffering an ACL injury. As many as 4.5% of the women playing in the top division injured their ACL.

1.5 ACL injury risk factors in sport-specific maneuvers

Considering the prevalence of ACL injuries in sports in general, and handball especially, a substantial amount of research has been dedicated to finding the relevant risk factors associated with non-contact ACL injury for the past decades (Bencke et al., 2018).

1.5.1 Biomechanical risk factors

Hewett et al (2005) found an association between biomechanical variables and ACL injury risk among female athletes. A total of 205 athletes were tested using 3D motion analyses during a vertical drop jump (VDJ) test. A total of nine athletes injured the ACL and found that both knee valgus angle at IC, peak values, and peak knee abduction moments, were associated with an ACL injury.

Further, Quatman et al (2011) found that relative to normal landings, a combination of tibial movements such as tibial anterior translation, knee abduction, and external rotation, resulted in ACL strain. In terms of cutting maneuvers, Zebis et al (2021) found that both hip flexion angle at IC and internal knee rotation angle at IC were associated with ACL injury risk.

1.5.2 Neuromuscular risk factors

Neuromuscular activity is among the risk factors that have gained interest in this specific research field. Especially, the role of the quadriceps and hamstring muscles to protect the ACL when the strain on the knee ligaments is high and to provide dynamic knee stability is a point of interest in this context. Focusing on one of the most prominent injury situation in female handball (side-cutting maneuver) in addition to the neuromuscular activity of the hamstring and quadriceps muscles, researchers have gained knowledge that could be of interest in ACL injury prevention. Neuromuscular activity is also one of few modifiable risk factors associated with ACL injury, which gives hope in the work of preventing future ACL injuries.

Studies have shown that female athletes are more prone to non–contact ACL injuries, compared to men (Myklebust et al., 1998). One of the reasons for this might be explained by the different muscle activation patterns. Female athletes demonstrate a systematically increased quadriceps activation during landing and cutting movements.

Considering that increased quadriceps activation is associated with increased anterior tibial shear force, resulting in ACL strain, the quadriceps activation is contributing to the risk of ACL injury. Additionally, female athletes show a tendency to dominantly activate the VL during cutting movements (Zebis et al., 2009). When considering that knee abduction is a risk factor for non–contact ACL injuries, the increased VL activation might increase ACL injury risk due to the more open medial knee joint space.

A prospective study that investigated muscle activation patterns during side-cutting movements in female handball and football athletes as a possible risk factor for non-contact ACL injuries, found significant differences in muscle activation patterns among athletes who injured their ACL, compared with those who did not. In a study by Zebis et al. (2009) fifty-five elite female team handball and football players with no previous ACL injury were investigated. The athletes did the side-cut with as much force and speed as possible, resembling a match situation.

After screening the athlete's neuromuscular activity patterns via electromyography (EMG) in VL, VM, RF, BF, and ST, during the side-cutting maneuver, the incidence of ACL ruptures was registered in the two following match seasons (Zebis et al., 2009).

A total of three handball players and two football players ruptured their ACLs on their preferred push-off leg, in the follow-up period. The results from the post hoc tests of the injured players showed a lower pre-activity of the ST (21% ± 6% vs 40% ± 17%; $P < .001$) and a higher pre-activity of the VL (69% ± 12% vs 35% ± 15%; $P < .01$), compared to the non-injured players. Respectively, the difference in VL and ST EMG pre-activity for injured and non-injured was 47% ± 14% and 2% ± 25% ($p = .0006$) (Zebis et al., 2009). The results of this study underline the importance of ST muscle activation, providing protection against ACL injury among elite female handball and football athletes (Bencke et al., 2018); Zebis et al., 2009).

In another prospective study, ninety adolescent elite female handball and football players were screened for biomechanical and neuromuscular activity risk factors during a side-cutting maneuver. VL, VM, ST, and BF were screened during the side-cutting maneuver, using EMG equipment. The side-cutting maneuver was done with a run-in distance of five meters, ending at a force plate. The players did the side-cut maneuver as fast as possible and on the preferred push-off leg (Zebis et al., 2021).

The players were prospectively followed for two years after the baseline testing. A total of nine first-time ACL injuries were registered (six handball players, three football players) in the follow-up period (injury incidence 10.0% (95% confidence interval (CI) 5.4–18.6%)) (Zebis et al., 2021). Six of the nine injuries were sustained during a non-contact situation.

A total of sixteen risk factors on the relative risk (RR) of ACL injury were evaluated, and four of them were associated with the risk of ACL injury; hip flexion angle at IC, internal knee rotation angle at IC, external hip rotator strength, and ST EMG activity 50 ms prior to IC. The RR of ST EMG activity was 0.62 (95% CI 0.43–0.89). The only neuromuscular risk factor disposing for ACL injury during side-cutting maneuver was reduced ST pre-activity. The risk of ACL injury decreased by 38% when the ST pre-activity increased by 10%-points (RR 0.62 (95% CI 0.43–0.89), P=0.01), (Zebis et al., 2021).

1.6 Muscle activation strategies

The rate of ACL tears is alarmingly high in a number of different sports, including handball. Simultaneously, the rate of female participation in sports has increased over the years (Ireland, 2016). Interestingly, the rate of ACL injuries increases with the increased female participation in sports. Research shows that females are more prone to non-contact ACL injuries compared to males in several sports. One of the reasons for this is the difference in neuromuscular activity during cutting maneuvers (Ireland, 2016). To be able to counter the load induced upon cutting, landing after a jump, or other dynamic movements the muscles use different strategies. Taking into consideration that there are more thigh muscles than there are degrees of freedom, the central nervous system has several different muscle activation strategies to counter the upcoming external loads during cutting maneuvers. Nevertheless, two main strategies have been proposed (Llewellyn et al., 1990; Lloyd & Buchanan, 2001).

The first strategy is characterized by a “selective activation” of the muscles that are in the most suitable place to counter the external loads. For example, when doing a cutting maneuver, the muscle activation of ST would increase to counter valgus moment. The second strategy is generalized co-contraction. In terms of ACL injury, this would typically mean a coactivation of the hamstring and quadriceps muscles, only without any selective muscle activation (Llewellyn & Prochazka, 1990; Lloyd & Buchanan, 2001).

Female athletes exhibit differences in muscle recruitment and timing compared to male athletes which can affect the dynamic knee stability (Besier et al, 2001). Koga et al. (2010) reported that the ACL injury occurs approximately 40 ms after IC, leaving no time for muscle feedback to sufficiently activate the muscles surrounding the knee. Neuromuscular deficits and ineffectual timing of neuromuscular firing may therefore potentially lead to undesirable joint angulations that put the ACL under strain and at risk of injury (Myer et al., 2005). Hence, neuromuscular pre-activity, which allows for feedforward recruitment of the muscles surrounding the knee is important.

The feedforward neuromuscular control resulting in dynamic knee stability is developed through previous movement and is crucial in the timing of the muscle activity. The pre-activity may activate the muscles surrounding the knee prior to dynamic movement, stiffening the knee prior to IC and absorbing the forces at IC, which puts less stress on the ACL (Beard et al., 1993; Lephart et al., 2002). Besier et al. (2003) stated that the muscle activity pattern of the hamstring and quadriceps during cutting maneuvers are pre-planned to counter the loading from varus, valgus and rotational moments in the knee.

When anticipating the destabilizing forces, e.g., during a pre-planned side-step cutting maneuver to feint an opposing player, the central nervous system is adjusting the muscle activation patterns to resist the upcoming forces. This supports the idea that anticipatory postural adjustments are pre-planned (Benvenuti et al., 1997). For example, Cowling & Steele (2001), reported that during a dynamic landing task the hamstring muscles were activated prior to IC. The pre-activity of the hamstring muscles is thought to counter the anterior tibial translation that is induced after landing and thereby protect the ACL (Cowling & Steele, 2001).

Considering that postural adjustments are anticipatory, it is also believed that unanticipated maneuvers may limit the central nervous system's time to plan an appropriate muscle activation strategy to stabilize the increasing joint load that occurs during unanticipated maneuvers (Besier et al., 2001). In addition, female athletes display a latency delay, called electromechanical delay, between the preparatory and reactive muscle activation (Winter & Brookes, 1991). Accordingly, female athletes may be at greater risk of sustaining an ACL injury.

The quadriceps muscles are often associated with ACL injury because the muscle group contributes to ACL injury by pulling the tibia in the anterior direction, and by putting tension on the ACL at low knee flexion angles. This could lead to a displacement of the lateral femoral condyle as described by Koga et al. (2010). Although, ACL injury induced by quadriceps loading is only found in cadaveric studies. DeMorat et al. (2004) simulated a quadriceps loading of 4500N on twelve cadavers and found that the load was sufficient to tear the ACL in six cases. In these six cases, the ACL is thought to tear because of the pull on the patellar tendon induced by the quadriceps loading, resulting in anterior tibial translation. However, this suggests that quadriceps loading alone could tear the ACL. McLean et al. (2004) later found that during cutting maneuvers quadriceps loading never exceeded the loading suggested by DeMorat et al (2004). Meaning that realistically, the quadriceps loading alone cannot tear the ACL. However, the researchers found that realistic neuromuscular perturbations could cause knee valgus loads large enough to injure the ACL (McLean et al., 2004). Increased lateral quadriceps activation has also previously been hypothesized to add more valgus loading (Palmieri-Smith et al., 2008; Zebis et al., 2008). On the other hand, research on cadaveric specimens has limited usefulness, as the cadavers are often structurally degraded.

Further, female athletes demonstrate increased activation of the quadriceps, relative to the hamstring muscles during cutting maneuvers (Malinzak et al., 2001). The increased anterior shear force is a result of this disproportional agonist-antagonist relationship which often appears during cutting and landing movements in combination with low knee flexion angles (Myer et al., 2005). When the knee flexion is less than 30° the ACL loading increases as a result of the anterior pull of the patellar tendon on the tibia, induced by the quadriceps (Koga et al., 2010).

Although the quadriceps muscles create a substantial anteriorly directed shear force (Hirokawa et al., 1992), the absorption of this force is not only dependent on the ACL's ability to counteract this force, but also on the co-activation of the hamstring muscles (Draganich & Vahey, 1990). The hamstring muscles balance the quadriceps contraction, resulting in less anteriorly directed shear force by carrying the load on the articular contact surface, rather than on the ACL (Aagaard et al., 2000).

Female athletes also demonstrate a disproportionate medial to lateral hamstring muscle activation-ratio. Rozzi et al. (1999) found that during landing female athletes show a four times greater firing of the lateral hamstring compared to males. Further, Myer et al. (2005) showed that female athletes demonstrate a decreased medial to lateral quadriceps muscle activation-ratio during athletic maneuvers associated with an increased risk of ACL injury.

