Evidence-based testing of the hamstring muscles using EMG considering the kinematics and injury mechanisms of the hamstring muscle group

Karen Kotila

Thesis for the degree of Master of Science

Supervisor: Dr. Árni Árnason

Masters committee: Dr. Árni Árnason, Dr. Thorarinn Sveinsson, Dr. Per Hölmich

Faculty of Medicine

Department of Physiotherapy

September 2014

UNIVERSITY OF ICELAND
SCHOOL OF HEALTH SCIENCES
FACULTY OF MEDICINE

Gagnreynd prófun á vöðvavirkni aftanlærisvöðva með vöðvarafriti að teknu tilliti til hreyfingafræði og mekanisma meiðsla

Karen Kotila

Ritgerð til meistaragráðu

Umsjónarkennari: Dr. Árni Árnason

Meistaranámsnefnd: Dr. Árni Árnason, Dr. Þórarinn Sveinsson, Dr. Per Hölmich

Læknadeild

Námsbraut í sjúkraþjálfun

September 2014

UNIVERSITY OF ICELAND
SCHOOL OF HEALTH SCIENCES

FACULTY OF MEDICINE

Printing by Háskólaprent ehf.

Reykjavik, Iceland 2014

Abstract

Hamstring injuries and re-injuries are frequent in soccer and literature shows that there is a continuous need to find tests that can be included in a return to sport algorithm.

Bound jumping (BJ), Nordic hamstring lower (NHL), Single leg horizontal hop (SLHH) and Timed 30m sprint (S) are four exercises that could be used to screen for motion skills, asymmetry, strength, stability and speed, for example regarding hamstring muscles and possible some injury mechanisms.

A literature search shows that S and SLHH are reproducible performance tests. BJ has not been tested and NHL has in one study been found not to be reproducible.

The aim of this study was to test the test-retest reliability of BJ, NHL, SLHH and S as hamstring muscle tests, assessed with different EMG parameters. Sixteen soccer players and four physiotherapists participated in the study.

The current study found BJ, SLHH and NHL to be not reliable tests when assessed by the parameter of Peak EMG, with typical error ranging from ±25-53%MVC. S is equally not reliable when assessed by the parameter of Total power EMG (Typical error ±48%MVC), and S and NHL assessed by the parameter of median frequency are of equally low reliability (typical error ±20-24Hz).

BJ, NHL, SLHH and S may be reliable performance tests but are in the study at hand not reliable as EMG tests for the hamstring muscle group.

Keywords: Hamstring muscle group, surface EMG, peakEMG, totalpowerEMG, median frequency, bound jumping, Nordic hamstring lower, single leg horizontal hop, 30m sprint, test-retest reliability

Útdráttur

Meiðsli og endurtekin meiðsli aftanvert í læri eru algeng meðal knattspyrnumanna. Fyrri rannsóknir benda til að þörf sé á að finna aðferðir sem hægt er að styðjast við til að meta hvenær leikmenn eru tilbúnir til þátttöku eftir meiðsli.

Lárétt skiptihopp þar sem lent er á hægri og vinstri til skiptis (Bound jump, BJ), „Nordic hamstring lowers“ (NHL), einnar fótar lárétt hopp (Single leg horizontal hop, SLHH) og 30 m sprettir á tíma (Timed 30m sprint, S) eru fjórar æfingar sem gætu nýst til að skima fyrir hreyfifærni, ósamhverfu í hreyfingum , styrk, stöðugleika og hraða m.a. með tilliti til aftanlærisvöðva og hugsanlega mekanisma meiðsla.

Leit í gagnabönkum sýndi að S og SLHH eru áreiðanlegar árangursmælingar. BJ hefur ekki verið rannsökuð með tilliti til þessa og ein rannsókn gaf til kynna að NHL sé ekki áreiðanleg sem árangursmæling.

Marmið þessarar rannsóknar var að mæla áreiðanleka vöðvarafrits (EMG) á aftanlærisvöðva í BJ, NHL, SLHH og S milli ólíkra matsmanna á mismunandi dögum. Sextán knattspyrnumenn og fjórir sjúkraþjálfarar tóku þátt í rannsókninni.

Helstu niðurstöður rannsóknarinnar voru að BJ, SLHH og NHL prófin reyndust ekki áreiðanleg hvað varðar hæsta EMG gildi, með mælivillu frá ±25-53%. Áreiðanleiki S var álíka þegar hann var skoðaður með tilliti til heildar EMG afls (mælivilla ±48%). Áreiðanleiki S og NHL var einnig álíka m.t.t. miðtíðni (mælivilla ±20-24Hz).

BJ, NHL, SLHH og S geta verið áreiðaleg með tilliti til árangursmælinga, en í þessari rannsókn reyndust EMG mælingar þeirra fyrir aftanlærisvöðva ekki áreiðanlegar.

Lykilorð: Aftanlærisvöðvar, yfirborðs EMG, hámarks EMG, heildar EMG afl, miðtíðni, lárétt skiptihopp, Nordic hamstring lowers, einnar fótar lárétt hopp, 30m sprettir, endurtekningar áreiðanleiki.

Acknowledgement

First of all, a “thank you” to my wonderful family who carried me through with laughs and encouragements, in sickness and in health.

Also thank you to my advisors Árni Arnason and Thorarínn Sveinsson who with their expertise, advise and perseverance helped me through countless conversations and correspondences over mail and skype.

Thank you to the staff at KINE.is for lending me equipment and giving me technical support along the way.

And to all the soccer players and my colleagues, who participated as test subjects and testers, thank you for your help.

Lastly, thank you to Gunnhildur Gunnarsdóttir for being my Guiney pig!

Table of Content

List of abbreviations

BF	*m. biceps femoris*
BJ	Bound jumping
EMG	Electromyography
HSI	Hamstring Strain Injury
Hz	Hertz
IZ	Innervation Zone
MATLAB	Matrix Laboratory
MF	Median Frequency
MH	Medial Hamstrings (mm*. semitendinosus/ semimembranosus)*
MVC	Maximal Voluntary Contraction
NHL	Nordic Hamstring Lower
OR	Odds Ratio
PT	Physiotherapist(s)
RMS	Root Mean Squared
S	Timed 30m Sprint
sEMG	surface Electromyography
SENIAM	Surface Electromyography for noninvasive Assessment of Muscles
SLHH	Single Leg Horizontal Hop

List of Figures

List of Tables

List of Appendix

1. Introduction

One of the most frequent injuries in soccer is strain of the hamstring muscle group (Árnason et al, 2004; Petersen et al, 2010; Beijstervaldt et al, 2012). This injury often holds the player out of competition for weeks and has an irritating tendency to reoccur.

1.1 Definition of hamstring strain injury (HSI)

The hamstrings are the large group of muscles in the back of the thigh, consisting of *m. semitendinosus, m. semimembranosus* and *m. biceps femoris.* The two former will hereafter be referred to as medial hamstring (MH) and the latter BF. In this research, HSI is defined as a partial or complete tear of a hamstring muscle either located in the fibers of the muscles, the myotendinous junction or at the enthesis.

1.2. Definition of recurrent injury

An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury. A recurrent injury occurring within 2 months of a player's return to full participation is referred to as an ''early recurrence''; one occurring 2 to 12 months after a player's return to full participation as a ''late recurrence''; and one occurring more than 12 months after a player's return to full participation as a ''delayed recurrence''. (Fuller et al, 2006)

1.3. Incidence of all hamstring injuries among soccer players

A literature search (appendix 1) of the incidence of hamstring injuries in soccer revealed 0.3 -19% of all injuries reported in the prospective cohort studies included, were hamstring injuries (lowest to highest reports: LeGall et al, (2008); Eirale et al (2010)). Using the definition of epidemiological incidence proportion by Knowles et al (2006), where the number of new cases of injury during the study period is calculated, between 1.6% and 29% (mean: 17%) of the athletes in the studies were at risk of sustaining a hamstring injury. The incidence rate reported (injuries/1000h exposure) showed a range between 0.02-3.7 hamstring injuries/1000h (lowest to highest reports: LeGall et al (2008); Ekstrand et al (2011)) (evidence level IIa).

Recurrent injuries to the hamstrings constituted of 12-47% of all injuries among male and female soccer players. (lowest to highest reports: Woods et al (2004); Eirale et al (2010)). One study on the incidence of soccer injuries in British academy soccer (Price et al, 2004) concluded that 33% of all sprain- or strain re-injuries were to the hamstring muscle group; however no definition of re-injury was described. Only one study (Petersen et al 2010) clearly distinguished between new and recurrent hamstring injuries during their 12 month recording period and found an incidence rate of 25% recurrent hamstring injuries in adult male soccer players (evidence level IIa). The large range of reported injury incidence could be a result of differences in the definition of hamstring injury between studies, where it ranges from strain, only to including contusions, abrasions etc. The summary of the literature is depicted in appendix 1.

1.4 Hamstring strain injury (HSI) risk in soccer

The risk factors of sustaining HSI have been extensively researched. In prospective cohort observational studies the risk of incurring a hamstring strain injury increased up to sevenfold in soccer players with a history of HSI to the same leg and location (Beijstervaldt et al 2012; evidence level I; Arnason et al 2004, Engebretsen et al 2010, Hägglund et al 2006; evidence level II). A literature search (appendix 2) showed a range from 2-7 Odds Ratio (OR) in favour of a recurrent HSI had one previously been sustained. Conflicting evidence is found for age and hamstring flexibility as risk factors. Less is known about modifiable factors such as joint stability, hamstring/ quadriceps strength ratio, speed, results from agility tests and player exposure. A tendency towards decreased flexibility and high exposure rate is described but the number needed in research to establish certainty of these risk factors is so great that none of the studies found in this literature search live up to that standard (Engebretsen et al 2010). Most often, HSI injuries are reported to occur during matches with an increase at the end of each half which leads to believe, that fatigue is a contributing risk factor (Woods et al 2004).

1.5 Analysis of hamstring strain injury mechanisms

In soccer, most hamstring strains occur while players are sprinting (Arnason 1996, Schache et al 2009, Petersen 2011). Schache suggests that there are two major components to the risk of sustaining HSI. One is pure stretching and lengthening of the hamstring muscles. One is eccentric contraction during deceleration of the flexion of the hip. (Schache: evaluating leg function during sprinting; video conference, Sportskongres 2011). Schache hypothesizes that the hamstrings are susceptible to injury during terminal swing before initial heel strike. He reasons this with the logic that the hamstrings appear to be most biomechanically exposed during terminal swing. Most of the inertial force acting about the knee joint at this time is potentially imparted onto the hamstrings are working to decelerate knee extension and also becoming an active extensor of the hip joint. He supports his logic reasoning in his observational study on a virtual hamstring strain occurrence during sprinting. Interestingly, the data providing us with the insight of the mechanism of a hamstring strain presented by Schache (2009) were obtained unexpectedly during a routine quantitative gait analysis assessment conducted prior to the athlete returning to competition following previous right hamstring strains. The athlete was fully participating in training and was scheduled to return to Australian league football competition.

1.6 Return to soccer after Hamstring strain injury

Although the incident described by Schache (2009) above provided us with unique insight to the mechanisms of the HSI, it also underlines the inadequacy of the testing procedures by the team clinician evaluating an athlete's readiness to return to sport following a HSI. Orchard and Best (2002) concluded that 1/3 of recurrent hamstring injuries in Australian football league occurred in the first week of return. Dvorak et al (2000) concluded that "Previous injuries and inadequate rehabilitation are the most important and well-established intrinsic risk factors for future football injury". Mendiguchia and Brughelli (2011) noted in their commentary on return to sport following a HSI: "Despite a thorough and concentrated effort to prevent and rehabilitate hamstring injuries, injury occurrence and re-injury rates have not improved over the past 28 years". This they based on the hamstring injury incidence rapports by Ekstrand and Gillquist from 1983 and Hägglund et al from 2009.

In an attempt to create an algorithm for return to sport following a HSI Mendiguchia and Brughelli (2011) studied the literature in regards to accepted clinical indicators of the player's readiness to return to sports. They found 7 studies that classified the HSI rehabilitation into 1) the acute phase, 2) the subacute phase and 3) the functional phase. (Table 1-1). In only 3 of the 7 studies in the Table below (1-1), objective measures to distinguish between the phases were mentioned. In the three articles, tests like flexibility test, self-reported pain free participation and isokinetic strength test were included in the test battery in order to progress from one phase to the next.

Table 1- 1 Previous literature on the criteria for progression; (adapted from Mendiguchia and Brughelli 2011)

Study	Acute phase criteria	Sub-acute phase criteria	Functional phase criteria
Worell (1994)	Inflammation down Inflammation down	None	Pain free sports movements.
Petersen and Hölmich (2005)	<1 week	None	Pain free sports movements. <10% isokinetic strength compared to un-injured. .
Clanton and Coupe (1998)	Roughly 5 days post-injury	Pain free Full ROM	Pain free sports movements. <10% isokinetic strength compared to un-injured.
Hunter and Speed (2007)	None	Full ROM Generate force Control eccentric movement	Pain free sports movements. 4 consecutive repetitions of maximum effort manual strength test (90 degrees and 15 degrees)
Drezner (2003)	Normal walking stride without pain Very low speed jog without pain	None	<5% isokinetic functional ratio compared to uninjured
Heiderscheit et al (2010)	Pain free isometric contraction against sub-maximal (50-70%) resistance during prone knee flexion (90degrees) manual strength test	Full strength (5/5) without pain during prone knee flexion (90 degrees) manual strength test Pain free forward and backward jog, moderate intensity	

In Mendiguchia and Brughelli's (2011) return to sport algorithm (Table 1-2). the objective testing for the final phase of the algorithm, consists of optimum peak tension measures by method of isokinetic dynamometer, strength testing of the hip extensors by the method of isokinetic testing, core stability testing by method of active straight leg testing, imaging of size of edema by means of MR scanning, and symmetry testing in running by the method of electromyography.

Table 1- 2 Return to Sport Algorithm. Description of progression from functional phase to be cleared to play, including variables, tests and criteria for progression as proposed by Mendiguchia and Brughelli (2011).

Functional phase		
Variable	**Test**	**Criteria for progression**
• optimal angle of peak torque	• isokinetic knee flexion at 60°/second	• < 28° during knee flexion and < 8° asymmetry between legs
• Hip extension strength	• isokinetic hip extension at 60°/second	• <10% asymemetry between legs
	• non-motorized treadmill at 80% maximum running velocity	• <20% asymmetry between legs
• MRI	• hamstring image	• Edema size and or length
• Lumbar rotation stability	• ASLR test	• No Anterior pelvic Tilt

The ultimate goal of the hamstring return-to-sport testing must be to identify and treat deficits (i.e. neuromuscular and biomechanical deficits) that influence performance and re-injury. Hamstring injuries are thought to occur when the muscle is activated beyond their optimum length, during terminal swing before initial heel strike where the hamstring muscles are working to decelerate knee extension (Schache, 2009). The long head of BF is the most commonly injured hamstring muscle (Askling et al, 2010; Mendiguchia and Brughelli, 2011). One reason for this could be that BF has been shown to be activated at longer lengths (i.e.15-30 degrees of knee flexion), compared to the MH muscles (i.e. 90-105 degrees of knee flexion. (Schache, 2009) In this research it is proposed that it is important to test the muscles where the optimum length of the hamstring muscles is challenged, as well as it is important to test the reaction of muscle in question and not only the power output of the entire muscle chains.

It is likely that no one testing procedure of the post-injured hamstring muscle can stand alone. Human movement is complex and the body's ability to adapt to change and hence compensate for lack of strength, flexibility, endurance, power, etc. is immense. It is most likely that an entire test battery is needed to assess the post-injured hamstring muscle, and that this test battery includes functional tests that take the HSI mechanisms described above into consideration. Lastly, a test battery need also take into consideration that a normal variability of movement takes place during functional tasks. There is a considerable variability of movement that is necessary to have efficient coping strategies. For the purpose of its reliability, the test battery must be standardized as much as possible as well as take possible learning effects into consideration.

Various functional testing assessments of jumping and sprinting are described in the literature. The focus in these studies is the power (strength and velocity) of the jumps and sprints and less attention is given to the quality of the jumps (such as timing of muscle onset or strength ratio of specific muscles). Furthermore, the tests applied to the post- hamstring injured individual must be reliable tests to the hamstring muscle group. A functional jump test, reliable to the post surgery knee might not apply and prove reliable as a test of the hamstring muscle group. In the research at hand four functional tests, that take the kinematics of injury mechanisms of the hamstring muscle group into account, are tested for their reliability. The four tests are Bound Jumping (BJ) ,Nordic Hamstring Lower (NHL), Single leg horizontal hop for distance (SLHH) and Timed 30m Sprint.

1.6.1 Bound Jumping

BJ is adapted from track and field exercising. The nature of the BJ assessment replicates the cyclic and eccentric loading of the hamstring muscle group in the sprint, but with an exaggeration of the length of the strides that exposes the hamstring muscles ability to cope with the stretch and eccentric loading followed by a the concentric contraction. The object is to raise the front knee up and kick the back leg out as far as possible, giving the player the longest stride possible. With the left knee rising up, the right elbow is also raised up for power and stability of the truncus to the opposite hip. This part of the movement demands pelvic stability as well as flexibility of the hamstrings, as lengthening of the hamstring gives way to raising the knee up high. As the front heel strikes the ground, the workload of the hamstring muscles changes from eccentric to concentric workload with the gluteus maximus as primary synergist to the concentric force. As the player is transferring all his weight to this side the hamstring are also co-working with the external and internal rotators of the hip, the adductors of the thigh and mm. *abdominalis externus* and *internus* to create a stable proximal base for transferral of weight. During the stance period, opposite leg is brought forward for knee flexion and at toe off the gluteus maximus and hamstrings work concentrically to extend the hip and knee joints (Figure 1.1).

Figure 1.1 BJ with permission from Juan Carlos Santana, MEd, CSCS
http://www.performbetter.com/webapp/wcs/stores/servlet/PBOnePieceView?storeId=10151&languageId=-1&pagename=59

1.6.1 Nordic Hamstring Lower

Dynamic eccentric tests are proposed to be of most importance when assessing a player's ability to return to sport following a hamstring strain injury. (Askling et al, 2010). Eccentric loading of the hamstring muscle like NHL, is the only exercise that to date has proven to reduce hamstring strain injuries (Petersen et al, 2011, Arnason et al 2008) and was included in this study for its success in targeting and loading of the hamstring muscles. In a previous study on intrinsic risk factors for hamstring strain injuries, Engebretsen et al (2010) tested the intertester reliability of the hamstring lower exercise. The testers were to identify if the player could hold the position of beyond 30 degrees forward flexion (strong) or not (weak). They found a very low reliability between testers showing that the same player will not necessarily be scored the same way on 2 separate tests by two different testers. The Nordic Hamstring Lower exercise is performed with the player sitting on his knees, hips and back straight and arms along sides. One sits behind the player holding on to the player's ankles. The player is instructed to slowly descend to the ground (Mjölsnes et al 2004). In this position the hamstrings are activated as soon as the player starts his descend, working eccentrically. The *m. gluteus maximus*, lower back extensors as well as *m. gastrocnemius* are also key forces, holding the player back from falling on his chest (Figure 1.2).

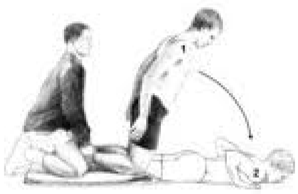


Figure 1.2 NHL Reproduced from Bahr and Mæhlum (2004) with permission from the publisher (©Lill-Ann Prøis & Gazette bok).

1.6.3 Single Leg Horizontal Hop

The hamstring strain injury mechanism in soccer players is cyclic in nature why it would make sense to try and replicate this type of force development in multiple single-leg horizontal hops. If SLHH assessment would prove reliable it would appear to have an advantage over bilateral jump assessment like the squat jump, as differences in limb symmetry can be identified and measurements of the non-injured limb can serve as the biological baseline to which the injured limb should return. Maulder and Cronin (2005) studied the reliability of horizontal hop and vertical jumps and reported ICC values of 0.95-0.97 (CV 1.8-1.9 for non-dominant and dominant leg respectively) (recommendation level c). In Maulder's research the outcome measures were hop length and calculated symmetry index between dominant and non-dominant leg. In SLHH the player starts standing with both hands resting on hips and legs parallel. He hops forward on one leg, hop again forward on same leg and lands on both legs (Figure 1.3). He is instructed to jump for length. He is allowed to use arms at take-off. If the player does not land standing still, the trial is counted as 0 cm.

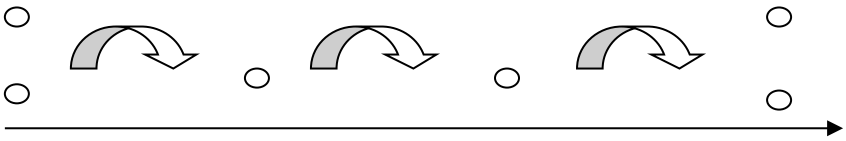


Figure 1.3 Single Leg Horizontal Hop

At take-off, the hamstrings work concentrically with *m.gluteus maximus* for maximum power. As one leg is brought forward the hamstring muscles work eccentrically to stop the knee extension. As the heel strikes the ground, the workload of the hamstring muscles changes from eccentric to concentric workload, with m. *gluteus maximus* as primary synergist to the concentric force. As the player is transferring his weight from the heel strike to the forefoot for push off, the hamstring muscles are also co-working with the external and internal rotators of the hip, *mm. abdominal externus* and *internus* as well as the adductors to create a stable proximal base for weight transferral. During the final landing on both legs the hamstring muscles work in cooperation with the quadriceps creating a squat landing for balance and stability.

1.6.4. Timed 30m Sprint

Sprint is listed as the prime source of the incurrence of a hamstring strain in soccer (Beijsterveldt et al. 2012; Schache, 2009), being the main reason for including it as one of the tests for this study. Sprint is often used as a performance test to test a player's readiness to return to soccer (Wragg et al. 2000), however it was the researcher's clinical experience that the post injured player could show good sprinting results and yet still be prone for a reinjury of the hamstring muscle. EMG testing in sprinting is a tool, commonly used to see the trends in muscle activity during a sprint cycle, from stand phase to swing phase to stand phase where multiple lower limb muscles are compared (Wiemann and Tidow, 1995). However, studying muscle activity from the point of comparing the specific level of activity during a sprint through the means of EMG is limited (appendix 14). Researchers agree that EMG activity during sprinting cannot be considered a steady parameter, because even during the same stage, the characteristic of each burst or active period can vary concurrently with changes in stride length and frequency. (Albertus-Kajee et al. 2011). However, in Schache et al's (2009) analysis on the injury mechanisms of a hamstring strain in one athlete during sprinting, the pre-injury trials data showed a very low variety in joint angles and normalized muscle-tendon lengths, indicating a very steady performance of sprint with little changes in stride length and frequency. Schache (2009) did not include EMG in his analysis.

During sprinting core and pelvic stability is imperative in order to transfer as much power from the legs as possible to the sprint. With right knee rising up, the left elbow is also raised up for power and stability of the truncus to the opposite hip. This part of the movement demands pelvic stability as well as flexibility of the hamstrings, as lengthening of the hamstring gives way to raising the knee up high. As the front leg approaches heel strike, the workload of the hamstring muscles changes from eccentric to concentric workload. *M. gluteus maximus* works as primary synergist to the concentric force. As the player is transferring all his weight to this side the hamstring muscles are also co-working with the rotators of the hip and *mm. tibialis anterior* and *posterior* to create a stable knee. During the stance period, opposite leg is brought forward for knee flexion and at toe-off, *m. gluteus maximus* and hamstring muscles work concentrically to extend the hip and knee joints (Figure 1.4).

