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The feasibility of a new task assessing
knee control in female footballers – using
EMG to measure muscle pre-activity
during a side-cutting task

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Abstract

Screening tasks for assessing risk of anterior cruciate ligament (ACL) injury cannot predict injuries, and more challenging tasks for assessing knee control in athletes should be examined. Neuromuscular assessments of knee control are thought to play a critical role in the prevention of ACL-injuries, but few studies have investigated tasks other than vertical drop jump and side-cut manoeuvres.

A new task aiming to replicate side-step movements seen in ACL-injury situations in football matches was developed. The objective of this study was to determine the feasibility of a task developed for assessing knee control in female footballers. It was examined if electromyography (EMG) could successfully be recorded during the new task, and whether EMG pre-activation would undergo clinically relevant changes as a function of ball release frequency and visual stimulus. A repeated measures experimental study was designed, with 16 female footballers with no history of ACL-injury as participants. EMG pre-activation (50ms prior to initial contact) for the semitendinosus (ST), vastus lateralis (VL), gluteus medius (GMED), and gluteus maximus (GMAX) was recorded during a task with multiple change-of-directions that mimicked situations in football matches where a defender is pressing an attacker. Participants reacted to a table tennis ball being launched, with a cutting motion to stop the ball with their feet. Comparisons between conditions with visual stimulus (VS) and without visual stimulus (NOVS) were made in the unanticipated task.

EMG pre-activation could not be captured successfully for all the GMED or GMAX during the task. EMG-data from the VL could be obtained from 397 cuts (36.1%). The ST had valid data from 266 cuts (24.6%). A trend for lower EMG pre-activation of the ST was seen in the VS condition compared to the NOVS condition. The ST was the only muscle with statistically significant decreased EMG pre-activation in the VS condition in the two easiest difficulty levels. No other statistically significant differences as a function of ball release frequency and visual stimulus were seen.

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Abbreviations

ACL	Anterior cruciate ligament
PCL	Posterior cruciate ligament
MCL	Medial collateral ligament
LCL	Lateral collateral ligament
RF	Rectus femoris
VM	Vastus medialis
VIM	Vastus intermedius
VL	Vastus lateralis
BF	Biceps femoris
SM	Semimembranosus
ST	Semitendinosus
GMAX	Gluteus maximus
GMED	Gluteus medius
IC	Initial contact
VDJ	Vertical drop jump
EMG	Electromyography
KAM	Knee abduction moment
GRF	Ground reaction force
TA	Tibialis anterior
LH	Lateral hamstrings
MH	Medial hamstrings
MG	Medial gastrocnemius
LG	Lateral gastrocnemius
vGRF	Vertical ground reaction force
MVIC	Maximum voluntary isometric contraction

TLF	Tensor fascia latae
mV	millivolt
μ V	microvolt
Hz	Hertz (frequency, equivalent to cycles per second)
ICC	Intraclass correlation coefficient
RMS	Root mean square
SENIAM	Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles
EMD	Electromechanical delay
sEMG	Surface electromyography
VS	Visual stimulus

1. Theory

1.1 *Background theory*

Injuries to the anterior cruciate ligament (ACL) have serious short- and long-term consequences, including high monetary costs of rehabilitation and possible surgery, and increased risk of knee osteoarthritis (Øiestad, Engebretsen, Storheim, & Risberg, 2009). Athletes in team sports that require pivoting (e.g. football (soccer), team handball, basketball) are especially at risk (Moses, Orchard, & Orchard, 2012), with the risk being 2-3 times higher for females (Arendt, Agel, & Dick, 1999; Hootman, Dick, & Agel, 2007; Prodromos, Han, Rogowski, Joyce, & Shi, 2007; Walden, Hagglund, Magnusson, & Ekstrand, 2011). ACL-injuries typically happen without direct player contact, and non-contact injuries are reported to account for about 70% of ACL-injuries seen in football (Boden, Dean, Feagin, & Garrett, 2000). A number of risk factors for ACL-injury have been identified, and exercise prevention programs have been created in order to prevent injuries. Several exercise prevention programs have been shown to be effective for reducing ACL-injuries, and efforts to implement exercise programs to prevent these injuries have been made (Soligard et al., 2008; Sugimoto, Myer, McKeon, & Hewett, 2012). Despite this, injury rates have remained the same over the last 10 years in men's professional football (Walden, Hagglund, Magnusson, & Ekstrand, 2016).

Screening tests to assess and to predict risk of ACL-injury have also been examined. There is however evidence to suggest that the screening tests cannot predict future injuries, as the current screening tasks are not sufficiently specific and sensitive (Bahr, 2016; Krosshaug et al., 2016; Smith et al., 2012). It is thought that more complex tests are required to make more thorough assessments of injury risk (Krosshaug et al., 2016; Smith et al., 2012). Additionally, a complex task may also give insight into the mechanisms with which specific exercises reduce ACL-injury risk.

The theory chapter aims to describe the development of such a complex task for assessing knee control. An overview of the current knowledge in ACL-injury incidence and prevalence, the mechanisms and consequences of an ACL-injury and proposed risk factors will be presented. Methods used in the study will be further discussed in the extended methods chapter. Last, the research article will be presented.

1.1.1 Human body definitions

Studies on human movements require a shared use of terms and definitions to be useful to others. Standardised terms are used to define movements of, and locations on or within the human body.

Universal body directions are one set of these standardised terms, and can be seen in *Figure 1*. *Superior-inferior*: superior is towards the head, inferior is away from the head. *Anterior-posterior*: anterior is towards the front, posterior is towards the back. *Medial-lateral*: medial is towards the centre of the body, lateral is away from the centre of the body. *Proximal-distal*: proximal is closer to the point of interest or closer to the centre of the body, distal is away from the point of interest or away from the centre of the body. *Deep-superficial*: Deep is towards internal part of the body, superficial is toward the external part of the body.

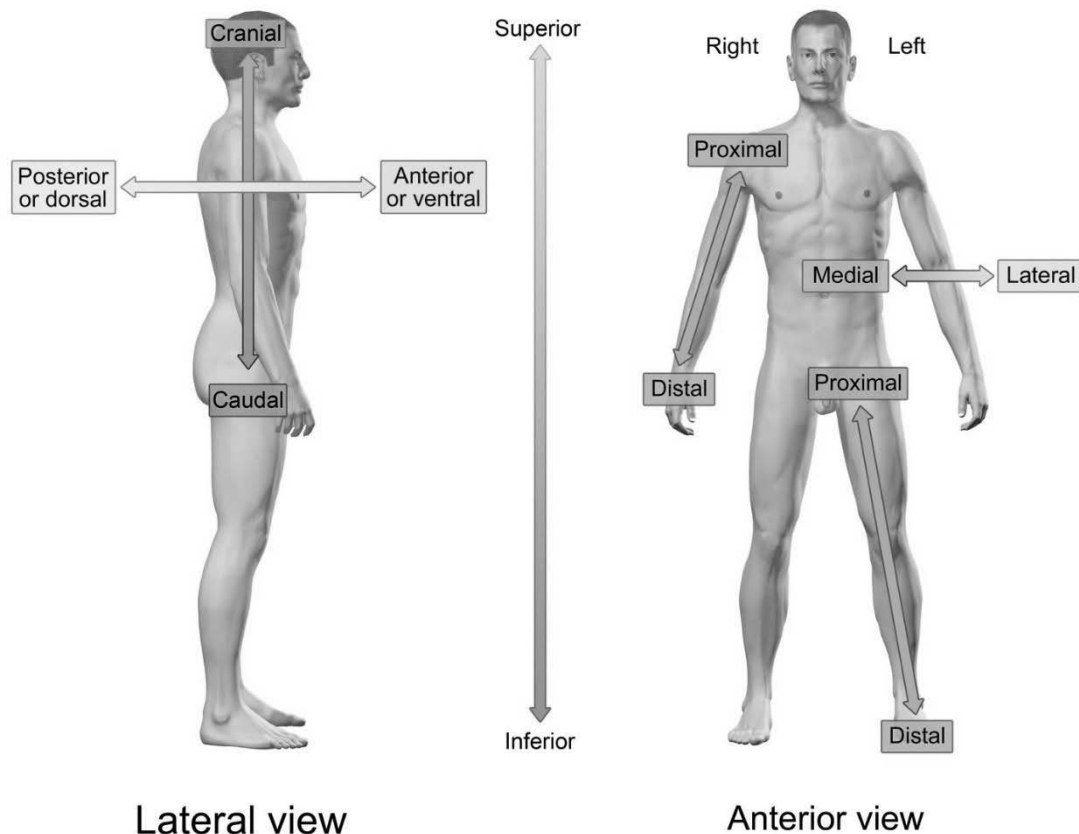


Figure 1. Universal body directions. Note. Adapted to greyscale, from Blausen.com staff (2014) «Medical Gallery of Blausen Medical 2014». *WikiJournal of Medicine* 1 (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436. -Own work, CC BY 3.0, <https://commons.wikimedia.org/w/index.php?curid=31339201>

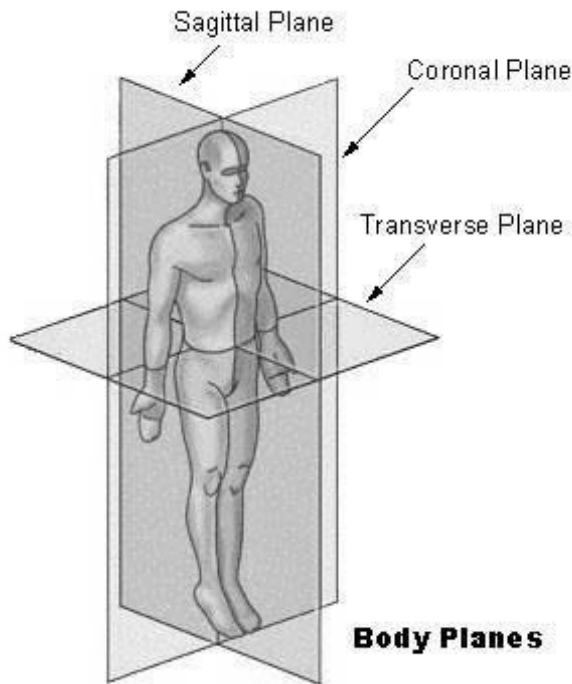


Figure 2. Body planes. Note. Adapted to greyscale, from Wikimedia Commons. In the public domain. <https://commons.wikimedia.org/wiki/File:BodyPlanes.jpg>

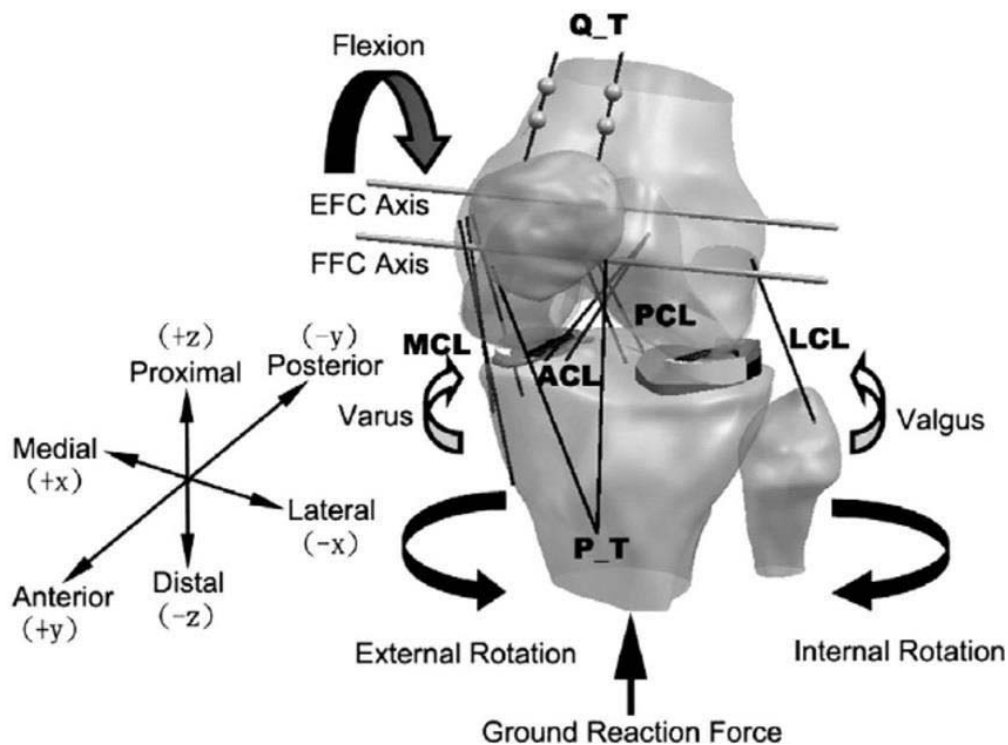


Figure 3. Axis of the knee. Note. From Liu, Yu-Liang et al (2011). Anatomic-like polyethylene insert could improve knee kinematics after total knee arthroplasty – A computational assessment. *Clinical Biomechanics*, Volume 26, Issue 6, p. 613. Copyright 2011 Elsevier Ltd. Reproduced with permission from author.

Human movements occur in one or more of the following planes; frontal, sagittal and transverse (see *Figure 2*). Knee joint movements that occur within the frontal plane is defined as valgus/abduction and varus/adduction, which occur around the sagittal axis (see *Figure 3*). Movement in the sagittal plane is defined as flexion and extension, and occur around the transverse axis. Transverse plane movements are defined as rotations, either internal or external, and occur around the longitudinal axis. In addition to rotations, anterior-posterior translations also occur in the knee in the transverse plane, which do not rotate around any axis.

1.1.2 General knee anatomy

As part of the lower extremity, the knee is made up 3 bones; the femur, the tibia and the patella (see *Figure 4*). The knee is further comprised of 2 separate joints; the patellofemoral joint and the tibiofemoral joint. The tibiofemoral joint is the largest joint in the human body, and is usually the joint referred to when talking about the knee joint. Axial load is carried by the tibiofemoral joint, while the patellofemoral joint works to increase the moment arm for the quadriceps tendon to decrease the muscle force required for knee extension moments.

Ligaments in and around the knee joint connects the femur, the tibia and the fibula. The anterior cruciate ligament (ACL) is positioned between the anterior tibial plateau and the lateral posterior femoral notch. Its primary function is to restrict anterior translation of the tibia in relation to the femur. The posterior cruciate ligament (PCL) is positioned between the posterior tibial plateau to the posterior femur. It restricts posterior translation of the tibia in relation to the femur. The medial collateral ligament (MCL) connects the femur and the tibia, on the medial side of the knee. The lateral collateral ligament (LCL) connects the femur and the fibula, on the lateral side of the knee.

Articular cartilage protects the femur and tibia from bone-to-bone contact. Menisci made up of cartilaginous tissue sits on the medial and lateral tibial plateau. It disperses compressive forces and decreases knee joint friction. An articular capsule is encompassing the knee joint, its ligaments, menisci, bursa and the patella.