The increased lateral hamstring activation can potentially contribute to a more open medial joint space, which could lead to more knee valgus, putting more load on the ACL (Zebis et al., 2008). In these instances, the ST seems to be particularly important as it serves as a "knee adductor", preventing knee valgus, by compressing the medial knee joint compartment (Zebis et al., 2009). Hence, the ratio between the medial and lateral activation of the hamstring muscles is of importance in terms of controlling knee valgus.

As with the hamstring muscles, the quadriceps muscles also contribute to valgus prevention. When investigating the relationship between quadriceps muscle activity and peak knee valgus angels, female athletes with low peak knee valgus demonstrated a high vastus medialis activity. The increased activity of the medial thigh musculature acts as a counteracting force, preventing knee abduction (Palmieri-Smith et al., 2008). Although certain muscle activation patterns can be associated with increased ACL injury risk, ACL tears are thought to be multifactorial and occur as a result of several factors.

1.7 ACL injury screening methods

The importance of fully understanding what the contributing factors are in regards to ACL injury is not only of interest to researchers, but also clinicians developing screening and injury prevention programs (Almonroeder et al., 2015). Multiple attempts have been made to create screening methods to identify the relevant risk factors associated with ACL injury. However, there is no consensus among researchers regarding which screening methods that give the most valid results.

1.7.1 Generic and sport-specific screening

A generic screening test, like the vertical drop-jump test (VDJ), is a well-known screening method that aims to predict which athletes are particularly exposed to ACL injuries based on biomechanical analyses. Hewett et al. (2005), who was one of the first to recommend the VDJ test as a screening method, carried out a study using this method. A total of nine athletes injured their ACL in the 1year follow-up period. Characteristics of the injured athletes were higher knee abduction moments, large reactional forces, and shorter stance times. Based on these findings the study concluded that the knee joints movements and loads during a VDJ test are predictors of ACL injury among female athletes (Krosshuag et al., 2016; Hewett et al., 2016).

However, research that has been carried out in recent times has not been able to reproduce the results of this study. Mørtvedt et al. (2019) did a study where different professions tried to predict which athletes had a presumed higher risk of sustaining an ACL injury, based on video analyses of the VDJ test. The results showed that neither doctors, physiotherapists, personal trainers, researchers nor coaches could predict the athletes who were at risk. Furthermore, the results show that the judgment ability of the respondents was equal to random guessing, which calls for speculations regarding which screening methods to use.

Another study compared knee abduction moments and valgus position on the knee joint between the VDJ test and a handball-specific cutting maneuver. The results showed that the knee abduction moments were six times higher in the cutting maneuver, compared to the VDJ test (Kristianslund & Krosshaug, 2013). Given that large knee abduction moments are a risk factor for ACL injuries, the cutting maneuver may be a more representative screening method for handball players.

Oslo Sports Trauma Research Center did a study looking at risk factors for ACL injury among female athletes by using the VDJ test. Additionally, a sport-specific cutting maneuver was used as a screening method. The study concluded that the VDJ test is not a suitable test for risk assessment of ACL injuries because the test is not challenging enough, and thus provides a picture that is far from the situations where the ACL injuries actually occur (Krosshaug et al., 2016). That being said, a generic test like the VDJ test, or generic tests in general, would be great if it could be implemented for all sports.

The results from the above-mentioned studies constitute the need for a more sport-specific screening method to be used in order to give a more valid result, as it resembles a sport-specific movement associated with an increased risk of ACL injury (Krosshaug et al., 2016). Recently, researchers have contributed valuable information about neuromuscular activation patterns in lower extremity muscles during sport-specific movements as potential risk factors for ACL injury (Zebis et al., 2009; Zebis et al., 2021).

Although sport-specific screening appears to be a more valid screening method, compared to generic screening, the value of screening is debatable. A comment by Bahr (2016) suggests that screening should not be used as a tool to consider who should and who should not take part in injury prevention training, based on the results of the screening. Bahr (2016) states that if there is a proven risk reduction, everyone should do injury prevention training. Also, the current research is not anywhere near accurately determining risk on an individual level (Bahr, 2016).

By measuring neuromuscular activity using a sport-specific screening approach, we can still determine factors that make some players more susceptible to injury. Nevertheless, the research on sport-specific screening of ACL injury is lacking regarding the importance of mimicking game-like scenarios. Even though an accurate screening method should be performed in a laboratory setting, it is important that both the movements executed, surroundings, and stimuli are as close to a realistic situation as possible (Bolt et al., 2021). As mentioned by Bahr & Krosshaug (2005), overlooked factors such as the behaviour of opponents and playing position are all playing an important role when investigating injury mechanisms. Accordingly, EMG measurements during side-cutting tasks in combination with anticipation status under game-like scenarios can provide great insight into the neuromuscular activation strategies under suboptimal conditions.

1.7.2 Electromyography in screening

The objective of EMG is to investigate neuromuscular activation of the muscles, by recording changes in electric potential, typically during a defined task. When examining changes in electric potentials, one looks more specifically at what happens during depolarization and repolarization in muscle fibers of a specific muscle when an electric potential passes through (Konrad, 2005). As a result of the depolarization and repolarization, the changes in the electrical potential create a shape similar to a waveform. This wave can be found in every muscle fiber that is connected by the same motor unit. By connecting EMG sensors and electrodes to a specific muscle it is possible to record waves from the same muscles but from several motor units. The recordings from all of the motor units can be merged into a raw EMG-signal to create an overall wave (Konrad, 2005) (Figure 4).

When measuring a muscle, an increase in amplitude corresponds with an increased muscle force, when measured in V (Staudenmann et al., 2010). Also, when measured in hertz (Hz), motor units create action potentials that have a higher frequency, when the muscle force increases (Hug, 2011). This frequency can then be analyzed to tell what frequencies that produce the most power in an EMG-signal.

On the other hand, there are several factors that could influence the quality of EMG – signals. These factors are divided into intrinsic and extrinsic, and both produce noise. However, noise from extrinsic factors can be reduced by applying filters that filter out noise, or with the help of other electronics. Intrinsic noise is produced from the electronics itself, such as the amplifier, and between the interface of the skin and the electrode (DeLuca et al., 2010).

Movement artifacts, which could be caused by movement, are one of the primary sources to EMG-signal noise (DeLuca et al., 2010). Movement artifacts are typically caused by movement between the skin and the surface electrode which is attached to the muscle belly, or when the skin moves in relation to the muscle (De Luca et al., 2010).

Also, an increased distance between the electrode and the recorded muscle, caused by fat or anatomical nature, can affect the quality of the EMG-signal (DeLuca et al., 2010).

To get an understandable output from the EMG-data, different types of filters are usually applied to the raw EMG-signal (DeLuca et al., 2010). In sports science, where the muscle activity typically is recorded during dynamic tasks, high – and bandpass Butterworth filters in addition to full wave rectification, are usually applied (Meinerz et al., 2015).

1.8 Anticipation status in sport-specific maneuvers

The majority of ACL injuries are non-contact and typically occur in sports with an external stimulus such as teammates, a ball, or opponents (Besier et al., 2001). The sport itself and the time of injury are often characterized by high-speed movements in addition to these stimuli, which cannot be anticipated. In these situations, the athlete is given a limited timeframe to identify the stimulus and do the neurocognitive processing which is required to perform a motor plan. When the timeframe to respond with a motor plan is decreased, the chances of completing a task successfully are decreased. Therefore, the unanticipated stimulus can result in poor motor plans which will put the athlete at risk of being injured (Almonroeder et al., 2015).

The fact that most ACL injuries occur as a result of cutting in response to unanticipated stimuli, and that the athlete's ability to do the necessary neurocognitive processing is reduced, has led researchers to investigate the effect of anticipated and unanticipated cutting maneuvers on lower extremity mechanics (Almonroeder et al., 2015). However, there is a limited amount of research that directly compares the effect of anticipated and unanticipated cutting maneuvers on muscle activity among female athletes. Most of the research revolves around male or a combination of both male and female athletes.

Meinerz et al. (2015) investigated the effect of a single-legged land and cut movement on eighteen female athletes in anticipated and unanticipated conditions. They found that peak muscle activity (%EMG MVIC) in VL was higher in the unanticipated cutting maneuver for both the pre-contact phase (0.33 ± 0.20) (100 ms before IC) and landing phase (2.10 ± 0.85) (first 20% after IC), compared to the pre-contact (0.28 ± 0.14) and landing phase (1.48 ± 0.96) of the anticipated condition.

For VM there was a higher peak muscle activity in the pre-contact phase of the anticipated condition (0.19 ± 0.15), compared to the unanticipated condition (0.16 ± 0.10). In the landing phase, the peak muscle activity was higher in the unanticipated condition (1.16 ± 0.73) compared to the anticipated condition (0.98 ± 0.67).

For BF, the peak muscle activity was close to identical for both conditions in the pre-contact phase. Peak muscle activity was 0.24 ± 15 and 0.24 ± 16 for the anticipated and unanticipated conditions, respectively. In the landing phase, the peak muscle activity was higher in the unanticipated condition (1.48 ± 1.11), compared to the anticipated condition (1.10 ± 0.69). However, none of the observed differences in peak muscle activity were statistically significant (Meinerz et al, 2015).

Another study comparing the effect between contact force and decision making on lower extremity biomechanics during a side-cutting maneuver in male athletes found that muscle activation was significantly different between the anticipated and unanticipated cutting maneuvers. Lower muscle activity was observed in the unanticipated cutting maneuver compared to the anticipated cutting maneuver in VL ($p < 0.001$), VM ($p < 0.01$), and lateral hamstring ($p < 0.01$). The difference in muscle activity was biggest in the 2nd peak of ground reaction forces (GRF) (the propulsive and active force), compared to the 1st peak (impact and passive force) (Kim et al., 2016).

Sell et al. (2006) investigated the effect of direction and reaction on neuromuscular characteristics of the knee during tasks that simulate non-contact ACL injury mechanisms in male and female athletes. The athletes were instructed to land on a force plate, and then either jump vertically, left or right, as instructed by a visual cue. The results show that the muscle activity for both VL and ST 150 ms before maximum deceleration of the body, was higher in the anticipated condition, compared to the unanticipated. However, in the unanticipated condition female athletes showed a higher muscle activation than males in both VL and ST. Though, none of the differences were significant (Sell et al, 2016).

Besier et al. (2003) investigated the difference in muscular activation patterns during different sport-specific maneuvers, in both anticipated and unanticipated conditions. In the pre-contact phase (50 ms before IC) of a side-cutting maneuver, there was a significant increase of approximately 25 % in net muscle activation of muscles surrounding the knee in the unanticipated condition, compared to the anticipated condition. The muscle activity during the weight acceptance phase was also investigated and the authors found a significant difference. In this phase, there was between 10 - 15 % higher net muscle activation in the unanticipated condition, compared to the anticipated condition.