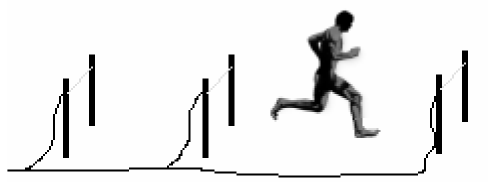


Figure 1.4 Timed 30 m sprint

1.7 Reliability

Mendiguchia and Brughelli's (2011) algorithm for return to sport includes objective testing before progression and is based on their literature search for reliable tests. To ensure that the test battery is in fact reproducible and relevant, a reliability testing of the tests and testing method must take place.Reliability refers to the extent to which measurements are consistent, dependable, and free from error and that the test measurements are not a result of the test's range of error or "noice". In other words how precise the test is in detecting true changes. (Portney and Watkins, 1990). In this study the statistical estimate of measurement error is typical error, defined as the SD of the random variation of repeated measurements. To be 95% confident that a true change has occurred during repeated measurements, the measurement would need to differ 3SD or 3 x the typical error. To be 76% confident a real change has occurred during repeated measurements, the measurement would need to differ by 2SD or 2 x the typical error (Hopkins, 2004).   Therefore, a test with a small typical error is more likely to detect even small changes in the muscle's activity level (Figure 1.5).

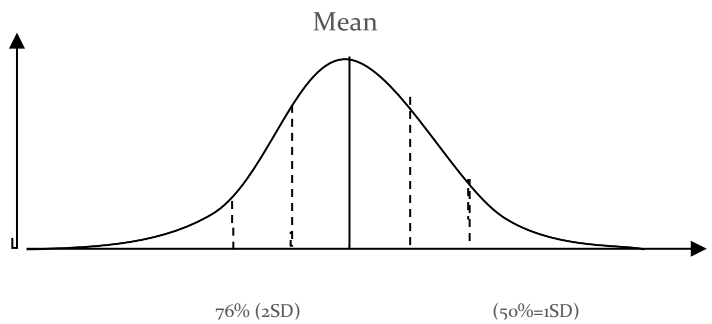


Figure 1.5 Normal distribution of measurements around the mean. The distribution of repeated measurements is assumed to resemble a normal curve with most measurements around the mean and a distribution of errors falling above and below the mean. A more reliable measurement would have most repeated measurement scores centered around the mean and hereby a low standard deviation. In regards to the inter-tester reliability the typical error indicates the precision of the measurement of placing the electrodes by two different testers by estimating the error of the placement.

Reliability also refers to the stability and consistency of measures with respect to time so that changes between the measurements can be attributed to the intervention. In this study calculation of between-subjects variability to assess the stability of the tests, and test-retest variability to assess the learning effect from test to retest was carried out. In order to assess and discuss reliability of sEMG procedures in this research, literature searches have been made and the review of the level of evidence for the different EMG analysis procedures are based on the studies found. A level of recommendation is sought applied based on the type of publication and subsequent classification of evidence (Table 1-3). Traditionally classification of evidence is limited to publications on treatment effect, prognosis, diagnostics and economic- and decision analyses. (www.sportsfysioterapi.dk/fagligt-katalog). Meta analysis studies, systematic review and randomized controlled trials (RCT), rank highest in the hieraki (evidence level Ia) and experts opinion lowest (evidence level IV). A classification of evidence of reliability studies has been developed by the researcher with inspiration from Practicing chiropractor's committee on radiology: Development of *PCCRP* Guidelines & Review (www.pccrp.org/docs/PCCRP%20Section%20I.pdf) and inspiration from "målemetoder, fysio.dk" http://fysio.dk/Upload/Graphics/PDF-filer/Maaleredskaber/Checkskema_MAa_HL.PDF. Levels of evidence and grades of recommendations are defined as depicted in Table 1-3.

Table 1- 3 Levels of evidence and grades of recommendations based on type of publication. Studies such as meta-analysis studies, systematic reviews, RCTs, cohort studies are classified with grade of recommendation A-D whereas reliability studies are classified with grades of recommendations a-d. (www.sportsfysioterapi.dk/fagligt-katalog*).*

Type of Publication	**Level of Evidence**	**Grade of recommendation**
Meta-analysis, systematic review, Randomized Controlled trials (RCT)	Ia Ib	A
Controlled, none-randomized trial Cohorte study Diagnostic test (direct diagnostic method)	IIa IIb	B
Case control study Diagnostic test (indirect nosografic method) Decisionmaking analysis Descriptive study	III	C
Small series, Overview articles Assessment by expert Expert opinion	IV	D
Consistent Reliability studies of Sound methodology* With > 30 test subjects 1 Consistent reliability study with > 30 test subjects		a
Consistent reliability studies of Sound methodology* with < 30 test subjects		b
A single consistent reliability study of Sound methodology* with < 30 test subjects		c
Inconclusive evidence		d

* Sound methodological approach includes listing procedure of exclusion of data and meeting the recommendations of ISEK on data reporting.

1.8 Electromyography

Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles (Konrad, 2005). EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells when these cells are electrically or neurologically activated. The signals can be analyzed to detect medical abnormalities, activation level, and recruitment order, or to analyze the biomechanics of human or animal movement. There are two kinds of EMG in widespread use: surface EMG and intramuscular (needle and fine-wire) EMG. Intramuscular EMG may be considered too invasive or unnecessary in some cases. Instead, a surface electrode may be used to monitor the general picture of muscle activation, as opposed to the activity of only a few fibers as observed using an intramuscular EMG. This technique is used in a number of settings; for example, in the physiotherapy clinic, muscle activation is monitored using surface EMG and patients have an auditory or visual stimulus to help them know when they are activating the muscle. This is known as biofeedback.

1.9 Electrode placement

Correct placement of the surface EMG is important, and the standardization of placement of the electrode is imperial since a small change in the electrode location from test to retest can change the recording levels significantly (Campanini et al 2007). Placement of the electrodes is a balance between avoiding the electrode picking up electrical activity of adjacent muscles (cross talk), and avoiding loss of detected signal due to displacement of the electrode in respect to the skin. Also, the closer the electrode is placed to a motor point or innervation zone (IZ) the less the signal. (Mesin et al, 2007). Wong and Ng (2006) concluded in their study of electrode placement of the quadriceps muscles, that different placements of the electrodes meant significant different recordings of timing levels and peak amplitude of the *m. vastus lateralis* in respect to the *m. vastus medialis*. Goodwin et al (1999) concluded in their study of reliability of leg muscle electromyography in vertical jumping that the poor reliability could be the result of the need of a better standardized electrode placement protocol.

A literature search revealed that different recommendations for electrode placement exist (appendix 3). In “Muscles Alive”(Basmajian and DeLuca, 1985) it is recommended that “the two detecting electrodes should be less than 2 mm of surface and less than 1 cm apart and placed perpendicular to the muscles in question for maximal detection”. The SENIAM group recommends that the electrode is placed parallel to the muscle fibers for both MH and BF (www.Seniam.org). The SENIAM groups protocol is widely accepted. However, the standardized protocol could raise discrepancies between testers in identifying the anatomical landmarks, and therefore it was the interest of the researcher, to challenge this protocol with a intertester reliability study of placement of electrodes on BF and MH. The conclusion of this study would subsequently be applied to the electrode placement procedure in the test-retest study.

In Table 1-4 the general recommendations for electrode placement by Konrad (2005) are described. These are the recommendations that were followed in this research (evidence level III, recommendation level a).

Table 1- 4 General recommendations for electrode placement (Konrad, 2005)

General recommendations of electrode placement
• Wet gel electrodes have the best skin impedance values
• Use small electrodes to increase the selectivity of your measures (avoid cross-talk)
• The smaller the electrode (active detection area) the higher the impedance values
• Select the closest possible inter-electrode distance to increase selectivity
• The general recommendation for the inter-electrode distance is 2 cm (center point to center point)
• Apply electrodes in parallel to the muscle fiber direction
• Use the most dominant middle portion of the muscle belly for best selectivity
• Avoid the region of motor points if possible
• Take care that the electrode site remains on the active muscle mass during muscle shortening
• Use a map system with measured distances between the electrode site and dominant anatomical landmarks
• Use electrodes with de-centralized snap/cable connection if you expect increased pressure on electrodes (e.g. sitting on electrodes)
(Konrad, 2005)

1.10 EMG Parameters

There are different ways of analyzing the EMG data. In the following, “Total power”, “Peak Power” and “Power Fatigue” will be introduced.

1.10.1 Total Power

Analysis of total power output assessed by the mathematical integral under the EMG amplitude is a method where a defined time span is assessed by the means of looking at how *much* the muscle is active within that time frame (Konrad 2005). The accuracy of this assessment is depended on accurate filtering of artifacts and directly dependent on the time duration selected for an analysis. It is also depended on the threshold level for onset of muscle activity and cessation as described in detail in the respective chapters (Konrad 2005).

1.10.2 Peak power

Analysis of peak power is assessed by looking at the amplitude of the EMG signal. The highest peak of the EMG signal is assessed within a defined time frame and gives you a figure of the maximum output the muscle had within that defined time frame. For instance, the maximum output of the hamstring muscles can be assessed in a landing and planting task defined time frame (Zebis et al 2009). Since the peaks and lows of the raw signal of a muscle contraction cannot be reproduced reliably then Root Mean Squared (RMS) is applied (Konrad 2005).

1.10.3 Power Fatigue

Median frequency (MF) is often used in research to assess fatigue of skeletal muscles. It is the parameter that divides the power spectrum into two equal parts. MF was initially proposed as an indicator of fatigue measurement in constant-force or isometric tasks. Studies of the fatigability of the lumbar spine, use a protocol where an isometric contraction is held and the change of the slope of the EMG power spectrum is quantified (Oddson, 1997). If an isometric contraction is performed to exhaustion the normal EMG power spectrum will show an unaltered frequency as muscle contraction is being held with ease and then an alteration to a lower frequency will be observed as the exhaustion sets in. In other words, the frequency spectrum shifts to the left on the spectrum graph as depicted below (Figure 1.6). This change of frequency can be quantified by MF because the accompanying decrease in MF is nearly linear during a fatiguing contraction. Therefore, the rate of decrease of the MF offers a convenient means of measuring fatigue (Konrad 2005).

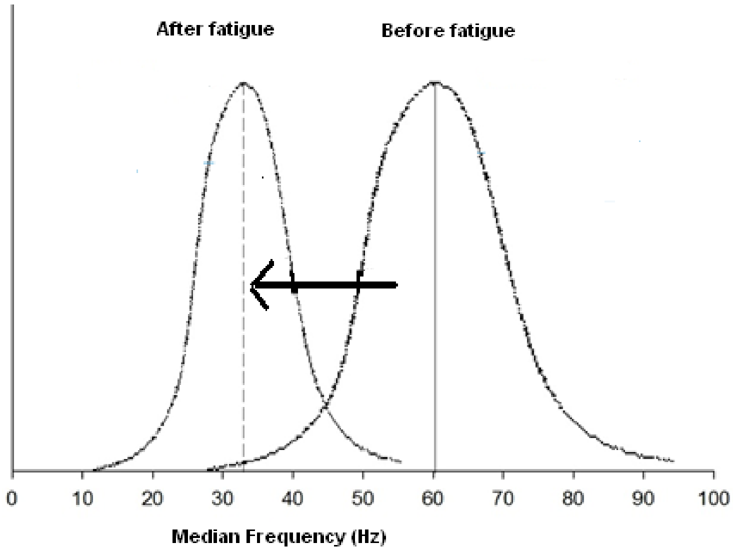


Figure 1 .6 Schematic illustration of muscle fatigue where the frequency shifts to lower values as the muscle fatigues. Adapted and redrawn from Konrad (2005)

1.11 NORMALIZATION PROCEDURE

Normalization of EMG data involves a process where a reference value is being used to normalize the absolute emg values (mV) to a percentage of the reference (Figure 1.7). In general, it is recommended that a normalization procedure is used as this improves the reliability of the EMG data (Burden 2010; recommendation grade C) (appendix 4A & B). Reliability in this context means that measurement methods should detect differences in % EMG amplitudes that resulted from changes in the performance of the exercise examined. Normalizing EMG data allows comparison between trials, between muscles and between individuals. A total of eight different normalization procedures are proposed in the literature:

- peak amplitude detected from the test under investigation
- mean EMG from the test under investigation
- submaximum isometric voluntary contraction
- submaximum dynamic voluntary contraction
- arbitrary angle isometric maximum voluntary contraction
- angle specific maximum dynamic voluntary contraction
- angle specific isometric maximum voluntary contraction
- angle and angular velocity specific maximum isokinetic voluntary contraction (Burden 2010)

Burden (2010) argues that different research aims call for different normalization procedures. He also argues that, since *mean* task and *peak* task type of normalization- or reference values are obtained from the task under investigation, which could be under the influence of learning-effects, *mean*-task EMG and *peak*-task EMG should *not* be used to compare between different trails, subjects or muscles. In order to compare between different trials, subject or muscles Burden (2010) argues that a standardized reference contraction should be applied where no learning-effect may take place. In this research a isometric maximum angle specific voluntary contraction is being used.

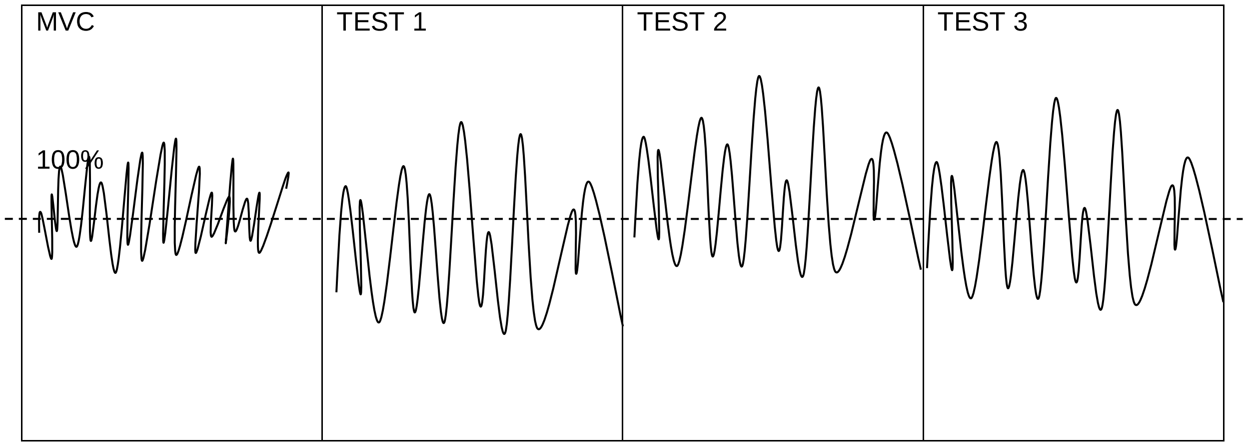


Figure 1.7 Normalization process. The MVC is 100% and the subsequent tests are converted to a percentage of the MVC (Konrad 2005)

2. Purpose of study

The purpose of this study is to test the reliability of using sEMG on the hamstring muscles of healthy individuals, during four functional tests, in order to use these tests on the post strain-injured hamstring muscle as a part of the return to sport algorithm.

2.1 Aim of study

To test the intertester reliability of surface electrode placement protocol

To test the between-days reliability of four functional exercises of the hamstring muscles using wireless surface Electromyography

2.2 Hypothesis:

Placement of surface electrodes by a standardized protocol (SENIAM) to MH and BF is a reliable method between testers.

BJ, SLHH, NHL, and timed 30m sprint are reliable tests between test days that can detect changes in muscle fatigue, peak power or total power output, using surface EMG as a testing tool on MH and BF muscles.

3. Methodology

3.1 Intertester reliability of electrode placement procedure

3.1.1 Test subjects for inter-tester reliability of electrode placement procedure

All girls aged 14-22 in the Stykkishólmur area of Iceland, active in the local basketball club, were invited to participate in the project (N=26). 24 girls (age mean= 16.6 year; median=17 year) agreed to participate as test subjects in the intertester reliability study (Figure 3.1). 4 physiotherapists (age 31—41 year; mean=36.5 year) practiced physiotherapy for 6-18 years (mean value=12 year; SD=6.9 year) participated as testers in the intertester reliability study. The testers were all coworkers to the investigator with no previous knowledge of the testing procedure and protocol.

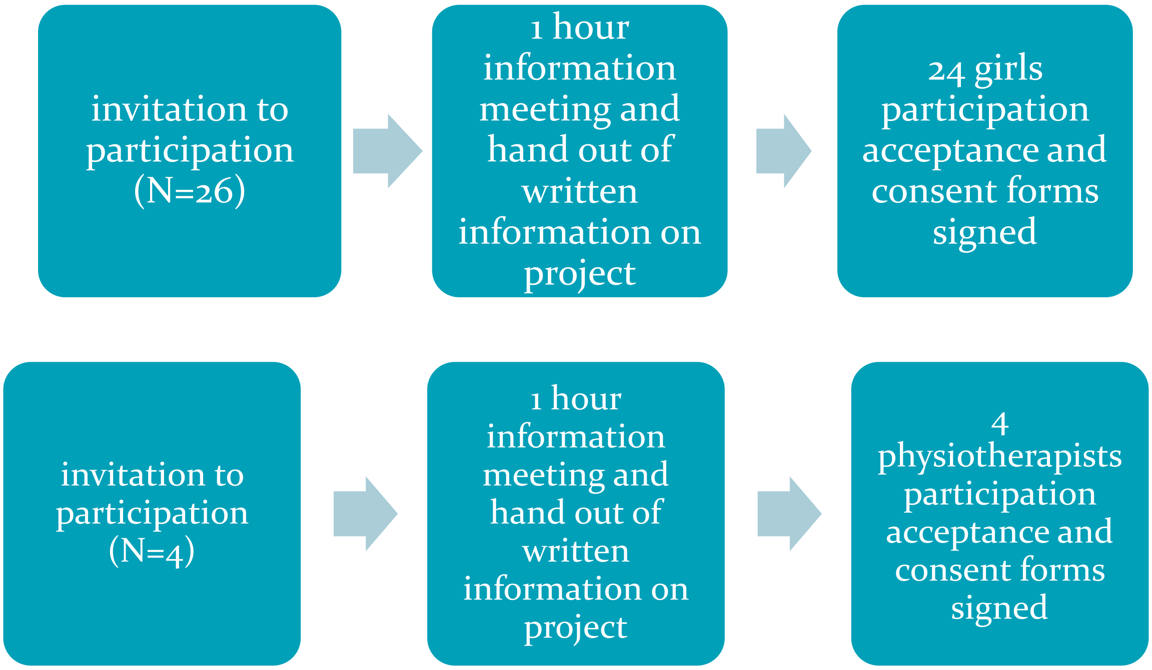


Figure 3.1 Flow chart for test-subjects

3.1.2 Method

The 4 physiotherapists (PT) were given 1 hour of instruction in manual testing of the location and function of the hamstring muscles and placement of the electrodes upon the muscles prior to the test sessions (appendix 5). They were told that the design required their participation on two different occasions, with one week's interval. All participants were verbally and in writing informed of the study and signed a consent form or had their legal guardian sign a consent form (appendix 6). The PTs were paired into all possible combinations. The PTs each tested 12 participants and each pair of PTs tested 4 participants in common. The right leg was used for measurement. The participants were all given an ID number to insure their anonymous participation (Table 3-1)

Table 3 - 1 Allocation of physiotherapists and test subjects and time table for testing

Test Days	Date	Time	Players	Tester
1	31. March	16.00	125, 126, 129, 130, 133, 134	1
2	1. April	16.00	127, 128, 137, 138, 141, 142	2
3	3. April	16.00	129, 131, 132, 139, 140, 145, 146	3
4	3 April	17.30	135, 136, 143, 144, 147, 148	4
5	5. April	9.00	127, 128, 131, 132, 135, 136	1
6	8. April	16.00	125, 126, 139, 140, 143, 144	2
7	10. April	16.00	130, 137, 138, 147, 148	3
8	10. April	17.30	133, 134, 141, 142, 145, 146	4

The PT tested the subject alone, following the test protocol, which was posted in the treatment room. The PT would write down her measurements on a paper, which only showed the ID number of the subject and the name of the muscles tested, and subsequently hand the paper in to the researcher immediately after testing. The PT would have no knowledge of previously recorded scores. Testing of one subject was performed with approximately one week interval. Washable crayon markers were used to disallow any knowledge of previous marked spots. The measuring tape was a standard measuring tape and the same equipment was used for each test session.

3.1.3 Test protocol

The objective was to locate the thickest part of the muscle belly of the designated muscle and mark the 50% mark of the length of the muscle. Also, the medial-lateral distance between the two 50% marks was measured. The testers were instructed to locate *tuber ischiadicum* and mark the point with the designated body marker. The distal marker was made to the point of the medial aspect of knee joint line (Figure 3.2a). A clinical isometric test with the leg in slight medial rotation, showed the muscle belly of MH and the 50% mark of the length of the muscle was marked on the top of the muscle belly. Then testers located *tuber ischiadicum* again and the distal marker was made to the point of lateral epicondyle of the tibia (Figure 3.2b). A clinical isometric test with the leg in slight lateral rotation, showed the muscle belly of BF and the 50% mark of the length of the muscle was marked on the top of the muscle belly. For BF, the electrode was to be placed in the direction of the line between the *ischial tuberosity* and the head of the fibula, with the reference electrode lateral to the joint line (Figure 3.2c). For MH, the electrode was to be placed in the direction of the line between the *ischial tuberosity* and the epicondyle of the tibia, with the reference electrode lateral to the joint line. Lastly, the distance between the two electrodes was measured. The distance was defined as the cm between the medial lateral lines on which the electrodes were placed (Figure 3.2d). For detailed review of the electrode placement procedure see appendix 5.

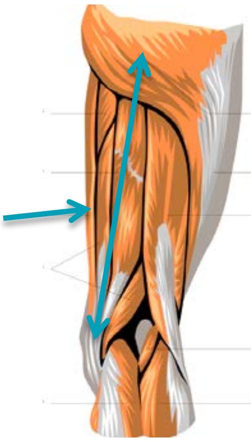


Figure 3.2a Location of 50% mark on MH

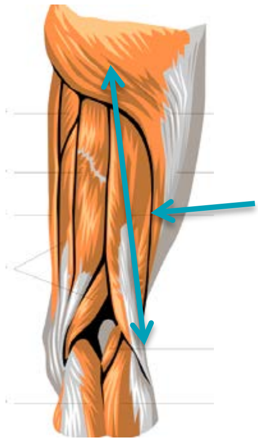


Figure 3.2b Location of 50% mark of BF

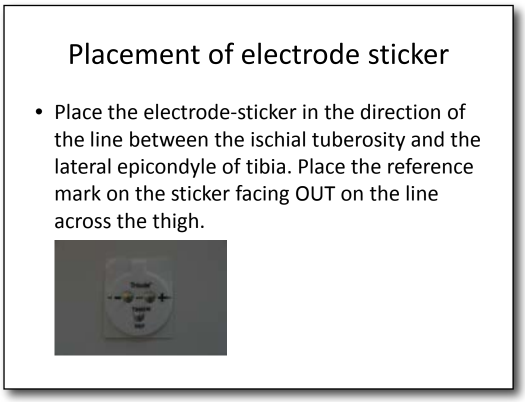


Figure 3.2c Placement of electrode sticker

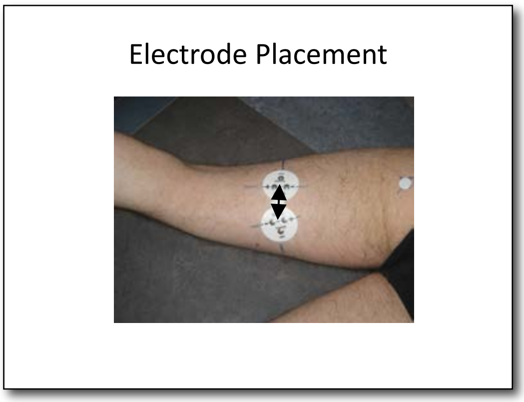


Figure 3.2d Electrode placement

3.1.4 Data analysis

Outcome measures for further analysis were:

A. The 50%length (cm) of the measurement of BF from the marked point of *tuber ischiadicum* to the marked point proximal to head of fibula.
B. The 50%length (cm) of the measurement of MH from the marked point of *tuber ishiadicum* to the marked point of the epicondyle of the tibia.
C. The length (cm) of the distance between the midpoints (proximal/ distal line) of the two electrodes on the muscle bellies of BF and MH.