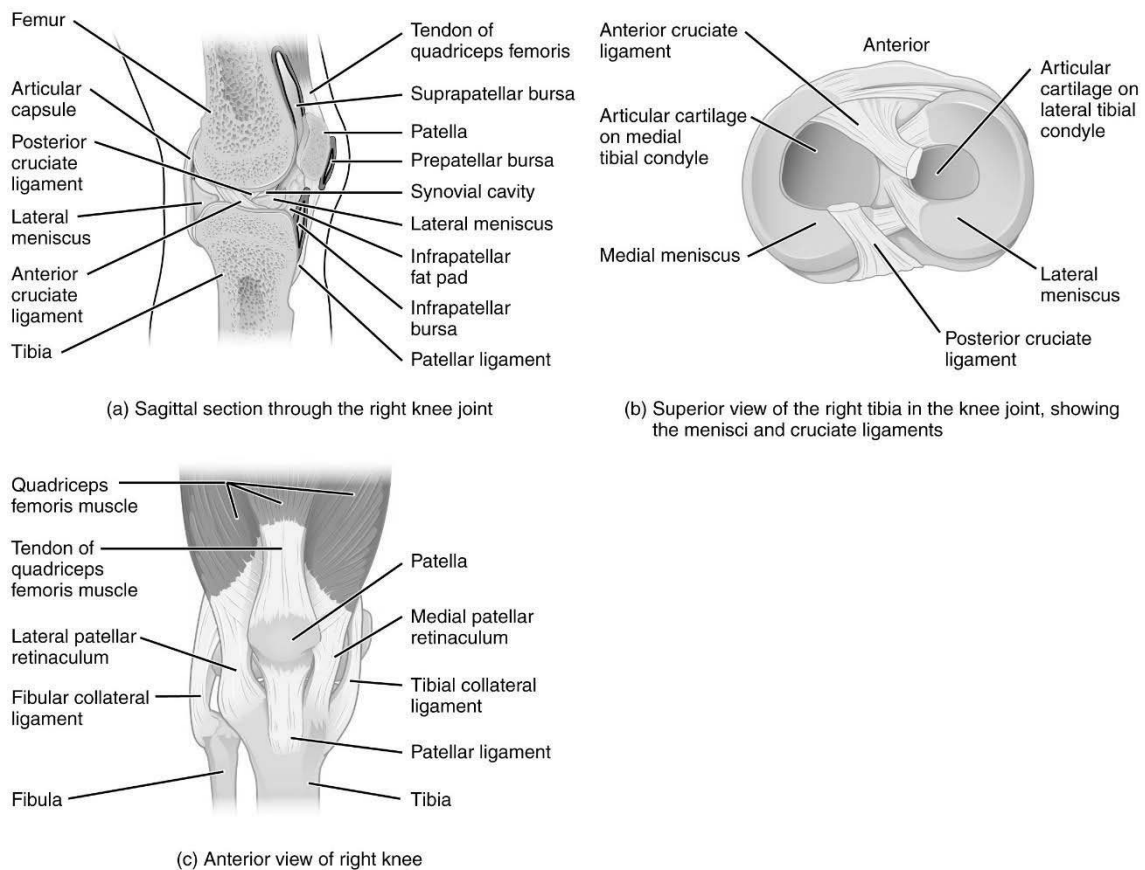
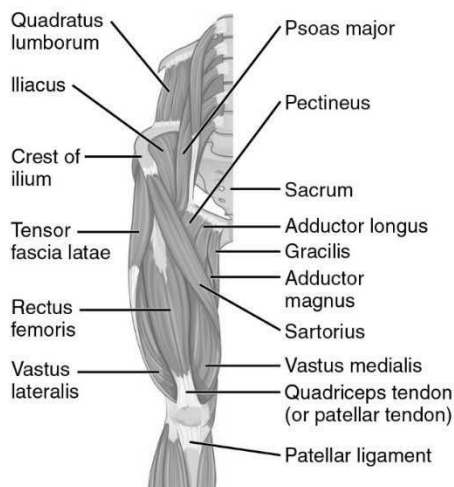


Figure 4. Anatomy of the knee. Note. Adapted to greyscale, from OpenStax College [CC BY 3.0 (<http://creativecommons.org/licenses/by/3.0>)], via Wikimedia Commons

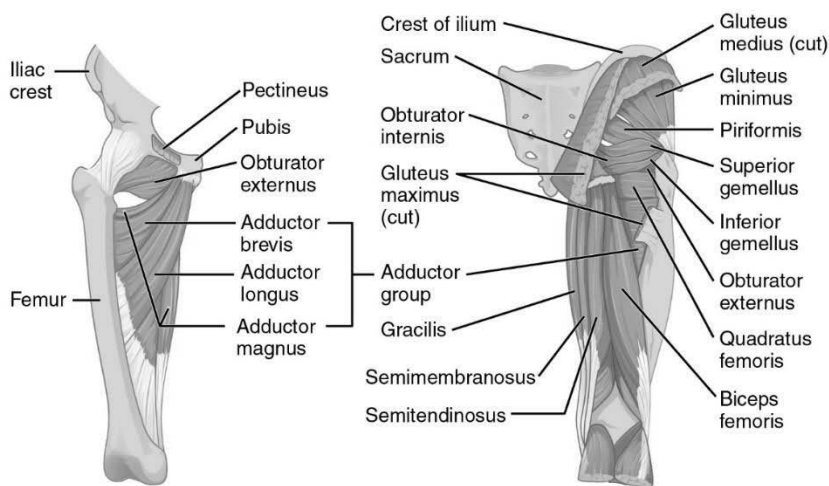
Muscles around the knee create forces and torques that are required for movement of the joint. Anterior on the femur is the quadriceps muscle group, which consist of the rectus femoris (RF), the vastus medialis (VM), the vastus intermedius (VIM) and the vastus lateralis (VL). The quadriceps connect through the quadriceps tendon, over the patella, into the patellar tendon which inserts onto the tibia. It is responsible for extending the knee. In addition, as the RF originates from the pelvis, it can also contribute to hip joint flexion. Because of the longer moment arm created by the patella, the quadriceps muscles also create an anterior shear force to the tibia in relation to the femur.

Posterior on the femur is the hamstring muscle group. It consists of the biceps femoris (BF), the semimembranosus (SM) and the semitendinosus (ST). The BF has two points of origin proximally, one on the tuber ischii on the pelvis, and one on the posterior femur. It inserts laterally on the head of the fibula, which articulate with the back of the lateral tibial condyle. The SM originates form the tuber ischii and inserts on the medial posterior surface of the tibia. The ST also originates from the tuber ischii and inserts on

the pes anserinus, which is located anteromedial on the tibia. The hamstring muscles are the primary knee joint flexors, and they also resist anterior translation of the tibia in relation to the femur. All hamstring muscles, except for the short head of the BF contribute to hip joint extension as well as knee joint flexion. Additionally, the BF also contribute to external rotation of the tibia and fibula (shank) in relation to the femur. The SM and ST contribute to internal rotation of the shank in relation to the femur. It is also reported that the ST contributes to compressing of the medial joint space to prevent knee valgus motion (Zebis, Andersen, Bencke, Kjaer, & Aagaard, 2009).



Superficial pelvic and thigh muscles of right leg (anterior view)



Deep pelvic and thigh muscles of right leg (anterior view)

Pelvic and thigh muscles of right leg (posterior view)

Figure 5. Muscles of the thigh. Note. Adapted to greyscale, from Open BC textbooks [CC BY 4.0 (<https://opentextbc.ca/anatomyandphysiology/chapter/11-6-appendicular-muscles-of-the-pelvic-girdle-and-lower-limbs/>)]

Muscles located around the hip joint is also of interest when studying knee joint movements, as these muscles control the abduction/adduction angle of the entire leg. The main hip joint extensor is the gluteus maximus (GMAX), with the hamstring muscles also contributing. The GMAX originates at the gluteal surface of the ilium, lumbar fascia, sacrum and the sacrotuberous ligament, and it inserts at the gluteal tuberosity of the femur and into the iliotibial tract. In addition to hip joint extension, the GMAX externally rotates the femur in relation to the pelvis, and contributes to hip joint abduction. The main hip joint abductor is the gluteus medius (GMED). It originates from the gluteal surface of the ilium, beneath the GMAX, and inserts on the greater trochanter on the femur. The GMED also contributes to internal rotation of the femur in relation to the pelvis.

There are several other muscles that affect the knee joint, but these will not be presented due to the large number.

1.1.3 ACL anatomy

In addition to resisting anterior tibial translation, the ACL acts to resist rotational loads (Duthon et al., 2006). The ACL is made up of collagen fibres and fibroblasts, which contribute to the viscoelastic properties of the ligament. Two bundles make up the ACL; the anteromedial and posterolateral bundles. Each bundle acts differently throughout knee range of motion, which allows the knee to resist anterior tibial translation from fully flexed to fully extended positions. The ACL also contains nerve fibres that are sensitive to stretching and rapid movement of the ligament (Duthon et al., 2006). These nerve fibres play an important role in providing feedback for what position the knee joint is in, and influences muscle control of the knee.

In the following parts of this chapter, there will be theoretical background as to the purpose of the development of the test described later.

1.1.4 Incidence and consequences of ACL-injuries

The extent of the problem of ACL-injuries has been thoroughly examined, with systematic reviews reporting annual incidence rates of 0.15-1.19 % among football players (Moses et al., 2012). Females have a 2-3 times higher risk of ACL-injury than males (Arendt et al., 1999; Hootman et al., 2007; Prodromos et al., 2007; Walden et al.,

2011). For active individuals that wish to continue playing a sport that requires pivoting, surgery is recommended (Kaplan, 2011). The cost of surgery for ACL-injuries in the United States has been reported to be \$7.6 billion annually (Mather et al., 2013), with additional rehabilitation costs after surgery. Severity of the injury cannot be measured only in monetary costs, and the considerable time away from sport participation (recommended 9-12 months after surgery, based on performance criteria) (Grindem, Snyder-Mackler, Moksnes, Engebretsen, & Risberg, 2016), the psychological factors and reduced quality of life (Ardern et al., 2016), and the high risk of later osteoarthritis (Øiestad et al., 2009) are also serious consequences for the individual. If the individual is participating in a team sport, the team also suffers from the individual's absence during this time.

1.1.5 Aetiology and mechanisms for ACL-injuries

ACL-injuries typically happen without direct player contact, with non-contact injuries reported to account for about 70% of ACL-injuries seen in football (Boden et al., 2000). Video analyses of ACL-injury situations have been performed in several different sports (Krosshaug et al., 2007; Montgomery et al., 2016; Olsen, Myklebust, Engebretsen, & Bahr, 2004). From video analysis, the estimated time of ACL-injury has been reported to be between 17 and 40ms after initial ground contact (IC) (Krosshaug et al., 2007). In football, there seems to be three distinct situations that are associated with non-contact ACL-injuries (Brophy, Stepan, Silvers, & Mandelbaum, 2015; Walden et al., 2015). These are in order of frequency: 1) pressing as a defender, which usually requires cutting in response to an attacker's movement, 2) re-gaining balance after kicking, and 3) landing after heading. Pressing as a defender was the most common situation for ACL-injury, accounting for 33-73% of all non-contact ACL-injuries in the video analyses (Brophy et al., 2015; Walden et al., 2015). In addition to the situations in which the injuries occur, the biomechanical joint positions associated with ACL-injuries have also been examined using video analysis (Koga et al., 2010) and location of bone bruises (S. Y. Kim et al., 2015; Patel, Hageman, Quatman, Wordeman, & Hewett, 2014). An example of an ACL-injury situation with a defender pressing in football can be seen in *Figure 6*.

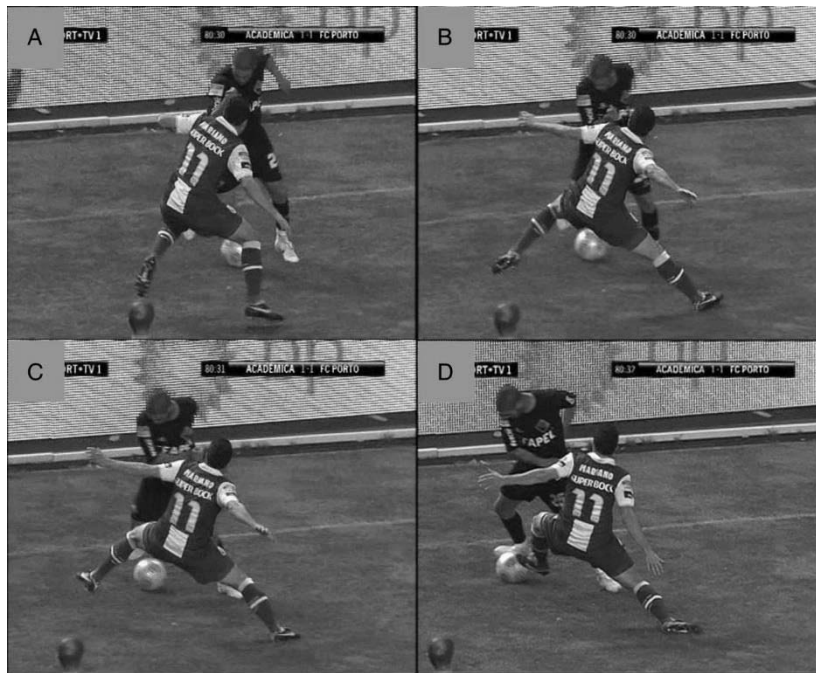


Figure 6. Example of non-contact ACL-injury pressing mechanism (right knee). (A) At -160ms , the defending player is running forward at high speed towards the opponent in possession of the ball. (B) At initial contact, he strikes the pitch with his right heel and makes a sidestep cut in an effort to reach the ball or to tackle the opponent, but no player contact. (C) At 80ms , he rotates the trunk towards his left leg and puts the entire load on his right leg. (D) At 240ms the right hip and knee joints are in abducted positions and the ankle joint is in eversion (dynamic valgus without collapse). Note. Adapted to greyscale, from Waldén et al (2015), *British Journal of Sports Medicine*, Volume 49, p. 1452-1460. DOI:10.1136/bjsports-2014-094573. [CC BY-NC 4.0]

1.1.6 Risk factors for ACL-injuries

Based on the previously mentioned video analyses of knee joint positions associated with ACL-injuries, studies have examined various risk factors for sustaining ACL-injuries. Risk factors for ACL injury have been categorised as either intrinsic or extrinsic (Anderson, Browning, Urband, Kluczynski, & Bisson, 2016). Extrinsic risk factors include rules of the game, playing surface, climate and weather, and footwear (Alentorn-Geli et al., 2014). Intrinsic risk factors include anatomical, neuromuscular and biomechanical risk factors (Anderson et al., 2016). Anatomical risk factors include narrow intercondylar notch (Posthumus, Collins, September, & Schwellnus, 2011). increased posterior lateral tibial slope (Wordeman, Quatman, Kaeding, & Hewett, 2012) and increased knee laxity (Posthumus et al., 2011; Serpell, Scarvell, Ball, & Smith, 2012). Neuromuscular risk factors include reduced hamstring muscle strength, and increased ratio of quadriceps to hamstring activation prior to foot-contact with the ground (Hewett et al., 2005; Hewett, Stroupe, Nance, & Noyes, 1996; Solomonow et

al., 1987; Zebis et al., 2009). Biomechanical risk factors include high knee abduction moments (Hewett et al., 2005) increased lateral trunk displacement (Mornieux, Gehring, Furst, & Gollhofer, 2014) and landing with more extended knees and hips (Griffin et al., 2000). From studies on bone bruise patterns and video analysis after ACL-injury, it seems like the most common mechanism for the injury is loading of the leg with the knee in a valgus position, coupled with internal rotation (S. Y. Kim et al., 2015; Koga et al., 2010; Patel et al., 2014). In addition to the previously mentioned risk factors, the biggest risk factor seems to be previous injury to the ACL (Fulton et al., 2014).

1.1.7 Screening tasks for assessing risk factors for ACL-injury

Screening tests have been used to assess biomechanical risk factors for ACL-injury. Common screening tests have been the vertical drop jump (VDJ), land-and-cut tasks, and run-and-cut tasks. The screening tests have tried to predict who will later go on to have an ACL-injury (Hewett et al., 2005), commonly by using high knee abduction moments as identifiers. Based on later studies, high knee abduction moments during the VDJ does not have sufficient sensitivity and specificity to make these predictions (Krosshaug et al., 2016; Smith et al., 2012). A thorough screening test (The Nine Plus screening battery (9+)) including multiple tasks has also been examined, with scores based on performance in these tasks added to make an overall score aimed at predicting lower limb injuries (Frohm, Heijne, Kowalski, Svensson, & Myklebust, 2012). The test's overall score showed no ability to discriminate between injured or uninjured football players, and the test therefore cannot be used to predict lower limb injuries (Bakken et al., 2017). A commentary from Bahr (2016) has also pointed out the difficulties with predicting injuries, but that does not mean we should not assess risk of injury and to improve current injury prevention programs. Although high knee abduction moments cannot predict injuries, one biomechanical factor that is related to the valgus motion is medial knee displacement, which has been associated with a higher risk of injury (Krosshaug et al., 2016).

A run-and-cut screening test that examined neuromuscular instead of biomechanical risk factors was published by Zebis et al. (2009). Their results suggested that a low ratio of ST to VL activity as measured by electromyography (EMG) in the 10ms time frame prior to IC was highly associated with later ACL-injury. Another study by A. S. Kim et al. (2016) examined the additional effects of cognitive tasks, and their results suggested

that extra cognitive demand decreased participants' reactive knee stiffness. The study examined seated participants, and with few other studies using additional cognitive tasks in combination with assessment of ACL-injury risk factors it is not possible to conclude that extra cognitive demands increase ACL-injury risk. It does however appear to be one possible way to further increase understanding of risk factors of ACL-injuries.

1.2 Literature review

A literature search for studies using neuromechanical and biomechanical risk factors for ACL-injury in unanticipated tasks was conducted in the time between May 2016 and May 2017. The key words used were a combination of the following; ACL, anterior cruciate ligament, injur*, "risk factor", "injury risk", kinematics, kinetics, neuromuscular, EMG, electromyography, mechanism, anticip*, unanticipated, pre-planned. PubMed, Google Scholar, SPORTDiscus and Web of Science were the databases that were searched. An example of a search string used was: "(ACL OR anterior cruciate ligament) AND ("injury risk" OR "risk factor") AND anticip*", which resulted in 18 results in PubMed on May 22nd, 2017. Titles and abstracts were screened, before relevant articles were read in full.