Later on, Donnelly et al. (2015) found that during pre-planned sidestepping, the total muscle activation increased in eight muscles crossing the knee, compared to unanticipated sidestepping in male Australian football players, both in the pre-contact phase (50 ms prior to weight acceptance) and weight acceptance phase (weight acceptance to first tough in GRF). Also, when looking at total hamstring muscle activation, the muscle activity was higher in the pre-planned sidestepping, compared to unanticipated sidestepping (Donnelly et al., 2015).

In summary, there is no consensus on the effect of anticipation on muscle activity based on the previous research, as results show both higher and lower muscle activity in anticipated maneuvers, compared to unanticipated maneuvers, and vice versa.

2. Methods

2.1 Participants

A total of fifty-one female handball players participated in the study. Participant information is shown in Table 1. The participants were required to compete in the Norwegian Premier division, 1st, 2nd or 3rd division and had to be at least 16 years old. Further the participants were required to be comfortable with cutting both to the left and to the right side. After the exclusion process described in chapter "2.5 Data analysis", twenty-eight participants were eligible for analysis.

Table 1: *Participant's anthropometrics (mean ± SD).*

	Mean	± SD
Age (years)	19.4	3.4
Height (cm)	170	0.06
Body mass (kg)	67.0	7.8

2.2 Ethics statement

Prior to testing an application for ethical approval was sent and obtained from The Ethics Committee of the Norwegian School of Sports Sciences (Appendix II). Approval for collection and storage of data, and its security, was obtained from the Norwegian Center for Research Data (Appendix III). All participants were informed about the experimental protocol and the potential risks that go along participating in the study. The participants were also informed about the right to withdraw from the study at any point, without providing a reason, through an information letter. All participants read and signed the consent form (Appendix I).

2.3 Experimental setup

The participant was instructed to change into shorts, sports-bra and ankle socks. Anthropometric data of the participants were measured using a measuring rod (seca 217, seca gmbh & co. kg., Hamburg, Germany) and an electronic weighing scale (seca 877, seca gmbh & co. kg., Hamburg, Germany). Information on age, playing position, preferred throwing arm, and previous knee injuries were documented in an Excel sheet, along with the anthropometric measurements. The selection of the leg to be analyzed was based on the playing position and desired throwing arm. For anonymization purposes, participant names were not saved.

2.3.1 Electromyography

The EMG data was recorded using a telemetered system (Aktos, Myon, Schwarzenberg, Switzerland) with a sampling frequency of 2000 Hz. Bipolar surface electrodes with a 24 mm diameter (Kendall Arbo H124SG electrode, Coviden, Minneapolis, USA) were attached to the skin of the musclebelly of VM, VL, BF and ST, which make up the thigh muscles recorded in this study. The electrode-placement on the musclesbellies mentioned above was done in accordance with Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations.

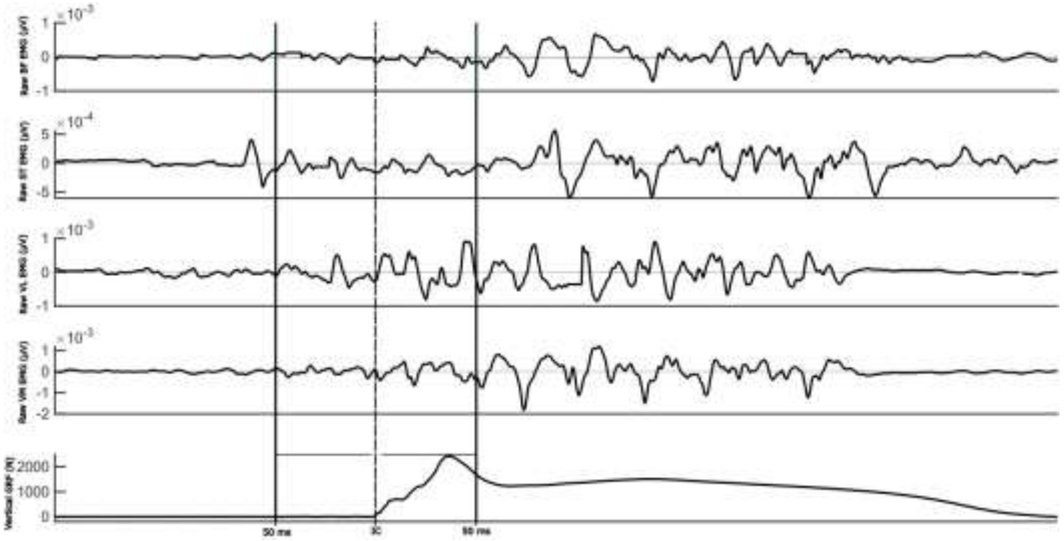


Figure 4:*Raw EMG signal of one participants BF, ST, VL and VM (µV) and vertical GRF (N). Solid lines represent 50 ms before and after IC. Dotted line represents IC.*

In order to determine the proper location of the electrodes, subjects performed a series of isometric contractions. After successful palpation of the desired attachment sites, the sensor locations were marked with a pen. The skin was then shaved using a single-use disposable razor and rinsed with alcohol (Isopropanol Prima, Kemetyl, Norway), in accordance with SENIAM recommendations.

Once the electrodes were attached to the skin on the musclebelly the electrodes were further secured with pre-cut elastic fixation tape (Fixomull Stretch, Essity, Norway). The EMG transmitters (Aktos waterproof EMG transmitter, Myon Schwarzenberg, Switzerland) were then connected to the electrodes and further secured using the pre-cut elastic fixation tape (Fixomull Stretch, Essity, Norway). EMG signals for the thigh muscles (VL, VM, BF, ST) were visually inspected for magnitude and clarity during the squats and jump squats, shown in Table 2.

2.3.2 Force plates

Ground reaction force data were captured using two embedded AMTI LG6-4-1 force plate platforms measuring 120cm x 60cm (AMTI, Watertown, MA, USA, 1000 Hz).

In the current study, only EMG and force plate data were used. However, multiple researchers gathered data, such as kinetics. Kinematic data were recorded at 200 Hz using a total of 24 infrared Opus 400 and 700 cameras (Qualisys AB, Gothenburg, Sweden). The cameras were set up in a 360-degree manner at different heights and angles throughout the laboratory, making sure that all movements and markers on the participants were registered when doing the side-cutting maneuvers. The focus and aperture for each camera were adjusted and set during the pilot testing. A total of eighty-two spherical reflective markers (12mm, Qualisys AB, Gothenburg, Sweden) in both cluster and singular form were placed on a large part of the body.

2.4 Experimental protocol

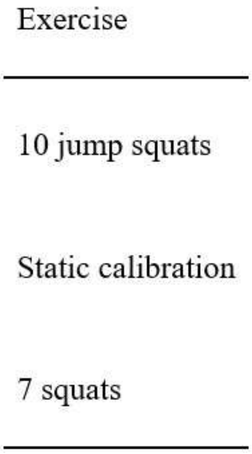
2.4.1 Warm-up procedures

The participants followed a standardized warm-up protocol consisting of five minutes of bicycling on a stationary bike. The participants were instructed to choose a voluntary load that would be sufficient for them to get warmed up. During the cycling, the participants were either shown a video or given an oral explanation of the tasks they were going to do during the testing. After the cycling was completed, the participants did 4 sets of 10 meters sideways-skipping going forward and backward.

2.4.2 Calibrations

The participant then did a series of exercises for the research team to do the necessary calibrations.

Table 2: *Exercises performed during the calibration process of participants.*



Exercise
10 jump squats
Static calibration
7 squats

2.4.3 Side-cut faking tasks

The laboratory was set up to be as representative to a handball field as possible in a laboratory setting. A handball goal was set up. In addition, we used sports tape to mark the goal area line at six meters and the free-throw line at nine meters. The free-throw line was taped across the middle of the force plates located directly in the center of the handball goal. At approximately 35 degrees and 5.5 meters away from the center of the free-throw line a cross was taped to the floor. This constituted the starting position for the participants depending on which leg that was recorded. The participants were instructed to do three different cutting tasks with increasing complexity. The cuts were done with full effort and in randomized order.

For Task 1 the participants did side-cuts in a predetermined direction without faking a defender, or receiving and handling a ball. For Task 2 the participants did side-cuts in the same predetermined direction as in Task 1, but in this scenario the participants had to fake a static defender. In addition, the participants received a pass and had to handle the ball while performing the side-cut. For Task 3 the participants were instructed to fake three dynamic opponents with a side-cut after receiving a pass. As soon as the participant caught the ball, the defender standing in the middle, and one of the defenders standing either to the right or left in relation to the middle-defender, moved towards the participant. The participant would then be forced to do a right - left, or left-right side-cut, to pass the defenders. Since the participants were instructed to cut away from the moving defenders, the resulting cutting direction was randomized.

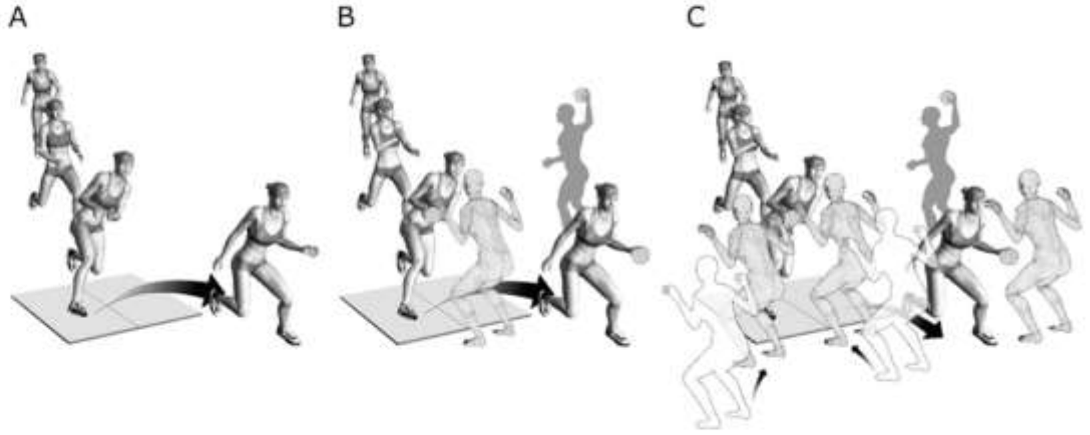


Figure 5: *A) Illustration of Task 1. B) Illustration of Task 2. C) Illustration of Task 3.*

The participants did a series of cuts until a minimum of five and eight valid side-cuts were achieved, shown in Figure 6. A side-cut was considered valid when the participant hit the force plate most distal relative to the participant. In addition, their whole foot, from the recorded leg, had to land within the force plate, without touching the other force plate. Furthermore, the non-recorded leg could not touch the same force plate as the recorded leg. For all three tasks, only the leg determined for Task 1 and 2 was analyzed.