3.2 Between-days reliability of four functional hamstring tests

3.2.1 The testers

Three last semester physiotherapist students (0 yrs in field of sports physiotherapy) and one physiotherapist (aged 37, 10 yrs of experience in field of sports physiotherapy) acted as testers in this part of the study. The three students were asked to participate, based on their interest in the area. Prior to testing sessions the physiotherapist students that had the testers role, received 2 hours of instruction of the protocol for placement of the electrodes and testing procedure. The physiotherapist acting as tester is also the investigator of the research project. Two of the testers were present at each session. One guided the player through each step of the tests as well as applying the electrodes on the player's BF and MH. The other tester acted as secretary, starting and ending the EMG recording upon the other tester's command. The tester was given a written and depicted test-manual.

3.2.2 Test subjects

Male players from 2 local soccer teams in Næstved, Denmark: one serie 1 team (n=22) and one junior division soccer team (n=22) and the local sports college active in soccer (n=4; total n=48), were invited to participate in the project. Inclusion criteria were no physical ailments and participation in soccer 3 times weekly. Exclusion criteria were injury to back or lower extremities or lack of desire to participate. Nineteen players (aged 15-17 year; mean 16 year; SD 1 year) accepted the invitation to act as test subjects in the between days reliability study. Of these, 14-16 players completed the testing (Figure 3.3). The anthropometric data of the subjects included height (mean 179 cm; range 170-191 cm) and weights (mean 70 kg; range 59–85 kg). All participants were verbally and in writing informed of the study (appendix 7), and signed a consent form or had their legal guardian sign a consent form (appendix 6). The participants were all given an ID number to insure their anonymous participation.

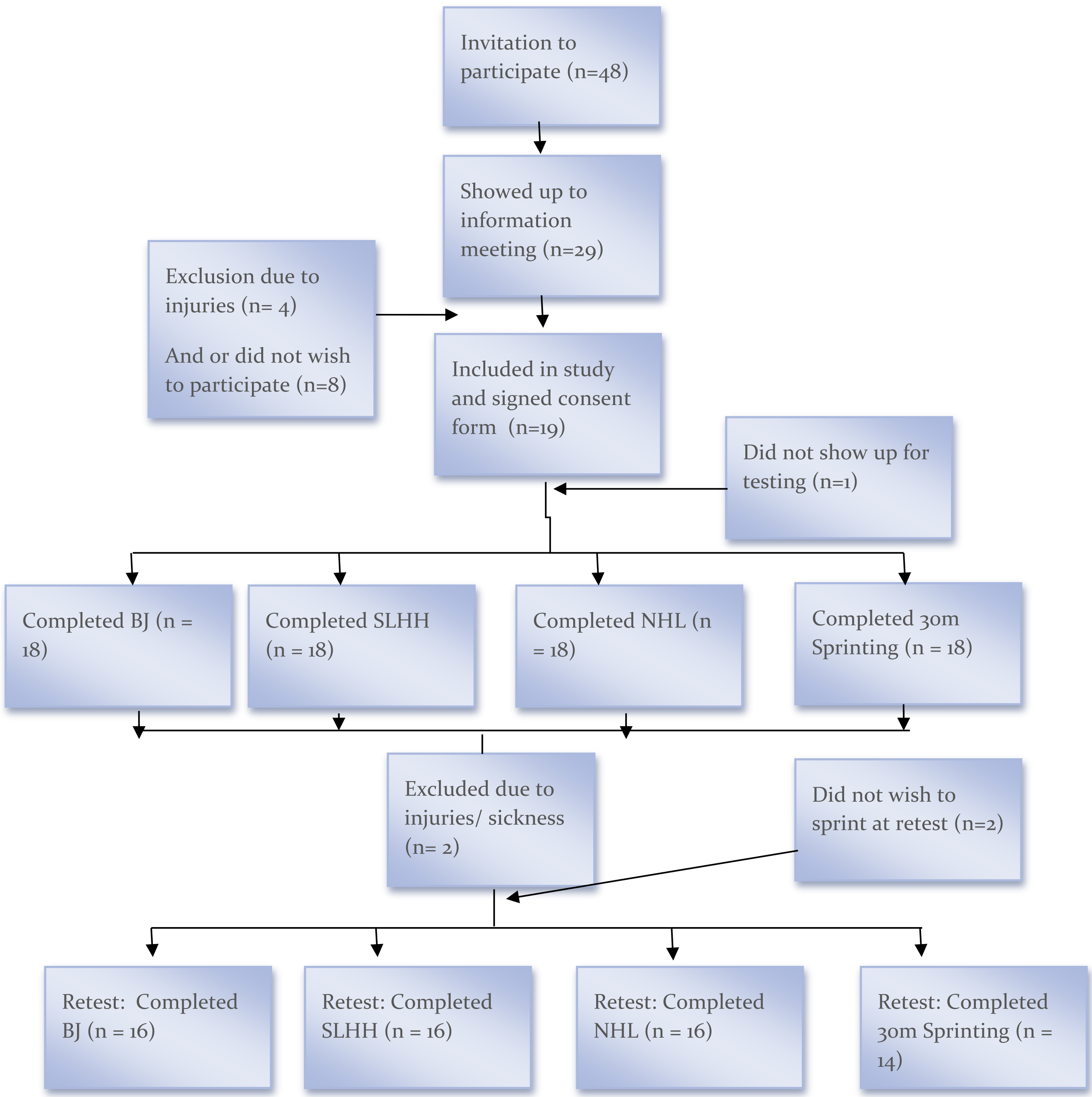


Figure 3.3 Flow Chart of inclusion and exclusion of test subjects

3.2.3 Method

The participants were given one hour verbal preparation of the project prior to the tests. The participants were also instructed to wear the same outfit (tights) and shoes at both test sessions. Also, in the preparation of the time tables, it was stressed, that the days leading up to the test sessions were as identical as possible in activity level, nutritional wise and sleep. Test interval between test and re-test was one week.

The test sessions were carried out at an indoor soccer field facility with artificial turf. Upon arrival, the players received an ID number and filled out a questionnaire on height, weight and age, and at retest they were again asked to fill out, if they had any injury or pain to the legs or lower back. The tester then started the protocol for placement of electrodes. This was done prior to the warm up session to ensure no change in skin impedance during testing. The warm up session consisted of 20 min of standardized warm up: 7 min of jogging, 3 min BJ, 3 min one leg horizontal jumping, 3 min running and 4 min stretching of hamstring, gluteus, and quadriceps. Immediately after warm up, the testing session was commenced. The order of tests ensured a slow increase in workload and allowed time between NHL and Timed 30 m Sprint (Figure 3.4).

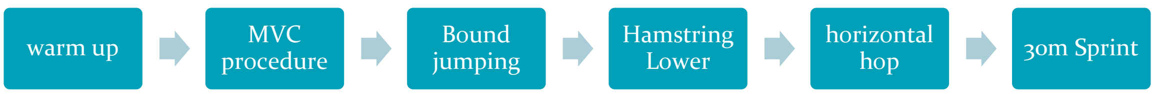


Figure 3 .4 Order of tests from warm up to 30 m sprint

3.2.4 Test protocol

The testers followed the test protocol described below:

- Maximum voluntary contraction (MVC) procedure
  Protocol/ instruction to tester: MVC is performed for MH and BF. A pressure biofeedback will measure the force to be used in the re-testing. Place the player lying face down with one foot under the bench with a unilateral flexion of the knee. The heel touches the designated biofeedback pad taped underneath the bench. The knee is rotated slightly inward for MVC testing of MH and slightly outward for MVC testing of BF. The player is asked to start contracting the hamstrings, forcing it against the bench, slowly increasing the force, reaching the maximum effort after 3 seconds, hold it for 3 seconds and calm down with 3 seconds.
  Tester verbally counts 1-2-3 GO 2-3 STOP 2-3
  Repeat it one time, with a pausing period of 60 seconds in between.

  EMG protocol/ video protocol instruction to secretary (the second tester): The system is set to record for the three seconds of maximal contraction

- BJ procedure:
  Protocol/ instruction to tester: The subject is instructed to start with legs parallel on designated white line. At the tester's command he jumps out on one leg and brings his knee up as high as he can as well as kick his other leg out as far back as he can to extend his hip. Alternating left and right, like running, the subject continues BJ until he reaches the goal (8 meter). The subject performs two trials on each leg.

  EMG protocol/ video protocol instruction to secretary: A 1 meter line in the middle of the camera frame indicates the reference line. The EMG & camera is started on the tester's command and runs for 5 seconds.

- NHL procedure:
  Protocol/ instruction to tester: The tester instructs the subject to slowly descend to lying flat on the ground, using all 5 seconds during descend. At the testers "go" the subject starts descending and the EMG recording is started. Count 5 repetitions & 5 second drop down.

  EMG protocol/ video protocol instruction to secretary: The system is set to record 5 seconds, starting on the tester's command recording 5 trials. Count out loud the 5 seconds.

- Single leg horizontal hop procedure:
  Protocol/ interaction to tester: The subject is instructed to start with legs parallel on designated white line. Hands on hips. At the tester's command he jumps out on one leg, skips out again on same leg and then lands on two parallel legs. If the subject fails to stand at landing, the trail is counted as 0 meter jump. The subject completes three trials on left leg and three trials on right leg.
  EMG protocol/ video protocol instruction to secretary: The EMG is started on the tester's command and runs for 3 seconds
  The length of the measurement is recorded.

- Timed 30 m Sprint procedure:
  The subject starts at the white line 50cm before the first set of photocells. At the tester's command "go" he sprints thru the photocells on a 30m straight course. He is instructed to sprint thru the last photocell and not stop his sprint too early. The subject jogs back to starting line and has 30 seconds until start of next sprint. The subject completes 7 sprints. He is however unaware of how many he is to complete. The time is recorded for each sprint.

  EMG protocol/ video protocol instruction to secretary: EMG is started at the start of every sprint.

3.2.5. Equipment

For the collection of the EMG and video recordings, a motion analysis system from Kine was used: KinePro, version 3.2.337; www.KINE.is (KINE, Hafnarfjordur, Iceland) four-channel wireless system, with a samling frequency of 1600Hz and a signal bandwith of 16-500 Hz. Signal sensitivity of 4 microvolts. The electrodes are triodes with a distance of 20mm between electrodes (Appendix 8). To measure the sprint times, photocells were used (T. Lund, Copenhagen, Denmark; 1,5V type D batteries of lights, 9V PP alkaline batteries in control unit. Measurement accuracy of ±5ms) (appendix *9*). For the video recording a video camera (Panasonic 3CCD, Panasonic Corporation of North America; One Panasonic Way Secaucus, NJ 07094) was used (appendix 10).

3.2.6 SEMG data analysis

For the sEMGdata analysis process an algorithm for data assessment was performed, insuring that each step would be documented (appendix 11).

3.2.6.1 Method of extracting the raw data

Each test and each trial was manually assessed by the researcher and the raw data was extracted and processed through the algorithm written in the MATLAB software (http://www.mathworks.se/).

3.2.6.2 Exclusion of data and Visual analysis

Exclusion of data was carried out in three different steps. Firstly, only successful recordings were exported to be processed in the MATLAB program. Secondly, the filters for each test were defined. Defining the filters for each test lays the ground for the criteria of data elimination. The filters are further described under each analysis of test in the following paragraphs. Finally, a visual inspection of the raw EMG signal on graphs created in MATLAB was carried out. The following Table (3-2) is a description of the criteria for exclusion of data by visual inspection and Figure 3.5 is a description of the exclusion process.

Table 3 - 2 Criteria for outliers. For each test outliers were defined based on the criteria described below.

Criteria for outliers
MVC: DC shift below 0 AND low amplitude <1,6V (10x -4) OR Hz only around 50 (bad connection).
BJ: no visible strides in raw and filtered figure OR > noise around 50Hz in frequency spectrum OR no peaks above threshold level in the amplitude figure. (21 outliers)
NHL: DC below 0 AND amplitude lower than 1.6V (10x -4) (109 outliers)
Single Leg Horizontal Hop: no visible strides in raw and filtered figure OR >noise below 50Hz in frequency spectrum OR no peaks above threshold level in the amplitude figure OR obvious peak artifacts due to movement (21 outliers)
Timed 30m Sprint: no visible strides in raw and filtered figure OR > noise around 50Hz in frequency spectrum OR no peaks above threshold level in the amplitude figure (245 outliers)

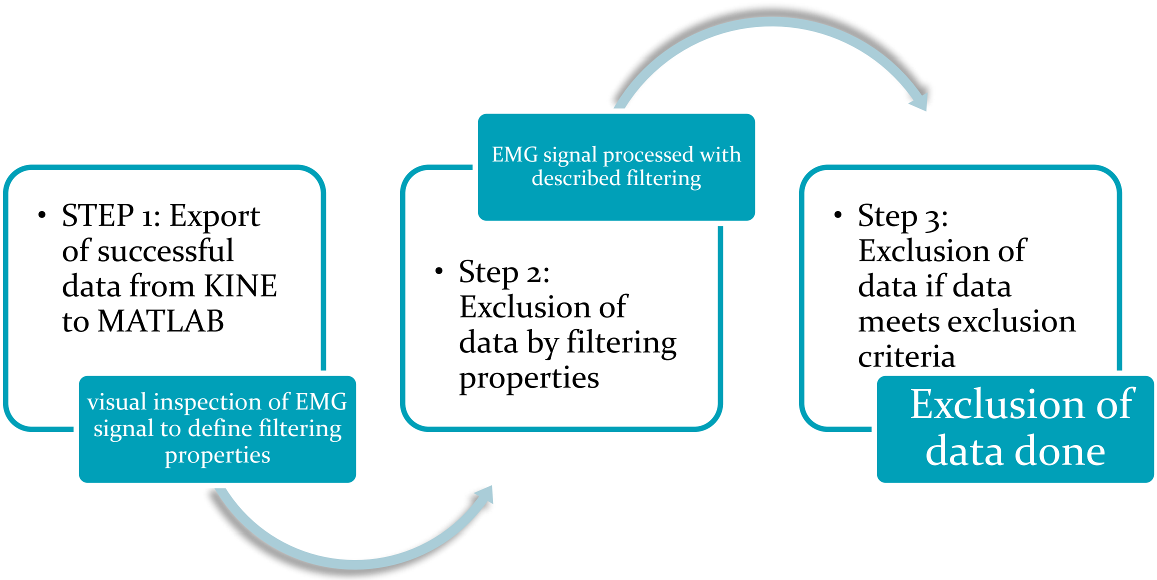


Figure 3.5 Process of exclusion of data step 1 through step 3, through visual inspection, exclusion by filtering and exclusion by outlier criteria

3.2.6.3 EMG signal analysis method using MATLAB

Method of analysis in MATLAB consisted of a process of filtering and smoothing of the signal. For all tests a bandpass filter 10/20 Hz, Butterworth 11th order was applied except for BJ. This filter was chosen to remove movement artifacts. Low-pass cut-off filter equal to 500 Hz as defined by KINEpro and high pass cut off filter equaled 20 Hz with no cut-off and a total cut-off at 10 Hz. (Konrad, 2005)

The smoothing process is described below. KINEpro system allowed 20 ms of sEMG recording per video frame.The objective of the MVC test was to obtain a reference value to normalize the EMG data from each of the four functional tests to a percentage value. Therefore, the processing of the MVC data was depended on which test it was used to normalize it for. That is, the bandpass filter, the smoothing process of the MVC signal was the same as it was for the test to be normalized in each case.

For Bound Jump, both trials, two for left leg and two for right leg, were used for analysis. The video frames that showed a planting and take off of the foot on the white 1 m line were analyzed. Within this envelope, the EMG was analyzed for the maximum amplitude, quantified as the maximum power output (MaxRMS or Peak EMG). A bandpass filter of 10/25 Hz, Butterworth 11th order was applied. RMS envelop size was 100 ms (Figure 3.6).

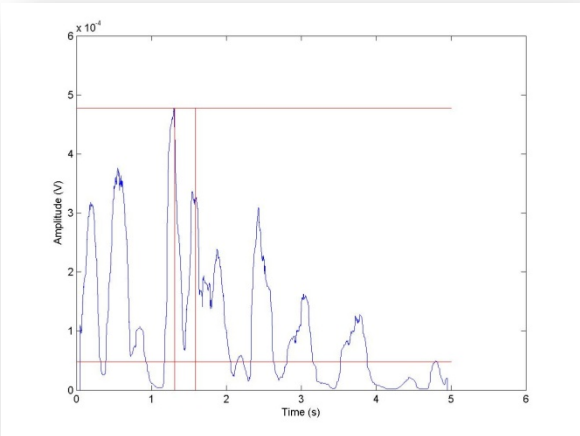


Figure 3.6 (BJ) EMG envelope chosen from the video frames that show planting and take off, right leg, MH, subject 125. Peak EMG within this envelope is chosen for analysis.

For the Nordic Hamstring Lower, the first objective for assessment of NHL test was to look at the fatigue of the muscles as the individual performs five repetitions (Fatigue assessment). Fatigue is quantified as the change in median frequency (MF) of the frequency spectrum. A negative slope of the frequency spectrum indicates the presence of neuromuscular fatigue during the NHL task of 5 seconds lowering to the ground, whereas a flat or positive slope indicates that no neuromuscular fatigue was present. The change in MF from first to last repetition was compared. The whole time span of 5 seconds is chosen for analysis. The second objective for the assessment of NHL test was to register the maximum RMS value during the 5 seconds of lowering to the ground (Peak EMG). The RMS of the EMG reflects the mean power of the signal. It is calculated by squaring the raw EMG signal after filtering, then taking the average of all data points over a defined running time frame (envelop); and then taking the square-root of the values. An RMS envelope of 1000 ms was chosen for the smoothing process (Figure 3.7).

A. B.

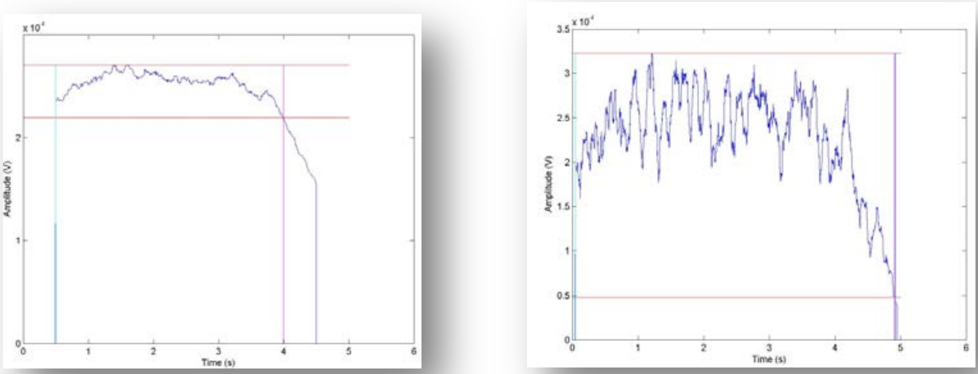


Figure 3.7 Subject 125 NHL test 1, right BF. Comparison of smoothing processes using 1000 ms RMS envelop (left) versus 100 ms RMS envelop (right) of the same test to show the mean trend of the signal**.**

For SLHH the subject's longest hop (in cm) of three trials was extracted for further EMG analysis. The objective of the assessment of the horizontal hop test was to look at the maximum RMS amplitude (the highest spike; Peak EMG) of the entire hop sequence for one leg and one muscle at a time and compare this to the retest hop. The RMS envelope equaled 100 ms. (Figure 3.8).

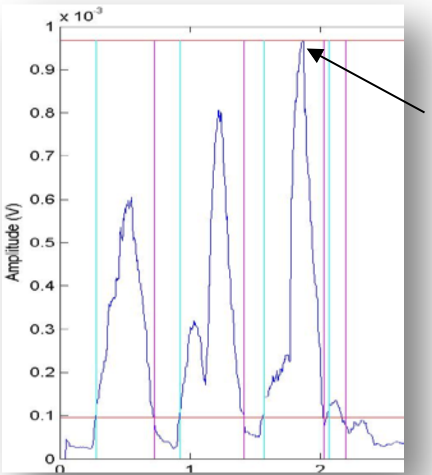


Figure 3.8 SLHH; Peak EMG of the hop sequence was chosen for analysis

For Timed 30m Sprint, the 2^{nd} s – 4^{th} s was chosen for analysis. The first objective of the assessment of the sprint test was to look at the total workload output (the area under the curve) for this timeframe. For the smoothing process an envelope of 100 ms was chosen. Threshold RMS was set to on-level of

50% and threshold RMS hysteresis of 5%, which means that the onset and cessation of the muscle activity is set to a 50% threshold of its maximum.

The second objective was to look at the fatigue of the muscles within the timeframe as the individual performed seven repetitions. Fatigue is quantified as the change in median frequency of the frequency spectrum. For the smoothing process an envelope of 100ms was chosen. Threshold RMS for the onset and cessation of the muscle activity is set to a 50% (hysteresis of 5%) threshold of its maximum.

3.3 Statistical analysis

In the inter-tester reliability study a statistical test, Analysis of variance (ANOVA) of Between-Subjects Effects was carried out with the variables 1. 50% of the length measurement of MH, 2. The 50% of the length measurement of BF, and 3. the inter-electrode distance between MH and BF. For the statistical procedure of systematic differences between testers, Tukey's honest significant difference (HSD) for multiple comparison was carried out following ANOVA. In the reliability study of the EMG outcome variables for the four functional tests, mixed ANOVA was used in the statistical procedure to compare test and retest while controlling for the effect of different variables. For the statistical procedure two or three different variables are included as fixed factors, namely 1) Muscle type (MH vs BF); 2) Side (left vs right leg); and 3) Repetition as continuous variable (for 2 out of 4 functional tests). All 2-way interactions of the fixed effect variables were also tested for. The test-retest variable was included as random factor as there were no indications of systematic differences between tests and retests. By default, between subject variability and within subject variability (typical error) are included in the mixed model analysis and thus also estimated. The three random factors (test-retest variability, between subject variability and within subject variability (typical error)) are always presented in the thesis as SDs (and CV).