1.2.1 Previous studies on neuromechanical and biomechanical risk factors during unanticipated tasks

The studies presented in *Table 1* and *Table 2* showed that tasks that are unanticipated significantly contribute to mechanics that are associated with higher risk of ACL-injury (Almonroeder, Garcia, & Kurt, 2015; Brown, Brughelli, & Hume, 2014). Studies with biomechanical outcome measures are included in *Table 1*, and studies with neuromuscular outcome measures are included in *Table 2*. This was the case for studies that included biomechanical and neuromuscular outcome measures. In total, 20 studies reported on biomechanical outcome measures, and 5 studies reported on neuromuscular outcome measures. Two of the studies (J. H. Kim et al., 2016; Meinerz, Malloy, Geiser, & Kipp, 2015) are included in both tables as they reported biomechanical and neuromuscular outcome measures. Biomechanical outcome measures were knee and hip joint angles and moments. Significant effects of the unanticipated condition were increases in peak knee flexion angle, peak knee abduction angle, knee abduction moments, peak internal knee adduction moments, and peak knee internal rotation angles and joints. Muscles measured in the neuromuscular studies were: biceps femoris (5/5

studies), rectus femoris (5/5 studies), vastus lateralis (4/5 studies), vastus medialis (4/5 studies), medial gastrocnemius (4/5 studies), lateral gastrocnemius (4/5 studies), semitendinosus (3/5 studies), gluteus medius (2/5 studies), semimembranosus (1/5 studies), tensor fascia latae (1/5 studies), and gluteus maximus (1/5 studies).

For studies examining run-and-cut tasks, the approach speed was 2.25-5.7 m/s. Increased approach speed has previously been shown to increase knee joint loading in a run-and-cut task (Vanrenterghem, Venables, Pataky, & Robinson, 2012), and video analysis of ACL-injury situations while pressing as a defender in football showed high horizontal speed at time of IC in 8/11 cases (Walden et al., 2015). Muscle activation patterns for the VL, BF and ST, measured by EMG have been shown to differ for anticipated one-legged hops, double-legged VDJ and run-and-cut tasks (Husted et al., 2016). The run-and-cut task was the only task that corresponded to the muscle activation patterns from Zebis et al. (2009).

Table 1: Overview of studies assessing the effect of anticipation using kinetics and/or kinematics as outcome measures, when investigating proposed risk factors for ACL-injuries.

Author	Design/purpose	Participants	Task	Outcome measures	Results	Approach speed
Almonroeder et al (2015)	Systematic review. Assess effect of anticipation on mechanics of the knee during tasks athletes frequently perform in competition	13 articles. 110 males, 159 females	Anticipated and unanticipated run-and-cut at 30°, 45° and 60°, land-and-cut laterally. Stimulus presented at 350ms-850ms prior to contact for change of direction	Knee joint angles and moments	Sagittal plane: 4/7 studies ↑ peak knee flexion angle. Frontal plane: 3/13 ↑ peak knee abduction angle, 6/13 ↑ KAM. Transverse plane: 4/6 ↑ peak knee internal rotation angles and moments	2.25-5.5 m/s
Cochrane et al (2010)	Investigate the effect of strength training and balance training on knee joint load during sporting manoeuvres of running and cutting.	n=50, healthy males	Run-and-cut under anticipated and unanticipated conditions	Knee joint angles and moments	No differences between anticipated and unanticipated conditions	4-4.5 m/s

Collins et al (2016)	Analyse combined effects of fatigue and anticipation on angles and moments of the knee during side-step cutting task	n=13, female collegiate athletes (21.6 years)	Run-and-cut task under anticipated and unanticipated conditions	Knee joint angles and moments, GRF	Unanticipated cuts, ↑ internal peak knee adduction moments	4.5-5 m/s
Dempsey et al (2009)	Examine whether changes in sidestep cutting technique could reduce knee loading, in a planned and unplanned condition	n=12, male, nonelite team sport athletes	Run-and-cut task under planned and unplanned conditions	Knee joint angles and moments, torso positions	No difference in knee loading between planned and unplanned sidesteps	5.1-5.7 m/s
Kim, J.H. et al (2016)	Compare the effect between GRF and decision making, and to identify which condition is more vulnerable to biomechanical risk factors of ACL-injury	n=16, male middle school soccer players	Run-and-cut task under anticipated and unanticipated conditions	Knee and hip joint angles and moments, GRF, EMG (RF, VM, TA, LH, MH, MG, LG)	Unanticipated cuts, ↓ GRF, ↑ hip flexion and internal rotation	3.5 m/s
Kipp et al (2013)	Determine if experience level influences knee joint kinematics and kinetics during land-and-cut either anticipated or unanticipated	n=30, female, 12 recreationally active, 18 collegiate athletes (19.8 years)	Single leg land-and-cut tasks under anticipated and unanticipated conditions	Knee joint angles and torques during stance phase	Unanticipated cuts, ↑ peak knee abduction angle in latter part of stance phase for recreational group	N/A

Landry et al (2007) Identify gender differences in lower limb kinematics, kinetics and neuromuscular patterns in adolescent soccer players during unanticipated side-cut manoeuvre

n=42, 21 males, 21 females, adolescent soccer players,

Run-and-cut task under unanticipated conditions

Joint angles and net external moments for hip, knee and ankle, EMG (RF, VL, VM, LH, MH, LG, MG)

Females ↑ RF EMG activation and hip external rotation throughout stance phase, ↓ hip flexion at foot strike

3.44-3.5 m/s

Meinerz et al (2015) Determine effects of anticipation on lower extremity neuromechanics in land-and-cut task

n=18, healthy female collegiate soccer players (19.7 years)

Single-legged land-and-cut task under anticipated and unanticipated conditions

Knee, hip and ankle joint angles and moments, vGRF, 100ms pre-contact %EMG_{MVIC} muscle activity of GMAX, GMED, BF, RF, VL, VM

Unanticipated cuts, ↓ knee flexion at IC, ↑ internal hip-abductor and external rotator moments, ↑ pre-activity of GMAX

N/A

KAM=Knee abduction moment, GRF=Ground reaction force, EMG=Electromyography, RF=Rectus femoris, VM=Vastus medialis, TA=Tibialis anterior, LH=lateral hamstrings, MH=Medial hamstrings, MG=Medial gastrocnemius, LG=Lateral gastrocnemius, VL=Vastus lateralis, vGRF=Vertical ground reaction force, MVIC=maximum voluntary isometric contraction, GMAX=Gluteus maximus, GMED=Gluteus medius, BF=Biceps femoris, IC=Initial contact

Table 2: Overview of studies assessing the effect of anticipation using EMG-activity as outcome measures, when measuring proposed risk factors for ACL-injury.

Author	Design/purpose	Participants	Task	Outcome measures	Results	Approach speed
Donnelly et al (2015)	Determine if balance and technique training in Australian football players training influence the activation/strength of muscles crossing the knee during pre-planned and unplanned sidestepping	n=58, male, Australian football players	Run-and-cut task under pre-planned and unplanned conditions	EMG (TFL, SM, BF, VL, VM, RF, MG, LG) and directed co-contraction ratios medial/lateral and flexion/extension 50ms pre-contact	↓ total muscle activation in unanticipated cuts	Unknown
Kim et al (2014)	Examine the effect of decision-making states (anticipated vs unanticipated) on biomechanics of lower limbs	n=37, male middle school soccer players	Run-and-cut side- and cross-cutting manoeuvres	Lower limb joint kinematics and kinetics, GRF, EMG (RF, VM, VL, TA, LH, MH, MG, LG)	↑ peak EMG activity in VL and VM, ↓ peak activity in LG in unanticipated cuts	3.5 m/s
Kim, J.H. et al (2016)	Compare the effect between GRF and decision making, and to identify which condition is more vulnerable to biomechanical risk factors of ACL-injury	n=16, male middle school soccer players	Run-and-cut task under anticipated and unanticipated conditions	Knee and hip joint angles and moments, GRF, EMG (RF, VM, TA, LH, MH, MG, LG)	Unanticipated cuts, ↓ GRF, hip flexion and internal rotation, no difference in EMG activity at IC	3.5 m/s
McClean et al (2010)	Examine whether lower limb muscle pre-motor times elicited during a simple choice reaction task correlated with knee abduction loads during separate single leg landings	n=20, female collegiate athletes (19.2 years)	Double-legged choice reaction task and single leg landings, anticipated and unanticipated	Lower limb joint kinematics and kinetics, GRF, EMG (TA, MG, VL, RF, VM, MH, LH, GMED)	Choice reaction task and single-leg landings, ↑external KAM with later onset of muscle activity in MH, mGM.	N/A

Meinerz et al (2015)	Controlled laboratory study. Determine effects of anticipation on lower extremity neuromechanics in land-and-cut task	n=18, healthy female collegiate soccer players (19.7 years)	Single-legged land-and-cut task under anticipated and unanticipated conditions	Knee, hip and ankle joint angles and moments, vGRF, 100ms pre-contact %EMG _{MVIC} muscle activity of GMAX, GMED, BF, RF, VL, VM	Unanticipated cuts, ↓ knee flexion at IC, ↑internal hip-abductor and external rotator moments, ↑ pre-activity of GMAX	N/A
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EMG=Electromyography, TLF=Tensor fascia latae, SM=Semimembranosus, BF=Biceps femoris, VL=Vastus lateralis, VM=Vastus medialis, RF=Rectus femoris, MG=Medial gastrocnemius, LG=Lateral gastrocnemius, GRF=Ground reaction force, TA=Tibialis anterior, LH=lateral hamstrings, MH=Medial hamstrings, IC=Initial contact, GMED=Gluteus medius, KAM=Knee abduction moment, vGRF=Vertical ground reaction force, MVIC=maximum voluntary isometric contraction, GMAX=Gluteus maximus,

1.3 Electromyography

Measuring muscle activation meant that we had to use EMG in the study. At first, we wanted to measure muscle activation bilaterally in the vastus medialis, vastus lateralis, semitendinosus, biceps femoris, gluteus medius and gluteus maximus. Having access to only 8 EMG-sensors, we decided to use the EMG-sensors to measure muscle activity in the VL, ST, GMED and GMAX. The VL and ST was chosen because of the previous results by Zebis et al. (2009). The GMED and GMAX was chosen because of the importance of the relationship between hip joint movements and forces, and knee joint movements and forces (Meinerz et al., 2015).

The purpose of EMG, or electromyography, is to study neuromuscular activation of muscles, most often during a defined task (Konrad, 2005). EMG records changes in electric potential that happens during depolarisation and repolarisation of muscle fibres when an action potential is passed through (Konrad, 2005). During depolarisation and repolarisation, the electric potential changes create a wave. The wave is similar for all muscle fibres that are innervated by the same motor unit. A pair of EMG-electrodes attached to an EMG-sensor is used to record these waves from multiple motor units in the same muscle, with these multiple recordings superimposed into the EMG-signal that is seen as one raw EMG-signal graph by the researchers (Konrad, 2005). An example of a raw EMG-signal can be seen in *Figure 7*.

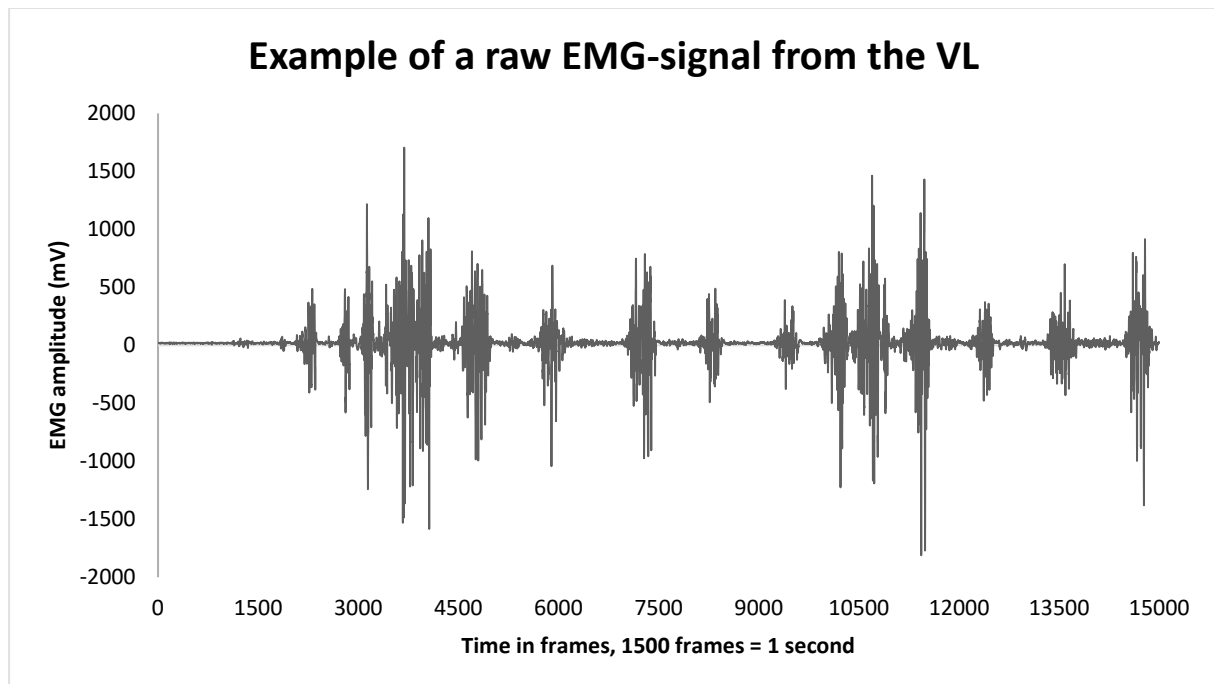


Figure 7: Example of a raw EMG-signal from the VL during a 10 second window, recorded during a trial in the study

The EMG-signal is sometimes used as a measure of muscle force, but this is only accurate during static contractions, as muscle length and contraction velocity confounds the force estimates based on EMG (Staudenmann, Roeleveld, Stegeman, & van Dieen, 2010).

However, in isometric contractions, increased amplitude, measured in voltage (in mV or μV) corresponds to increased muscle force (Staudenmann et al., 2010). Additionally, motor units conduct action potentials at a higher frequency, measured in Hz, when muscle force is increased (Hug, 2011). This frequency can be analysed by using power spectrum, that can relay information about what frequencies produce most power in the EMG-signal.

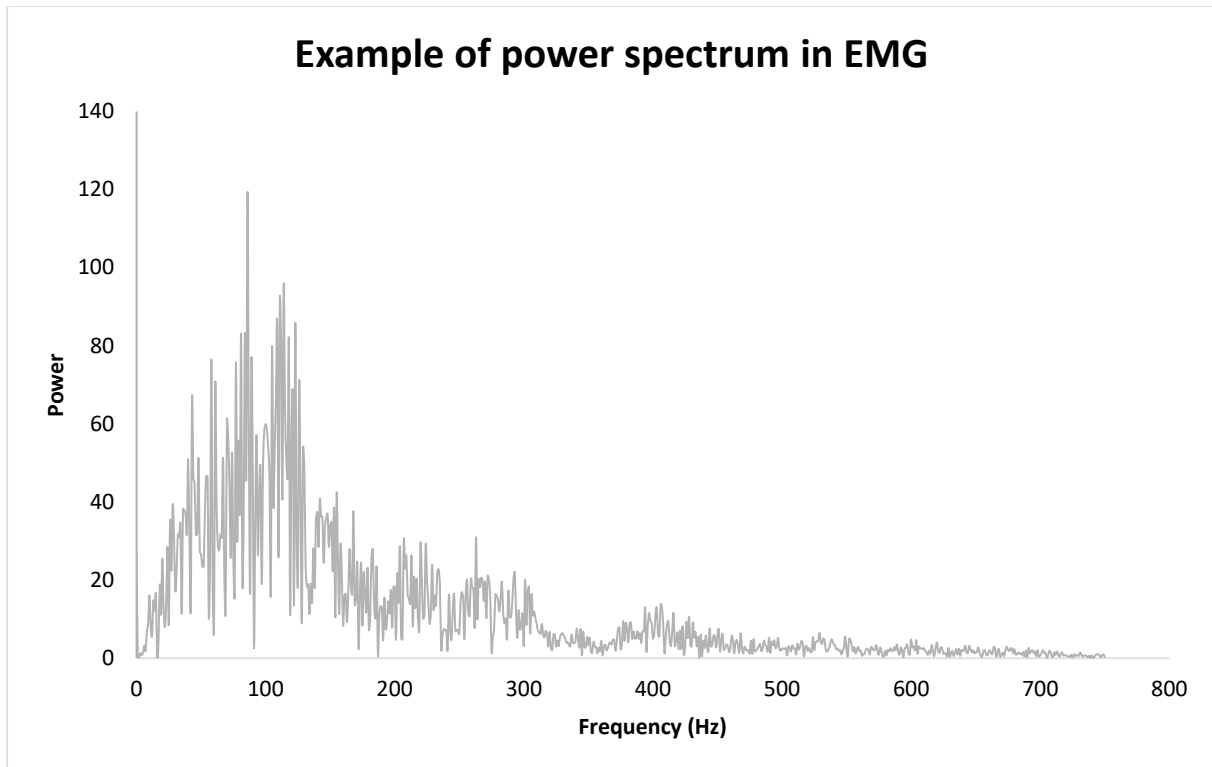


Figure 8: Example of power spectrum from a raw EMG-signal from the VL, recorded during a trial in the study

An example of the power spectrum can be seen in *Figure 8*. The example shows a slightly unusual distribution of the power, as it is usually concentrated between 50 and 80Hz, and the curve usually decreases and reaches zero within 500Hz (Konrad, 2005).