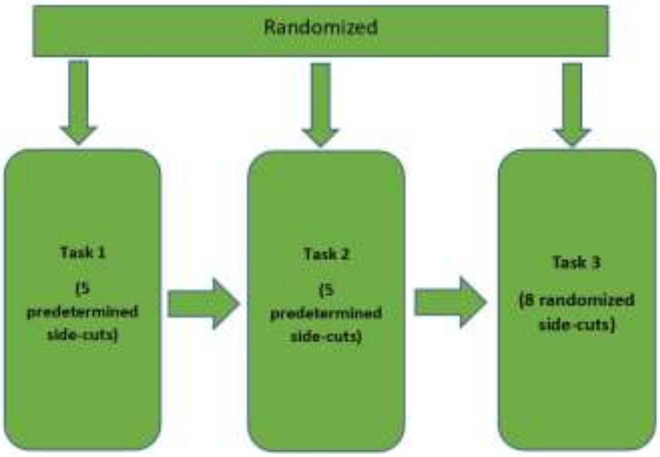


Figure 6: *Illustration of randomization and valid side-cuts needed for each task.*

Before each task, the participants were either shown how to do the side-cut by one of the research team members or given an oral explanation prior to executing the actual side-cut, if necessary. In addition, the participants were given the opportunity to practice the side-cuts before each task. Once the participant had understood the assignment and was able to do the side-cut with full effort, the recording started. The participants were instructed to execute the side-cut approximately at the free-throw line. This was done to ensure that we got valid side-cuts. The participants were not told to specifically hit the force plate since this could have interfered with their cutting technique.

2.5 Data analysis

For the filtering, EMG signals were rectified and smoothed by a 4th order high-pass Butterworth filter with a cut-off frequency at 5 Hz. Subsequently, a symmetrical moving root mean square (RMS) filter with a 30 ms time constant was applied. We determined the muscle pre-activation by calculating the average of the filtered EMG signal 50 ms before IC. Additionally, we calculated the average muscle activation 50 ms after IC. IC was determined where the unfiltered vertical ground reaction force exceeded a 30 N threshold.

Outlier identification was made based on the mean x 2.5 standard deviation (SD), both within measurements and total mean. After the outlier identification, a minimum of three consistent measurements were needed for every muscle and task both before and after IC to be included in the study.

For interpretation purposes, the EMG measurements were timed by one thousand and the number of decimals was reduced to two. Hence, the muscle activation is reported in volt (V).

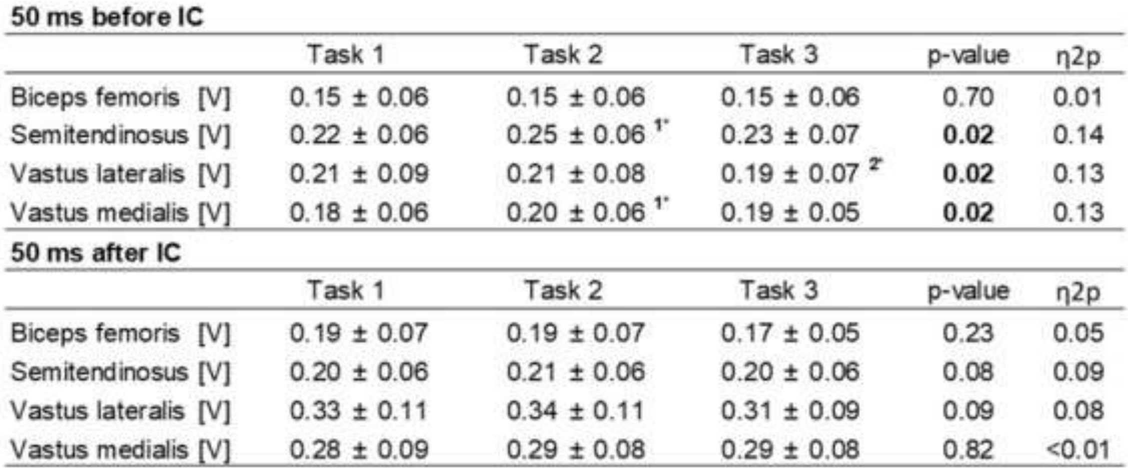
2.6 Statistical analysis

For the statistics we used repeated-measures ANOVA ($\alpha=0.05$) to compare the muscle activation of the VM, VL, ST, and BF during the three different tasks 50 ms before and after IC. Post-hoc analysis was performed using Bonferroni corrections. For the analysis, we used JASP (version 0.16.1) and Microsoft Excel 2016 (version 2204).

3. Results

The results of the statistical analysis showed that there were significant differences in average muscle activation between tasks in both ST, VL, and VM 50 ms before IC (p=<0.05). For ST and VL the difference in average muscle activation 50 ms after IC indicate a medium effect (η2p 0.08, 0.09), although not significant (p=0.08, p= 0.09).

Table 3: *Average muscle activity (V) for all tasks in BF, ST, VL, and VM (mean ± SD), main effect p-value (p-value), and partial eta squared (η2p), 50 ms before and after IC. * indicates p < 0.05.*



50 ms before IC

	Task 1	Task 2	Task 3	p-value	η2p
Biceps femoris [V]	0.15 ± 0.06	0.15 ± 0.06	0.15 ± 0.06	0.70	0.01
Semitendinosus [V]	0.22 ± 0.06	0.25 ± 0.06 ^{1*}	0.23 ± 0.07	**0.02**	0.14
Vastus lateralis [V]	0.21 ± 0.09	0.21 ± 0.08	0.19 ± 0.07 ^{2*}	**0.02**	0.13
Vastus medialis [V]	0.18 ± 0.06	0.20 ± 0.06 ^{1*}	0.19 ± 0.05	**0.02**	0.13

50 ms after IC

	Task 1	Task 2	Task 3	p-value	η2p
Biceps femoris [V]	0.19 ± 0.07	0.19 ± 0.07	0.17 ± 0.05	0.23	0.05
Semitendinosus [V]	0.20 ± 0.06	0.21 ± 0.06	0.20 ± 0.06	0.08	0.09
Vastus lateralis [V]	0.33 ± 0.11	0.34 ± 0.11	0.31 ± 0.09	0.09	0.08
Vastus medialis [V]	0.28 ± 0.09	0.29 ± 0.08	0.29 ± 0.08	0.82	<0.01

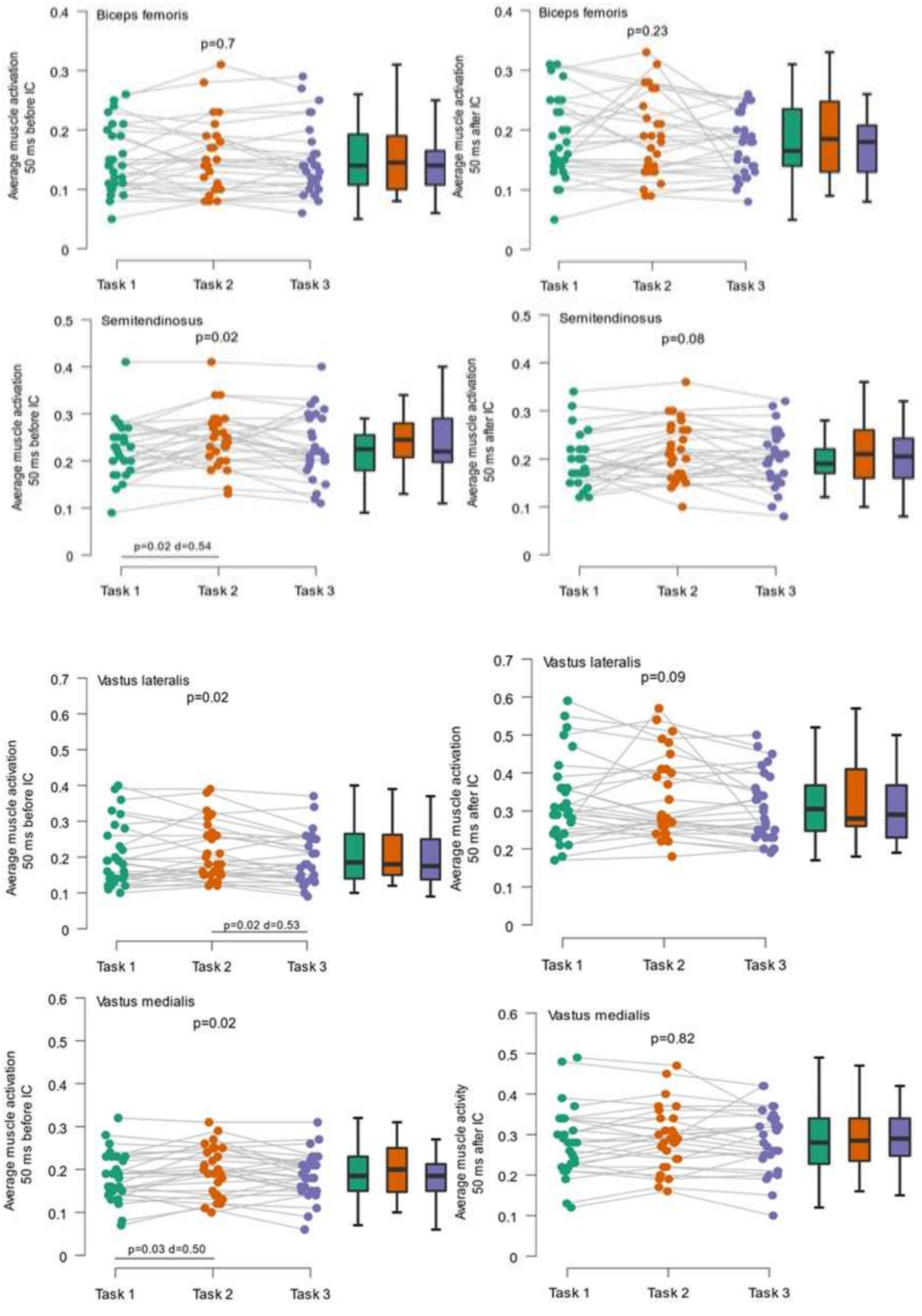


Figure 7: *Individual average muscle activation (V) for BF, ST, VL and VM, 50 ms before and after IC for all tasks. Main effect and post-hoc p-value (p=) and degrees of freedom (d=).*

Three out of four muscles 50 ms before IC showed a statistically significant difference in average muscle activity between tasks. The average muscle activation for both ST, VL, and VM all showed small, but significant differences between tasks, 50 ms before IC. However, for BF, no statistically significant differences were detected neither 50 ms before IC (η2p 0.01, p= 0.70), nor 50 ms after IC (η2p 0.05, p= 0.23), between the three tasks.

For ST the repeated measures ANOVA revealed that there was a statistically significant difference in average muscle activity between at least two tasks 50 ms before IC (η2p 0.14, p = 0.02). Post-hoc test for multiple comparisons found that the average muscle activity was significantly different between Task 1 (0.22±0.06) and Task 2 (0.25±0.06) p = 0.02. No significant differences were detected between the three tasks, 50 ms after IC (η2p 0.09, p= 0.08).