4. Results

4.1 Intertester reliability of electrode placement procedure

4.1.1 Typical error of measurement

Mean length of the measurement of 50% BF is 17.3 cm (range 13 – 21 cm; SD ±1.4 cm). The typical error of measurement for the length measurement of BF is ±1.1 cm (CV 6.5%), (appendix 12, A). Mean length of the measurement of 50% MH is 17.7 cm (range 15.5 – 20.2 cm; SD ±1.16 cm). The typical error of measurement for the length measurement of MH is ±.70 cm (CV 3.95%), (appendix 12, B). Mean length of the medial lateral distance measurement is 6 cm (range 3.5 – 8.5 cm; SD ±1.2 cm). The typical error of measurement for the measurement of the distance between BF and MH is ±0.91 cm (CV 15.17%), (appendix 12, C).

4.1.2 Systematic differences

There is a systematic error detected with tester 3 who consistently records a longer length measurement for BF (18.5 cm ± 1.2 cm) than her colleagues 1 (16.5 cm ± 0.5 cm, $p=0.002$) and 4 (16.8 cm ±1.7 cm, $p=0.002$) (appendix 13). There is a systematic error with tester 1 who measures consistently shorter length measurement of MH (17.1 cm ± 0.7 cm) than her colleagues 3 (18.3 cm ±1.2 cm, $p= 0.002$) and 4 (17.8 cm ± 1.2 cm, $p=0.047$) (appendix 13, B). In both length measurements tester 3 has a tendency to record longer measurements than her colleagues do**.** There is a systematic error detected with tester 3 who consistently records a shorter medial-lateral distance between MH and BF (4.7 cm ± 1.1 cm) than her colleague 1 (6.0 cm ± 0.8 cm, $p=0.009$), 2 (6.6 cm ± 1.2 cm $p<0.001$) and 4 (6.4 cm ± 0.8 cm, $p=0.001$) (appendix 13, C).

4.2 Reliability of the EMG outcome variables for the functional tests; Primary results

The variations of the measurements for the four functional tests that are not accounted for by the fixed factors, are presented in Table 4-1. The three random variables for all muscles combined, typical error (SD (and CV)), between subjects variability (SD) and test-retest variability (SD), are presented. The typical error represents the reliability (random error) of the EMG measurements for each variable for each test. The test-retest variability represents a systematic difference (systematic error) between the test and the retest measurements. The between subject variability represents the differences between different participants.

Table 4-1 Summation of results of random factors for all tests; total random variation of the measurements described as typical error (SD) (and (CV)), between subjects variability (SD) and test-retest variability (SD).

Function Test/ Variable	Mean value (range)	Typical error (SD (CV))	Between subjects variability (SD)	Test-retest variability (SD)
BJ (Peak) (67% of data)	90% of MVC (20-220%)	±38%MVC (CV 42%)	±25%MVC	±4%MVC
NHL (Peak) (55% of data)	102% of MVC (35-215%)	±28%MVC (CV 28%)	±18%MVC	±4%MVC
NHL (MF) (69% of data)	103 Hz (55-188Hz)	±20Hz (CV 19.4%)	±12Hz	0Hz
SLHH (Peak) (60% of data)	135% of MVC (33-297%)	±53%MVC (CV 39%)	±27%MVC	0%MVC
Sprint(totalEMG) (30% of data)	61% of MVC (6-455%)	±48%MVC (CV 78.6%)	±24%MVC	±14%MVC
Sprint (MF) (38% of data))	91 Hz (31.5–53.5Hz)	±24Hz 26% CV	±11Hz	±1Hz

4.2.1 Reliability for Bound Jumping (Peak EMG)

In total 16 subjects and 86 jumps were included for statistical analysis; 44 observations for test and 42 for retest (range of observations equals 0-8 for each subject, mean = 5.5). A total of 33% (42 of 128) of the jumps initially chosen for Peak EMG analysis were excluded before statistical analysis since they did not pass the exclusion criteria (Figure 4.1). The mean value for all measurements was 90%MVC (ranging 20-220%MVC), (Table 4-1). A typical error of ±38%MVC (CV 42%) was found for all muscles combined (Table 4-1). The test-retest variability was overall ±4%MVC (SD) and the overall between subject variability was ±25%MVC (SD).

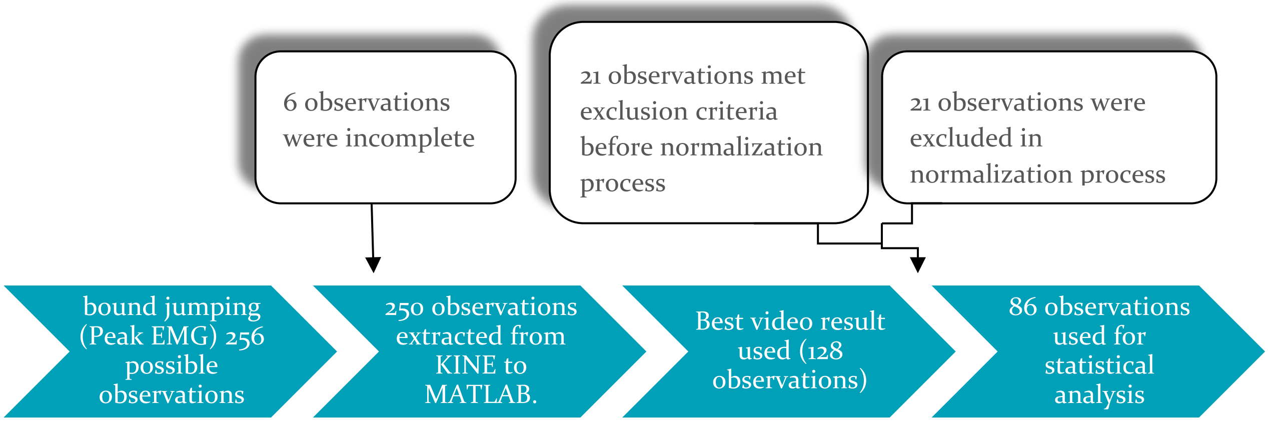


Figure 4.1 Data process line for BJ, Defragmentation of the process of eliminating and hence choosing observations for statistical analysis.

4.2.2 Reliability for Nordic Hamstring Lower (Peak EMG)

In total 15 subjects and 350 observations (mean of 21 observations per subjects, range 2-39; 183 observations for test and 167 for retest) were included for statistical analysis out of a possible 640 (16 subjects, 4 muscles, 5 repetitions, test and retest). A total 45% of data were dismissed before statistical analysis (Figure 4.2). For all measurements mean %MVC was 102% (ranging 35-215%MVC). An overall typical error of ±28%MVC (SD) was found for all muscles. An overall between tests variability was detected to ±4%MVC (SD) and the between subjects variability to ±18%MVC (SD).

4.2.3 Reliability for Nordic Hamstring Lower (Median Frequency)

Sixteen subjects and 438 observations (mean 27 observations for each subject,(range 6-39); test:242, retest 196) were included for statistical analysis of 640 possible observations (16 subjects, 4 muscles, 5 repetitions, test & retest). In all 202 (31%) of all possible data was dismissed from analysis (Figure 4.3). The overall average of measurements was 103 Hz (range 55-188 Hz). An overall typical error of ± 20 Hz (SD) was found for all muscles combined. The test-retest variability for NHL (MF) was 0 Hz (SD) and the between subjects variability ±12Hz (SD).

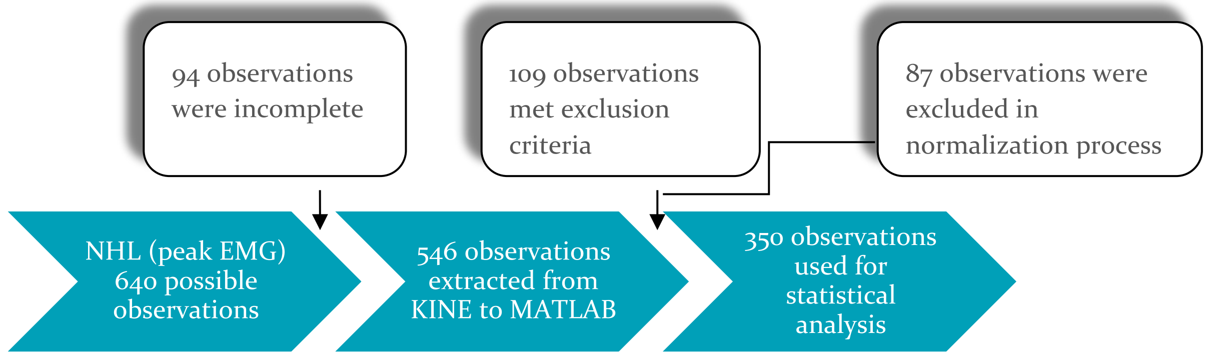
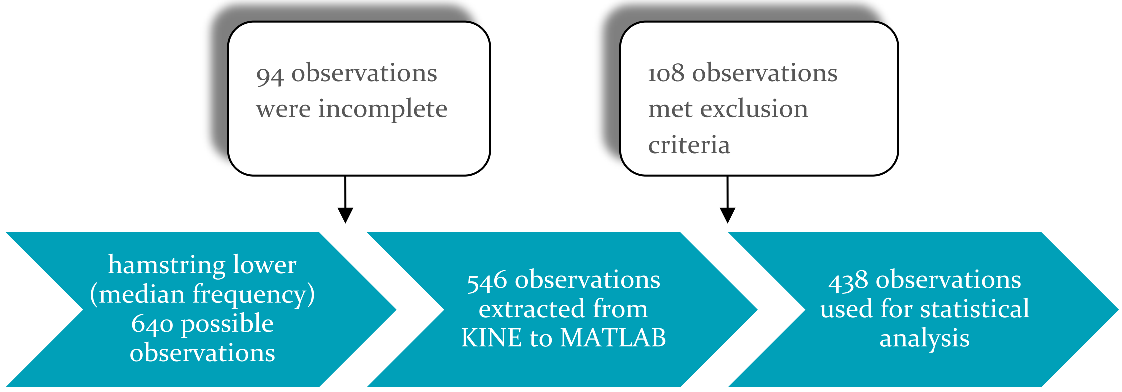


Figure 4.2 Process line of data analysis for NHL (PeakEMG). Defragmentation of the process of eliminating outliers.



.

Figure 4.3 Data process line for NHL (MF). Defragmentation of the process of eliminating outliers.

4.2.4 Reliability for Single Leg Horizontal Hop (Peak EMG)

Sixteen subjects and 76 jumps were included for statistical analysis (mean observation for each subject: 4.5 (range 1-8): 40 observations for test and 36 for retest),(Figure 4.4). Average jump length (m) for test was 5.93 m (± 0.74) and 5.98 m (±0.80) for retest. Three of the testers (the 3 physiotherapist students), studied the test-retest reliability of SLHH for the outcome measure of the measured length (cm) of the best out of three jumps, using Pearsons correlations statistics, and found a reliability of r =0,88 (p <0,001). Average of the measurements for SLHH (peak) was 135%MVC (range 33-297%MVC). An overall typical error of ±53%MVC (SD) was found for all muscles in the SLHH (peak EMG) test. There was no test retest variability detected (0%MVC; SD). A between subjects variability of ±27%MVC (SD) was detected.

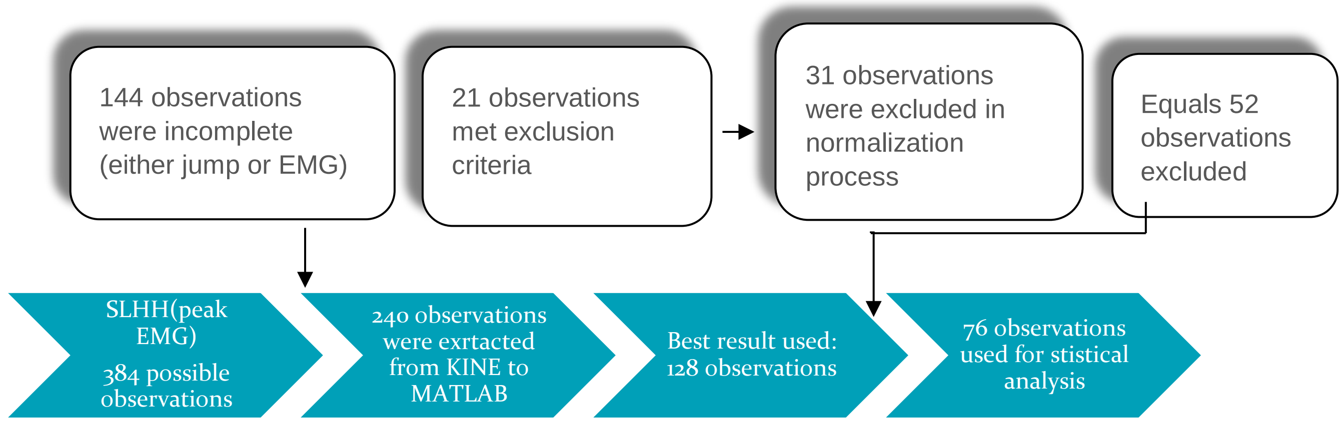


Figure 4.4 Data process line for SLHH (Peak EMG). Defragmentation of the process of eliminating outliers.

4.2.5 Reliability for Timed 30 m Sprint (Total EMG)

In assessing the sprint by means of total EMG, 14 subjects and 231 observations were used for statistical analysis (16.5 observations for each subject on average; range 7-40; 114 observations for test and 117 for retest). In all 553 observations were dismissed in the process, constituting 70% of all observations for 30 m sprint (total EMG), (Figure 4.5). The measurements showed a mean of 61% MVC (ranging 16-455%MVC). An overall typical error of ±48%MVC (SD) was found for all muscles in the Timed 30 m Sprint test (Total EMG). Test-retest variability was found to be ±14%MVC (SD) and the between subjects variability ±24%MVC (SD).

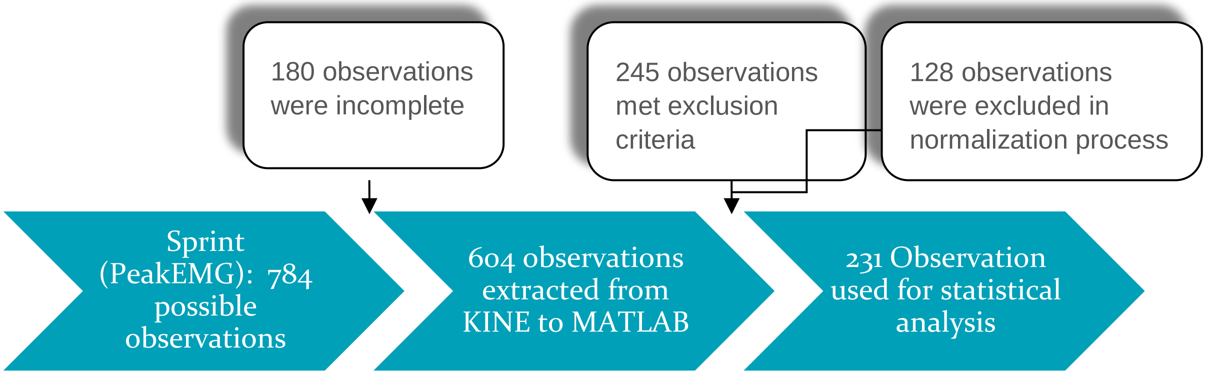


Figure 4.5 Data process line of 30 m Timed Sprint (Total EMG). Defragmentation of the process of eliminating outliers.

4.2.6 Reliability for Timed 30 m Sprint (Median Frequency)

Fourteen subjects and 297 observations were used for statistical analysis (on average 21.2 observations per subject, ranging 20-40; 156 for test and 141 observations for retest. of all possible observations, 487 (62%) were disregarded (Figure 4.6). Mean Hz for all measurements was 91 Hz (range 31.5-153.5 Hz). Typical error for 30 m sprint (median frequency) was ±24 Hz (SD). Test-retest variability was ±1 Hz (SD) and between subjects variability ±11 Hz (SD).

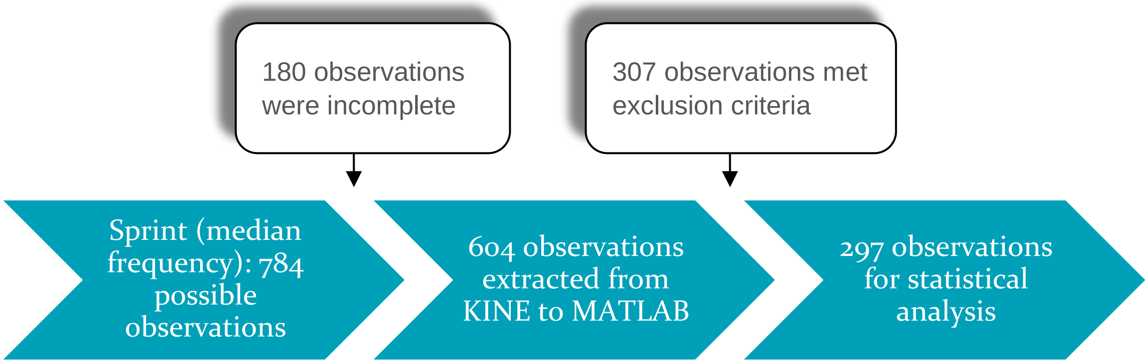


Figure 4.6 Data process line of 30m sprint (MF). Defragmentation of the process of eliminating outliers.

4.3 Systematic differences between muscles, between legs and between repetitions: secondary results

Although, it was not the main purpose of the study to examine the differences between muscles, sides and repetition, these variables were included in the statistical analysis as fixed factors or covariates in order to tease out the random factors (typical error, test-retest variability and subject variability). Table 4-2 shows the results of the inferential statistics for these systematic differences, i.e. the p-values. For BJ (Peak) a significant difference was found between MH and BF (Table 4-3). For NHL (Peak) a significant difference was found between MH and BF (Table 4-4) and between repetitions, with values decreasing from repetition 1 through 5 (Table 4-5). For the MF of the NHL no significant differences were found (Tables 4-6 and 4-7). For SLHH, a significant difference was found between right and left leg with muscles pooled (Table 4-8). For 30 m Timed Sprint (Total EMG) a significant difference was found between MH and BF (Table 4-9), but there was not a significant change with repetitions (Table 4-10). In the 30 m Timed Sprint (MF) a significant interaction of muscles and sides was found (left and right) with test and retest pooled (Table 4-11) and also for the interaction of repetitions and the two muscles (with sides pooled), (Table 4-12).

Table 4-2. Results for the hypothesis tests (p-values) of the systematic differences between legs with muscles pooled, between muscles with sides pooled, between repetitions for fatigue, and all two-way interactions. Significant difference is set to p<0.05.

	Difference between right leg and left leg with muscles pooled	Difference between MH and BF with sides pooled	Interaction of muscles and sides (left and right) with test and retest pooled	Repetitions	Interaction of repetition and sides with muscles pooled	Interaction of repetitions and the two muscles with sides pooled
Bound Jumping (Peak) (67% of data)	p=0.35	p=0.03	p=0.37			
NHL (Peak) (55% of data)	p=0.16	p=0.0016	p=0.51	p=0.0002	p=0.51	p=0.79
NHL (MF) (69% of data)	0.17	p=0.83	p=0.13	p=0.09	p=0.74	p=0.85

SLHH (Peak) (60% of data)	p=0.004	p=0.31	p=0.32			
Sprint (totalEMG) (30% of data)	p=0.24	p=0.03	p=0.57	p=0.14	p=0.31	p=0.30
Sprint (MF) (38% of data)	p=0.89	p=0.11	p=0.0009	p=0.33	p=0.71	p=0.0095

Table 4-3. Average normalized peak EMG measurements (%MVC) and standard deviation (SD) of BJ (Peak EMG) for each muscle, left and right and for test and retest.

	Number of subjects	Number of observations	Mean test (%MVC) (SD)	Mean retest (%MVC) (SD)
Left BF	12	21	102% (61%)	110% (41%)
Left MH	14	22	106% (74%)	81% (37%)
Right BF	10	17	105% (31%)	105% (34%)
Right MH	15	26	89% (52%)	68% (31%)

Table 4-4. Mean values for test and retest, and typical error for normalized NHL (Peak EMG) (%MVC) for muscles and sides.

	Number of subjects	Number of observations	Mean Test (%MVC)	Mean Retest (%MVC)
Left BF	12	92	120% (22%)	118% (38%)
Left MH	15	89	98% (37%)	93% (41%)
Right BF	10	66	110% (32%)	100% (36%)
Right MH	14	101	96% (30%)	82% (39%)

Table 4-5. Average normalized peakEMG measurements (%MVC) and standard deviation (SD) for repetitions 1 through 5 for NHL.

Repetitions	Number of observations	Mean (%MVC)	SD (%MVC)
1	83	113%	37%
2	75	104%	38%
3	78	100%	34%
4	58	95%	36%
5	56	93%	33%

Table 4-6. Mean MF values and SD for individual muscles and test and retest and test-retest combined for NHL.

	Number of subjects	Number of observations	Mean Test (SD),(Hz)	Mean Retest (SD), (Hz)
Left BF	15	108	105 (22)	105 (18)
Left MH	16	113	103 (23)	116 (22)
Right BF	15	99	103 (20)	100 (17)
Right MH	15	118	96 (26)	98 (31)

Table 4-7. Average MF values and SD (Hz) of NHL (Hz) for repetition 1 through 5.

Repetitions	Number of Observations	Mean (Hz)	SD (Hz)
1	99	100.8	24.9
2	93	103.6	24.6
3	100	104.5	23.3
4	74	102.0	22.3
5	72	104.6	21.5

Table 4-8. Normalized SLHH (Peak EMG)(%MVC) and mean values (SD) for test and retest for each muscle on each side.

	Number of subjects	Number of observations	Mean Test (%MVC) (SD)	Mean Retest (%MVC) (SD)
Left BF	11	19	159%(86%)	176% (81%)
Left MH	15	23	145% (75%)	132% (48%)
Right BF	7	10	113% (33%)	128% (39%)
Right MH	15	24	130% (55%)	95% (36%)

Table 4-9. Mean values of Total EMG for separate muscles and test and retest (%MVC) for the 30 m timed sprint test.

	Number of subjects	Number of observations	Mean Test (%MVC) (SD)	Mean Retest (%MVC) (SD)
Left BF	8	45	52% (41)	100% (109%)
Left MH	12	54	41% (44%)	62% (71%)
Right BF	8	44	74% (25%)	88% (30%)
Right MH	12	88	45% (31%)	50% (35%)

Table 4-10. Average and standard deviation (%MVC) of Total EMG of repetition 1 through 7 for the 30 m timed sprint test.

Repetition	Number of Observations	Test/ retest Mean (MVC%)	SD (MVC%)
1	41	72.4	56.1
2	36	68.5	60.0
3	32	79.9	82.7
4	32	68.5	58.5
5	34	50.4	32.7
6	29	55.4	37.4
7	26	44.3	28.9

Table 4-11. Mean values for individual muscles and for test and retest for the 30 m timed sprint test (MF).

	Number of subjects	Number of observations	Mean Test (Hz) (SD)	Mean Retest (Hz) (SD)
Left BF	8	62	108 (17)	91 (24)
Left MH	13	71	71 (22)	93 (38)
Right BF	13	70	90 (24)	83 (23)
Right MH	14	94	87 (29)	107 (28)

Table 4-12. Average and standard deviation of measurements (Hz) for repetition 1 through 7 for the 30 m timed sprint test (MF).