Factors that affect the quality of EMG-signals can be classified as either intrinsic or extrinsic in source. Extrinsic factors, referred to as extrinsic noise, are power line noise and cable motion artefact (De Luca, Gilmore, Kuznetsov, & Roy, 2010). The extrinsic noise can largely be eliminated with modern electronics, and by filtering out power line noise if necessary (De Luca et al., 2010; Sweeney, Ward, & McLoone, 2012). Intrinsic factors, or intrinsic noise, include noise from the electronics of the amplification system, and the skin-electrode interface. Additionally, EMG-signal noise can also be caused by movements, called movement artefact. This noise is caused when muscle and skin moves in relation to each other, and when there is movement between the skin and the attached electrode (De Luca et al., 2010). According to De Luca et al. (2010), movement artefacts are the most problematic source of EMG-signal noise.

The quality of EMG-signals is not only affected by noise. Electrodes record electrical changes, and is therefore dependent on the conductivity of tissue between the muscle belly and the electrode itself. An increased distance between the muscle and electrode, more subcutaneous fat, temperature and contaminants on the skin all increase resistance to electric charges passing through (impedance) and reduces the quality of recorded EMG signals (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000; Konrad, 2005; Minetto et al., 2013; Nordander et al., 2003).

Even after dealing with issues affecting signal quality, high reliability of surface EMG for the quadriceps and hamstrings muscles has been reported in isometric contractions and athletic tasks such as jumps, landings and cutting after a 10m sprint (Cavanaugh, Aboodarda, & Behm, 2017; Fauth et al., 2010). Intra- and inter-session intraclass correlation coefficient (ICC) values of 0.90-0.98 for the VL, 0.90-0.96 for the BF and 0.84-0.97 for the ST were reported from the athletic tasks (Cavanaugh et al., 2017; Fauth et al., 2010). In comparison, ICC values for isometric contractions were 0.95 for the VL, for the BF and 0.94 for the ST (Fauth et al., 2010). The smaller values seen in the dynamic tasks, compared to isometric contractions, were probably affected by one or more of the factors mentioned previously. Additionally, muscles that are bi-articular, as the hamstrings are, are probably more affected by changes in muscle length changes than muscles only crossing one joint (Fauth et al., 2010).

1.3.1 Processing of EMG-signals

Different methods of signal processing of EMG have been used to get practical meaningful information about the data (Devaprakash, Weir, Dunne, Alderson, & Donnelly, 2016). To decrease the amount of noise, while retaining the maximum amount of information from the original EMG-signal, filters are commonly applied to the raw EMG-signal (De Luca et al., 2010). Filters commonly used in sport science studies are high-pass and band-pass Butterworth filters and full wave rectification (root mean square, RMS) (Devaprakash et al., 2016; Husted et al., 2016; Meinerz et al., 2015). There are currently no recommendations for the type of filter to apply to EMG-signals acquired by surface EMG (sEMG) (Devaprakash et al., 2016). However, results from Devaprakash et al. (2016) show that muscle activation during an unanticipated cutting task did not clinically differ when using different filters.

When a signal is filtered, a common method to allow for comparisons of muscle activation between muscles is to normalise the signal against a reference value (Ball & Scurr, 2013). This reference value is often maximum voluntary isometric contraction (MVIC), but it can also be the peak measured muscle activity for a specific muscle during a specific task (Zebis et al., 2009). Ball and Scurr (2013) pointed out that isometric methods of normalisation should be used cautiously in highly dynamic tasks, and that dynamic methods of normalisation is preferred. It has been proposed that dynamic methods of normalisation should also be muscle and task specific (Ball & Scurr, 2013), making comparison between tasks difficult. Additionally, Devaprakash et al. (2016) showed “strong and significant influence on total muscle activation” between different normalisation methods.

Another consideration for EMG-signal analysis is whether to analyse peak or mean activation (Devaprakash et al., 2016; Hibbs, Thompson, French, Hodgson, & Spears, 2011). Mean activation is likely more reliable, but may not fully capture the challenges of the assessed task (Hibbs et al., 2011). Again, these different methods of analysis can make comparisons difficult.

The criteria for determining whether to include or exclude cuts from the analysis in this study (supraphysiological spikes ($>3000\text{mV}$), baseline shifts of $>200\text{mV}$ from 100 ms prior and up to IC, and movement artefacts seen as non-random artefacts) were based on recommendations from Konrad (2005) and from private correspondence with J. Bencke. Ultimately though, the decision to include or exclude cuts, based on visual examination of the EMG-signals, was the responsibility of the author. Because of the scope of the master thesis, no automatic method of determination of EMG-signal quality was investigated. This is a limitation in the study, and could lead to reduced reliability of the results.

1.3.2 Practical EMG measurements

A project called SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) was created by the European Union to facilitate collaboration and standardise practical use of sEMG among scientists. The project produced a standard of recommendations for use and placement of surface EMG-sensors (Hermens et al., 2000). The recommendations include the shape and size of EMG electrodes, inter-electrode distance, skin preparation, sensor location and orientation on the muscle and fixation on the skin. A website with

descriptions and pictures on where to attach electrodes on a number of muscles has been made public by the SENIAM project (www.seniam.org). Examples of electrode attachment sites used in this study can be seen in *Figure 9 & 10* in the Methods chapter.

2. Extended methods

2.1 Extended methods

The extended methods chapter includes more thorough explanations on the methods used in the study, in addition to a narrative of how the design of the study and the task assessed was developed.

2.1.1 Choosing the task and outcome measures in the study

With ACL-injuries occurring within 50ms of IC (Krosshaug et al., 2007), there is no time for reflexes or neuromuscular reactions to take place after IC (Zebis et al., 2009). Muscle activation prior to IC is therefore paramount to prevent ACL-injury. There is a delay from onset of muscle activity to the onset of muscle force reported to be 25-60ms for the hamstring muscles (De Ste Croix, ElNagar, Iga, James, & Ayala, 2015; Zhou, Lawson, Morrison, & Fairweather, 1995). This is called the electromechanical delay (EMD). Bearing in mind this delay, and the need for muscle activity to begin prior to IC, the current study aimed to measure muscle activation in the anterior and posterior thigh and extensors and abductors of the hip. sEMG was chosen because it allows us to measure muscle activity in individual muscles, whereas kinetics and kinematics only allow the total output of muscle force transmitted through a joint (Staudenmann et al., 2010). Additionally, sEMG is a non-invasive method that can be applied simultaneously with kinetics and kinematics. We also took note of comments by previous studies (Krosshaug et al., 2016; Smith et al., 2012), which speculated that more demanding screening tasks could be necessary to make valid assessments of ACL-injury risk factors.

We decided to only investigate an unanticipated task, as the studies included in *Table 1* all have investigated the effect of anticipation previously. Additionally, based on the situations associated with ACL-injury seen in video analysis, we included visual distractions as a means to simulate orientation seen in footballers in a match. This was theorised to make the task more cognitively demanding, and perhaps leading to similar effects in muscle activation and reactive knee stiffness as was seen by A. S. Kim et al. (2016).

2.1.2 Development of the new task for assessing knee control in football players

The study started with an aim that was to develop a task for assessing knee control during more demanding conditions than VDJ and run-and-cut tasks. From a proposal by the thesis adviser, a task where a table tennis serve robot would launch table tennis balls at participants, who then would try to stop the balls was conceived. We obtained a table tennis serve robot on loan from a local tennis table club, and tested the proposal first without any recording other than capturing the tests on video.

With the goal of replicating movements from situations seen in the study of ACL-injury situations in football by Walden et al. (2015), the task was continually developed throughout a series of pilot tests. We also wanted to examine the effects of increasing demands in frequency of ball release and visual orientation of some kind of stimulus on EMG pre-activation.

Initial testing was done with the table tennis robot and one and two participants trying to intercept the balls. When including two participants who alternated to stop every other ball, we saw visual-spatial orientation that resembled what is seen in football matches, but we found it impossible to standardise movements to an acceptable degree. After that, we decided to focus on only one participant at a time. To get the forward motion of the pressing defender, we included a run back toward a fixed point behind the participant. We then instructed participants to move forward and then attempt to stop the launched table tennis balls. Anticipated cuts were tested with 3 participants, but we found that the cutting motion was initiated before the balls were launched, and thus failed to get the width of the cut that we wanted. Every other test therefore included unanticipated cuts.

Further, to make the task more complex, we added a distracting element that the players would have to focus on during the task. This would serve as a distraction similar to when players have to look around to orient themselves to team-mates and opponents during matches. At first, we included hand signals as visual stimulus, before setting up the two screens with the participants activating the visual stimulus themselves by pressing a key on a modified keyboard. A custom LabVIEW program (National Instruments, LabVIEW, Austin, Texas) was used to randomly show a red circle on a screen either side of the participant as

they moved forward to stop the ball. This was done to standardise the timing of the visual stimulus, and the position the players would be in when the visual stimulus appeared.

Additionally, we tested different frequencies of balls per minute. The table tennis robot had to be modified to get accurate ball release frequencies. See *Figure 9* for an illustration of the robot with its control panel.

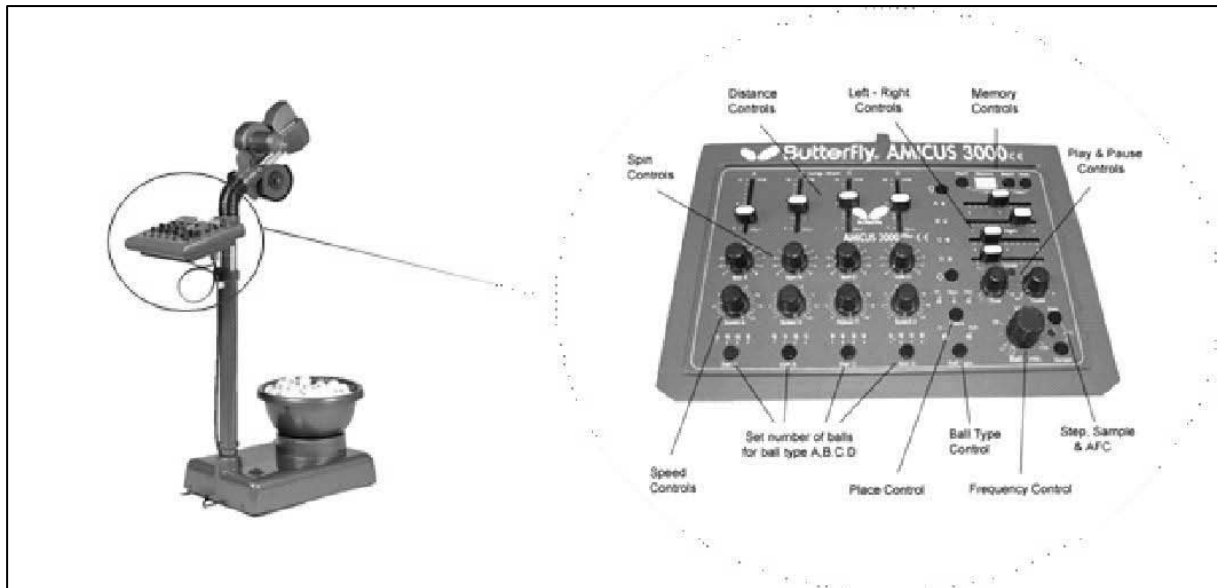


Figure 9: The table tennis robot (Butterfly Amicus 3000 Plus) with the control panel. Note. Adapted by Patrick Mai from the Amicus 3000 Plus user's manual.

We also examined giving no verbal instructions, different distances from the table tennis robot to the force plates, different distances from the force plates to the keyboard, delay from the participants pushing a button to the visual stimulus appearing on the screen, a higher number of cuts per trial (until exhaustion), and adding a jump to the task. None of these modifications resulted in cutting techniques seen in Walden et al. (2015), and we decided to investigate the test as it is described in the research article. We wanted to see what would happen to EMG pre-activation in the task with increasing demands in speeds and visual orientation. That is why the lowest difficulty levels are included, even though approach speed at IC is lower than previous studies. Another possible way of categorising cuts according to difficulty levels could be to use the approach speed at IC. Categorising cuts in that way could

have led to differences in absolute demands of the participants, and we decided to standardise the demands in our test.

2.1.3 Test day procedure

Total preparation time for each participant was 2 hours, with 45-75 minutes spent on testing for each participant. Two researchers were responsible for all practical preparations and testing. Responsibilities were divided between the researchers: one was responsible for logging all anthropometric data on a computer, skin preparation before attaching EMG-electrodes, inspecting and saving recordings from EMG and the 3D motion capture system during testing. The other researcher (the author) was responsible for recruitment of participants, oral information about the consent form and about procedures of the study, measuring anthropometric data, correct positioning of sEMG-electrodes and sensors, positioning and instructing participants during MVIC recording, marking and placing the reflective markers for the 3D motion capture system, instructions to participants during testing, and controlling the table tennis serve robot during testing.



Figure 10: EMG-electrode and reflective marker placement on participant, anterior view



Figure 11: EMG-electrode and reflective marker placement on participant, posterior view



Figure 12: MVIC test position for the ST, participant lying prone, strap around the ankle, with 10° knee flexion

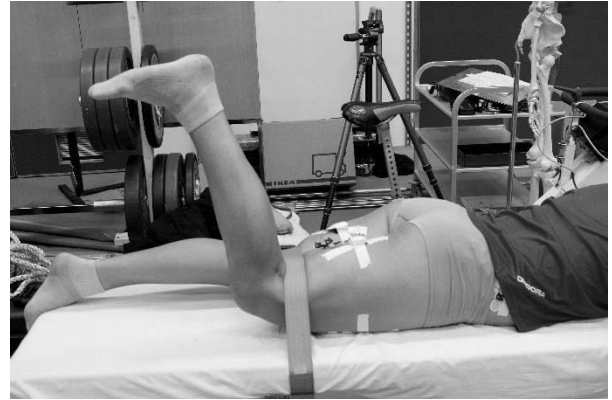


Figure 14: MVIC test position for the GMAX, participant lying prone, strap around distal thigh, with 90° knee flexion



Figure 13: MVIC test position for the VL, participant seated with leg hanging from a table, strap around ankle, 60° knee flexion



Figure 15: MVIC test position for the GMED, participant lying sideways, strap around the knee, 3cm between knees

2.1.4 Exclusion and inclusion of cuts

All cuts were screened by video recording of 3D reflective markers. The same two researchers that were responsible for testing also assessed the videos, conferring with a senior researcher when in doubt for which cuts to include or exclude. For a cut to be included there had to be a clear intention to stop the ball, and a lateral movement of the pelvis in the direction of the ball. The data for the time of IC was the first cut to change direction after reacting to the ball being launched. Attempts to automatically determine IC were made by using the frame with the highest lateral GRF (ground reaction forces), but this was not possible because a high percentage of the cuts had the highest lateral GRF during a second stutter-step when they extended the leg that stopped the ball. Categorisation of the cuts in this way is a limitation of

the study, as we were not able to fully describe movements or positions with objective measures, but based the assessments on experience and comparisons to video of ACL-injury situations.

A video camera recorded all cuts in the visual stimulus (VS) condition for all the participants from the position of the table tennis robot. The camera was used to determine if the participants looked at the screen with the red circle. Multiple cameras positioned above the computer screens would have been preferable to the camera position we used, as validation of the VS cuts could have been more accurate.

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Research article

Title page

The feasibility of a new task assessing knee control in female footballers – using EMG to measure muscle pre-activity during a side-cutting task

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Abstract

Background Screening tasks for assessing risk of anterior cruciate ligament (ACL) injury cannot predict injuries. More challenging tasks for assessing neuromuscular knee control in athletes are needed.

Aim To determine the feasibility of a new task for assessing knee control in female footballers. It was examined if electromyography (EMG) could successfully be recorded during the new task, and whether EMG patterns would undergo clinically relevant changes as a function of ball release frequency and visual stimulus.

Methods Sixteen female footballers, aged 22.8 ± 2.2 years with no history of ACL-injury, completed a task with multiple change-of-directions that mimicked situations in football matches where a defender is pressing an attacker. The participants reacted to a table tennis ball being randomly released, with a cutting motion to stop the ball with their feet. EMG pre-activation for the semitendinosus (ST), vastus lateralis (VL), gluteus medius (GMED), and gluteus maximus (GMAX) was recorded. Comparisons between trials with (VS) and without visual stimulus (NOVS) were made in the unanticipated test.