There was a significant difference in average muscle activity between two tasks for VL (η2p 0.13, p= 0.02). The post-hoc test found that the average muscle activity was significantly different between Task 2 (0.21±0.08) and Task 3 (0.19±0.07) p = 0.02, 50 ms before IC. No significant differences were detected between the three tasks, 50 ms after IC (η2p 0.08, p= 0.09).

In VM there was a statistically significant difference in average muscle activity between at least two tasks, 50 ms before IC (η2p 0.13, p= 0.02). Post hoc-test revealed that the average muscle activity was significantly different between Task 1 (0.18±0.06) and Task 2 (0.20±0.06) p = 0.02. No significant differences were detected between the three tasks, 50 ms after IC (η2p < 0.01, p= 0.82).

4. Discussion

The purpose of the study was to investigate the effect of anticipation on muscle activity in female handball athletes under game-like scenarios during side-cut faking maneuvers.

Specifically, we wanted to investigate how the muscle activity changed 50 ms before and IC during two side-cut faking maneuvers in a predetermined direction and one side-cut faking maneuver in a randomized direction. For Task 1, athletes were instructed to perform a fake-cut in a predetermined direction without catching a ball or faking a defender. For Task 2, athletes performed a fake-cut in a predetermined direction after catching a ball to fake one static defender. In Task 3 the athletes received a pass. When the ball was caught, two out of three defenders approached the athlete. The athlete would then be forced to cut away from the approaching defenders, resulting in a randomized cutting direction. To our knowledge, no other studies have investigated the effect of anticipation on muscle activity using this specific methodological design. Additionally, previous research has been lacking in making a realistic in-game side-cutting maneuver.

The main results from this study refer to three statistically significant findings. In ST there was a statistically significantly higher average muscle activation in Task 2 compared to Task 1, 50 ms before IC. In VL there was statistically significantly lower average muscle activation in Task 3 compared to Task 2, 50 ms before IC. In VM the average muscle activity was statistically significantly higher in Task 2 compared to Task 1, 50 ms before IC.

Koga et al. (2010) found that ACL injuries occur approximately 40 ms after IC, leaving no time for muscle feedback to activate the muscles surrounding the knee. Hence, pre-activity may activate the muscles surrounding the knee prior to the execution of dynamic movements, stabilizing the knee prior to IC and absorbing the forces at IC, which puts less strain on the ACL (Beard et al., 1993, Lephart et al., 2002). Meaning that, when a side-cut maneuver is predetermined the muscle activity is adjusted to counter forces at IC. However, when the movements performed are a result of unanticipated events, it is thought that the time to plan a muscle activation strategy decrease (Besier et al., 2001). Which in turn could lead to undesirable joint angulations, resulting in increased ACL strain (Myer et al., 2005). Therefore, special attention will be directed towards the pre-activity of the hamstring and quadriceps muscles in this chapter. Going further, the results from this study will be discussed in the light of previous research.

4.1 Previous research on muscle activation in sport-specific maneuvers

Efforts have been made to account for the lack of anticipation and creating a realistic in-game scenario in sports-specific maneuvers related to ACL injuries. However, studies investigating the effect of anticipation and game-specific elements in handball side-cut faking maneuvers are lacking. Still, understanding the effect of randomized change of direction tasks on muscle activity and the difference in muscle activity between simple and more complex side-cut faking maneuvers is essential when designing screening tools.

Our results are not fully comparable to the studies investigating the effect of anticipation on muscle activity mentioned earlier in this thesis. Due to the nature of the side-cutting tasks in our study, different EMG-normalization procedures and different definitions of phases in previous research, a direct comparison between results is impossible. Hence, a comparison of the general findings is used when relevant.

Our results show that 50 ms before IC, the average muscle activity in VL was statistically significantly lower (0.19 ± 0.07) in the randomized side-cut faking maneuver, compared to the predetermined side-cut in Task 2 (0.21 ± 0.08). The average muscle activity also showed a tendency to be lower in the randomized side-cut faking maneuver 50 ms after IC (0.31 ± 0.09), compared to the predetermined side-cut in Task 2 (0.34 ± 0.11) and Task 1 (0.33 ± 0.11). In contrast, Meinerz et al. (2015) found that peak muscle activity (% EMG MVIC) in VL was higher in the unanticipated cutting for both the pre-contact phase (0.33 ± 0.20) (100 ms before IC) and landing phase (2.10 ± 0.85) (first 20% after IC), compared to the pre-contact (0.28 ± 0.14) and landing phase (1.48 ± 0.96) of the anticipated maneuver.

For VM, Meinerz et al. (2015) found that there was a higher peak muscle activity in the pre-contact phase of the anticipated condition (0.19 ± 0.15), compared to the unanticipated condition (0.16 ± 0.10). Our results are in agreement with Meinerz et al. (2015). 50 ms before IC, there was a tendency towards a higher average muscle in Task 2 (0.20 ± 0.06) compared to Task 3 (0.19 ± 0.05). Additionally, there was a statistically significantly higher average muscle activity in Task 2 (0.20 ± 0.06) compared to Task 1 (0.18 ± 0.06). Conversely, the average muscle activity was slightly higher in Task 3 (0.19 ± 0.05) when compared to Task 1 (0.18 ± 0.06). In the landing phase, the peak muscle activity was higher in the unanticipated condition (1.16 ± 0.73) compared to the anticipated condition (0.98 ± 0.67). In contrast to Meinerz et al. (2015), the average muscle activity for VM was close to identical between the predetermined and randomized side-cut faking maneuvers, 50 ms after IC.

Our results are in agreement with what is found by Meinerz et al. (2015), 50 ms before IC for BF. We found that the average muscle activity was identical across all tasks (0.15 ± 0.06). Meinerz et al (2015) reported that for BF, the peak muscle activity was close to identical for both conditions in the pre-contact phase. Peak muscle activity was 0.24 ± 15 and 0.24 ± 16 for the anticipated and unanticipated conditions, respectively. However, in the landing phase, the peak muscle activity was higher in the unanticipated condition (1.48 ± 1.11), compared to the anticipated condition (1.10 ± 0.69). Contrastingly, our results show that 50 ms after IC, there was a tendency towards a lower average muscle activity in Task 3 (0.17 ± 0.05), compared to Task 1 (0.19 ± 0.07) and Task 2 (0.19 ± 0.07). However, it should be noted that 100 ms before IC and the first 20 % of IC is not directly comparable to 50 ms before and after IC, nor is average muscle activation and peak muscle activity.

Kim et al. (2016) found that in the 1st peak of GRF during a side-cutting maneuver the difference in muscle activation in VL, VM, lateral hamstring, and medial hamstring, was close to identical in the anticipated side-cut, compared to the unanticipated side-cutting maneuver. The authors did not specify which muscles the medial and lateral hamstring consisted of. However, our results show that the average muscle activity of BF and ST is in agreement with what was found by Kim et al. (2016). However, the muscle activity in ST was significantly higher in Task 2 (0.25 ± 0.06), compared to Task 1 (0.22 ± 0.06). In contrast to Kim et al. (2016), we found a significantly lower average muscle activity in the randomized side-cut faking maneuver (0.19 ± 0.07), compared to the predetermined side-cut in Task 2 (0.21 ± 0.08) in VL. For VM our results are harmonious with Kim et al. (2016). However, the average muscle activity was significantly higher in Task 2 (0.20 ± 0.06), compared to Task 1 (0.18 ± 0.06).

The difference in muscle activity changed significantly in VL, VM, and lateral hamstring ($p < 0.01$) from the 1st to 2nd peak in GRF, with the highest muscle activity being in the 2nd peak of the anticipated side-cut maneuver (Kim et al., 2016).

Our results show that the average muscle activity increased from 50 ms before IC to 50 ms after IC for most muscles across the three tasks, except for ST. Although, we do not know if it is significantly different.

That being said, the 1st peak in GRF and 50 ms before IC are not directly comparable considering that in the 1st peak of GRF, the athlete already has contact with the ground, nor is the 2nd peak in GRF and 50 ms after IC. Also, Kim et al (2016) only investigated sixteen male adolescent soccer players in middle school which is not directly comparable with female handball athletes with a mean age of 19.4 (Table 1). Studies have shown that males and females activate the quadriceps and hamstring muscles in different ways during anticipated and unanticipated sport-specific maneuvers (Sell et al., 2006). The quadriceps activation is also more dominant among females, compared to male, which is associated with an increased anterior tibial translation and ACL strain (Hirokawa et al., 1992; Malinzak et al., 2001; Hansson et al., 2008; Zebis et al., 2009; Koga et al., 2010).

Sell et al. (2006) found that the combined results of male and female athletes show that 150 ms before maximum body deceleration, the muscle activity was higher in both VL and ST in the planned jumps, compared to the reactive jumps. By 150 ms before maximum deceleration of the body, the authors referred to the peak posterior GRF, which can be pinned to approximately 25% of the stance phase (Sell et al., 2006). Given that the stance phase is approximately 200 ms long, this would imply that the measurement is made at roughly 100 ms before IC. Like Sell et al (2006), we found a higher average muscle activity in VL in the predetermined side-cut faking maneuver (0.21 ± 0.08), compared to the randomized side-cut maneuver in Task 3 (0.19 ± 0.07). In ST there was a tendency towards a higher average muscle activation in Task 2 (0.25 ± 0.06) compared to Task 3 (0.23 ± 0.07), harmonizing with the results of Sell et al.

(2006). However, there was a significantly higher average muscle activation in Task 2, compared to Task 1. Yet, there was a tendency toward a higher average muscle activity in Task 3, compared to Task 1, which is contradictory to Sell et al. (2006).

Besides the fact that the tasks are different, one key component is missing in many studies investigating anticipation in side-cutting maneuvers. That is a well-preserved athlete-environment relationship (Bolt et al., 2021). In all of the studies discussed so far, the athletes have reacted to a visual stimulus in the unanticipated condition, represented by a light or an arrow, indicating which way to move. The athletes in the current study, executed the side-cut in the randomized condition as a result of the behaviour of other players, as recommended by Bolt et al. (2021).

Regardless, we must admit that our results were surprising. We did not find any noteworthy differences in average muscle activity between the predetermined and randomized side-cut faking maneuvers. Not even between the most simple predetermined maneuver, Task 1, and the much more complex and challenging maneuver, Task 3. The only exception was a significantly lower average muscle activity in VL in Task 3, compared to Task 2. Besides that, the only significant changes in average muscle activity were between the two predetermined side-cut faking maneuvers. Additionally, all significant changes were observed 50 ms before IC. Even though Task 3 better represents a realistic in-game side-cut faking maneuver we did not find a difference between the side-cut faking maneuver with predetermined and randomized cutting direction. A possible explanation to this might be because of the uncertainty associated with Task 3, which could make the athletes hesitant in their movements. On the other hand, there was a significantly higher average muscle activation in ST and VM in Task 2 compared to Task 1. In these tasks, the element of uncertainty is eliminated which may provide the opportunity to embrace the task with more speed and power, resulting in higher muscle activity. Furthermore, Task 2 better represents a scenario where a side-cut faking maneuver would be performed, compared to Task 1, because of the static defender. Side-cut faking maneuvers such as Task 2 is also frequently used as a specific warm-up procedure in handball training.