Repetition	Number of Observations	Mean (Hz)	SD (Hz)
1	52	95.9	25.2
2	50	89.9	28.5
3	44	92.0	31.3
4	41	92.1	27.3
5	42	92.4	29.6
6	34	91.1	28.1
7	34	83.8	32.5

5. Discussion

5.1 Intertester reliability of electrode placement procedure

5.1.1 Summation of results

This part of the research aimed at testing the between testers reliability of electrode placement. The study resulted in an overall typical error ranging between ±0.70cm-1.1cm. The largest error of ±1.1cm was found in the longitudinal measurement of MH. A tendency towards a systematic error was found for one of the testers, who consistently recorded longer measurements than her colleagues in the length measurements of MH and BF and recorded a shorter horizontal distance between the two points for electrode placement for the respective muscles.

5.1.2 Considerations

The results in the study at hand indicate that experienced physiotherapists can place the electrodes from ±.70 to ±1.1cm accuracy (CV% 3.95 – 15.17) when following the SENIAM protocol. Especially the results of the medial-lateral distance measurement (CV% 15.17) is of great concern since, this has great implications for cross talk between muscles. Campanini et al. (2007) used a square grid of 9 electrodes on the lower limb, with 2cm between each electrode in the grid. In this study the variability of peak amplitude and total power between electrode locations and strides was studied during gait. A variation of 31% overall (ranging 6-31%) of the EMG measurements between the electrode locations of 2-4 cm apart was recorded. Compared to the findings of Campanini et al. (2007) a variance of ±1.1cm can make the variation in sEMG recordings up to 31% (range 6-31%) between testers.

In the study at hand, the same standard tape measure was used for all measurement and this was not considered a source of bias to the results. The reliability of use of tape measure in identifying leg length discrepancy has been found to have good accuracy (ICC 0.924) when compared to Computed Tomography (CT) as the golden standard (Jamaluddin et al., 2011). The results are interpreted as either a result of a disagreement between testers about the location of the proximal and distal anatomical landmarks, or a discrepancy between testers in locating the top of the muscle belly. One bias to the result of the study is that information of BMI, height, leg length, and a circumference measure of the thigh were not included. It could be more difficult to locate anatomical landmarks on girls with a high BMI, and thus this information could have been useful in stratifying the girls into heterogeneous groups

The SENIAM procedure for placement of electrodes on the hamstring muscle group uses *tuber ischiadium* as the proximal reference point. This alone is a source of error since palpation of *tuber ischiadium* through *m. glutei* could be very difficult to reproduce. The distal marking for BF is described as the point proximal of the head of fibula and distal of the knee joint line. There is no direct reference to how far anteriorly or posteriorly this point is. The distal reference marker for MH is described as to the point of the medial aspect of knee joint line; again no reference to how far anterior or posterior the mark. This consideration was acted upon in the test-retest reliability study of the four functional tests. The testers were instructed to palpate *tuber ischiadium* from the caudal point (from the crest of the buttock) and to mark the distal point of BF on the most prominent part of the head of the fibula and to mark the distal point of MH distal to the most prominent part of the medial tuberculum directly on the joint line. Also, the test subjects were placed on the same mat, using the same knee flexion for test and retest.

5.2 Reliability of the EMG outcome variables for the functional tests

5.2.1 Summation of results

The results show error of measurement (typical error) ranging between ±25-53% of the respective MVCs and ±20 – 224Hz. SLHH (peak EMG) tops the list with the largest margin of error of ±53%MVC. A low test-retest variability across the four functional tests (±0-14%MVC; ±1Hz SD) is found. The between subjects variability ranges between ±24 and 31%MVC (SD) and between ±11Hz and 12Hz (SD). The percentage of data used for statistical analysis ranges from 30-69%.

5.2.2 Test protocol

The set up was a test-retest design where each test session was initiated with a standardized warm up where the test subjects were allowed to practice the different tests except for the NHL. The latter was left out of the warm up in order to avoid any fatigue or irritation of the muscles in the subsequent testing. Warm up included the tests in question in order to eliminate learning effect during the tests. Learning effect in jump tests has been reported in a number of articles (Munro and Herrington 2011, Markovic et al., 2004) and also in sprinting (Wragg et al., 2000). A low variability between tests, indicating no systematic error due to learning effect was found for BJ (test retest variability ±4%MVC (SD)), NHL (test retest variability 0% - ±4%MVC (SD)), SLHH (test retest variability 0%MVC (SD)) and 30m Sprint (test retest variability 0% - ±14%MVC (SD)), which could be the result of the standardized warm up protocol. NHL also did not show any learning effect, despite the fact that it was not included in the warm up, perhaps as a result that this exercise was familiar to the players from their daily training. The order of the tests was fixed as to slowly increase the load. NHL was executed before the horizontal hop and not right before the sprint in order to allow for recovery of any muscle fatigue.

5.2.3 Test subjects

The test subjects in the test-retest reliability study were all between 15-17 years of age. This age group can also prove to affect the results since variability of movement has been reported to be associated with age (Ferber & Hamstra-Wright. 2006; Meylan et al., 2012). Meylan et al. (2012) investigated the between days reliability of two bilateral counter movement jump exercises in forty-two male and female participants between 9 and 16 years of age. The children were included in different maturity groups based on anthropometric variables. Although biomechanical data varied, jump length did not vary substantially, A less mature state was ‘‘likely’’ to ‘‘very likely’’ to reduce the reliability of the jump lengthening phase (concentric phase) in the horizontal counter movement jump between test days, and yet the reliability of the jump length (cm) was reliable across all maturity groups. This suggests that children of a less mature status alter their jump strategy from jump to jump without any effect to the jump length.

5.2.3.1 Methodological considerations

The test subjects in this study were all active in sports (soccer). The test subjects were excluded if they had any ailment to the lower limb or back. However, there was no recording of previous injuries to the hamstring muscles. The lack of this information must be taking into account. Previous injuries to the hamstring have been reported to have an influence on muscle strength up to two years later (Mendiguachia, 2011) and therefore can have a bearing on the validity of the results. In this research, there was no consideration of the maturity stage of the subjects. The anthropometric data of the subjects' height (mean 179cm; range 170-191 cm) and weight (mean 70 kg; range 59 – 85 kg) show a great range which could influence the results.

5.2.4 Functional tests

Functional testing following a HSI is one of the final steps in the test battery used by physiotherapist when testing a player's ability to return to sport. As part of this last test, Mendiguchia et al. (2011) proposed isokinetic testing and running. Previously, hand held dynamometer isometic testing such as testing of hip extension (SEM 12%) and knee flexion (ICC 0.83-0.95) has shown to be reliable tests (Thorborg et al., 2010; Mendiguchia & Brugelli, 2010). No such measures has been found for functional tests such as jumping and sprinting by means of EMG and it is therefore difficult to establish a golden standard in terms of acceptable measurement errors. However if the imprecision of the measurement is ±25%MVC in practical terms this means that if the change from week one peak EMG NHL to week two is 15%MVC then this equals 15%MVC ±25%MVC and hence the noise is larger than the detected change. Thumb of rule is, that you always want the noise to be less than the minimal detectable change (Hopkins, 2004).

5.2.4.1 Bound Jumping

BJ is, like the horizontal hop for distance, a very complex task. The reason for including BJ in this research was to include an exercise that in its bounding nature and exaggerated motion, forces propulsion of one hip into extension and ipsilateral hip into flexion. A typical error of ±38%MVC was found meaning that any true change in the muscle peak power from test to retest lays outside the range of ±38%MVC. The error of measurement could be the result of the age and maturity stage of the test subjects as discussed above, and it could also be the result of the task being unspecific and complex.

No significant difference between left and right leg was found, indicating no dominant and non-dominant leg for the subjects in this task. BJ is cyclic in nature but calls for coordination and a difference between leg power output would not be expected in healthy individuals. However, a significant difference was found between MH and BF of the same leg during the interval of landing and take off. This is likely the result of the muscles working medially and laterally to the knee respectively and hence adding to the stability of the knee during landing. Any adduction or abduction of the knee due to either lack of hip stability or as a result of an uneven surface would result in a correctional contraction of the respective hamstring muscle.

5.2.4.1.1 Methodological considerations

The object in this research was to investigate the reliability of the peak EMG parameter for this task from the time of landing to the time of toe off. A video recording of the task was synchronized with the EMG readings and the timeframe of the task was visually inspected and chosen. The KINE PRO system allowed 20 ms of recording per video frame. Some uncertainty of the visual inspection of each video frame must be brought to attention. The video used was a regular video, in a standardized setting, with the test subject in full figure. No attempt was made to zoom in on the foot to enhance the frame accuracy of the landing and take-off. Even so, the researcher did not find it difficult to determine the landing and take-off tasks in the visual inspection and the peaks of the muscle work did seem to occur during the chosen frames.

5.2.4.2 Nordic Hamstring Lower

The objective of studying the NHL, was to test the between days reliability of the test using peak amplitude (maximum power) and fatigue (median frequency) as outcome measurements. A typical error of ±25%MVC was found for NHL (peak EMG, mean 100%MVC, range 35-215%MVC)) and ± 20Hz for NHL (median frequency) with mean recorded Hz of 103. This means that detection of a true change in the muscle work lays outside the range of ±25% of MVC for peak EMG and outside 20 Hz for median frequency. No significant difference was found between left and right leg during the task for both parameters NHL Peak EMG and NHL median frequency. A significant difference between MH and BF was found for the same leg in NHL (Peak EMG), indicating a muscle preference during this task. This muscle preference was not significant for NHL (median frequency). A sensitivity to changes was found in NHL Peak EMG where a significant difference was found from repetition 1 to 5 with peak EMG values decreasing significantly, indicating that Peak EMG could be used to detect muscle fatigue. This significance was not detected with median frequency as the outcome parameter. This finding contradicts the current understanding of median frequency as the primary detector of muscle fatigue (Oddsson et al., 1997; Kollmitzer et al., 1999; Singh et al., 2007).

5.2.4.2.1 Methodological considerations

In the set up at hand there are many variables that contribute to the results~~,~~ The different time frame between tests could be the result of a player's inability to hold the descend for 5 seconds. The only instruction to the player as of how to proceed, was to perform a smooth continuous descend to the mat during the count of 5. There was no controlling if the player would spend the 5 seconds in an almost upright position and then drop to the mat which of course influences how much muscle power is needed to slowly descend to the mat. The strength of the tester is also an issue to mention. It was evident during the tests, that holding the player's ankles down to the mat proved difficult and this could have influenced how long the player held the descend.

A change of muscle length during contraction can alter the conduction velocity and thereby the frequency content of the sEMG signals. It has been found that a 10% change in muscle length would result in approximately 10% change in frequency. Hence, the change of joint range for any given movement will affect the frequency content of the sEMG signal (So, 2009). Therefore not controlling the speed and the degree of descend is most likely a contributing factor to the results of the between days reliability of the fatigue of the hamstring muscles during the NHL. For a future research a camera and a grid wall parallel to the test subject could ensure, that the same angle of descend is chosen for test and retest and thus improving the reliability of the test.

Singh et al. (2007) argue, that in tasks where muscle fatigue is sought, it is important to identify a spectrum for analysis where the muscle works at maximum in order to detect changes in the power spectrum between repetitions. In this study, the threshold RMS was set to 10. This means the on-level for the muscle activity was set to 10% of its maximum workload and thus the whole time span is chosen. An alternative method could have been to have chosen a higher threshold level and thus have solely included a shorter time span and higher values of the power spectrum as Singh et al. (2007) suggested.

5.2.4.3 Single Leg Horizontal Hop

In the study at hand the peak EMG was the object of investigation. A typical error of ±53% MVC was found meaning that any detection of a true change must lie outside the range of ±53% MVC. A systematic error (p=0.0036) was found between left and right leg, indicating a true difference between left and right leg and the presence of a dominant and non-dominant leg. No significant difference was found between the peak values of MH and BF. A number of studies test the reliability of horizontal hop tests such as the “one-leg hop test” (Booher et al., 1993), “cross over hop test” (Reid et al., 2007), “triple hop for distance (Reid et al., 2007, Maulder et al., 2005)”. Even though the tests might differ in protocol and subjects, the horizontal hop tests are generally thought as a very reliable, reproducible tests (evidence level recommendation level D & a) (appendix 14). However, the outcome measurements have seldom been EMG parameters of specific muscles but more often a “hop for distance measurement”. Goodwin et al. (1999) tested the reliability of leg muscle electromyography in vertical jumping. Results showed good test retest reliability of *m. rectus femoris* (ICC 0.88), moderate reliability of *m. vastus medialis* (ICC 0.70) and poor reliability of the two muscles *mm gastrocnemius* (ICC 0.01) and BF (ICC 0.24). In accordance to Goodwin et al (1999) one must speculate that the poor test retest reliability found in this research could be due to the variability in action and timing of two joint muscles compared to single joint muscles. As the hamstring muscles are working as stabilizers in lateral-medial translation of the knee joint any functional instability or instability of surface may cause a variability too random for sEMG to be a reliable tool.

5.2.4.3.1 Methodological considerations

One bias to the interpretation of the results in this study is the fact that no switch mat was used to synchronize the EMG peaks during landing and take-off. The question is: are the peaks in fact landing or are they artifacts? Visual inspection of the signal and the filtering process diminishes this error but a camera or switch mat could have ensured the validity of the peaks.

5.2.4.4 Timed 30m Sprint

The aim of researching 30m sprint test was to test the hypothesis, that total power EMG and median frequency EMG testing of the hamstring muscles of healthy subjects during a selected envelope of sprint are reliable tools in detecting any true changes between trials in the same subject. In the study at hand, a typical error of ±48% of MVC was found. The large typical error can reflect the fact that it the hamstring muscles not only work as prime movers in hip extension, but also work as stabilizers of the knee joint, correcting and adapting the force output to the optimal for a balanced stride. A significant difference in the workload of MH and BF of the same leg as found in this research indicates that this is the case, as it also showed in the BJ.

5.2.4.4.1 Methodological considerations

No external synchronization to speed camera or ground reaction force systems was used in assessment of Timed 30m Sprint. This has implications for choosing the frame of the 2nd to the 4thsecond. External devises would have allowed for accurately selecting phases of the running cycle at the same joint angle or same speed. Without these systems, the reasons for variability in EMG activity during running must be based on speculation only.

The between days reliability of the outcome measures total power EMG and median frequency EMG is depended on the subjects' ability and also willingness to obtain maximum or at least the same speed during the 2nd – 4th second of the sprint from test to retest. In order to make the subjects run "all out" during all seven sprints, they were not informed of how many sprints they were to perform. This was done in order to eliminate possible bias of the subjects pacing their speed and thus influencing the results. Yet, no significant difference was found between repetitions.This finding is influenced greatly by the large random error of measurement. MF has previously been reported to be a measurement capable of detecting changes over time or repetitions. As mentioned previously MF was initially proposed as an indicator of fatigue measurement in constant-force or isometric tasks. In dynamic tasks like sprinting it is likely that the fluctuating recruitment of muscle fibers in order to correct for any unbalances makes MF an unsuitable measurement of fatigue in sprints.

5.2.5 Methodological considerations of assessing electromyography in dynamic tasks

Reliable techniques to predict muscular forces and co-ordination during controlled muscle activities via sEMG have been found. One controlled muscle activity test frequently described is an isometric bilateral back muscle contraction test (Oddsson, DeLuca 2003). However, controlled muscle activities do not represent the complex activities of daily life that are experienced by athletes. The reliability of sEMG during functional activities has only been reported by a small number of studies, and those findings have varied (Goodwin et al. 1999). The reliability of EMG is highly depended on the researcher's initial decision making on what outcome measure is relevant for the test in question and the subsequent parameters that are applied to the analysis process. The reliability of the comparable sEMG is depended on the normalization procedure and the reliability of the EMG is also highly depended on the researcher's qualitative assessment of the raw signal. The latter is done by looking at the EMG figures to check the raw signal for artifacts and to see if the raw signals are similar in repeated measurements. It is also here that the parameters such as threshold levels (cut off levels) and envelopes (signal smoothing) are looked upon. Decisions for the setting of these parameters are made based on the qualitative assessment of the signal. The decision is of course also based on the consensus in the literature. However, very few studies include this information in their articles.

5.2.5.1 Discussion of algorithm

The international society of electrophysiology and kinesiology (ISEK) outlines a set of recommended standards for reporting EMG data in articles (http://www.isek-online.org/standards.html). There seems, however, little consensus to be found in the literature how the EMG data ought to be processed. The processing of the EMG signal seems to be based upon the researcher's experience and qualitative assessment of the raw signal in respect to which outcome measure (peakEMG, TotalpowerEMG, fatigueEMG) is to be applied. In this research an algorithm was developed in order to clarify to the reader each step of the signal processing. Since the researcher is a novice of EMG signal interpretation, the qualitative assessment was highly depended on the support from the expert opinion of the methodology counselor, which was greatly appreciated. In the following a discussion of the choices made for processing the raw EMG signal in MATLAB will take place.

5.2.5.2 Discussion of normalization procedure

As one will notice in the review of literature for normalization procedure of lower extremity, conflicting recommendations of an EMG normalization procedure are reported (recommendation grade d, evidence level III) (appendix 4, B.). The articles mentioned all refer to sound methodological research, including the recommended standards for reporting EMG data in articles (http://www.isek-online.org/standards.html) set by "The international society of electrophysiology and kinesiology" (ISEK). However, only one author includes information on data exclusion/ inclusion process. Rainoldi et al. (2001) mention the data exclusion procedure (no MVC data excluded). This information can prove vital to the legitimacy of the research!

In this research a standardized isometric angle specific MVC was applied as a reference value to the different dynamic tests based on the recommendations from the SENIAM group. The method was also chosen based on its clinical "easy-to-perform" level. This method could be criticized since the pattern and output of the isometric angle specific MVC only reflects the particular angle chosen. However, Burden et al (2010) argues that only minor differences exist between the isometric MVC and the isokinetic MVC normalization procedures for the knee flexors and extensors (CV). Based on the above the standardized isometric angle specific MVC used in this research is a normalization procedure with a recommendation grade d.

Kollmitzer et al. (1999) studied two angle specific normalization procedures: MVC and 50%MVC performed on a Cybex 6000 dynomometer. Both PeakEMG (RMS) and Fatigue EMG (MF) was analyzed. Kollmitzer concluded that the 50% MVC performed as an isometric angle specific MVC is highly superior to the 100% isometric angle specific MVC. The longer the interval between trials, the less reliable the MVC procedure proved to be.

In 2011 Albertus-Kajee included various normalization methods of lower limb muscles during a sprint. He concluded that isometric MVC and the mean peak amplitude derived during sprinting were equally reliable between days as normalization procedures of 30 m sprint (running start). He also concluded that detection of changes (sensitivity) in EMG within the same test day was possible when performing the peak normalization procedure. Controversially, Ball and Scurr (2011) concluded that EMG data from a 20 m sprint is reliable between test days when normalized with the peaks within the sprints but NOT when normalized with the isometric MVC. They also found that no detection of change (sensitivity) between sprints within the same test day was possible when performing the peak normalization procedure. Detection of changes between sprints was possible with the isometric normalization procedure but this in turn was not reliable between test days.

Ball and Scurr's results (2011) correspond with the results of the current research where an isometric angle specific MVC was used to normalize the EMG data of total Power of the 2nd to the 4th second of the sprint. EMG data from the hamstring muscles during a 30 m sprint, normalized with an isometric angle specific MVC was highly unreliable between test days with a calculated error of ±48%. In contrast to Ball and Scurr (2011)**,** in this research a detection of changes in amplitude between repetitions (EMG Peak) was not possible.

5.2.5.2.1 Methodological considerations

Critic must also be pointed at the MVC procedure compared with the submaximal VC procedure. Does the MVC truly reflect a maximum 100% contraction? In this study the players were asked to "give it all you got" for the MVC. A biofeedback pad was attached to the bench used for pressing up against, and the players were told, that we were looking at how much they could move the arrow of the biofeedback and therefore it was deemed a 100%MVC. Another issue to discuss is the positioning of the player in a prone position with a straight hip, compared to the positioning performed by Kollmitzer el al (1999) in a cybex machine where the subject is sitting. In the prone position, the tension from the hip flexors might prove it difficult for the player to contract to a maximum. However, this position also reflects a true hamstring contraction by eliminating a cocontraction from the hip flexors. Furthermore, this position enables the tester to control the rotation of the leg as the object is to perform an MVC of both MH and BF.

5.2.5.3 Threshold level for analysis

The threshold level defines the on level and the cut off level for the EMG signal. Onset and offset values allow investigators to identify the desired regions of muscle activity or muscle bursts in the EMG recording for further analysis, since the values below the cut off level will not be analyzed. It is proposed that setting of an appropriate threshold level may diminish crosstalk from adjacent muscles (Johanson, and Radtaka 2006). The appropriateness of the threshold level is depended on the exercise at hand and is depended on the type of analysis applied (fatigue, peak, total power), (recommendation grade d) (appendix 15, A & B.).However even within the same type of dynamic exercising little consensus is found in the literature. Özgünen et al. (2010) examined 4 different threshold levels to determine a proper threshold value in a constant speed incremental cycling exercise for accurate EMG signal analyses of EMG total power (RMS). What Özgünen found was, that onset of fatigue towards the end of the cycling exercise influenced the visual clarity of the expected EMG bursts. In this research it is not proposed that onset of fatigue influenced the clarity of the signal but rather the movement of the electrodes influenced the clarity, because of the high velocity and power of movement. This is a definite cause of the many outliers. However, it cannot be denied that with the development of fatigue, the burst duration might increase or burst like activities might occur because of the inefficient relaxation of the fatigued fibers. In the research study at hand the appropriateness of the threshold level was determined from a random qualitative assessment of the EMG signal of the Timed 30 m Sprint. That is, the EMG signal, was randomly picked for visual inspection. For the Timed 30 m Sprint a threshold level of 50% of maximum amplitude was applied. The cyclic nature of the strides allowed for a clear visible distinction between strides. The reason for choosing a threshold level of 50% was to reduce the risk of including noise due to the movement of the electrodes during sprinting and thus reducing the between-test variability.

5.2.5.4 Smoothing process

The smoothing process is a process of eliminating the random fluctuations of the signal to present a more “linear” or average representation of the signal (Niemenlehto and Juhola 2009). In tasks where the peaks and spikes of the signal are objects for analysis the smoothing process must be less whereas in tasks where parameters such as total power and median frequency are of interest, a higher degree of smoothing process is relevant. In this research, two different parameters has been applied 1000ms and 100ms. This was chosen based on the visual inspection of the signal and the consequent consensus between counselor and student. No consideration to the literature was made as only general information on this topic is revealed in the literature and no consensus was found among the different experimental studies.

6. Conclusion

6.1 Intertester electrode placement procedure - Implication for practice

The research in hand showed a typical error of electrode placement of ±0.70 – 1.1cm (CV 3.95 – 15.17) between different testers and a systematic error in one of four testers. All testers were experienced physiotherapists but had no prior experience in electrode placement. The hypothesis that the electrode placement procedure is a reliable method between testers cannot be approved as a whole because of the large discrepancy between testers in the medial-lateral distance measure. The result highlights the need for following a specific protocol of electrode placement that includes specification of anatomical landmarks. It also highlights the necessity of including this information in published articles in order to make comparative notes between results of different research.

6.2 Reliability of the EMG outcome variables for the functional tests - Implication for practice

Error of measurement (typical error) of the four tests ranges between ±25-53% of the respective MVCs, and between ±20 – 224Hz. The hypothesis that functional testing of MH and BF by means of sEMG is reliable is rejected in the current setting of 15-17 year olds. A test that is designed to detect changes from test to retest should have a low range of error in order to detect true changes. In the current setting, the margin of error in Bound jumping, Nordic Hamstring Lower, Single Leg Horizontal Hop and Sprint is too large to give us an insight to the conditions of the specific muscles from test to test.