Results From 1101 cuts, no data could be used from the GMED or GMAX. Valid EMG-data from the VL could be obtained from 397 cuts (36.1%). The ST had valid data from 266 cuts (24.2%). A trend for lower EMG pre-activation of the ST was seen in the VS condition compared to the NOVS condition.

Conclusions EMG pre-activation was not captured successfully for all muscles during the task. The ST showed statistically significant decreased EMG pre-activation in the two easiest levels in the VS condition. No other statistical differences as a function of ball release frequency and visual stimulus were seen.

Introduction

Injuries to the anterior cruciate ligament (ACL) have serious short- and long-term consequences, including high monetary costs of rehabilitation and/or surgery and increased risk of knee osteoarthritis.¹ Athletes in team sports that require pivoting (e.g. football (soccer), team handball, basketball) are especially at risk,² with the risk being 2-3 times higher for females.³⁻⁶ ACL-injuries typically happen without direct player contact, with non-contact injuries reported to account for about 70% of ACL-injuries seen in football.⁷ Efforts to implement training programs to prevent these injuries have previously been made.⁸⁻¹² Despite this, injury rates have remained the same over the last 10 years in men's professional football.¹³

Proposed risk factors for ACL-injuries include reduced or delayed muscle activation in the hamstrings, and reduced hamstrings-to-quadriceps ratio (H/Q-ratio) activation prior to ground-contact.¹⁴⁻¹⁸ As injuries typically occur within 50ms of ground contact,¹⁹ reflexes or neuromuscular adjustments do not have sufficient time to take place.¹⁵ It is therefore believed that muscular pre-activity before ground-contact is essential in further understanding and screening for ACL-injury. Pre-activation of the muscles must also consider the electromechanical delay (EMD), which has been defined as the time between onset muscle activity and the onset of force generation by that muscle contraction.^{20 21} The EMD for the hamstring muscles in eccentric contractions have been reported to be between 25-60ms.²¹ The semitendinosus muscle (ST) has been proposed as an important knee stabiliser in both the frontal and the sagittal plane, as it both resists anterior translation of the tibia in relation to the femur, and it could compress the medial joint space to prevent knee valgus motion.^{14 15} A pilot study from Zebis, et al.¹⁵ indicated that reduced electromyography (EMG) pre-activity of ST and increased EMG pre-activity of the vastus lateralis muscle (VL) during a pre-planned handball-specific side-cutting task was significantly associated with ACL-injury.

Video analysis of ACL-injuries in football have revealed three common patterns of movement for non-contact ACL-injuries, with pressing as a defender the most common.^{22 23} Based on the injury mechanisms and proposed risk factors for ACL-injuries, efforts have been made to develop screening tests to predict which athletes are at higher risk for ACL-injury. A vertical drop jump (VDJ) has been studied as one such screening test, with results indicating no predictive value for future ACL-injury.^{24 25} It has been speculated that a more demanding screening task is necessary to make valid assessments of which athletes are at a higher risk of ACL-injury.^{24 25} Unanticipated tasks, compared with pre-planned tasks, have been shown to increase forces at the knee joint.²⁶⁻²⁹ In addition, an external focus with visual stimulus has also been associated with higher knee joint forces.³⁰ Few studies have investigated EMG pre-activity in an unanticipated task including visual stimulus.^{31 32} Results from one study indicate that during an unanticipated cutting task, the participants displayed a more hip-dominant cutting strategy, with increased EMG pre-activity of the gluteus maximus and medius.³¹ However, results were from a land-and-cut task, and it is unknown whether the results are transferable to match-specific situations.

EMG-measurements have been shown to be reliable in ballistic jumping and cutting tasks.³³
³⁴ There are however inherent challenges in recording and processing EMG-data.³⁵⁻³⁸

Movement artefacts can make recorded data unusable,³⁹ and researchers have had to discard data from the gluteal muscles because of poor quality.⁴⁰ Studies examining gluteal EMG-activity in running,⁴¹ cutting,⁴² and ballistic^{43 44} movements have not reported any challenges regarding EMG-recording. However, they have all included short bursts of activity, generally one repetition, followed by rest. The present study involves prolonged activity with several changes-of-direction, possibly complicating the recording of EMG-signals because of movement artefacts³⁸ and the effects of subcutaneous fat.⁴⁵ Thus, the aim of the study is to test the feasibility of a new, sport-specific test to evaluate knee control in football players. Specifically, we wanted to investigate:

- 1) if we were able to successfully capture EMG pre-activation during the new task
- 2) if EMG patterns would undergo clinically relevant changes as a function of ball release frequency and visual stimulus

Method

Design

The project was a pilot of a repeated measures experimental study. We measured EMG, kinetic and kinematic data as part of the pilot study, but only the data on EMG-measurements is presented here. Video from 3D motion capture was used to assess quality of cuts. Kinetic data from two force plates were synchronised with 3D motion data to determine time of initial contact (IC) and approach speed.

Development of the study

The cutting task was continually developed throughout a series of pilot tests. Initial testing was done with the table tennis robot and one or two participants trying to intercept the balls. From that, we included the run back toward a table, in order to get a forward motion when attempting to get to the balls. We made the direction of cutting unanticipated. To make the task more complex, we added a visual distraction in the form of one red circle on either of two computer screens that the players would have to focus on during the task. This would serve as a distraction similar to when players look around to orient themselves to team-mates and opponents during matches. We decided to compare conditions with and without the distracting elements (visual stimulus) to see if this would result in differences in muscle pre-activation. Two screens were placed on both sides of the participants so that they would turn their head to see them going forward toward the balls, with the participants activating the visual stimulus by pressing a spacebar on a keyboard themselves. This was done to standardise the timing of the visual stimulus, and to standardise the position in which the players would be in when the visual stimulus appeared.

During testing we noticed that the width between where the balls landed was too narrow for the first 8 participants (2.4m), and we increased this width by 20cm for the last 8 participants (2.6m). Video inspection of the differences in ball landing width showed a change in how the participants changed directions, as the last 8 participants used a wider cutting technique than the first 8 participants.

Participants

Sixteen healthy female semi-professional (n=8) and amateur (n=8) football players were included in the study (age 22.8 ± 2.2 years; height 167.2 ± 8.5 cm; weight 61.9 ± 10.3 kg) (Table 1). They were recruited by the main author, either via a short study-presentation at a training session, by emailing the student body of a sports university or by posting on social media. Players were excluded if they had any injuries to the lower extremities or back in the last 12 months, or played the position of goalkeeper.

A regional ethics committee considered the study before commencement. Before the start of the study, we explained the test procedures, and the players gave written consent in accordance with the Declaration of Helsinki.

Table 1 Participant characteristics

	Mean	Minimum	Maximum	SD
Age	22.8	20	27	2.2
Height (cm)	167.2	151.0	182.0	8.5
Weight (kg)	61.9	47.7	77.5	10.3
Highest level of experience (league level)	2.6	1	5	1.3
Experience on current level (years)	3.5	1	10	2.7
Experience in total (years)	14.4	8	20	3.7
Time since last training session (hours)	30.4	2	96	25

Participant characteristics, n = 16. SD = Standard deviation

Test day procedure

Players were given oral information about the procedures and tasks of the study before we started. The study protocol consisted of 7 steps: 1) measurement of anthropometric data (age, height, weight, and body part circumferences related to kinetic and kinematic data measurement), 2) positioning of surface EMG-electrodes (sEMG-electrodes), 3) standardised warm-up, 4) maximum voluntary isometric contraction (MVIC), 5) positioning of reflective markers for 3D motion capture, 6) standardised familiarisation with the test, 7) test of cutting task with change of direction, increased level of difficulty, with and without external visual stimulus.

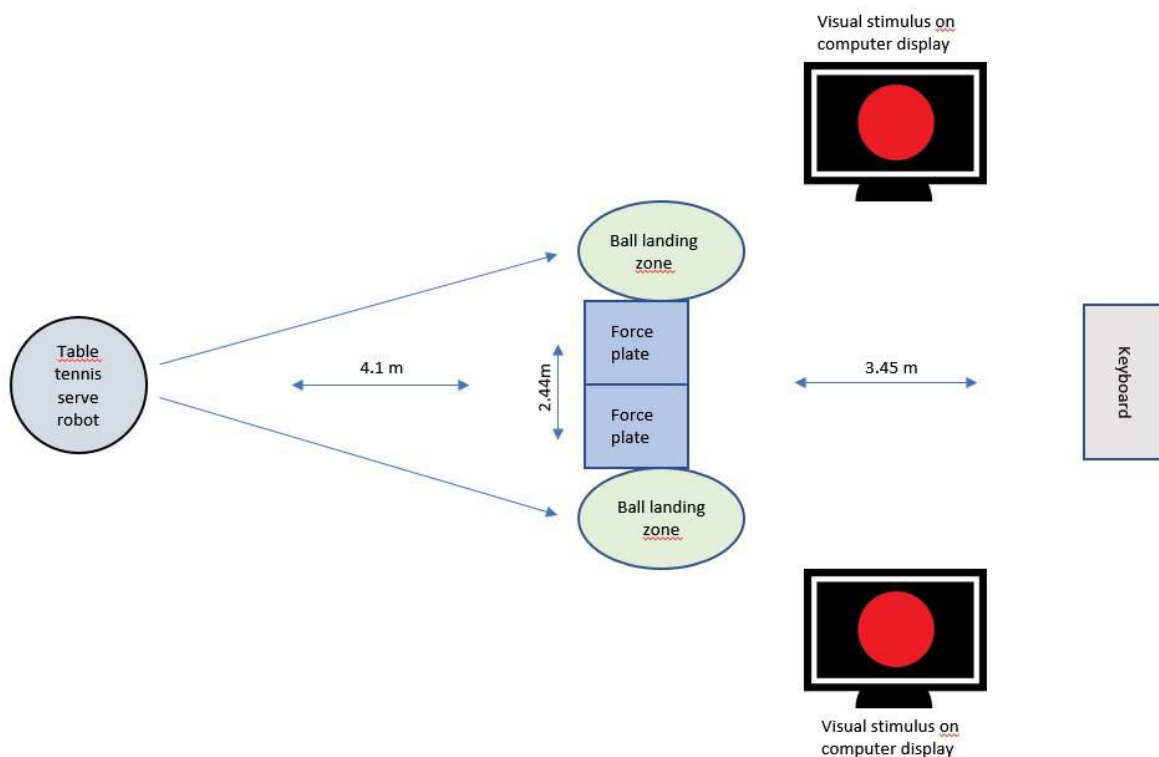
Task

The task was developed to mimic situations in football matches where a defender is pressing an attacker, and must react with a cutting motion to intercept the ball. These situations have previously been shown to coincide with ACL-injuries in professional male football players²². Each trial was a continuous run-and-cut test where the player had to react to 8 balls, with the first ball not included in the data collection. The trials started with the player standing still (Figure 2,1) in an area with two force plates (AMTI LG6-4-1, Watertown, Massachusetts, USA). A table tennis serve robot (Butterfly Amicus 3000 Plus, Tamsau Butterfly Europe, Moers, Germany) was used to shoot a table tennis ball to either side of the force plates. The player then had to react to the ball, trying to intercept it as they would a pass in a football match (Figure 2, 2). The player then had to turn, run in the opposite direction of where the ball came from (Figure 2, 3), press a button on a modified computer keyboard (Figure 2,4),

turn and run forward (*Figure 2,5*) to intercept the next ball (*Figure 2,6*). After pressing the keyboard, the player was told to either keep running forward with no external visual stimulus (NOVS condition), or to locate a red circle on a computer screen on either side before running forward to intercept the next ball (visual stimulus (VS) condition).

Trials were in the same order for all participants. Difficulty levels (L1-6) were based on the ball release frequency (*Table 2*). Familiarisation was done with one test-run at L1 and L3, in the NOVS and VS condition respectively. Players completed trials in the NOVS condition first. They started at L1, and were given a rest of 1-2 minutes after completing 8 balls at the same difficulty level. We then increased the ball release frequency trial by trial, until the player could no longer get back to the force plates in time for the next ball. After completing the trials in the NOVS condition, the players started at L1 in the VS condition. The players were given instructions to get back to where the force plates were located, but were not given a reason for this until after they had completed the testing. Players were also instructed to adjust their speed so that they would be stepping on to the force plate area when the next ball was launched.

Figure 1



Overview of the test. The table tennis serve robot launches table tennis balls to either side of the force plates. Participants stop the ball with their foot, run toward the keyboard and press the spacebar. Depending on condition, either nothing happens and the player moves toward the force plates to stop the next ball (NOVS), or a red circle appears on a computer screen either side of the player which the player has to look at before moving toward the force plates to stop the next ball (VS). Drawing is not to scale.

Figure 2

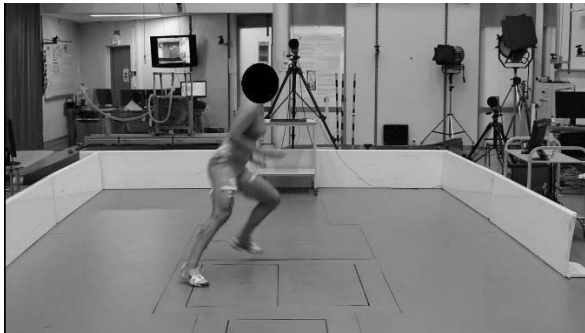
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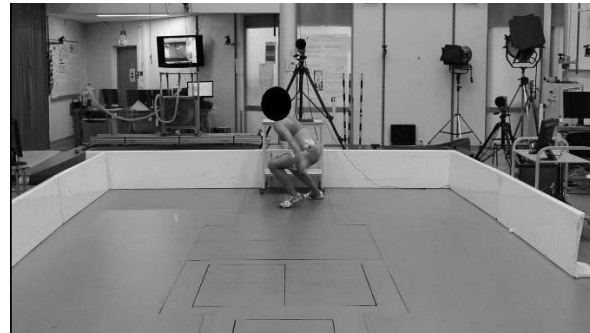
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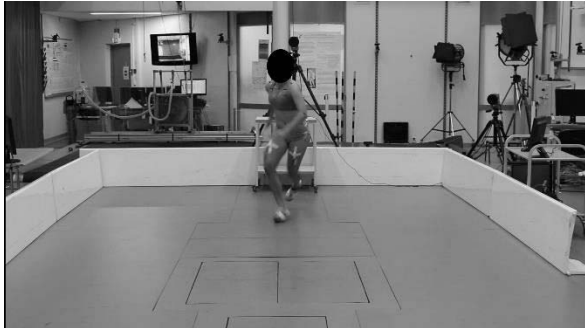
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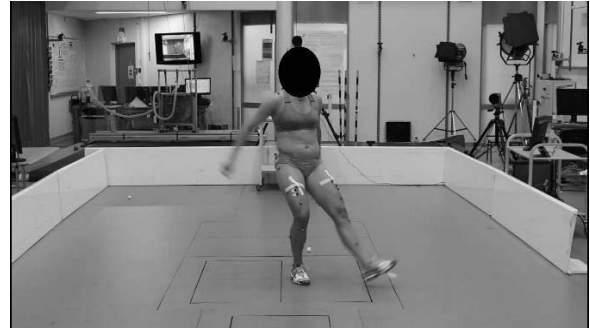
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5



6



A participant completing one cut during a trial, starting on the embedded force plates (1), stopping the ball with one foot (2), turning and running in the opposite direction (3), pressing a key on a keyboard (4), running toward table tennis robot while looking at visual stimulus on a screen either side in the VS condition, or running straight ahead in the NOVS condition (5), stopping the ball with the foot with the support leg standing on one of the force plates (6).

Table 2 Number of balls released per minute in each difficulty level

Level	Balls/min
1	10
2	12
3	14
4	16
5	18
6	20

EMG-electrode placement and MVIC

We sought to measure muscle activity prior to IC with EMG from the VL, ST, GMED and GMAX muscles in a cutting task. 50 ms prior to IC was chosen as ACL-injuries have been shown to happen between 17 and 50 ms after IC.¹⁹ This short window leaves no time for mechano-sensory feedback to alter muscle forces aimed at preventing injury.¹⁵

Before placing the sEMG-electrodes we shaved, gently abraded and cleaned the skin with alcohol to minimise skin resistance.³⁹ We placed sEMG-electrodes on m. vastus lateralis (VL), m. semitendinosus (ST), m. gluteus medius (GMED) and m. gluteus maximus (GMAX) bilaterally in accordance with SENIAM guidelines.⁴⁶ The sEMG-electrodes (Ambu, Neuroline 720, Ag/AgCl) were placed with 1 cm inter-electrode distance. sEMG-electrodes were connected to wireless sensors (Noraxon DTS EMG LOSSLESS). The same researcher placed all sEMG-electrodes and sensors on the players. Sensors were taped in place to reduce movement artefacts. However, as players started to sweat during testing, some sensors had to be re-attached during testing.