4.2 Muscle activation patterns in relation to ACL injury risk

In a prospective study by Zebis et al. (2009) they screened female handball and football players' muscle activation patterns as a possible risk factor for non-contact ACL injury. The pre-activity (10 ms before IC) of VL, VM, RF, and ST were measured during a side-cutting maneuver. The results from the study show that there were significant differences in pre-activity among the injured, compared to the non-injured athletes. The injured athletes had a reduced pre-activity of ST (21% ± 6% vs 40% ± 17%; $P < .001$) and an elevated pre-activity of VL (69% ± 12% vs 35% ± 15%; $P < .01$), compared to the non-injured athletes. The present study is not directly comparable to Zebis et al. (2009), however, we can compare trends in muscle activity between the predetermined and randomized side-cut faking maneuver.

In the study by Zebis and co-researchers, the athletes did a side-cut maneuver, similar to Task 1 in our study. Although ACL injuries typically occur during a side-cut maneuver, Myklebust et al. (1997) found that the injury often occurs when trying to fake an opponent and when handling a ball. Also, the behaviour of other players and opponents should be accounted for when investigating injury mechanisms, similar to Task 3 (Bahr & Krosshaug, 2005; Bolt et al., 2021). Based on previous research it is thought that the movements that are performed as a result of unanticipated events such as in Task 3, would decrease the time to plan an effective muscle activation strategy to stabilize the knee at IC, and vice versa during anticipated movements (Besier et al., 2001; Myer et al., 2005). Hence, one could argue that side-cuts such as Task 3 better represent a non-contact ACL injury situation, compared to side-cuts similar to Task 1 and Task 2. Therefore, one would intuitively expect that Task 3 would show a muscle activation pattern associated with increased risk, as shown by Zebis et al. (2009).

In ST there was a tendency towards a lower average pre-activity in Task 3 (0.23 ± 0.07), compared to Task 2 (0.25 ± 0.06). In this specific muscle, our results are in line with what is found by Zebis et al. (2009). Meaning that when simulating in-game scenarios, there is a reduced pre-activity of ST, which is associated with an increased risk of ACL injury. However, no significant differences were observed. Interestingly, there was a significantly higher average muscle activity in Task 2, compared to Task 1. Also, there were tendencies towards a higher average pre-activity in Task 3 compared to Task 1, which is contradictory to what Zebis et al. (2009) found in regard to ACL injury risk.

However, Task 1 was a predetermined maneuver and does not fully represent a realistic injury situation.

For quadriceps, Zebis et al. (2009) reported that an elevated pre-activity of VL was associated with an increased risk of ACL injury. Our results show that there was a significantly lower average pre-activity in Task 3 (0.19 ± 0.07), compared to Task 2 (0.21 ± 0.08). Also, when comparing Task 1 to Task 3, there were tendencies towards a lower pre-activity. This implies that even when simulating a realistic in-game scenario, including the effect of unanticipated factors, there are no signs of elevated risk of ACL injury in regards to what Zebis et al (2009) found in VL pre-activity.

In another prospective study, elite female handball and football players were screened for neuromuscular risk factors by measuring the pre-activity (50 ms before IC) of VL, VM, ST, and BF (Zebis et al., 2021), using the same side-cut faking maneuver as in the previous prospective study (Zebis et al., 2009). However, the “run-in” distance was 2 meters in the first prospective study, and 5 meters in the second. Based on the results of the injured, compared to non-injured athletes, the researchers found four risk factors associated with increased risk of ACL injury, one of them being reduced ST EMG activity 50 ms prior to IC. Similar to the first prospective study (Zebis et al., 2009), our results show that there was a tendency towards a reduced average pre-activity of ST in Task 3, compared to Task 2. However, there was a significantly higher average pre-activity in Task 2, compared to Task 1. There was also a tendency towards a higher average pre-activity in Task 3, compared to Task 1.

To summarize our results in regards to the two prospective studies, there were no strong findings pointing in the direction of the findings by Zebis and co-authors in terms of reduced ST pre-activity or elevated VL pre-activity when comparing the most simple side-cut, to the most complex and challenging side-cut. Although, we did find a tendency towards a reduced pre-activity in ST 50 ms before IC in Task 3, compared to Task 2. However, Task 2 does not resemble a typical non-contact injury situation in female handball and the difference was not statistically significant (Myklebust et al., 1997; Olsen et al., 2004). Surprisingly, we even found a statistically significantly reduced pre-activity of VL in Task 3, compared to Task 2.

This would imply that the pre-activity, which is deemed crucial to knee stabilization at IC, does not significantly change when simulating in-game scenarios that best represent non-contact ACL injury situations, compared to much less representative injury situations, except from a reduced average VL pre-activity. However, this has not been linked to increased injury risk. The only exception was a tendency towards a reduced average ST pre-activity in Task 3, compared to Task 2, which does not fully represent a realistic injury situation.

That being said, the evidence basis for the proposed risk factors in neuromuscular pre-activity is limited. In the first prospective study a total of fifty-five female athletes were screened, and five sustained an ACL injury (Zebis et al., 2009). In the second study, ninety athletes were screened and nine sustained an ACL injury (Zebis et al., 2021). Hence, one should interpret both the comparison and the results from the two prospective studies with caution. Also, both football and handball athletes injured the ACL. Although there are similarities between the side-cut faking maneuver in both sports, the sports are fundamentally different. External factors such as weather, floor and turf type, and sports equipment such as shoes, could play an important role in the injury situation (Bahr & Krosshaug, 2005). Secondly, our study has measured average pre-activity in the 50 ms leading up to IC, whilst the other measured the 10 ms interval before IC (Zebis et al., 2009). Therefore, we cannot rule out that data of importance has been left out.

One possible explanation to why we did not find a difference between the predetermined side-cutting tasks and the randomized side-cutting task, is that the randomized cutting task contains the element of uncertainty. Therefore, there is a possibility that the athletes may have executed Task 3 with more caution in order to handle the uncertainty associated with the task, compared to the predetermined side-cutting tasks. On the other hand, we did not find a muscle activation pattern associated with increased risk of injury in Task 3 compared to Task 1 and Task 2, based on the research by Zebis et al. (2009; 2021). This could indicate that the athletes may already have developed a pre-programmed muscle activation response, which is used when faced with unanticipated tasks. Executing the task with more caution may therefore be a result of a pre-programmed response, where the pre-activity is adjusted to deal with uncertainty, whilst simultaneously protecting the knee.

That being said, knee abduction moments data from the same project, using the same side-cut faking tasks, also did not find any noteworthy differences between the three tasks (Mai et al., 2021). Considering that KAM is a well-established screening method for risk factor identification, compared to muscle activity, in combination with the results of the current study, provides a basis for speculations regarding the use of realistic in-game side-cut faking maneuvers in neuromuscular screening.

Meanwhile, Bolt et al. (2021) stated that an ecological approach is necessary to acquire generalizable information about risk factors and injury mechanisms. An ecological approach would, according to Bolt et al. (2021), contain a preserved athletes-environment relationship and inclusion of playing positions and other players. To our knowledge, this is the very first study to specifically investigate how muscle activity changes through three side-cutting tasks whilst the task complexity increases in terms of external stimuli and anticipation. This is the biggest strength of this study. Previous studies, which have investigated muscle activation and anticipation status in side-cutting maneuvers, have been deficient in making a realistic non-contact ACL injury situation (Bolt et al, 2021), until now. Athletes' movement patterns during screening have previously been restricted and generalized, e.g., moving in a pre-defined trajectory at a given speed, and jumping or cutting at a fixed position (Bolt et al., 2021). This would make the test protocol more standardized and repeatable, although it does not resemble a realistic non-contact ACL injury situation. By using realistic in-game scenarios which preserve an athlete-environment relationship and include elements such as ball handling, playing position, and opponents, the generalizability of the results increases as they resemble a realistic non-contact ACL injury situation (Bahr & Krosshaug, 2005, Bolt et al., 2021). In accordance with Bolt et al. (2021), Task 3 may be one of the most generalizable side-cut faking tasks and is, therefore, the most representative task for injury mechanisms and ACL risk factor research.

Still, using realistic in-game tasks comes at a price. When increasing the complexity of the tasks, the number of uncontrolled variables will also increase the complexity of the dataset. Researchers should therefore step carefully when adding multiple layers to create a game-like athlete-environment (Bolt et al., 2021). Consequently, the research team spoke with multiple handball coaches, handball players, other researchers, and faculty members to ensure that the tasks were as representative for a realistic in-game scenario as possible. In addition, a pilot study was conducted where handball players performed different side-cut faking maneuvers and gave constant feedback on different aspects to consider when making a realistic in-game scenario. Hence, we feel confident that realistic side-cut faking maneuvers with a well-preserved athlete-environment relationship was achieved.

Efforts have been made to account for the lack of anticipation and creating a realistic in-game scenario in sport-specific maneuvers related to ACL injuries. Still, studies investigating the effect of anticipation and game-specific elements in handball side-cut faking maneuvers are lacking. However, understanding the effect of randomized change of direction tasks on muscle activity and the difference in muscle activity between simple and more complex side-cut faking maneuvers is essential when designing screening tools. Considering the small differences in average muscle activation between the predetermined and randomized side-cut faking maneuver found in the current study, future research should consider only including one of the side-cut faking tasks. It should be noted however, that this recommendation is based exclusively on our results. The results of this study are yet to be reproduced and might not be applicable for certain research, as the complexity of the tasks contains many uncontrollable variables. For research aiming at understanding injury mechanisms during side-cut maneuvers, tasks similar to Task 3 is recommended (Bahr & Krosshaug, 2005; Bolt et al., 2021). Also, ACL injuries are considered multifactorial (Bahr & Krosshaug, 2005). Hence, screening of muscle activity narrows the point under investigation. Both anatomical, biomechanical, neuromuscular, and hormonal factors are linked to risk of ACL injury (Ireland, 2016). In addition, the study is not flawless and multiple factors may have influenced the results.

4.3 Limitations of the study

One of the limitations of this study lies within the use of EMG as a measurement tool itself. Although the options are limited in terms of measuring muscle activity, there are some weaknesses associated with this method of measurement.