In order to possibly improve the reliability of EMG testing of the hamstring muscles in a functional testing, there are many improvements in the set up that are necessary. The use of video camera, grid wall and force plate could possibly improve the reliability. At the same time the need for this apparel makes the functional testing less clinical practical. The objective was to test the exercises in a setting that would be clinically practical. The outcome of the tests as performed in the current setting shows that, muscle testing of the hamstrings with sEMG is not easily applied to functional testing, and cannot be recommended by the researcher as part of the return to sport algorithm. Between 31-70% of the data was excluded based on the criteria for outliers. It is essential that the criteria for outliers are published in future research in order to make comparisons between the results of different research.

Functional testing such as jump and sprint - without the use of EMG is commonly used in the return to sport algorithm. It is the researcher's advice to be aware of contributing good performance results in hop testing and sprint testing, such as change in muscle recruitment pattern in order to reach a benchmark set during previous testing or by ipsilateral leg. Age and maturity stage of test subjects may interfere with results and muscle recruitment patterns can vary with age and skill level (Ferber et al., 2006, Meylan et al., 2012). The current research does not include information on skill level of the participants, nor how many years the test subjects have participated in soccer. Further research into this phenomenon is needed.

Reference List

Albertus-Kajee Y., Tucker R., Derman W., Lamberts R.P., Lambert M.I. (2011). Alternative methods of normalising EMG during running. *Journal of Electromyography and Kinesiology,* 1(4), 579-86*.*

Albertus-Kajee Y., Tucker R., Derman W., Lambert M.I. (2010). Alternative methods of normalising EMG during cycling. *Journal of Electromyography and Kinesiology,* 20(6),1036-43.

Arnason A., Andersen T.E, Holme .I, Engebretsen L., Bahr R. (2008). Prevention of hamstring strains in elite soccer: an intervention study. *Scandinavian Journal of Medicine and Science in Sports,* 18(1), 40-48.

Árnason A., Sigurdsson S., Gudmundsson A., Holme I., Engebretsen L., Bahr R. (2004). Risk Factors for Injuries in Football. *The American Journal of Sports Medicine,* 32(1), 5s-16s.

Arnason A., Gudmunddon A., Dahl H.A, Johannsson E (1996). Soccer injuries in Iceland. *Scandinavian Journal of Medicine and Science in Sports,* 6(1), 40-45.

Askling C.M., Nilsson J., Thorstensson A. (2010). A new hamstring test to complement the common clinical examination before return to sport after injury. *Knee Surgery, Sports Traumatology, Arthroscopy,* 18(12), 1798–1803.

Bahr R., Mæhlum S. (2004). Clinical guide to sports injuries. Windsor: Human kinetics.

Ball N., Scurr J. (2011). Efficacy of current and novel electromyographic normalization method for lower limb high-speed muscle actions. *European Journal of Sports Science,* 11(6), 447-456*.*

Basmajian J.V. and De Luca CJ (1985). *Muscles Alive.* Baltimore, Williams and Wilkins.

Beck T.W. (2009). Electrode placement over the innervations zone affects the low- not the high-frequency portion of the EMG frequency spectrum. *Journal of Electromyography and Kinesiology,* 19(4), 660-666.

Beijsterveldt A.M.C., Van de Port I.G.L., Vereijken A.J., Backx, F.J.G. (2012). Risk factors for hamstring injuries in Male soccer players: A systematic review of prospective studies. *Scandinavian Journal of Medicine and Science in Sports*, Published online DOI 10.1111/j.1600-0838.2012.01487.x.

Bolgla L.A., Keskula D.R. (1997). Reliability of lower extremity functional performance tests. *Journal of Orthopaedic Sports Physical Therapy,* 26(3),138-4.

Booher L.D., Hench K.M., Worrell T.W., Stikeleather J. (1993). Reliability of three single-leg hop tests. *Journal of Sports Rehabilitation, 2, 165-170.*

Bradley P.S., Portas M.A. (2007). The relationship between preseason range of motion and muscle strain injury in elite soccer players. *Journal of Strength and Conditioning Research,* 21(4), 1155–1159.

Burden A. (2010). How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research*. Journal of Electromyography and Kinesiology* 20(6),1023-35.

Campanini I., Merlo A., Degola P., Merletti R., Vezzosi G., Farina D. (2007). Effect of electrode location on EMG signal envelope in leg muscles during gait. *Journal of Electromyography and Kinesiology,*17(4), 515-26.

Clanton T.O., Coupe K.J. (1998). Hamstring strains in athletes: diagnosis and treatment. *Journal of the American Academy of Orthopaedic Surgeons,* 6(4), 237-48.

Drezner J.A. (2003). Practical management: hamstring muscle injuries. *Clinical Journal of Sports Medicine,* 13(1), 48-52.

Dvorak J., Junge A., Chomiak J., Graf-Baumann T., Peterson L., Rösch D., Hodgson R. (2000). Risk Factor Analysis for Injuries in Football Players: Possibilities For a Prevention Program. *The American Journal of Sports Medicine,* 28(5), S69-74.

Eirale C., Hamilton B., Bisciotti G., Grantham J., Chalabi H. (2010). Injury epidemiology in a national football team of the Middle East. *Scandinavian Journal of Medicine and Science in Sport*s*,* 22(3), 323-9.

Ekstrand J., Hägglund M., Waldén M. (2011). Epidemiology of Muscle Injuries in Professional Football (Soccer). *The American Journal of Sports Medicine,* 39(6), 1226-32.

Ekstrand J., Timpka T., Hägglund M. (2006). Risk of injury in elite football played on artificial turf versus natural grass: a prospective two-cohort study. *British Journal of Sports Medicine,* 40(12), 975-980.

Ekstrand J,Gillquist J; Soccer Injuries and their Mechanisms. *Medicine and Science in Sports and Exercise*, 1983, 15(3), 257-270.

Engebretsen A.H., Myklebust G., Holme I., Engebretsen L., Bahr R. (2010). Intrinsic risk factors for hamstring injuries among male soccer players: a prospective cohort study. *The American Journal of Sports Medicine.,* 38(6),1147-53.

Fauth M.L., Petushek E.J., Feldmann C.R., Hsu B.E., Garceau L.R., Lutsch B.N., Ebben W.P.(2010). Reliability of leg muscle electromyography in vertical jumping. *Journal of Strength and Conditioning Research,* 24(4), 1131-7.

Ferber R., Hamstra-Wright K. (2006). Gender comparisons of dynamic restraint and motor skill in children. *Clinical Journal of Sports Medicine,* 16(1), 56-62*.*

Finni,T., Cheng, S. (2009). Variability in lateral positioning of surface emg electrodes. *Journal of applied Biomechanics,* 25(4), 396-400.

Fuller C.W., Ekstrand J., Junge A., Andersen T.E., Bahr R., Dvorak J., Hägglund M., McCrory P., Meeuwisse W. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *British Journal of Sports Medicine,* 40(3), 193–201.

Goodwin P., Koorts K., Mack R., Mai S., Morrissey M.C., Hooper D.M. (1999). Reliability of leg muscle electromyography in vertical jumping. *European Journal of Applied Physiology,* 79, 374-378.

Heiderscheit B.C., Sherry M.A., Sider A, Chumanov E.S., Thelen D.G. (2010). Hamstring strain injuries: recommendations for diagnosis, rehabilitation and injury prevention. *Journal of Orthopaedic & Sports Physical Therapy.* 40(2), 67-81.

Henderson G., Barnes C.A., Portas M.D. (2010). Factors associated with increased propensity for hamstring injury in English Premier League soccer players, *Journal of Science and Medicine in Sport,* 13(4), 397-402.

Hopkins W.G. (2004). How to Interpret Changes in an Athletic Performance Test. *Sportscience,* 8, 1-7.

Hopkins W.G., Schabort E.J., Hawley J.A. (2001); Reliability of power in physical performance tests; *Sports Medicine,,*31(3):211-34*.*

Hodges P.W., Bui B.H. (1996). A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. *Electroencephalography and Clinical Neurophysiology,*101, 551–519.

Hunter D.G., Speed C.A. (2007). The assessment and management of chronic hamstring/ posterior thigh pain. *Best Practice and Research of Clinical Rheumatology,* 21(2), 261-77.

Hägglund M., Waldén M., Ekstrand J. (2009). Injuries among male and female elite football players. *Scandinavian Journal of Medicine and Science in Sports*, 19(6), 819-27.

Hägglund M., Waldén M., Ekstrand J. (2006). Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. *British Journal of Sports Medicine,* 40(9), 767–772.

Jamaluddin S., Sulaiman A. R., Kamarul Imran M., Juhara H., Ezane M. A., Nordin S. (2011). Reliability and accuracy of the tape measurement method with a nearest reading of 5 mm in the assessment of leg length discrepancy *Singapore Medicine Journal,* 52(9), 681–684.

Johanson M.E., Radtka S.A. (2006). Amplitude threshold criteria improve surface electrode specificity during walking and functional movements. *Gait and Posture,* 24(4), 429-34.

Kollmitzer J., Ebenbichler G., Kopf, A. (1999). Reliability of surface electromyographic measurements. *Clinical Neurophysiology*, 110(4), 725-734.

Konrad P. (2005). *The ABC of EMG: A Practical Introduction to Kinesiological Electromyography*. www.noraxon.com.

Knowles S., Marshall S.W., Guskiewicz K.M. (2006). Issues in Estimating Risks and Rates in Sports Injury Research; *Journal of Athletic Training,* 41(2), 207–215.

LeGall F.,,Carling C., Reilly T. (2008). Injuries in young elite female soccer players: an 8-season prospective study. *The American Journal of Sports Medicine,* 36(2), 276-84.

Markovic G., Dizdar D., Jukic I., Cardinale M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength and Conditioning Research.,*18(3), 551-5.

Maulder P., Cronin J. (2005). Horizontal and vertical jump assessment: reliability, symmetry, discriminative and predictive ability. *Physical Therapy in Sport,* 6,74–8.

Mendiguchia J., Brughelli M. (2011). A return-to-sport algorithm for acute hamstring injuries. *Physical Therapy in Sports,*12(1), 2-14.

Mesin L., Merletti R., Rainoldi A. (2007). Surface EMG: The issue of electrode location. *Journal of Electromyography and Kinesiology,*19 (5), 719-726.

Meylan C.M., Cronin J.B., Oliver J.L., Hughes M.G., McMaster D.T. (2012). The reliability of jump kinematics and kinetics in children of different maturity status. *Journal of Strength and Conditioning Research,* 26(4),1015-26.

Mjölsnes R., Arnason A., Osthagen T., Raastad T., Bahr R. (2004). A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. . *Scandinavian Journal of Medicine and Science in Sports*, 2 (14), 311–317.

Munro A.G., Herrington L.C. (2011). Between-session reliability of four hop tests and the agility T-test. *The Journal of Strength and Conditioning Research.* 25(5),1470-7.

Niemenlehto P.H., Juhola M. (2009). Application of a modified two-point backward difference to sequential event detection in surface electromyograph; *Journal of Medical Engineering Technology,* 33(5), 349-60.

Oddsson L., De Luca C. (2003). Activation imbalances in lumbar spine muscles in the presence of chronic low back pain. *Journal of Applied Physiology,* 94(4), 1410-20.

Oddsson L., Giphart J. E., Buijs R., Roy S., Howard T., De Luca C. (1997). Development of new protocols and analysis procedures for the assessment of LBP. Journal of *Rehabilitation Research and Development,* Vol 34, (4), 415-426.

Orchard J., Best T. (2002). The Management of Muscle Strain Injuries: An Early Return Versus the Risk of Recurrence. *Clinical Journal of Sport Medicine,* 12(1), 3-5; Guest Editorial.

Petersen J., Thorborg K., Nielsen B.M, Budtz-Jørgensen E., Hölmich P. (2011). Preventive effect of eccentric training on acute hamstring injuries in men's soccer: a cluster-randomized controlled trial. *The American Journal of Sports Medicine,* 39(11), 2296-303.

Petersen J, Thorborg K, Nielsen B.M, Hölmich P. (2010). Acute hamstring injuries in Danish elite football: A 12-month prospective registration study among 374 players. *Scandinavian Journal of Medicine and Science in Sports,* 20(4), 588–592

Petersen J., Hölmich P. (2005). Evidence based prevention of hamstring injuries in sport. *British Journal of Sports Medicine,* 39(6), 319–323.

Price R.J, Hawkins R.D., Hulse M.A., Hodson A. (2004). The Football Association medical research football programme: an audit of injuries in academy youth. *British Journal of Sports Medicine,* 38(4), 466-471.

Portney L.G, Watkins M.P. (1990) *Foundations of Clinical Research. Application to Practice.* Boston: Pearson Prentice Hall.

Rainoldi A., Bullock-Saxton J.E., Cavarretta F., Hogan N. (2001). Repeatability of maximal voluntary force and of surface EMG variables during voluntary isometric contraction of quadriceps muscles in healthy subjects; *Journal of Electromyography and Kinesiology,* 11(6), 425-38.

Reid A., Birmingham T.B., Stratford P.W., Alcock G.K., Giffin J.R. (2007). Hop testing provides a reliable and valid outcome measure during rehabilitation after anterior cruciate ligament reconstruction. *Physical Therapy,* 87(3), 337-49.

Schache A.G, Wrigley, T.V, Baker R, Pandy M.G. (2009). A Biomechanical response to hamstring muscle strain injury. *Gait & Posture,* 29(2), 332-8.

Singh V.P., Kumar D.K., Polus B., Fraser S. (2007). Strategies to identify changes in SEMG due to muscle fatigue during cycling. *Journal of Medical Engineering & Technology,* 31(2),144-151.

So R.C.H, Ng J.-F, Lam R.W.K, Lo C.K.K, Ng G.Y.F. (2009). EMG Wavelet analysis of quadriceps muscle during repeated knee extension movement. *Medicine and Science in Sports and Exercise,* 41(4), 788-796.

Staude, G., Flachenecker, C., Dunner, M. and Wolf, W. (2001), Onset Detection in Surface Electromyographic Signals: A Systematic Comparison of Methods. *EURASIP Journal on Applied Signal Processing,* 2,67- 81.

Thorborg K., Petersen J., Magnusson S.P., Hölmich P. (2010). Clinical assessment of hip strength using a hand-held dynamometer is reliable. *Scandinavian Journal of Medicine and Science in Sports,* 20(3), 493-501.

Vaisman L., Zariffa J., Popovic M.R. (2010). Application of singular spectrum-based change-point analysis to EMG-onset detection. *Journal of Electromyography and Kinesiology* 20(4), 750-60.

Walden M., Hägglund M., Ekstrand J. (2005). UEFA Champions League study: a prospective study of injuries in professional football during the 2001–2002 season. *British Journal of Sports Medicine,* 39(8), 542–546.

Wiemann K., Tidow G. (1995). Relative activity of hip and knee extensors in sprinting - implications for training. *New Studies in Athletics,* 10(1), 29-49*.*

Witvrouw E., Danneels L., Asselman P., D'Have T., Cambier D. (2003). Muscle Flexibility as a Risk Factor for Developing Muscle Injuries in Male Professional Soccer Players A Prospective Study. *American Journal of Sports Medicine*, 31(1), 41-46.

Wong Y.M., Ng G. (2006). Surface electrode placement affects the EMG recordings of the quadriceps muscles. *Physical Therapy in Sport,* 7(3), 122-1*.*

Woods C., Hawkins R.D., Maltby S., Hulse M., Thomas A., Hodson A. (2004); The Football Association Medical Research Programme: an audit of injuries in professional football—analysis of hamstring injuries. *British Journal of Sports Medicine,* 38(1), 36–41.

Worell T.W. (1994); Factors Associated with Hamstring Injuries; An approach to treatment and prevention measures. *Sports Medicine,*17(5), 338-345.

Wragg C.B., Maxwell N.S., Doust J.H. (2000). Evaluation of the reliability and validity of a soccer specific field test of repeated sprint. *European Journal of Applied Physiology,* 83, 77-83.

Zebis M., Bencke J., Kjær M., Aagaard P. (2009). Identification of athletes at future risk of anterior cruciate ligament ruptures by neuromuscular screening. *The American Journal of Sports Medicine*, 2(37),1967-1973.

Özgünen K.T., Çelik U., Kurdak S.S. (2010). Determination of an optimal threshold value for muscle activity detection in EMG analysis. *Journal of Sports Science and Medicine,* 9(4), 620-628.

Fagligt katalog; www.sportsfysioterapi.dk/fagligt-katalog.

Development of *PCCRP* Guidelines & Review; www.pccrp.org/docs/PCCRP%20Section%20I.pdf

Måleredskaber;
http://fysio.dk/Upload/Graphics/PDFfiler/Maaleredskaber/Checkskema_MAa_HL.PDF.

Recommendations for sensor locations on individual muscles; www.seniam.org

Recommended standards for reporting EMG data in articles (http://www.isek-online.org/standards.html)http://www.isek-online.org/standards.html)

Appendix 1

The Table is a summary of articles selected from the literature search of the incidence of hamstring injuries in soccer and the chosen articles' reference list. Studies up until February 2011 were included. In accordance to the consensus statement described by FIFA, information in this summary includes type of study, data collection method, definition of injury, diagnostic assessment, population studied and injury incidence rate (incidence/1000h exposure) (Fuller et al 2006). Additional information on re-injury definition as well as the number of hamstring injuries and re-injuries reported in proportion to all injuries is also included for comparative measures. Reported number of hamstring injuries in proportion to all injuries is sometimes based on researcher's calculation: "*" refers to the percentage of all hamstring injuries based on calculations on the reported number of total injuries. The epidemiological incidence proportion is also calculated by the researcher: "**" refers to the percentage of players at risk of a hamstring injury within the number of the study population during the study-period (number of HSI minus re-injury cases/ athletes x 100). Information on the percentage of returned data is included since it adds to the validity of the study.

The bibliographic database MEDLINE was searched via Pubmed (up until 2011). The terms were searched as MESH terms and keywords. From the selected articles, reference lists were checked for further relevant studies.

Literature search matrix (Medline via Pubmed) on hamstring muscle strain injury incidence

AND	Epidemiology [MeSH]	Athletic injuries [MeSH]	Soccer [MeSH]	Hamstring Muscle strain
OR	Epidemio* Incidence Occurrence	Athletic injuries Sports injuries Epidemiology sports injuries	Soccer Football [MeSH] Football	

Title and author **(Original literature)**	**Type of study**	**Data collection method**	**Definition of injury**	**Diagnostic assessment**	**Population studied**	**% of returned data**	**Number of all injuries recorded**	**Reported Hamstring injury incidence rate (incidence/1000h exposure)**	**Reported no. of hamstring injuries in proportion to all injuries**	**Epidemiological incidence proportion ((the number of athletes in study at risk of a new hamstring injury)**	**Reported reinjuries (%)**	**Definition of reinjury**
Ekstrand et al (2011) Epidemiology of muscle injuries in professional football (soccer). *Am J Sports Med*. 39(6), 1226-32.	Prospective cohort study	Team medical staff recorded individual player exposure and time-loss injuries during the years 2001 to 2009	"A traumatic distraction or overuse injury to the muscle leading to a player being unable to fully participate in training or match play."		51 football teams, comprising 2299 players from top European football clubs		2908 muscle injuries were registered (0.6 per player)	Training: 0.43/1000h Match: 3.7/1000h	12% of all injuries were to the hamstrings	**349 hamstring injuries/ 2299x100= 13%**	Total 174. (16%)	

Eirale et al (2010) Injury epidemiology in a national football team of the Middle East. *Scand J Med Sci Sports.* 22(3):323-9.	Prospective cohort study	All injuries that were incurred during training and matches were recorded, together with match and training exposure time by the same clinician 17 months (June 2007–October 2008)	Any physical complaint during a match or training resulting in the inability to fully participate football training or match play	Clinically diagnosed by team physician	The senior male Qatar national football team. 36 players (23.8 years)		78 injuries	1,5/1000h	equals 19%of all injuries reported*	22%**	7 out of 15 were recurrent comprising 47% of all HSI were recurrent injuries	Recurrent injuries were defined as ''an injury of the same diagnosis and at the same site, which occurred after return to full participation from the same injury within a two month period''
Petersen et al (2010) Acute hamstring injuries in Danish elite football: a 12-month prospective registration study among 374 players. *Scand J Med Sci Sports*, 20(4), 588-92.	Prospective study	Team physiotherapist and/or physician recorded all hamstring injuries and exposure using a specific injury registration form designed for this study	suddenly occurred physical complaint of the posterior thigh sustained during football match or training, irrespective of the need for medical attention or time-loss from football activities.'' Contusions were excluded		374 elite football players, 16 teams (aged 17-35+)	242 of 374, 65%		46 first-time hamstring injuries; incidence rate 1,82/1000h in matches and 0.12/1000h in training)		12%**	8 recurrent hamstring injuries equals 25% of the first time hamstring injuries	The definition for a recurrent injury was' 'a posterior thigh injury of the same type and at the same site as the index injury, after the player had returned to full participation from the index injury.''