Maximum voluntary isometric contraction (MVIC) recording was done after a standardised warm-up where the player cycled on a stationary bike for 10 minutes. They were instructed to warm-up and not exhaust themselves. Positioning for the MVIC testing for the VL and ST was done as described by Husted, et al.⁴⁷ Positioning for the GMED and GMAX MVIC testing was done as described by Boren, et al.⁴⁰ A visual inspection of EMG signals was done before recording to ensure correct placement of sEMG-electrodes. MVIC was performed for five seconds, three times per muscle and side, with 30 second rest between tests. Verbal encouragement was given to ensure maximum effort.

Excluding and including cuts

In total, there were 1101 cuts completed by 15 players. Using the video data from the 3D motion capture system, we could visually assess all cuts prior to EMG-analysis. 544 cuts had to be excluded before analysing EMG data, leaving 557 cuts to be assessed by quality of EMG signal. Reason for exclusion was one or more of the following: 1) not having force plate data to ensure correct time of IC, 2) not doing a lateral cut, 3) doing a cross-over cut and 4) standing still or having no forward motion at IC. Inclusion and exclusion was jointly determined by two researchers. When there was disagreement or uncertainty, a third researcher experienced in ACL-injury research determined whether to include or exclude the cut.

EMG collection and analysis

EMG data was sampled wirelessly with an A/D converter (Noraxon Desktop DTS) at 1500Hz. Data from EMG, kinetics and kinematics were synchronised and recorded with

Qualisys Tracking Manager software (version 2.13, Qualisys, Gothenburg, Sweden). Using a custom MATLAB script (version 2013b, MathWorks, Natick, MA, USA) all EMG data were high-pass filtered with 20Hz cut-off value, using a 4th order Butterworth filter. After this step, the raw and filtered data was visually inspected by the researcher to ensure the quality of the data. Efforts to standardise and use objective measures for this quality check proved beyond the scope of this study. With the help of researchers experienced in assessing EMG data, the following criteria for excluding data was used: 1) supraphysiological spikes (>3000mV), 2) baseline shifts of >200mV from 100 ms prior and up to IC, and 3) non-random artefacts. IC was determined when GRF > 20N on either of the two force-plates (AMTI LG6-4-1, Watertown, Massachusetts, USA). Cuts with >200% of MVIC values were also excluded from analysis (n=39).

The EMG data was then smoothed by a symmetrical moving RMS 30-ms window with successive one-millisecond steps. The MVIC values for each muscle were calculated as the maximum EMG values recorded from the three attempts after filtering and smoothing. The average of the filtered and smoothed data from 50 ms prior to IC, up until the time of IC was then normalised to the MVIC. This value will be referred to as pre-activation from here.

Statistical analysis

Mean differences in pre-activation in the NOVS and VS conditions in the separate difficulty levels were analysed with a one-sample t-test. Differences in H/Q-ratio in the NOVS and VS conditions between levels were analysed with paired-samples t-test. Statistical significance was set to $\alpha = .05$. All statistical analyses were performed using SPSS statistical software (version 18.0; IBM Corp, Armonk, NY, USA).

Results

Data from 15 subjects could be analysed. One subject was excluded because of missing MVIC values. We recorded 1101 total cuts, of which we were able to accurately determine IC by force plate data in 557 cuts (50.6%). Of these 557 cuts, valid EMG-data from the VL could be obtained from 397 cuts (71.3%). The ST had valid data from 266 cuts (47.8%). Data from the GMED and GMAX were excluded after visual inspection, because of too much movement artefacts and baseline noise. See *Figure 6* for an example of valid EMG-data from the VL that was included. *Figure 6-9* show examples of EMG-data from the VL that were excluded, based on supraphysiological spike, baseline shift and non-random artefacts, respectively. The number of valid cuts for each difficulty level and each condition is shown in *Table 4*.

L1 and L2, from now referred to as L1-2, were analysed together as there was no practical difference for the players in the testing. Results from L6 were discarded as only 2 participants reached this level, giving only 1-3 valid cuts for each muscle in the VS and NOVS conditions. We found no differences in EMG pre-activation between conditions with or without visual stimulus, with the exception of significantly ($p = 0.031$) higher ST pre-activity in L1-2 in the NOVS condition. ST pre-activity increased from the easiest difficulty levels (L1-2) to the most difficult (L5). VL pre-activity increased from the easiest difficulty levels (L1-2) to L4. Variability between trials, as measured by standard deviation, ranged from 11.2% of MVIC to 33.1% of MVIC and there was no pattern in differences between levels or

conditions (See *Table 3*). Increased difficulty level increased the EMG pre-activity in both visual stimulus conditions. The increases were seen both in the ST and the VL.

The H/Q-ratio is shown in *Figure 5*. No significant differences between the NOVS and the VS conditions were found in any of the difficulty levels.

Table 3 Mean EMG pre-activity in % for the ST and VL, and H/Q-ratio in VS and NOVS conditions

Level	Semitendinosus				Vastus lateralis				H/Q-ratio	
	NOVS		VS		NOVS		VS		NOVS	VS
1-2	25.0	(19.3)	15.5	(11.2)	36.2	(32.8)	25.6	(19.3)	0.69	0.60
3	26.6	(23.6)	20.9	(13.2)	37.2	(27.8)	38.0	(33.1)	0.72	0.55
4	29.1	(17.3)	25.0	(13.1)	45.9	(22.0)	49.6	(30.1)	0.63	0.50
5	36.1	(13.1)	33.3	(15.7)	48.4	(24.6)	45.6	(23.1)	0.75	0.73

% mean EMG pre-activation (SD) for the m. semitendinosus and m. vastus lateralis, in different levels of difficulty and different conditions of visual stimulus. NOVS = no visual stimulus. VS = visual stimulus. H/Q-ratio = hamstring to quadriceps pre-activation ratio

Table 4 Number of valid cuts for the ST and VL for every difficulty level, in VS and NOVS conditions

Level	Semitendinosus		Vastus lateralis	
	NOVS	VS	NOVS	VS
1-2	32	35	51	60
3	45	37	67	53
4	38	37	49	52
5	18	21	34	25

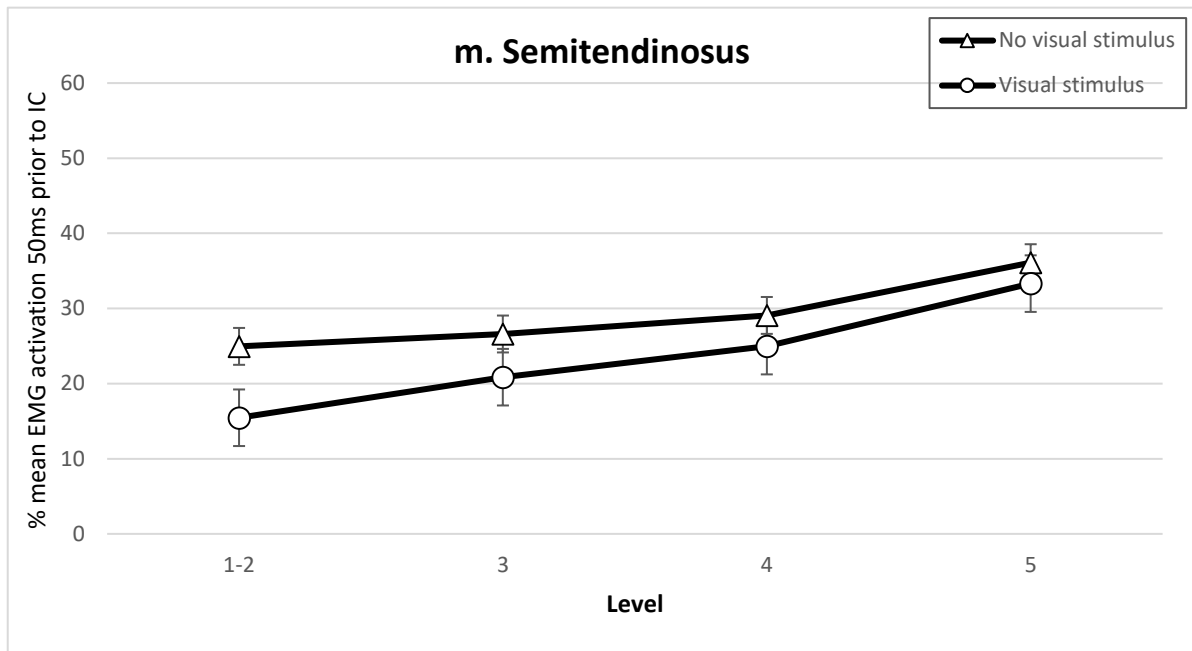
Number of valid cuts for the semitendinosus and m. vastus lateralis for every level of difficulty in both conditions of visual stimulus. NOVS = no visual stimulus. VS = visual stimulus

Table 5 Approach speed at initial contact (m/s) in every difficulty level

Level	Mean	Minimum	Maximum	SD
1-2	1.40	.49	2.44	0.46
3	1.78	.80	2.86	0.53
4	2.19	.90	3.74	0.62
5	2.48	.88	3.79	0.66
6	2.73	1.63	3.66	0.62

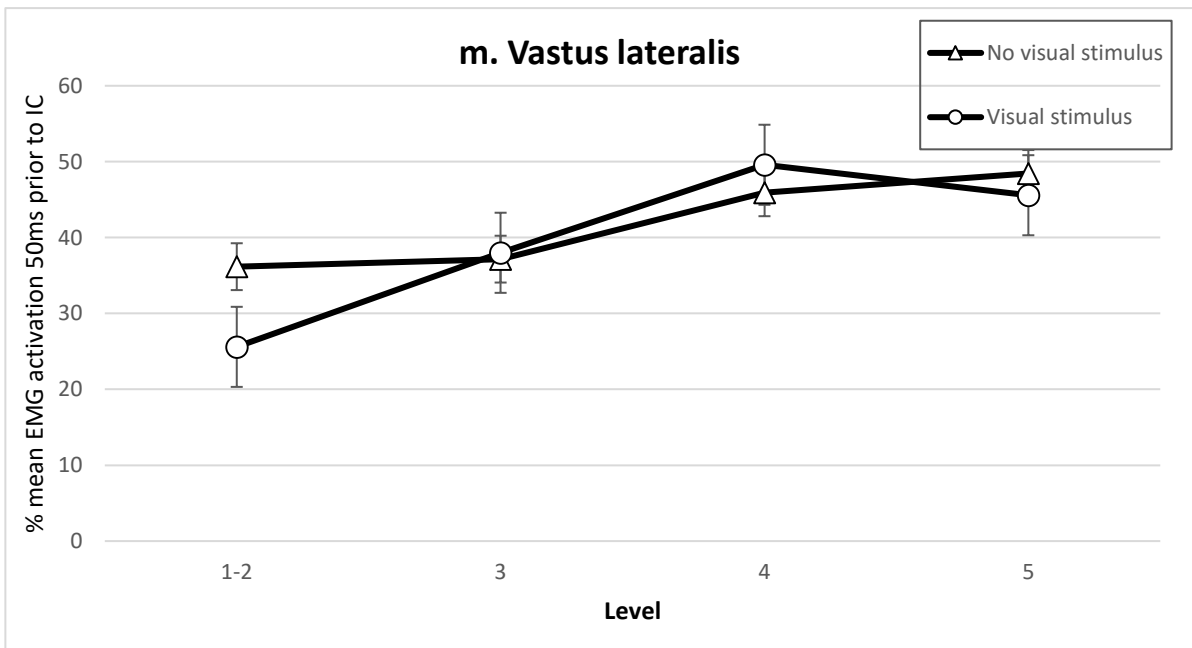
SD = Standard deviation

Figure 3



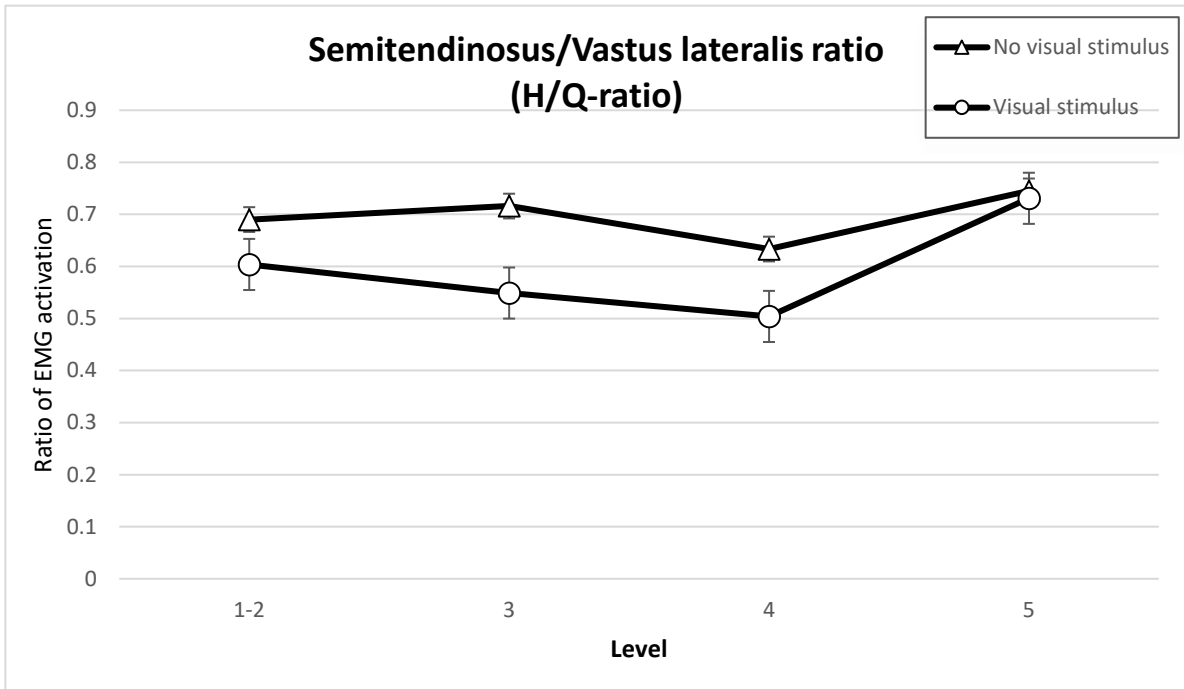
Mean EMG pre-activation of the m. semitendinosus for different levels of difficulty, with and without visual stimulus. Error bars are standard error of the mean.

Figure 4



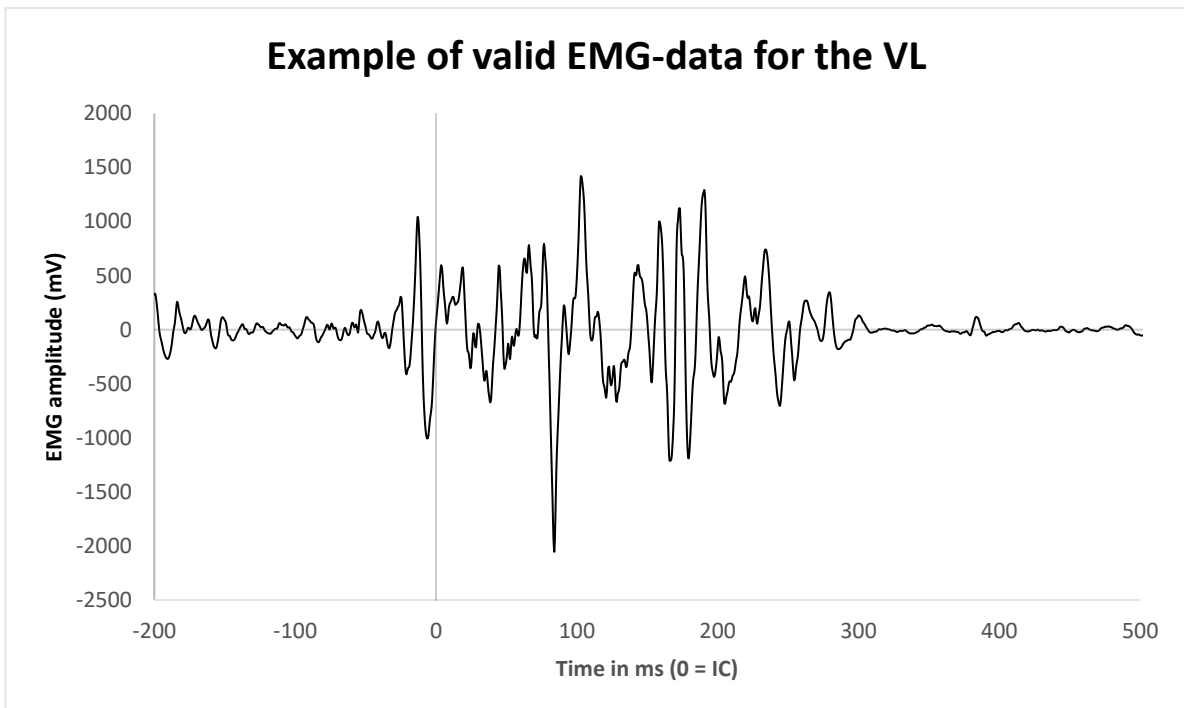
Mean EMG pre-activation of the m. vastus lateralis for different levels of difficulty, with and without visual stimulus. Error bars are standard error of the mean.