Due to the nature of our tasks, especially Task 3, being a highly dynamic and rapid movement, it is plausible that movement artifacts have occurred during testing. We also experienced some difficulties with EMG-sensors not staying in place. To prevent movement artifacts, horizontally pre-cut elastic fixation tape was used to cover the area surrounding the electrodes without interfering with the cables. Further, EMG-sensors were secured using the same procedure. Also, this study was a part of a larger project where multiple researchers gathered data, including EMG, using shorts with integrated electrodes that were put on top of the electrodes used in this study. This might have been another contributing factor to movement artifacts. Although, there is reason to believe that this might have affected the signals of the EMG-shorts to a greater extent compared to the electrodes in the Myon EMG setup.

Other factors, such as the distance between the electrode and the muscle could negatively influence the EMG-signal due to increased resistance in the electrical charges passing through. An increased distance between the muscle and the electrode could be caused by a high level of subcutaneous fat, because of the anatomical nature, or a combination of both (Nordander et al., 2003; Konrad, 2005). However, there is no reason to believe that this has had a massive impact, as the majority of athletes were both lean and muscular. Under no circumstances did we experience noteworthy problems with identifying muscles as a result of subcutaneous fat. In addition, the muscles recorded in this study were quite superficial. Still, both EMG signal noise and the interface between electrodes and muscles are contributing factors. To reduce the EMG-signal noise a 4th order high-pass Butterworth filter with a cut-off frequency of 5 Hz was applied to the EMG-signals. To gain further clarity of signals and reduce EMG-signal noise the skin was shaved with a single-use disposable razor and rinsed with alcohol as recommended by SENIAM. Additionally, muscle crosstalk, potentially leading to misinterpretation of EMG-data, was reduced by strictly following the SENIAM guidelines for electrode size, inter-electrode distance, and identification of the correct muscles. The athletes also performed a series of isometric contractions and the muscles were marked with a pen to ensure the proper location of electrode placement. Further, EMG-signals were visually inspected for magnitude and clarity during jump and jump squats, prior to the side-cut faking maneuvers. Additionally, the EMG data went through a quality assurance process for outlier identification to ensure realistic and consistent measurements.

Another potential limitation of the study is that we did not normalize the data to either maximal voluntary isometric contraction (MVIC) or peak muscle activation in a given movement, making comparisons challenging. In that sense, the magnitude of the muscle activation is also unknown. On the other hand, a normalization was not required to compare muscle activity across tasks. There is a large span in different normalization methods used in the existing literature, making comparison difficult either way. Besides, the majority of literature on anticipation and EMG in sport-specific movements does not report EMG-data on individual muscles. On the contrary, normalized data would still give a better understanding of the magnitude of muscle activity, regardless of comparison.

Another limitation could be that the defenders in Task 3 exposed their movement too early. This would turn what was essentially a randomized side-cut into a predetermined side-cut. It is therefore possible that some of the EMG-data in Task 3 does not fully represent a randomized side-cut faking maneuver. However, we did not ask, nor register what cuts who potentially were perceived as predetermined and randomized. Data from the same project show that 0.94 ± 0.15 seconds passed between the initiation of the block by the defenders and the athletes contact with the ground in Task 3 (Mai et al., 2021). It is unclear whether this is enough time to provoke a realistic in-game situation, as previous studies using light signals in single-legged landing tasks reported between 350 to 650 ms between light signal and IC. However, the athletes in the present study had to look at a teammate, receive a ball and react to defenders before executing the cut. During testing we also experienced that some athletes were insecure and hesitated during the side-cut in Task 3, and some athletes even collided with the defenders, which essentially is perceived as unfortunate and was discarded from the data. On the contrary, the collisions between athletes and defenders might also be a result of righteous timing of the defenders, further strengthening our thought that we created a realistic in-game situation. Future research should consider including data from tasks that usually is discarded as a measure of performance, or to investigate factors such as coordination of failed tasks. This would be yet another step towards a further improved athlete-environment relationship (Bolt et al., 2021).

5. Conclusion

No differences were detected between the simplest tasks with a predetermined cutting direction compared to the randomized cutting direction. The only exception was a reduced VL pre-activity between Task 3 and Task 2. Implying that the pre-activity, which is crucial to knee stability is not affected by the task complexity. Significant, yet small differences were detected within the predetermined side-cuts. Thus, a simple task seems to be sufficient for EMG-screening when simulating in-game scenarios. There were no indications towards muscle activation patterns associated with increased ACL injury risk across tasks.

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Appendix I

Vil du delta i forskningsprosjektet

” Hva er den optimale fintetesten for å vurdere risiko for fremre korsbåndskade?”?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å forstå hvordan ulik grad av kompleksitet i en finte-test påvirker knebelastning, muskelaktivering og prestasjon. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål

Våre tidligere studier viser at finteteknikk påvirker risiko for å få en fremre korsbåndskade hos kvinnelige håndballspillere på elitenivå. Vi vil nå sammenlikne den originale fintetesten med varianter som er enklere, eller mer komplekse og idrettsspesifikke. I tillegg vil vi gjennomføre en prestasjons/retningsforandringstest (505 test). Hensikten med studien er å lære mer om hvordan ulik grad av kompleksitet i testene påvirker knebelastning, muskelaktivering og prestasjon. I tillegg vil vi sammenlikne ulike metoder for å måle krefter og bevegelser. 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 50 kvinnelige håndballspillere på elitenivå fra østlandsområdet. Du må ha fylt 16 år for å kunne delta. Kvinnelige håndballspillere på elitenivå 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 elektroder og refleksmarkører på kroppen din. Elektrodene leser av muskelaktivering, og refleksmarkører filmes når du gjennomfører de ulike fintebevegelsene. Etter oppvarming vil du gjennomføre 5-10 repetisjoner av hver av de 3 finteoppgavene. Du vil også bli filmet av et vanlig videokamera, for å kunne verifisere at opptaket kan brukes. Du må ha på deg en kort shorts, sports-BH og skoene du bruker når du spiller håndball. Du må påregne å være i laboratoriet i ca 2,5t.

Vi gjør oppmerksomme på at finter og retningsforandringer kan medføre risiko for skade, inkludert korsbåndskade, og at spillere med tidligere skade har økt risiko for en ny skade.

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. Prosjektet gjøres i samarbeid med Universitat Politècnica de Catalunya og Eurecat Technology Center of Catalonia, samt German Sport University Cologne, som dermed også vil ha tilgang til data. Navnet og kontaktopplysningene dine vil bli anonymisert, og vi vil kun benytte forsøkspersonnummer i databehandlingen. Individuelle deltakere vil ikke kunne gjenkjennes i publikasjoner.

Personopplysninger vil imidlertid bli tatt vare på i 14 dager før sletting, pga. koronaviruset. Dette gjør det mulig å kontakte deg hvis noen i prosjektet blir smittet eller har vært i kontakt med andre smittede.
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 01.07.2023. Alle persondata vil være anonymisert, men alle data, inkludert videoopptak vil oppbevares på Norges idrettshøgskole i 5 år etter prosjektslutt pga etterprøvbarhet av forskningsdata. Videofilmene vil kun fokusere på underekstremiteten, dvs at hodet ikke vil filmes.

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), og
- 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 personvernregelverket.

Hvor 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 *Anniken Tidemann Pedersen (annikentidemann@hotmail.com), Mathias Midthjell Eggerud (mathiasme@student.nih.no) eller veileder/prosjektleder Tron Krosshaug (tron.krosshaug@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 *Mathias Midthjell Eggerud* *Anniken Tidemann Pedersen*
(Forsker/veileder) (Masterstudent) (Masterstudent)

Samtykkeerklæring

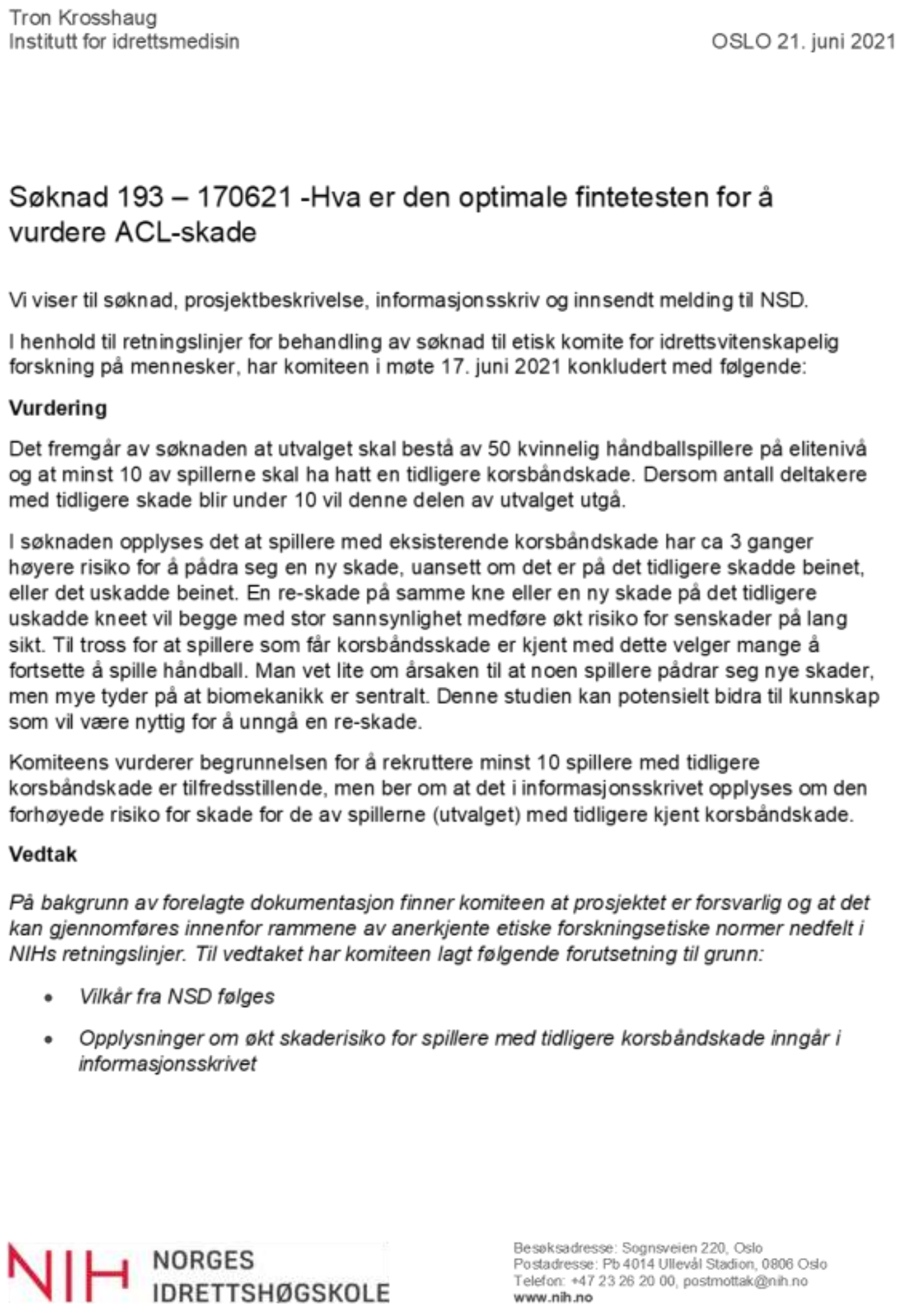
Jeg har mottatt og forstått informasjon om prosjektet «*Hva er den optimale fintetesten for å vurdere risiko for fremre korsbåndskade?*», og har fått anledning til å stille spørsmål. Jeg samtykker til:

☐ å delta i eksperimentet
☐ at videoopptak lagres i 5 år etter prosjektslutt

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

----
(Signert av prosjektdeltaker, dato)

Appendix II



Tron Krosshaug
Institutt for idrettsmedisin

OSLO 21. juni 2021

Søknad 193 – 170621 -Hva er den optimale fintetesten for å vurdere ACL-skade

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 17. juni 2021 konkludert med følgende:

Vurdering

Det fremgår av søknaden at utvalget skal bestå av 50 kvinnelig håndballspillere på elitenivå og at minst 10 av spillerne skal ha hatt en tidligere korsbåndskade. Dersom antall deltakere med tidligere skade blir under 10 vil denne delen av utvalget utgå.