Hägglund et al (2009) Injuries among male and female elite football players. *Scand J Med Sci Sports*,.19(6), 819-27.	Prospective cohort study	Individual exposure (playing time), injuries (time loss), and days lost due to injury) were recorded by the team medical staffs. prospectively during the 2005 season	Injury was defined as a physical complaint resulting from football training or match play leading to absence from any training session or match		12 female football clubs (228 players aged 23 ± 4) and 11 of 14 male clubs (239 players, aged 25 ± 5) in the Swedish premier league were followed		548 injuries reported in male players 299 injuries reported in female players	Hamstring injuries in male players: 1.0/1000 hours (0.8–1.2) Hamstring injuries in female players 0.8/ 1000 hours (0.6–1.1) 0.41	Male: 68 (12%) Female: 44 (15%)	Male: 29%** Female: 19%**	Not reported specifically for hamstring injuries	A re-injury was defined as an injury of the same type and at the same site as an index injury occurring after a player's return to full participation from the index injury
Le Gall et al (2008) Injuries in young elite female soccer players: an 8-season prospective study. *Am J Sports Med*., 36(2), 276-84.	Prospective cohort study	All injuries were diagnosed and recorded over the whole study period by the same CNFE physician covering the entire playing season	Injury was defined as a physical complaint from football training or match leading to absence from any training or match	Clinical assessment	119 young elite female soccer players from 15 to 19 years of age at the Clairefontaine CNFE during the years from 1998 and 2006		619 injuries	2 hamstring injuries were reported with an incidence rate of 0.02/1000hours	Equals 0.3% of all injuries incurred to the hamstring	1.6%**		Reinjuries were defined as the same type of injury to the same side and location within 2 months after the final rehabilitation day of the previous injury

Walden et al (2005) UEFA Champions League study: a prospective study of injuries in professional football during the 2001–2002 season. *Br J Sports Med.*, 39(8), 542–546.	Prospective cohort	A club doctor was responsible for recording each injury, A standard attendance record sheet was used for recording	Any injury occurring during a scheduled training session or match causing the player to miss the next training session or match.		266 male players from 5 countries and 11 teams (aged26 ±4)		658 injuries		HSI equals 10% of all injuries*	25%**	Not recorded specifically for hamstring re-injuries	Reinjury was defined as an identical injury (same side, type, and location) within two months of the final rehab day of the previous injury.
Woods et al (2004) The Football Association Medical Research Program: an audit of injuries in professional football - analysis of hamstring injuries*. BrJ Sports Med*, 38(1), 36-41.	Prospective cohort	Injury reports were collected over two seasons by medical team Injury audit questionnaire	One sustained during training or competition that prevented the injured player from participating in practice or competition for more than 48 hours (not including the day of the injury)	95% clinically 5% US or MR	91 professional football clubs 2376 players in England (Aged 17-35+)	First year: 87% Second year: 76%	796 hamstring injuries (94% strains) . No recording of all injuries		12% of all injuries were hamstring strain injuries 53% to the biceps femoris	28%	12% of hamstring strains were recurrent	Reinjury was defined as an injury of the same nature and location involving the same player in the same season

Price et al (2004) The Football Association medical research football programme: an audit of injuries in academy youth. *Br. J. Sports Med.*, 38(4),466-471	Prospective epidemiological study	Two complete seasons recorded by the academy's medical personnel, following specific reporting guidelines. Injury data and were transferred to an audit questionnaire designed for this study.	A recordable injury was defined as one that prevented the participant from training or playing for more than 48 hours, not including the day of injury		38 English football club youth academies from the ages of 9 to 19 years. A total of 4773 players	76%	3805 injuries were reported		11% of all injuries were to the hamstring muscles*	6%**	72% of all recurrent injuries were strain or sprains. 33% of all strain or sprain re-injuries incurred to the hamstring muscles	Not described
Arnason et al (2004) Risk Factors for Injuries in Football. *Am. J. Sports Med.*, 32(1), 5s-16s.	Prospective cohort study	Injuries were recorded through-out the Competitive season (4 months) 1999 by the team physical therapist on a special form, which was collected by one author (AA) once a month	A player was defined as injured if he was unable to participate in a match or a training session because of an injury that occurred in a football match or during training	Clinically	306 male football players, 17 teams, from the two highest divisions in Iceland (mean age, 24; range, 16 to 38 years)		244 injuries	31 injuries to the posterior thigh. 0.9/ 1000 hours exposure	Equals 13% of all injuries incurring to the hamstring muscles*	10%**		

Ekstrand et al (1983) Soccer Injuries and their Mechanisms. *Med Sci Sports Exerc* 15(3), 257-270	Prospective epidemiological study	1980 season	An incidence occurred during scheduled games or practices, causing the player to miss at least one subsequent practice or game	Clinical	180 Swedish senior soccer players (age 24,6 ± 4.6, range 17-38yrs)		236 injuries		HSI equals 13%	9%		

Appendix 2

The bibliographic database MEDLINE was searched via Pubmed (up until 2011). The terms were searched as MESH terms and keywords. From the selected articles, reference lists were checked for further relevant studies.

Literature search matrix, MEDLINE via Pubmed; known risk factors of sustaining hamstring strain injury

Risk factors	Hamstring injury
Probability Risk [MeSH]	Hamstring strain

Table: Risk factors of injuries in soccer. Inclusion criteria of articles on hamstring injury risk factors include the following: Risk factors of injury in soccer or European style football with detailed description of hamstring injuries, outcome measures and predefined variables and method of analysis. Prospective observational studies were included until 2011 (see search matrix). One systematic review from 2012 was included. Exclusion criteria: non English written articles. Articles on American football, Australian rules football or rugby. The Table below describes the conclusion of their study based on the population studied, their predefined variables and their method of analysis.

Title and Authors	Type of study	Aim	Conclusion	Study population	Primary outcome measures	Predefined determinants/ variables	Study period	Injury definition	Analysis	Drop out rates
Beijsterveldt et al (2012) Risk factors for hamstring injuries in Male soccer players: A systematic review of prospective studies. *Scand J Med Sci Sports, Published online. DOI 10.1111/j.1600-0838.2012.01487.x*	Systematic review	To identify risk factors for hamstring injuries in male adult soccer players	Previous hamstring injury is the most commonly recognized risk factor. Conflicting evidence is found for age and hamstring flexibility	7 articles		English or German articles Multivariate analysis, logistic regression analysis, Prospective design, males over 18yrs		Acute or overuse injury to the posterior thigh sustained during soccer training or match	Qualitative assessment of methodology	4 articles excluded

Henderson et al (2010) Factors associated with increased propensity for hamstring injury in English Premier League soccer players. *J Sci Med Sport*. 13(4), 397-402.	Prospective cohort study	To investigate the combined influence of a range of physical characteristics and performance capabilities on propensity for hamstring injury over a period of one full season	age and non-counter movement jump performance, decreases in active hip flexion ROM combined. Increase risk of hamstring injury Age was the only variable to be dependently related to pro-pensity for injury (x1.78)	Thirty six healthy, male, elite, professional soccer players (age 22.6±5.2 years)	Injury predisposition based on baseline tests compared to recorded injuries	Anthropometry, active and passive ROM, peak torque, HQ ratio, , counter movement jump (CMJ), non counter movement jump aerobic test anaerobic test	45 week competitive season	One that would result in a player being unable to participate in general training for a period of 48 h or more	Multiple logistic regression analysis was performed to link individual physical and performance capabilities with propensity to sustain a hamstring injury	

Engebretsen et al (2010) Intrinsic risk factors for hamstring injuries among male soccer players: a prospective cohort study. *Am J Sports Med,.* 38(6), 1147-53.	Prospective cohort study	1. to investigate if simple screening tests, can be used to identify individuals at risk. 2. to examine potential intrinsic risk factors for injuries to the hamstrings in a prospective cohort study among subelite male soccer players	A previous acute hamstring injury is a significant risk factor OR < 2	508 players (31 teams). Norwegian 1.-3. Division men	Injury predisposition based on baseline tests compared to recorded injuries match and training exposure taken into account	Questionnaire: 1. previous HSI, age, and player position. 2. HaOS, CMJ, 40m sprint speed, passive ROM palpable soreness, poor hamstring strength (NHL), HQ Ratio	2004 season	Any physical complaint sustained by a player that resulted from a soccer match or soccer training and made him seek medical assistance, as well as, forcing him to miss or being unable to take full part in future soccer training or match play	Multiple logistic regression analysis	1 team (17 players)

Bradley & Portas (2007) The relationship between preseason range of motion and muscle strain injury in elite soccer players. *J Strength Cond Res*, 21(4), 1155–1159.	Prospective cohort study	To determine the influence of preseason lower-extremity range of motion (ROM) on the risk of muscle strain injury during a competitive season for elite soccer players	Tightness of knee flexors is a risk factor to incurring a hamstring injury	36 healthy, male, elite, professional soccer players (age, 25.6 ± 4.7 Years)	Injury predisposition based on baseline tests compared to recorded injuries and player exposure	Maximum static ROM for Hip flexion & extension knee flexion & extension ankle dorsi- and plantarflexion	2003–2004 English FA Premier League season	A recordable injury was defined as any musculotendinous damage to the lower extremity sustained during training or competition that prevented the player from participating in training or competition	A multivariate statistical analysis of all measured variables was performed with the use of a forward stepwise logistic regression procedure	
Ekstrand et al (2006) Risk of injury in elite football played on artificial turf versus natural grass: a prospective two-cohort study. *Br J Sports Med.*, 40(12), 975-980.	Prospective two-cohort study	To examine the injury risk associated with playing elite football on artificial turf compared with natural grass	No significant increase in hamstring injury was found when playing on 3rd generation artificial turf compared with natural grass	The artificial turf cohort (10 teams from Sweden and Europe, 290 players). The control cohort (9 teams from Sweden, 202 players)	Intra-cohort differences in injury incidence (injuries/ 1000h of exposure) in training and match play on artificial turf and grass were used to assess the effect of the playing surface	Playing and training on 3rd generation artificial turf.	4–32 months (mean (SD) 16 (9) months), and all clubs in the control cohort participated over 10 months	An injury resulting from football training or match play leading to a player being unable to take full part in training or match play at any time after the injury	Intra- and inter cohort analysis. Injury incidences were compared using rate ratios	4 out of 10 team in the artificial turf group dropped out

Hägglund et al (2006) Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. *Br J Sports Med*., 40(9), 767–772.	Prospective cohort study	To study whether prospectively recorded injuries during one season are associated with injuries sustained during the following season and to compare injury risk and injury pattern between consecutive seasons	Players with a previous hamstring injury, were two to three times more likely to suffer an identical injury in the following season	12 elite Swedish male football teams 197 players	Injuries compared to reinjuries of the same location. Match and training exposure taken into account	Previous injuries, age, height, weight, and body mass index (BMI)	Two full consecutive seasons (2001 and 2002)	Any injury occurring during a scheduled training session or match causing the player to miss the next training session or match	A multivariate model was used to determine the relation between previous injury, anthropometric data, and the risk of injury	18 players

Arnason et al (2004) Risk factors for injuries in football. *Am J Sports Med.*, 32(1), 5S-16S.	Prospective cohort study	To investigate the incidence of injury (type, location, and severity of injuries in elite male football players and to examine whether different factors (age, body size, body composition, range of motion [ROM], power, jumping ability, peak O2 uptake, ankle or knee instability, previous injury, or player exposure) could be identified as risk factors for injuries	Players with a previous hamstring injury had a seven fold increased risk of sustained a recurrent hamstring injury. Age and previous injury to the hamstring were the two significant risk factors found	306 male football players from the two highest divisions in Iceland	Injury predisposition based on baseline tests compared to recorded injuries and player exposure	Height, weight, body composition, flexibility, ankle and knee joint mechanical stability, power, CMJ, one leg CMJ, standing jump (SJ) height, peak O2 uptake, and history of previous injuries	4 month (1999) study period	A player was defined as injured if he was unable to participate in a match or a training session because of an injury that occurred in a football match or during training	Univariate and multivariate logistic regression analysis to evaluate potential predictor variable	About 50% participated in all tests. All 306 players answered questionnaire

Witvrouw et al (2003) Muscle Flexibility as a Risk Factor for Developing Muscle Injuries in Male Professional Soccer Players: A Prospective Study. *Am J Sports Med*, 31(1) 41-46	Prospective cohort study	To determine whether muscle tightness is a predisposing factor for muscle-tendon injuries of the lower extremities in elite soccer players.	A significant correlation between players with decreased flexibility of the hamstring muscles (less than 90°) and the occurrence of a hamstring muscle injury was found (P 0.02) when tested with active SLR	146 male professional soccer players in the Belgian league. All players with history of muscle injury to the lower extremity were excluded	Injury predisposition based on baseline tests compared to recorded Injuries	Flexibility of the hamstring, quadriceps, adductor, and gastrocnemius muscles was measured goniometrically on both sides	1999–2000 season	Injury was defined as any tissue damage caused by soccer participation that kept a player out of practice or a game	Multivariate analysis with stepwise logistic regression.	

Appendix 3

The bibliographic database MEDLINE was searched via Pubmed (up until 2011). The terms were searched as MESH terms and keywords. From the selected articles, reference lists were checked for further relevant studies.

A. Literature search matrix, MEDLINE via Pubmed for electrode placement procedure:

	Surface EMG	AND	Reliability	AND	Electrode placement
OR	Surface emg		Reliab*		
			Intertester reliability		Electrode position
			Intratester reliability		
			Test retest reliab*		
			Reproduci*		
NOT	"Needle EMG"				

B. Placement of the electrode away from the IZ. Articles selected from literature search. From the articles selected placement of the electrode away from the IZ is proposed (level of evidence III). No level of recommendation concerning the acceptable range of medial-lateral or longitudinal displacement of the hamstring muscle group is proposed due to lack of research.

Name	Type of publication	Conclusion	Level of evidence/ grade of recommendation	Number of participants/ studies	Statistical outcome measurement	ISEK recommendation of data reporting	Data Exclusion/inclusion criteria	Systematic error reported

Beck T.W (2009) Electrode placement over the innervations zone affects the low- not the high-frequency portion of the EMG frequency spectrum. *Journal of Electromyography and Kinesiology*, 19(4), 660-666.	To examine the influence of the electrode placement over the IZ on VL on the shape of the frequency spectrum	Placing the electrodes closer to the IZ affects the frequency bands below 110Hz	Level of evidence III, grade of recommendation C	10	Three way ANOVA, one way and two way ANOVA with tukey post hoc comparison, and paired samples t tests	Yes	No	yes
Finni, T & Cheng, S (2009) Variability in lateral positioning of surface emg electrodes**.** *Journal of applied Biomechanics*. 25, 396-400.	Consistency of medial-lateral positioning of electrodes to *mm. vasti* when using the SENIAM recommendations	Medial-lateral placement of electrodes vary considerably	Recommendation level c	19	SD and range	Yes	No	No
Mesin et al (2007) Surface EMG: The issue of electrode location. *Journal of Electromyography and Kinesiology*. 19(5), 719-726.	Discussion based on simulation and experimental findings	The IZ should be avoided for optimal signal The size of the electrode should be small in order to avoid IZ under movement	Level of evidence III, grade of recommendation C	6 studies and 44 participants	ANOVA; Dunns post hoc test	Yes	yes	yes

Campanini I et al (2007) Effect of electrode location on EMG signal envelope in leg muscles during gait. *J Electromyogr Kinesiol*. 17(4), 515-26.	Analysis of EMG envelope as a result of different electrode locations	Different electrode locations affects the outcome measurements peak and total power	Level of recommendation c	10	Repeatability of time series: CV Variability ratio (VR) to calculate 1. intra subject repeatability and 2. within electrode location variability. ANOVA and post hoc test for pair wise comparison	Yes	yes	no
Wong Y and Ng G (2006) Surface electrode placement affects the EMG recording of the quadriceps muscle. *Physical Therapy in Sports*. 7(3), 122-127.	Reliability study	The electrode positions have great significance on the reading of the timing and strength ratio of VL and VMO The electrodes should not be placed over the innervations zone	d	8 participants	Random error: ICC, CI95%; reliability of repeated measures ANOVA	Yes	No	no

Appendix 4

The bibliographic database MEDLINE was searched via Pubmed (up until 2011). The terms were searched as MESH terms and keywords. From the selected articles, reference lists were checked for further relevant studies.

A. Literature search matrix, MEDLINE via Pubmed; normalization procedure

	Electromyography	AND	Reliability	AND	“normalization procedure”
OR	Surface EMG				
	EMG		Reliab*		“maximum voluntary contraction”
	sEMG		Typical error		MVC
			Reproducibility of results[MeSH]		
NOT	“Needle EMG”				

B. Normalization procedure; Based on articles selected form literature search the normalization procedure “ isometric-arbMVC” is given a recommendation grade d.

Name	Type of publication	Conclusion	Grade of recommendation	Number of participants/ studies	ISEK recommendation of data reporting	Data Exclusion/inclusion criteria	Systematic error reported

Albertus-Kajee Y (2011) Alternative methods of normalising EMG during running. *J Electromyogr Kinesiol.*, 21(4), 579-86	Reliability study	Peak amplitudes during sprint and IsoMVC: good repeatability and reliability for BF 70% peak running showed best for detection of changes between sprints (sensitivity)	d	> 30 participants	Yes	No	no
Albertus-Kajee et al (2010) Alternative methods of normalising EMG during cycling. *J Electromyogr Kinesiol.*, 20(6), 1036-43.	Reliability study	SubMVC as a normalization procedure showed Highest repeatability and reproducibility between tests in cyclic exercise	d	< 30 participants	Yes	No	No
Ball N & Scurr J (2010) An assessment of the reliability and standardisation of tests used to elicit reference muscular actions for electromyographical normalisation. *J Electromyogr Kinesiol.*, 20(1), 81-8.	Reliability study	Peak Normalized EMG of a 20m sprint is highly reliable between days; but ISO- and ISOKIN normalized EMG is not	d	16	Yes	no	no

Burden A (2010) How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. *J Electromyogr Kinesiol.*, 20(6), 1023-35.	Review	Different aims call for different normalizatio n procedures	C			no	
Bolgla LA & Uhl TL (2007) Reliability of electromyographic normalization methods for evaluating the hip musculature. *J Electromyogr Kinesiol.*,17(1), 102-11.	Reliability study	MVIC method provided the highest measureme nt reliability for determining differences in activation amplitudes between hip abductor exercises in healthy subjects	d	< 30 participant s	yes	no	No
Rainoldi et al (2001) Repeatability of maximal voluntary force and of surface EMG variables during voluntary isometric contraction of quadriceps muscles in healthy subjects. *J Electromyogr Kinesiol.*,11(6), 425-38.	Reliability study	High Repeatabilit y of MVC procedure of UE muscles	c	< 30 participant s	Yes	Yes	No

Kollmitzer Jet al (1999) Reliability of surface electromyographic measurements. *Clin Neurophysiol.,* 110(4), 725-34.	Reliability study	50% isometric subMVC performed with visual feedback is the most reliable within and between days normalization procedure compared to the MVC	d	< 30 participants performing 810 repetitions	Yes	no	No

Appendix 5

1

Recommended sensor placement procedure:

- Starting posture
- Lying on the belly with the face down with the thigh down on the mat and the knees Foot rests on top of bench (to ensure same degree of flexion)

- For biceps femoris – thigh in slight lateral rotation
- For semitendinosus – thigh in slight medial rotation

seniam.org

2

Electrode placement biceps femoris

The electrode needs to be placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia.

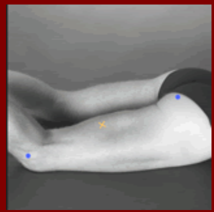
Mark the ischial tuberosity and lateral epicondyle.

Measure the distance with a measuring tape and mark the point with a pen across the thigh.

3

Electrode placement Biceps femoris

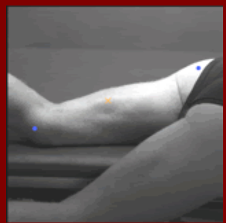
- With the leg in slight <u>lateral rotation</u>
- Ask the subject to perform an isometric contraction of the thigh and mark the top of the muscle belly which appears on the line already drawn



4

Electrode placement semitendinosus

- The electrode needs to be placed at 50% on the line between the ischial tuberosity and the medial epicondyle of the tibia.
- Mark the medial epicondyle
- measure the distance



5

Sensor placement procedure

- skin is shaved over the area of electrode placement (Hamstrings)
- skin is cleaned with Alcohol. Allow time for the alcohol to vaporize

» Seniam.org

6

Electrode placement semitendinosus

- Ask the subject to perform an isometric contraction of the thigh and mark the top of the muscle belly which appears on the line already drawn
- Now you have two marks on the same line

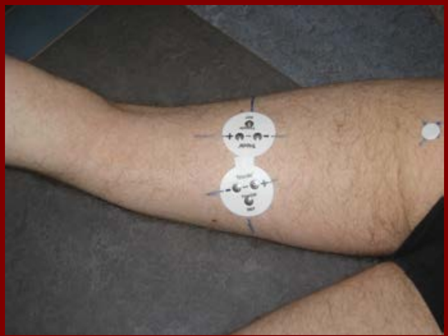
7

Placement of electrode sticker

- Place the electrode-sticker in the direction of the line between the ischial tuberosity and the lateral epicondyle of tibia. Place the reference mark on the sticker facing OUT on the line across the thigh.

8

Electrode Placement



Appendix 6

Háskóli Íslands

Læknadeild

Upplýst samþykki

Gagnreynd próf á aftanlærisvöðvum með þráðlausu EMG til að greina hættu á endurteknum meiðslum

Undirritaður samþykkir að taka þátt í rannsókn á stöðlun prófa sem hugsanlega geta gefið vísbendingar um hvenær einstaklingar eru tilbúnir til þátttöku í knattspyrnu eftir aftanlæristognanir. Með undirskrift þinni staðfestir þú að þú hafir fengið upplýsingar og kynnt þér upplýsingablað um tilgang og markmið rannsóknarinnar og um leið hvaða aðferðum verður beitt, svo og mögulegan ávinning og áhættu af rannsókninni.

Farið verður með allar upplýsingar sem trúnaðarmál.

Þér er frjálst að hætta þátttöku í rannsókninni hvenær sem er á meðan á henni stendur, án allra skýringa.

Reykjavík ______________________

________________________________ ___________________

Undirskrift þátttakanda Kennitala
þátttakanda

________________________________ ___________________

Undirskrift forráðamanns Kennitala
forráðamanns (ef þátttakandi er yngri en 18 ára)

Rannsakandi:

____

Karen Kotila, sjúkraþjálfari

Appendix 7

Háskóli Íslands

Læknadeild

Evidencebased testing on the hamstring muscles with wireless EMG to analyze the risk of recurrent injury

Information to involved participants in research

Supervision: Arni Arnason , PT , PhD , Associate Professor

Affiliation: University of Iceland, physiotherapy , Skógarhlíð 10 , 105 Reykjavik

Email: arnarna@hi.is

Phone : 525 4007

Researcher : Karen Kotila, physiotherapist

Workplace: Morelvej 13 , 4700 Næstved

Email: kkotila@stofanet.dk

Phone : 30 82 00 47

Affiliates: Kine ehf , Bæjarhrauni 8 , 220 Hafnafjordur, Iceland

Dear participant

You are hereby invited to participate in a study to standardize tests on the hamstring muscles with muscle EMG and video recording. This study is part of the master student (Karen Kotila) .

Studies show that muscle strains in the hamstring muscles are the most common injuries footballers suffer . The rate of recurrent injury is high and no reliable measurements are available , which indicate when players are ready to participate in games after hamstring strains .

The aim of this study is to test four functional tests and investigate their reliability in regards to the hamstring muscles. These tests have the potential to indicate when players are ready to compete.

Participants in the study : Four physiotherapists involved in the study act as testers along with forty – eight football players. It is important that players participating in the study are not injured in the legs, do not have symptoms from previous injuries and are not allergic to sports tape . Before the start of the study , participants must sign an informed consent stating that they have received adequate information about the research . If a participant is under 18 years of age, a parent or guardian must also approve his participation in the study and signed informed consent .

Study period

The study will be conducted over two weeks in week 40 and 41 (2009). Participants must attend two sessions and is scheduled for each time takes approximately two hours. First , participants are asked to answer one questionnaire about age , height and weight (within 5 minutes). Then they will be asked to warm up and perform the four tests for the hamstring muscles . Electrodes for for the electromyographic will be placed on the participants‘ hamstring muscles and they are then asked to perform bound jumping, single leg horizontal hop, nordic hamstring lower and 30m sprint (see additional information on poster) .

The benefit / risk of the study

Participants receive information about running at his maximum speed and use hop techniques potentially known from practice. Participants may feel delayed onset muscle soreness after testing , but it depends on the training state of the participant.

Confidentiality of participants

All participants get a running number which will be used for statistical analysis so that the names of participants will not appear anywhere . Once the investigation is complete , all the personal data deleted , so that will be impossible to connect the results with individual players.

Where can you obtain more information relevant to the study ?

If you have questions about the study you may contact the person responsible Dr . Arni Arnason, professor , tel 525 4007 , email arnarna@hi.is or researcher Karen Kotila phone 30820047, email kkotila@stofanet.dk .

Your participation in this study is voluntary and you may withdraw from the study at any time and without any further explanation.

The study has been approved by the National Bioethics Committee and reported to the Data Protection Authority.

Supervision investigator; Dr . Arni Arnason, physiotherapist, Associate Professor

Karen Kotila, physiotherapist

IF YOU HAVE QUESTIONS ABOUT YOUR RIGHTS AS A PARTICIPANT IN RESEARCH OR WANT TO STOP PARTICIPATING IN THE STUDY, YOU CAN CONTACT BIOETHICS, VEGMÚLI 3, 108 REYKJAVIK. PHONE: 551-7100, FAX: 551-1444.