Figure 5



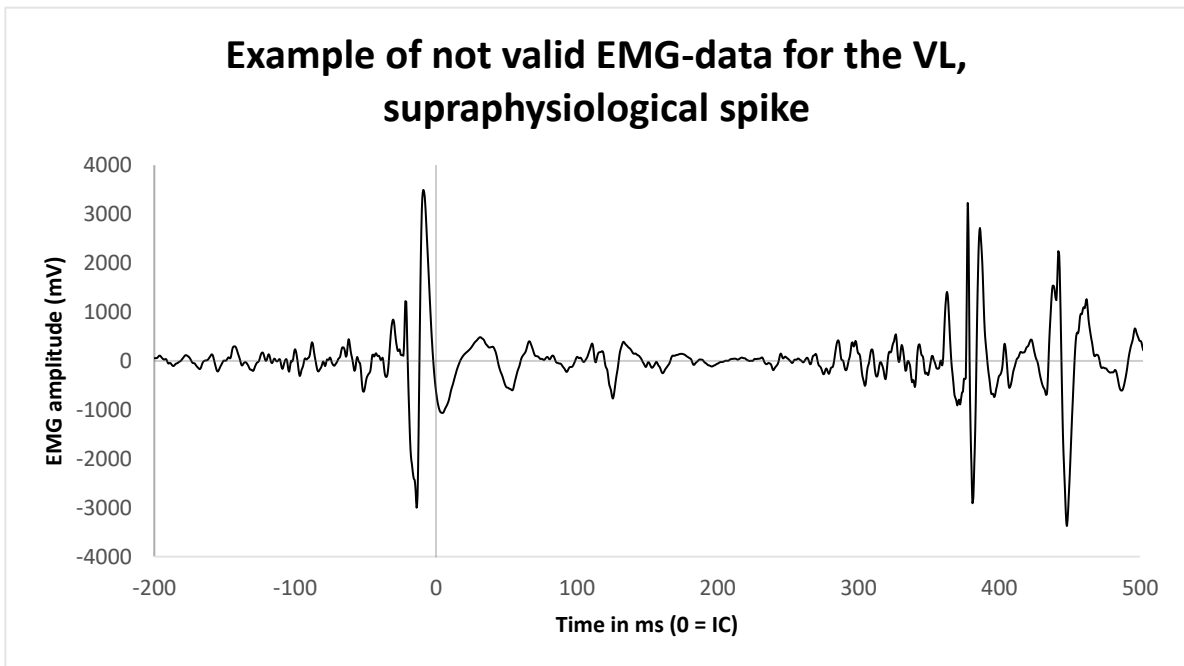
Mean hamstring to quadriceps ratio of pre-activation for different levels of difficulty, with and without visual stimulus. Error bars are standard error of the mean.

Figure 6



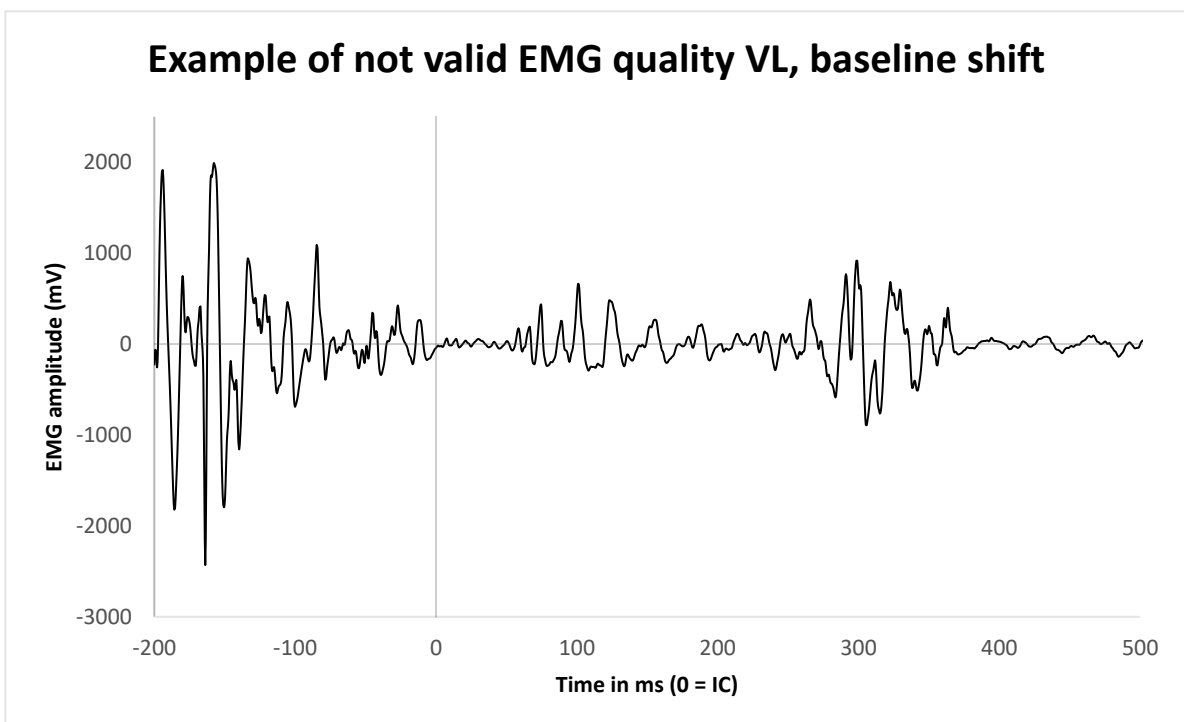
Example of valid EMG-data from the m. vastus lateralis from a window 200ms prior to initial contact, to 500ms after initial contact. Initial contact is at 0.

Figure 7



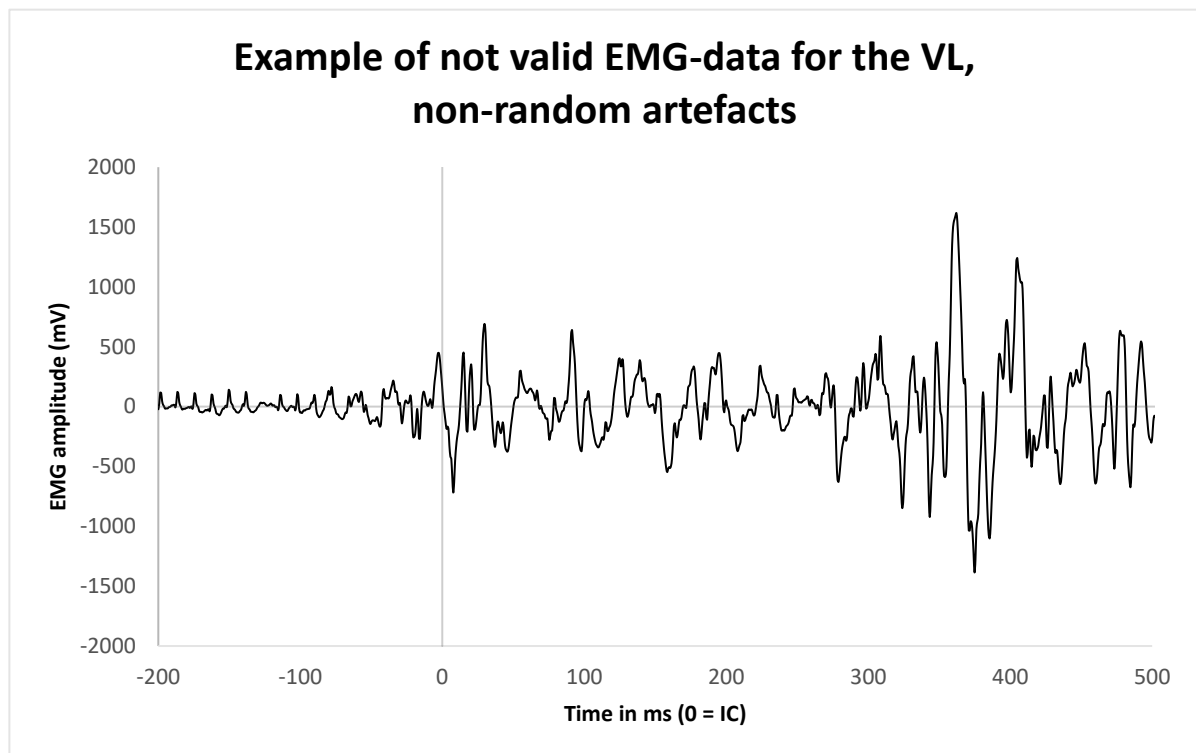
Example of not valid EMG-data from the m. vastus lateralis from a window 200ms prior to initial contact, to 500ms after initial contact. This was rejected because of the supraphysiological spike of >3000mV prior to initial contact. Initial contact is at 0. Note the amplitude scale.

Figure 8



Example of not valid EMG-data from the m. vastus lateralis from a window 200ms prior to initial contact, to 500ms after initial contact. This was rejected because of baseline shifts of more than 200mV prior to initial contact. Initial contact is at 0.

Figure 9



Example of not valid EMG-data from the m. vastus lateralis from a window 200ms prior to initial contact, to 500ms after initial contact. This was rejected because of non-random artefacts to the baseline prior to initial contact. Initial contact is at 0.

Discussion

Sixteen female football players were tested in a change-of-direction task that mimicked movements of a defender in a football match. The aim of the study was first to determine whether we were able to successfully capture EMG pre-activation during the new task, and second to see if EMG patterns would undergo clinically relevant changes as a function of ball release frequency and visual stimulus.

Principal findings

Our main findings were that the percentage of valid cuts out of the total 1101 cuts was 36.1% for the VL, and 24.6% for the ST. In addition, EMG pre-activation of the ST and VL increased, although not statistically significant, with increased ball release frequency and movement speed. There was a trend that increased cognitive demands in the form of visual stimulus decreased muscle pre-activation, but no 'critical' cut-off point could be identified. Approach speed at IC was 1.4-2.7 m/s.

Share of cuts included

The share of included cuts was found to be low for all the measured muscles (VL, ST, GMED and GMAX). While we were able to successfully capture EMG pre-activation during the task for a low share of the VL and the ST, the share of GMED and GMAX cuts was too low to be included in preliminary analysis. It has been reported that recorded EMG-data is of poorer quality when measured in areas with more subcutaneous fat.^{45 48} This may have

contributed to the low quality of EMG-data we recorded from the gluteal muscles, and testing males instead of females may alleviate this issue somewhat. Some of the previous studies that have reported EMG from the gluteal muscles include studies with females in a run-and cut task,⁴² females in a land-and-cut task,³¹ females in a single-leg forward-jump task,⁴⁹ females and males in a drop landing task,⁵⁰ and males in a soccer kick task.^{51 52} None of these studies reported on issues relating to the quality of recorded EMG data from the gluteal muscles. One possible explanation for why we experienced poor EMG-quality from the gluteal muscles could be that the task our participants performed included higher impact-forces as they were maximally accelerating and decelerating throughout each trial, which included 9 cuts. We could only re-assess the EMG-sensors after each trial, whereas other studies have only included one repetition of the task before being able to readjust EMG-sensors if necessary.

For the VL and the ST, the low percentage of included cuts was partly due to not being able to accurately determine time of IC because of the push-off leg not standing on either force plate. As we did not explicitly instruct participants on how to approach the force plates, they were free to solve the task as they wished, as they would be in a match-setting. This may have negatively added to the lack of IC data, since we saw a large percentage of cuts that did not have push-off on one of the force plates. We chose not to inform them of the role of the force plates until after the participants had completed testing as we thought it would influence their movement patterns and therefore interfere with the goal of studying match-like movements.

EMG pre-activation with and without visual stimulus

Results showed that there was a significantly lower pre-activation of the ST at L1-2 in the VS condition compared to the NOVS condition. The high number of discarded cuts affected the power of the study, and there were no significant differences in pre-activation in either the ST or the VL in the NOVS and VS condition in any of the other levels. There was however a trend that we recorded lower EMG pre-activation values of the ST in the VS condition in all levels. This is consistent with the results another study that showed decreased reactive knee stiffness when performing a cognitive task simultaneously compared with no cognitive task.⁵³ A keynote paper on the link between cognitive function and ACL-injuries points out that “if the brain’s executive functioning is unable to successfully negotiate the rapidly changing environmental conditions, then the action-planning networks are disrupted”.⁵⁴ Subsequent neuromuscular control may be diminished because of the disruption.

We found no increase in the variability in the higher levels as we theorised we might have seen. Our results showed variability of 11.2-33.1 SDs in VL and ST pre-activation in the different levels and two conditions. The theory was that at some point we might see a ‘critical point’, where EMG pre-activation would decrease as the physical and cognitive demands of the task would be greater than the participants’ ability. This would imply that the test was not able to tax participants sufficiently for them to reach this ‘critical point’, or that there is no ‘critical point’ at which EMG pre-activation decreases.

Findings in relation to EMG pre-activity in other studies

One study that is directly comparable with the present study is Meinerz, et al.³¹, who investigated EMG pre-activity in a land-and-cut task that was both anticipated and unanticipated. Because of different time intervals of the EMG pre-activity (50ms pre-IC in

the present study vs 100ms pre-IC in Meinerz, et al.³¹), and the present study using mean EMG pre-activation and Meinerz, et al.³¹ using peak EMG pre-activation, a direct comparison is difficult. However, peak EMG pre-activity in Meinerz, et al.³¹ of 24% for the biceps femoris and 33% for the VL is lower than the 36.1% for the ST and 49.6% for the VL we recorded. As we used mean values, we would expect our results to show lower EMG pre-activation. Based on preliminary analysis from only 3 of the included participants in our study, the hip and knee flexion angles at IC in L3 and L4 was equal to the angles reported from Meinerz, et al.³¹

The approach speed at IC was 1.4-2.7 m/s, which is at the lower end of the range of the 2.25-5.7m/s previous studies have reported.^{26 55} However, random selections of participants and cuts found maximum velocity prior to IC to be at least 6 m/s at L5 and L6, and closer to the maximum levels reported in *Table 5* for L1-4. This is in line with what was observed during testing at the higher levels, that the participants were decelerating in order to change direction.

Findings of H/Q ratios in relation to EMG pre-activity in other studies

The H/Q-ratio we measured varied from 0.50 to 0.75, showing that ST pre-activation was 50-75% of VL pre-activation. The VS condition tended to produce lower H/Q-ratios than the NOVS condition in the lower levels (1-4), but no statistical significance between levels or conditions could be seen. As Zebis, et al.¹⁵ has previously suggested that the H/Q-ratio is of critical importance in order to control the knee and to prevent ACL-injuries, it may be necessary to gain knowledge of what factors might influence EMG pre-activation. Our results were slightly lower than the 0.84-1.27 Zebis, et al.⁵⁶ reported during pre-planned side cutting in the 10ms time interval prior to IC. The present study's H/Q-ratio was also slightly lower than the land-and-cut task by Meinerz, et al.,³¹ which showed a H/Q ratio (biceps femoris to vastus lateralis) of 0.86 in the anticipated condition and 0.73 in the unanticipated condition. Donnelly, et al.³² reported H/Q ratios (semimembranosus and biceps femoris to vastus medialis, rectus femoris and vastus lateralis) of 1.22-1.38 during pre-planned sidestepping, and 1.11-1.17 during unanticipated sidestepping. The high H/Q ratios could be because the study included male participants,³² while the other studies only included female participants^{31 56}. Age-wise the participants in our study were older, with an average age of 22.8 years, compared with 21 years³², 19.7 years³¹ and 15.8 years.⁵⁶ The age-difference could affect the results, as ACL-injury rates have been reported to change with age in female youth football.⁵⁷ The tasks were also different, with Zebis, et al.⁵⁶ investigating a pre-planned side cutting manoeuvre, Meinerz, et al.³¹ evaluating a land-and-cut task with anticipated and unanticipated conditions and Donnelly, et al.³² examining pre-planned and unanticipated sidestepping. It could be that the additional uncertainty of not knowing which side to cut to, and the visual stimulus in our study affected the participants' H/Q-ratio. A proposal from Zebis, et al.¹⁵ is that the H/Q-ratio should not be below 0.67 during anticipated side cutting.¹⁵ This was the level at which they saw a markedly increased risk of ACL-injury in their cohort study on risk factors for ACL-injuries, albeit limited by only 5 included ACL-injuries. Their method of measuring EMG pre-activity differed from ours, in that they used EMG pre-activity in percent of peak EMG-activity during the side cut. It is therefore unclear if, and if so by how much, our results differ from their results. Due to differences in results from our study compared to previous results, our results may indicate that future knee control

assessment tasks should be made more difficult than the screening tasks that are now commonly used, such as the vertical drop jump (VDJ)⁵⁸ and the side cutting task.¹⁵

Methodological limitations of the study

Challenges with reliability of EMG-measurements

Previous reports on intra- and inter-session reliability for EMG-measurements have given ICC values between 0.90 and 0.98 for the quadriceps and hamstrings during jumping, landing and cutting.^{33 34} We expected our results to be reliable, but considering the percentage of excluded cuts and no reliability measurements in the present study, we cannot be sure of this. We also experienced that getting EMG-sensors to stay attached was difficult. This issue could be caused by the nature of the test, with it being a maximal-effort high acceleration and deceleration task that caused the participants to sweat in varying degrees. Our solution to this was to use tape around the extremities where this was possible, but we had to contend with re-attaching some of the sensors on some players between trials. The fact that we had to re-attach some EMG-sensors could be one cause of movement of the sensors, with altered skin resistance as a result, even though we followed SENIAM-guidelines when re-attaching the sensors.⁴⁶ The sweat and resulting movement of EMG-sensors could have contributed to the high number of invalid EMG-data we recorded.^{36 38} This is a methodological challenge that should be addressed in future studies that include tasks of the same high-impact, high-effort nature.