I søknaden opplyses det at spillere med eksisterende korsbåndskade har ca 3 ganger høyere risiko for å pådra seg en ny skade, uansett om det er på det tidligere skadde beinet, eller det uskadde beinet. En re-skade på samme kne eller en ny skade på det tidligere uskadde kneet vil begge med stor sannsynlighet medføre økt risiko for senskader på lang sikt. Til tross for at spillere som får korsbåndsskade er kjent med dette velger mange å fortsette å spille håndball. Man vet lite om årsaken til at noen spillere pådrar seg nye skader, men mye tyder på at biomekanikk er sentralt. Denne studien kan potensielt bidra til kunnskap som vil være nyttig for å unngå en re-skade.

Komiteens vurderer begrunnelsen for å rekruttere minst 10 spillere med tidligere korsbåndskade er tilfredsstillende, men ber om at det i informasjonsskrivet opplyses om den forhøyede risiko for skade for de av spillerne (utvalget) med tidligere kjent korsbåndskade.

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*
- *Opplysninger om økt skaderisiko for spillere med tidligere korsbåndskade inngår i informasjonsskrivet*

NIH NORGES IDRETTSHØGSKOLE

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Postadresse: Pb 4014 Ullevål Stadion, 0806 Oslo
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www.nih.no

Komiteen forutsetter videre at prosjektet gjennomføres på en forsvarlig måte i tråd med de til enhver tid gjeldende ifbm Covid-19 pandemien.

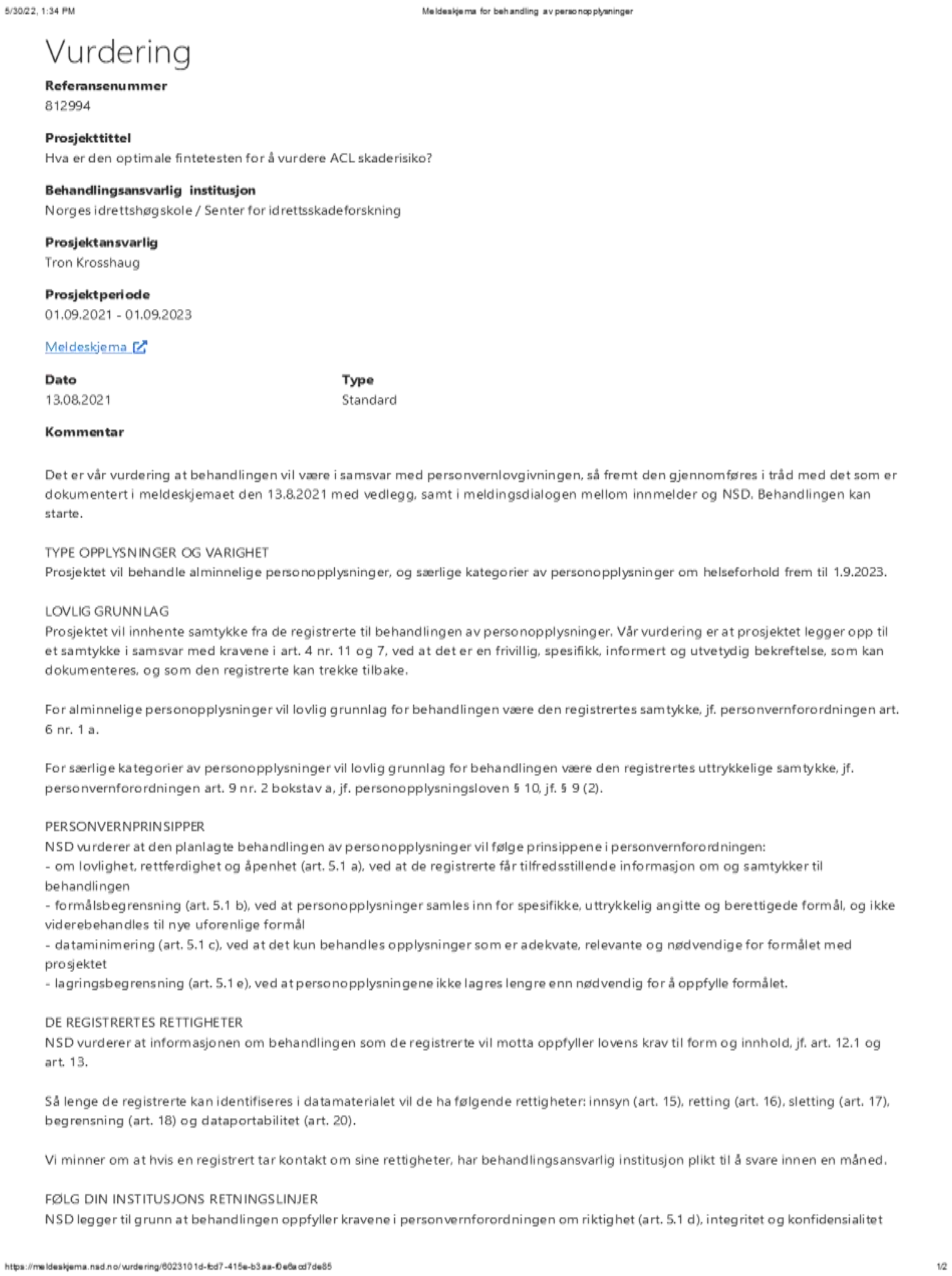
Komiteen gjør oppmerksom på at vedtaket er avgrenset i tråd med fremlagte dokumentasjon. Dersom det gjøres vesentlige endringer i prosjektet som kan ha betydning for deltakernes helse og sikkerhet, skal dette legges fram for komiteen før eventuelle endringer kan iverksettes.

Med vennlig hilsen

Anne Marte Pensgaard

Professor Anne Marte Pensgaard
Leder, Etisk komite, Norges idrettshøgskole

Appendix III



Vurdering

Referansenummer
812994

Prosjekttittel
Hva er den optimale fintetesten for å vurdere ACL skaderisiko?

Behandlingsansvarlig institusjon
Norges idrettshøgskole / Senter for idrettsskadeforskning

Prosjektansvarlig
Tron Krosshaug

Prosjektperiode
01.09.2021 - 01.09.2023

Meldeskjema

Dato	**Type**
13.08.2021	Standard

Kommentar

Det er vår vurdering at behandlingen vil være i samsvar med personvernlovgivningen, så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet den 13.8.2021 med vedlegg, samt i meldingsdialogen mellom innmelder og NSD. Behandlingen kan starte.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige personopplysninger, og særlige kategorier av personopplysninger om helseforhold frem til 1.9.2023.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 nr. 11 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse, som kan dokumenteres, og som den registrerte kan trekke tilbake.

For alminnelige personopplysninger vil lovlig grunnlag for behandlingen være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 a.

For særlige kategorier av personopplysninger vil lovlig grunnlag for behandlingen være den registrertes uttrykkelige samtykke, jf. personvernforordningen art. 9 nr. 2 bokstav a, jf. personopplysningsloven § 10, jf. § 9 (2).

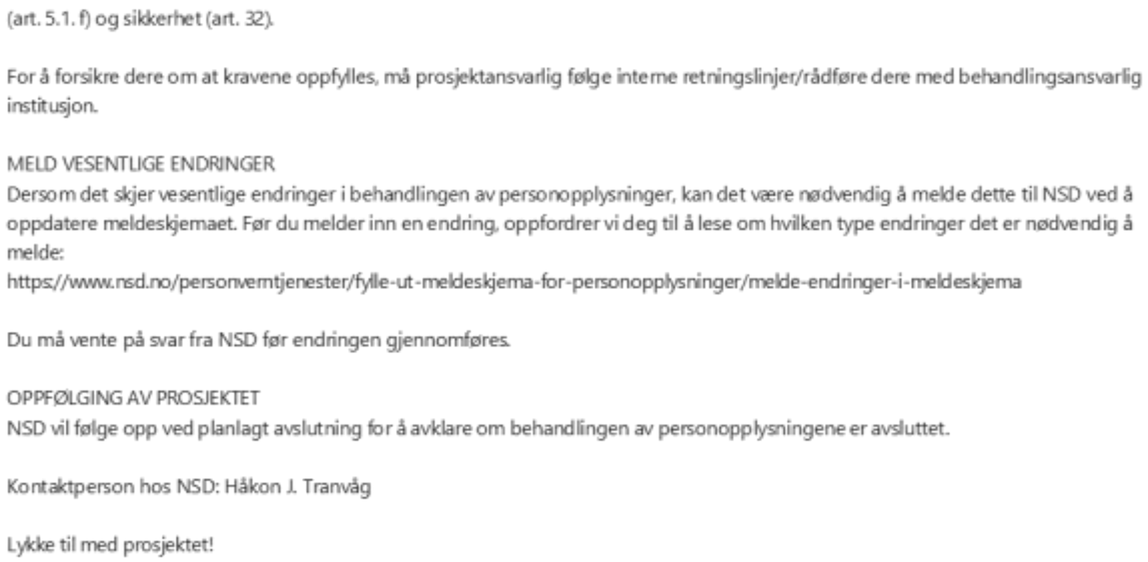
PERSONVERNPRINSIPPER
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen:
- om lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
- formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke viderebehandles til nye uforenlige formål
- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet.

DE REGISTRERTES RETTIGHETER
NSD vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.

Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18) og dataportabilitet (art. 20).

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet



(art. 5.1. f) og sikkerhet (art. 32).

For å forsikre dere om at kravene oppfylles, må prosjektansvarlig følge interne retningslinjer/rådføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilken type endringer det er nødvendig å melde:
https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema

Du må vente på svar fra NSD før endringen gjennomføres.

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

Kontaktperson hos NSD: Håkon J. Tranvåg

Lykke til med prosjektet!