We were able to get some valuable pre-activation data from the VL and the ST, but we spent approximately 3.5 hours testing each participant, without taking preparation or analysis into account. The time spent on each participant also may have affected fatigue and concentration levels, and this is something that should be monitored in future tests. A systematic review has showed no consistency in the effects of fatigue on surface-EMG,⁵⁹ but bearing in mind that the tasks assessed were both single- and double-legged we cannot be sure that their results apply to our study. Another limitation of the study is that there are a number of different methods to collect,⁶⁰ filter,^{37 38} normalise⁶¹ and assess⁶²⁻⁶⁴ EMG-data. One of the issues making reproducibility challenging is the fact that assessment of EMG-data is subjective, and that there are no objective criteria that are universally agreed upon.⁶⁵ As the researchers responsible for testing were initially not experienced in EMG-data collection this may also have influenced both the gathering and the assessment of EMG-data. Using real-time assessment of EMG-data during testing could possibly alleviate the problem with poor quality EMG-data

Determination of IC

Limitations of the study include the already discussed issues of the large number of invalid trials. Both a lack of data for exact IC and poor quality of EMG-data were responsible for this. Having sensors embedded in the shoes or insoles measuring force-data could allow for exact IC times to be recorded without needing force plate data. In the analysis of determining IC times we manually screened video from a 3D motion capture system. We went through every cut by every participant, determining IC when GRF was > 20N. We also tried to determine IC times without having force plate data, using the height of retroreflective markers placed on the lateral malleolus of the tibia and on the heel. When we then wanted to validate this method, we compared cuts without valid force plate data to cuts with force plate

data. However, there was no consistent height on either of the retroreflective markers that corresponded to the recorded IC times from the force plate data.

Order of trials and changes to study protocol during testing

We did not randomise the order of trials during testing. As we completed testing in the NOVS condition before testing the VS condition, this may have led to fatigue in the VS condition and possible learning effects. We tried to eliminate learning during testing by having 4 test-trials for each subject. The test-trials were done with one test-run at L1 and L3, in the NOVS and VS condition respectively. Being a pilot- and feasibility study we did not calculate the power of the study before starting, and the scope of the study was limited as the project was done as part of a master thesis. Also owing to the fact that we conducted a feasibility- and pilot study were the fact that we made changes to the study protocol during testing, specifically the width of where the balls landed. These changes resulted in movements more closely resembling those described in video analysis of ACL-injury situations.^{22 23}

Unanswered questions and future research

Future research should ensure successful capture of EMG-data in muscles that are deemed relevant to knee control (e.g. quadriceps, hamstrings, gluteal, calf muscles) in tasks that challenge the participants with unanticipated conditions and with distractions similar to what is seen in matches. Development of this test specifically could benefit from ensuring valid IC data from all cuts, by increasing the area that captures GRF, by measuring GRF with shoes or insoles, or by adding constraints or instructions to make sure the participants are stepping onto a force plate. Having valid EMG-data for majority of cuts would decrease number of cuts needed, and focusing on one or two levels would decrease that number even more. Using real time EMG during testing could result in more valid EMG-data. Having a robot launching footballs could be beneficial to increase realism of the task. Additionally, measuring the time from the ball launching to the participant reacting could be of value.

Conclusion

We were not able to successfully capture EMG pre-activation during the task for all included muscles, and the percentage of cuts that had valid data was low (24.6-36.1%). The ST showed statistically significant decreased EMG pre-activation in the two easiest levels in the VS condition compared to the NOVS condition. No other statistical differences as a function of ball release frequency and visual stimulus were seen.

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Appendix

Consideration from regional ethics committee

Fra: post@helseforskning.etikkom.no <post@helseforskning.etikkom.no>

Sendt: 28. juni 2016 13:02

Til: Tron Krosshaug

Emne: Sv: REK sør-øst 2016/1069 Endring i knekontroll ved økende vanskelighetsgrad i en oppgave som simulerer forsvarsspill i fotball

Vår ref.nr.: 2016/1069 C

Hei.

Vi viser til innsendt skjema for fremleggingsvurdering av ovennevnte prosjekt, mottatt 13.06.16.

Søker angir følgende om formålet med prosjektet:

Ukontrollerte frontalplansbevegelser i kneet er assosiert med fremre korsbåndskader. Nyere studier i fotball viser at press mot ballfører er den vanligste situasjonen der fremre korsbåndskader inntreffer. Dette prosjektet har som mål å beskrive endringer av knekontroll ved økende krav til løpshastighet og fokus på omgivelsene. Vi vil måle endring i muskelaktivering og leddbevegelser hos kvinnelige fotballspillere i en fotballspesifikk bevegelsesoppgave som simulerer press på ballfører.

Helseforskningslovens gjelder for medisinsk og helsefaglig forskning, forstått som virksomhet som utføres med vitenskapelig metodikk for å skaffe til veie ny kunnskap om helse og sykdom, jf. helseforskningslovens § 4.

I dette prosjektet vil man studere knebelastning hos friske frivillige, konkret knyttet til en type treningsøvelse som simulerer førsteforsvarerpress. Konsekvensen av aktiviteten kan muligens knyttes opp mot korsbåndsskader, men det er ikke et slikt utkomme man per se etterspør i studien.

Prosjektet omfattes dermed ikke av helseforskningslovens virkeområde, jf. helseforskningslovens § 2. Prosjektet er ikke fremleggelsespliktig, jf. helseforskningslovens § 4 annet ledd.

Vi antar for øvrig at prosjektet kommer inn under de interne regler for behandling av opplysninger som gjelder ved ansvarlig virksomhet. Søker bør derfor ta kontakt med enten forskerstøtteavdeling eller personvernombud for å avklare hvilke retningslinjer som er gjeldende

Vi gjør videre oppmerksom på at konklusjonen er å anse som veiledende jfr. forvaltningsloven § 11.

Dersom dere likevel ønsker å søke REK, vil søknaden bli behandlet i komitémøte, og det vil bli fattet et enkeltvedtak etter forvaltningsloven.

Med vennlig hilsen
Tor Even Svanes

seniorrådgiver

post@helseforskning.etikkom.no<<mailto:post@helseforskning.etikkom.no>>

T: 22845521

Regional komité for medisinsk og helsefaglig forskningsetikk REK sør-øst-Norge (REK sør-øst) <http://helseforskning.etikkom.no>

Information to prospective participants prior to inclusion in the study

Ny, vitenskapelig test for å måle prestasjon og knebelastning i fotballspesifikke bevegelser

Senter for idrettsskadeforskning utvikler en ny, banebrytende test der vi vil måle prestasjon, muskelbruk og knebelastning i en fotballrelatert test. Målet er å forstå hvilke mekanismer som bidrar til økt risiko for korsbåndskader i retningsforandringer. Det langsiktige målet er å redusere den høye forekomsten av korsbåndskader i kvinnefotball.

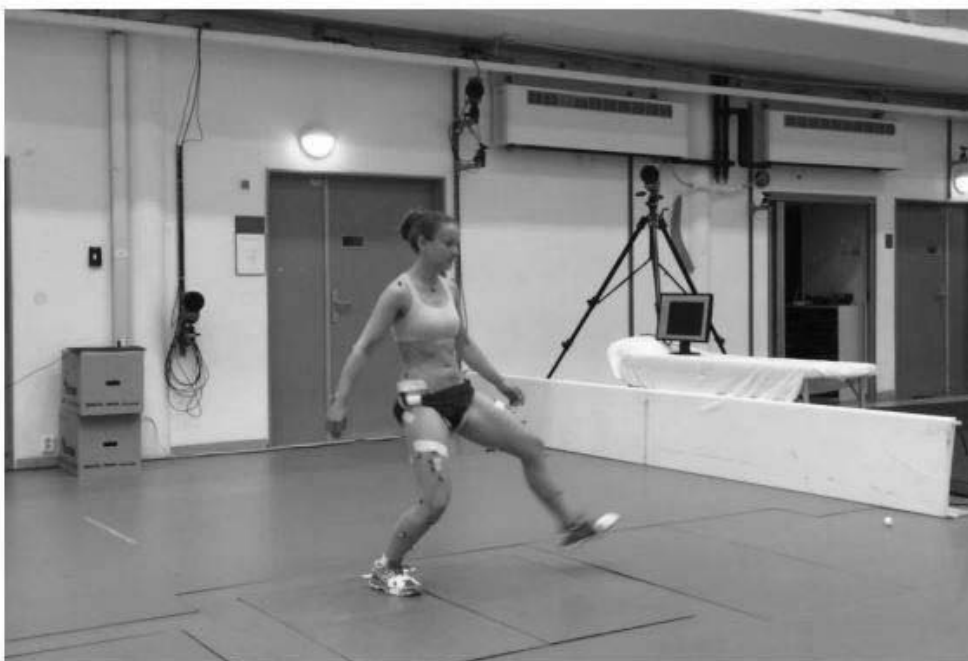
Hva går det ut på?

Din oppgave er å stoppe bordtennisballer som blir skutt ut av en robot med føttene. Mellom hver ball gjør du et kort løp med vending. Dette gjøres med økende hastighet. Under testen vil det være 15 infrarøde kamera som filmer refleksmarkører som er festet på kroppen. Disse metodene tilsvarer det som benyttes i Hollywood-filmer. Samtidig måler vi muskelaktivitet og belastning fra underlaget.

Hva får du ut av deltakelse i prosjektet?

Med deltakelse i denne testen kan DU bidra til å forebygge fremtidige korsbåndskader i jentefotball. Om ønskelig kan vi hente ut dine prestasjonsdata og sammenligne resultatene med gjennomsnittet i gruppen. Vi kan enkelt se på hvilket nivå du behersker i testen sammenlignet med resten av gruppen, samt i hvilken grad ytre fokus (lyssignaler) påvirker prestasjonen.

Her er et bilde fra selve testen:



Testingen vil foregå fra 25.08 tom. 01.09. Vi kan avtale et tidspunkt som passer for deg, både tidlig morgen og seint på kveld er mulig å få til.

Interessert i å delta eller ønsker mer info? Ta kontakt med Hans Martin Bjørkevoll (fysioterapeut og masterstudent) på epost: hmbjorkevoll@gmail.com, eller tlf. 920 14 313.

Consent form

FORESPØRSEL OM DELTAKELSE I PROSJEKTET:

”Endring i knekontroll ved økende vanskelighetsgrad i en oppgave som simulerer forsvarsspill i fotball”

Bakgrunn for undersøkelsen

Korsbåndsskader i fotball og håndball har i de siste årene vært et svært aktuelt tema, både i media og i forskningssammenheng. Dette skyldes først og fremst den relativt store hyppigheten av denne alvorlige skaden, spesielt blant kvinnelige utøvere, som ser ut til å skade seg 2-3 ganger hyppigere enn menn. Problemet så langt er imidlertid at vi vet for lite om årsaken til korsbåndsskader. Denne informasjonen er viktig når vi forsøker å forebygge skader, både for å kunne vite hvem som vil ha størst glede av forebyggende trening og for å kunne utvikle mest mulig effektive treningsmetoder.

Senter for idrettsskedeforskning er en forskningsgruppe bestående av fysioterapeuter, kirurger og biomekanikere med kunnskap innen idrettsmedisin. Vår hovedmålsetting er å forebygge skader i norsk idrett, med spesiell satsning på fotball, håndball, ski og snowboard.

Målsetningen med denne studien er å undersøke i hvilken grad muskelaktivitet og leddbevegelser i beina endrer seg ved økende vanskelighetsgrad i en oppgave som simulerer forsvarsspill i fotball for kvinnelige fotballspillere. Denne kunnskapen skal brukes videre i forbindelse med skadeforebyggende trening knyttet til fremre korsbåndsskader.

Gjennomføring av undersøkelsen

Testingen vil finne sted på Norges idrettshøgskole, og tar ca 3 timer. Testdagen starter med at du får festet 4 små EMG-sensorer (som måler muskelaktivitet) på hvert ben. Disse festes på framsiden av låret, på baksiden av låret, på yttersiden av hoften og på den store setemuskelen. Etter en kort oppvarming måler vi muskelaktivitet ved en bevegelse for alle musklene som blir undersøkt med EMG-sensorene.

Etter påsetting av 37 små refleksmarkører gjennomføres testen, som går ut på å reagere på bordtennisballer som blir skutt ut av en robot. Du skal forsøke å stoppe ballene med føttene, og mellom hver ball skal du gjøre et kort løp med vending. Dette gjøres med økende frekvens. Under testen vil det være 15 infrarøde kamera som filmer markørene, samtidig som vi måler muskelaktivitet og kreftene fra underlaget. Dataene fra markører, kraftplattform, EMG-sensorer og anatomiske mål benyttes i en matematisk modell som gir ut leddkrefter og momenter.

Fordi refleksmarkørene og EMG-sensorene skal festes på huden, vil testen bli utført i kun sports-BH og bokser/truse. Det er også viktig at du ikke smører deg inn med body-lotion på test-dagen, for da vil ikke teipen og markørene feste seg på huden.

Behandling av testresultatene

Dataene vil bli behandlet konfidensielt, og kun i forskningsøyemed. Alle som utfører testingen og forskere som benytter dataene er underlagt taushetsplikt. Resultatene fra testene anonymiseres etter 1.1.2017.

Hva får du ut av det?

Vi kan ikke tilby noe honorar for oppmøtet, men du kan få testresultatene dine målt mot gjennomsnittet i gruppen ved prosjektets slutt om du ønsker.

Angrer du?

Du kan trekke deg fra forsøket når som helst uten å måtte oppgi noen grunn. Alle data som angår deg vil uansett bli anonymisert.

Spørsmål?

Ring gjerne til Hans Martin Bjørkevoll, tlf.: 92 01 43 13, eller Tron Krosshaug, tlf: 45 66 00 46, hvis du har spørsmål om prosjektet, eller send e-post til hmbjorkevoll@gmail.com eller tron.krosshaug.nih.no.

”Endring i knekontroll ved økende vanskelighetsgrad i en oppgave som simulerer forsvarsspill i fotball”

SAMTYKKEERKLÆRING

Jeg har mottatt skriftlig og muntlig informasjon om studien «Endring i knekontroll ved økende vanskelighetsgrad i en oppgave som simulerer forsvarsspill i fotball». Jeg er klar over at jeg kan trekke meg fra undersøkelsen på et hvilket som helst tidspunkt.

Sted

Dato

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Underskrift

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Navn med blokkbokstaver

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Adresse

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Mobiltelefon

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E-postadresse

Confirmation of permission for the use of Figure 3

Dear Hans:

You have my permission to use that figure in your master thesis. Thank you for your interesting to cite our article and use one figure in your master thesis.

Good luck for your study!

Best wishes,

Prof. CHENG

Cheng-Kung Cheng, Ph.D.
From my iPhone

Hans Martin Bjørkevoll <hmbjorkevoll@gmail.com> 於 2017年5月10日 下午8:41 寫道 :

Dear Professor Cheng

I'm writing you hoping to request the use of 'Figure 1' from your publication: "Anatomic-like polyethylene insert could improve knee kinematics after total knee arthroplasty – A computational assessment" in my master thesis.

The thesis is about the feasibility of a new task for assessing knee control, and it would be very helpful if you would be so kind as to grant permission to use the figure in my theory chapter.

I understand you are busy and that you may be unable to reply, but hoping for a positive reply.

Regards

Hans Martin Bjørkevoll

Master student in sports physiotherapy

Norwegian School of Sport Sciences (<http://www.nih.no/en/>)