Appendix 7A

University of Iceland
Faculty of Medicine

<u>Information about test session to soccer players:</u>

1. filling out questionnaire
    a. When you arrive for the first test session you will be given an ID number and a questionnaire to fill out. This takes about 5 minutes

2. placement of electrodes
    a. Before you can start being active, a set of 4 electrodes will be placed on the back of your thighs. The electrodes will be placed on you thighs with stickers and these will stay on until the test session is over.

3. warm up
    a. You will start a half an hour warm up consisting of 10 min. jogging, bound jumping, one leg jumping, sub maximal sprinting and light stretching. You will be allowed to practice the tests on your own.
4. testing
    a. The tests consist of 30m sprinting, 3 x one leg jump, 5 x bound jumping and 5 x hamstring lower. You must expect some delay or waiting and you will be allowed to practice the tests on your own during these periods

5. finishing
    a. The total time you spend at one session will be about two hours
    b. there will be light refreshments after testing is finished

Appendix 8

Motion analysis system

EMG unit

dynamic input range	± 2 [mV]
resolution	3.846 [µV/bit]
CMRR	110 dB
input impedance	10 GOhm
analog bandwidth	16-500 Hz
sampling frequency	1600 Hz
battery charge cycles	300 cycles 1C/1C, >80% of capacity
battery shelf storage life	5 years, with annual charging to 40%-60% of capacity
weight of EMG unit	30 g
size of EMG unit	16x46x56 mm
compression	ADPCM

Base unit

input voltage	9[V]
input current	200[mA/channel]
data communication port	RS232

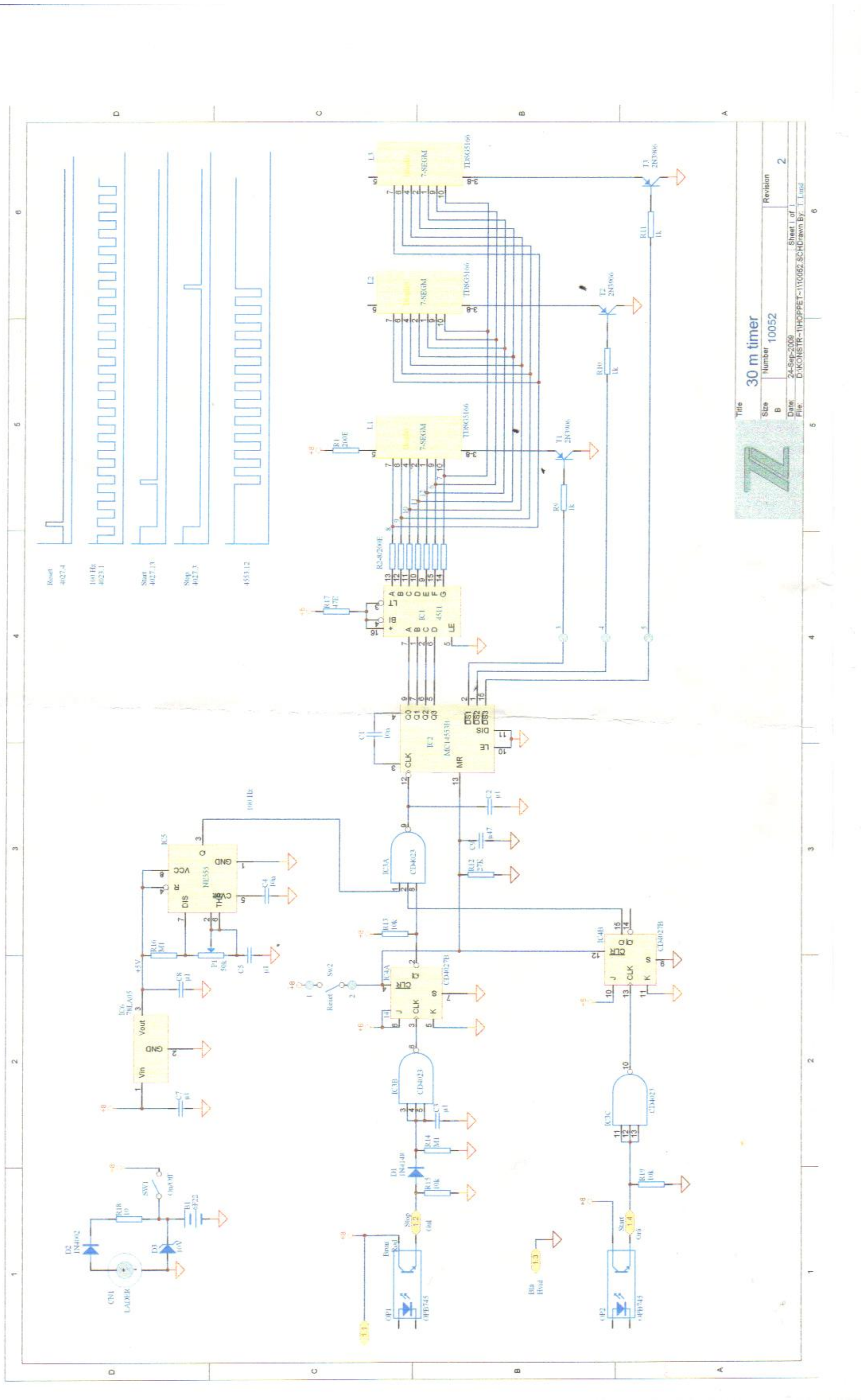
System

communication frequency	433.05 – 434.79 MHz, ISM band
Max number of channels	12
Operating system	Windows 2000 or later

Microsoft Office for documentation.

Appendix 9

Specifications photocell system:



30 m timer betjeningsvejledning

1. Placer målestanderen med det lange kabel ved startmærket
2. Indstil sensorhøjden som ønsket
3. Placer en lysstander overfor målestanderen i en afstand < 2 m
4. Juster og centret lyskeglen mod sensoren
5. Forbind kablet med stikket på standeren med kontrolenheden
6. Placer målestanderen med styreenheden ved slutmærket
7. Indstil sensorhøjden som ønsket
8. Placer en lysstander overfor målestanderen i en afstand < 2 m
9. Juster og centret lyskeglen mod sensoren
10. Tænd styreenheden
11. Tryk *reset*
12. Start testen
13. Noter resultatet og tryk *resset* for næste test

Tekniske data:

Batterier i lysgivere	1,5 V type D
Batteri i kontrolenhed	9 V PP alkaline eller genopladelig celle
Udlæsning	0 – 10 s i spring på 10 ms
Målenøjagtighed	± 5 ms

Appendix 10

Specifications Panasonic camera

Others

Specifications

Digital Video Camcorder
Information for your safety

Power source:
DC 7.9/7.2 V
Power consumption:
Recording
5.2 W

Recording format:
Mini DV (Consumer-use digital video SD format)
Tape used:
6.35 mm digital video tape
Recording/playback time:
SP: 80 min; LP: 120 min (with DVM80)
Video
Recording system:
Digital component
Television system:
EIA Standard: 525 lines, 60 fields NTSC color signal
Audio
Recording system:
PCM digital recording
16 bit (48 kHz/2 ch), 12 bit (32 kHz/4 ch)
Image sensor:
1/6-inch 3CCD image sensor
[Effective pixels]
Moving picture: 640 K×3 (4:3), 540 K×3 (16:9)/
Still picture: 710 K×3 (4:3), 540 K×3 (16:9)/
Total: 800 K×3
Lens:
Auto Iris, F1.8 to F2.8, Focal length; 3.0 mm to 30.0 mm, Macro (Full range AF)
Filter diameter:
37 mm
Zoom:
10:1 Power zoom
Monitor:
2.7-inch LCD
Viewfinder:
Color electronic viewfinder
Microphone:
Stereo (with a zoom function)
Speaker:
1 round speaker ∅ 20 mm
Standard illumination:
1,400 lx
Minimum required illumination:
8 lx (Low light mode: 1/60)
1 lx (MagicPix mode)
Video output level:
1.0 Vp-p, 75 Ω
S-Video output level:
Y Output: 1.0 Vp-p, 75 Ω
C Output: 0.286 Vp-p, 75 Ω
Audio output level (Line):
316 mV, 600 Ω

USB:
Card reader/writer function, USB 2.0 compliant (Hi-Speed)
No copyright protection support
PictBridge-compliant
Digital interface:
DV input/output terminal (IEEE1394, 4-pin)
Dimensions:
78.5 mm (W)×72.6 mm (H)×136.0 mm (D)
3.091 inch (W)×2.859 inch (H)×5.355 inch (D)
(excluding the projecting parts)
Mass:
Approx. 450 g (0.99 lbs)
(without the supplied battery, DV cassette and lens cap)
Operating temperature:
0 °C to 40 °C (32 °F to 104 °F)
Operating humidity:
10% to 80%
Card memory functions
Recording media:
SD Memory Card: 8 MB/16 MB/32 MB/64 MB/128 MB/256 MB/512 MB/1 GB/2 GB (Maximum)
(FAT12 and FAT16 format corresponding)
SDHC Memory Card: 4 GB (Maximum)
(FAT32 format corresponding)

Please confirm the latest information on the following website.
http://panasonic.co.jp/pavc/global/cs

Still picture recording file format:
JPEG (Design rule for Camera File system, based on Exif 2.2 standard), DPOF corresponding
Still picture size:
2048×1512
2048×1152
1600×1200
1280×960
1280×720
640×480
640×360
WEB camera
Compression:
Motion JPEG
Image size:
320×240 pixels (QVGA)
Frame rate:
Approx. 6 fps

Appendix 11 Algorithm for data assessment Color code: pink: KINEPRO;, blue MATLAB; rose: OUTLIER PROCESS-

Algorithm for Hamstring Lower median frequency (MF) assessment

- data extraction from KINEpro: choose all 5 repetitions
- extract as raw signal
- define filter properties by KINE: None
- Objective: the objective is to look at muscle fatigue
- choose threshold RMS on level of 10 and threshold RMS hysteresis of 2
- smoothing process: choose envelope of 1000
- choose input filtres (bandpass filter): 10/20
- Exclusion of data by visual analysis

Algorithm for hamstring lower assessment for maximum power output (MaxRMS)

- data extraction from KINEpro: choose all 5 repetitions
- extract as raw signal
- define filter properties by KINE: None
- Objective: The objective is to look at the maximum power output
- choose threshold RMS on level of 10 and threshold RMS hysteresis of 2
- smoothing process: choose envelope of 1000
- choose input filtres (bandpass filter): 10/20
- Exclusion of data by visual analysis
- MVC normalisation procedure for maximum power output: calculation of MaxRMSnorm: MVCenv1000/MaxRMSNorm HL

Algorithm for sprint Total output (HO)

- data extraction from KINEpro: choose all 7 sprints
- extract as raw signal
- define filter proprties by KINE: None
- Objective: the objective is to look at the total power output
- choose input filtres (bandpass filter):10/20
- smoothing process: choose envelope of 100*
- define leg cycle: choose threshold RMS on level of 50 and threshold RMS hysteresis of 5
- choose timespan: from the 2nd sec to the 4th sec
- Exclusion of data by visual analysis
- MVC normalisation procedure:calculation of HO_*norm*: MVCenv100/HO_Sprint

Algorithm for sprint median Frequency (MF) assessment

- data extraction from KINEpro: choose all 7 sprints
- extract as raw signal
- define filter properties by KINE: None
- Objective: the objective is to look at muscle fatigue
- choose input filtres (bandpass filter):10/20
- smoothing process: choose envelope of 100*
- define leg cycle: choose threshold RMS on level of 50 and threshold RMS hysteresis of 5
- choose timespan: from the 2nd sec to the 4th sec
- Exclusion of data by visual analysis

Algorithm for bound jumping assessment

- data extraction from KINEpro: choose the video frames in which the planting and take off on the white marker is present
- extract as raw signal
- define filter proprties by KINE: None
- Objective: The objective is to look at the maximum power output
- smoothing process: choose envelope of 100*
- choose threshold RMS on level of 10 and threshold RMS hysteresis of 2
- choose input filtres (bandpass filter):10/25
- choose the timespectrum of the landing and take off, defined by the video
- Exclusion of data by visual analysis
- MVC normalisation procedure: calculation of *MaxRMSnorm*: MVCenv100/MaxRMSNormHH
- Statistical analysis

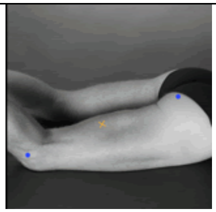
Algorithm for single leg horisontal hop assessment for maximum power output (MaxRMS)

- data extraction from KINEpro: choose longest jump
- extract as raw signal
- define filter properties by KINE: None
- Objective: The objective is to look at the maximum power output
- choose input filtres (bandpass filter): 10/20
- smoothing process: choose envelope of: 100*
- define leg cycle: choose threshold RMS on level 10 and threshold RMS hysteresis 2
- choose the largest spike of them all
- Exclusion of data by visual analysis
- MVC normalisation procedure: calculation of *MaxRMSnorm*: MVCenv100/MaxRMSNormHH

Appendix 12

A. Results; Tests of Between-Subjects Effects: BF

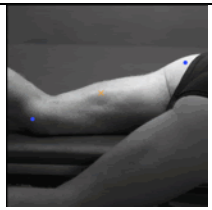
Tests of Between-Subjects Effects



Dependent Variable: *BF*

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Tester	19,536	3	6,512	5,374	,007
Subject	41,013	23	1,783	1,472	,189
Error	25,447	21	1,212		
Total	14405,515	48			
Corrected Total	94,902	47			
RMSE=typical error *BF*			1,10		

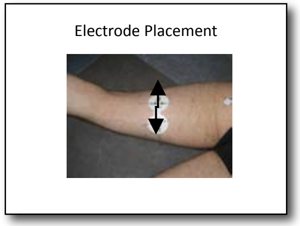
B. Results; Tests of Between-Subjects Effects: MH

Tests of Between-Subjects Effects					
Dependent Variable: *MH*					
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Tester	7.749	3	2.583	5.326	0.07
Subject	44.130	23	1.919	3.957	.001
Error	10,184	21	.485		
Total	15115,590	48			
Corrected Total	63,507	47			
RMSE=typical error for *MH*			0.70		

C. Results; Tests of Between-Subjects Effects: Medial-lateral distance measurement between BF and MH

Tests of Between-Subjects Effects

Dependent Variable: Distance

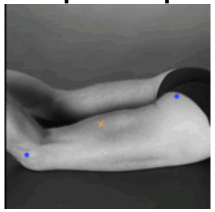

Electrode Placement

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Tester	10,068	3	3,356	4,038	,021
Subject	29,282	23	1,273	1,532	,165
Error	17,452	21	,831		
Total	1780,440	48			
Corrected Total	71,587	47			
RMSE=typical error medial-lateral distance between *BF* and *MH*			0,91		

Appendix 13

A. Results; Tukey HSD; Length measurement BF

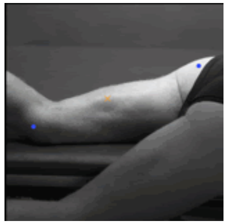
Multiple comparison



(I) Tester	(J) Tester	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.90	.449	.222	-2.15	.36
	3	-1.93*	.459	.002	-3.22	-.65
	4	-.06	.441	.999	-1.29	1.17
2	1	.90	.449	.222	-.36	2.15
	3	-1.04	.459	.140	-2.32	.24
	4	.84	.441	.259	-.39	2.07
3	1	1.93*	.459	.002	.65	3.22
	2	1.04	.459	.140	-.24	2.32
	4	1.88*	.451	.002	.62	3.13
4	1	.06	.441	.999	-1.17	1.29
	2	-.84	.441	.259	-2.07	.39
	3	-1.88*	.451	.002	-3.13	-.62

B. Results; Tukey HSD; Length measurement MH

Multiple comparison



(I) Tester	(J) Tester	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.675	.2843	.113	-1.467	.117
	3	-1.245*	.2907	.002	-2.055	-.434
	4	-.785*	.2788	.047	-1.562	-.008
2	1	.675	.2843	.113	-.117	1.467
	3	-.570	.2907	.235	-1.380	.241
	4	-.110	.2788	.978	-.887	.667
3	1	1.245*	.2907	.002	.434	2.055
	2	.570	.2907	.235	-.241	1.380
	4	.459	.2853	.394	-.336	1.255
4	1	.785*	.2788	.047	.008	1.562
	2	.110	.2788	.978	-.667	.887
	3	-.459	.2853	.394	-1.255	.336

C. Results; Tukey HSD; medial-lateral measurement between BF and MH

Electrode Placement

(I) Tester	(J) Tester	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.51	.372	.533	-1.55	.53
	3	1.37*	.381	.009	.31	2.43
	4	-.35	.365	.775	-1.37	.67
2	1	.51	.372	.533	-.53	1.55
	3	1.88*	.381	.000	.82	2.94
	4	.16	.365	.972	-.86	1.18
3	1	-1.37*	.381	.009	-2.43	-.31
	2	-1.88*	.381	.000	-2.94	-.82
	4	-1.72*	.373	.001	-2.76	-.68
4	1	.35	.365	.775	-.67	1.37
	2	-.16	.365	.972	-1.18	.86
	3	1.72*	.373	.001	.68	2.76

Appendix 14

The bibliographic database MEDLINE was searched via Pubmed (up until 2011). The terms were searched as MESH terms and keywords. From the selected articles, reference lists were checked for further relevant studies.

A. Literature search matrix, MEDLINE via Pubmed; Single leg horizontal hop

	AND		
OR	Reliability	Hopp*	Electromyography
	Reliab* Typical error Reproducibility of results [MeSH]	Jump*	Electromyography [MeSH] Emg sEMG “surface electromyography”

		AND	
OR	Reliability	Hopp*	Electromyography
	Reliab* Evidence based medicine [MeSH] Validity	Jump* Horizontal hopping Forward jumping Horizontal hop Forward hop	Electromyography [MeSH] Emg sEMG “surface electromyography”

	AND	
	Hopp*	Electromyography
OR	Jump*	Electromyography [MeSH] Emg sEMG “surface electromyography”

B. Single leg horizontal hop; articles selected from literature search. Based on literature search grade a of recommendation has been given to the reliability of functional SLHH testing (evidence level D) and grade d of recommendation is given to the reliability of functional testing with EMG of the hamstring muscle group

Name	**Type of publication**	**Conclusion**	**Grade of recommendation**	**Number of participants**	**Outcome measurement**	**Data exclusion criteria described**	**ISEK requirements met**
Meylan et al (2012) The reliability of jump kinematics and kinetics in children of different maturity status. *J Strength Cond Res*. 26(4),1015-26.	Reliability study	Poor reliability of horizontal counter movement jumps indicating that children can alter their strategy to maintain jump performance in the HCMJ	b	42	CV for between days reliability of each individual; %change of mean for systematic error; ICC for relative reliability between subjects;, CV between groups	No	
Munro AG, Herrington LC. (2011) Between-session reliability of four hop tests and the agility T-test. *J Strength Cond Res*. ,25(5),1470-7.	Between days reliability study	Learning effect took place. The jump and agility tests were between days reliable	b	22	ICC, SEM and smallest detectable change for random error,	No	

Fauth et al (2010) Reliability of surface electromyography during maximal voluntary isometric contractions, jump *l*andings, and cutting. *J Strength Cond Res.,24*(4),1131-7.	Reliability study	Peak EMG is a reliable method for testing the quadriceps and hamstring muscles during landing from depth jump and “sprint and cut movements” within a single session	C	24	ICC, CV inter (for variability between subjects), CV intra (for measurement error)	No	yes
Reid et al (2007) Hop testing provides a reliable and valid outcome measure during rehabilitation after anterior cruciate ligament reconstruction. *Phys Ther*., 87(3),337-49.	Prospective study on validity; Between days Reliability study	Hop tests are reliable tests in the post ACL reconstructed rehabilitation	a	42 (35 for between days reliability and 39 for validity study)	ICC, SEM minimal detectable changes (CI%90), pearson correlation between hop distance and self reports.	yes	
Maulder P, Cronin J(2005) Horizontal and vertical jump assessment; reliability symmetry discriminative and predictive ability. *Physical therapy in Sports* 6, 74-82	Between days reliability of single leg jumps; discriminative ability between limbs and Correlation to sprint performance	Horizontal jump tests are reliable between days and correlate better to sprint performance than vertical jumps.	c	18 (10 for between days reliability	ICC; t test for symmetry index; pearsons correlation; CV for within trial variation	yes	

Markovic et al (2004) Reliability and factorial validity of squat and countermovement jump tests. *J Strength Cond Res.* , Aug.,18(3),551-5.	Between days reliability study Standing jump, standing triple jump etc	The horizontal triple jump is highly reliable. Some learning effect takes place.	a	93	ANOVA, and Tukey post hoc for systematic error; cronbach for intertester reliability; CV and ICC for intrasubject reliability		
Hopkins et al (2001) Reliability of power in physical performance tests. *Sports Med.* , 31(3),211-34. Review.		Vertical and horizontal Hop tests are reliable. Caution should be applied to the different methodology	D	3 studies	CV		
Goodwin et al (1999) Reliability of leg muscle electromyography in vertical jumping. *Eur J Appl Physiol Occup Physiol*. , 79(4),374-8.	Reliability study	Poor reliability (ICC 0,24)of the IEMG of the hamstring muscles	c	15	ICC	incomplete	incomplete
Bolgla LA, Keskula DR. (1997) Reliability of lower extremity functional performance tests. *J Orthop Sports Phys Ther.,* 26(3),138-4.	Between days reliability (48 hours) study	Horizontal hop tests are reliable tests; no learning effect took place for the triple hop.	c	20	ICC, SEM	No	

Booher et al (1993) Reliability of three single-leg hop tests. *Journal of Sports Rehabilitation, 2, 165-170*	Reliability study	The one-leg hop test has shown good reliability, with ICCs ranging from .97 to .99	C	18	ICC		

Appendix 15

The bibliographic database MEDLINE was searched via Pubmed (up until 2011). The terms were searched as MESH terms and keywords. From the selected articles, reference lists were checked for further relevant studies.

A. Literature search matrix, MEDLINE via Pubmed; 30m Timed Sprint

		AND
OR	Sprint Sprint*	Electromyography Electromyography [MeSH] Emg sEMG “surface electromyography”
NOT		“Needle EMG”

B. 30m Timed Sprint; articles selected for determining grades of recommendation

Name	**Type of publication**	**Conclusion**	**Grade of recommendation**	**Number of participant**	**Outcome measurement**	**Data exclusion criteria described**	**ISEK requirements met**
Albertus-Kajee et al (2011) Alternative methods of normalising EMG during running. *J Electromyogr Kinesiol*. Aug, 21(4), 579-86.	Between days reliability, repeatability and sensitivity of EMG amplitude	Peak amplitudes during sprint and IsoMVC: good repeatability and reliability for BF 70% peak running showed best for detection of changes between sprints (sensitivity)	C	12	ICC for reliability; CV for intrasubject reliability; Tukey post hoc test for differences between trials ANOVA for calculating significant differences between the methods	No	yes
Ball N & Scurr J. (2010) An assessment of the reliability and standardisation of tests used to elicit reference muscular actions for electromyographical normalisation. *J Electromyogr Kinesiol*. Feb;20(1), 81-8.	Between days reliability study *(m. triceps surae)*	Peak Normalized EMG of a 20m sprint is highly reliable between days; but ISO- and ISOKIN normalized EMG is not.	C	16	Typical error, CV%	No	yes

Schache et al (2009) A biomechanical response to hamstring strain *Gait & Posture*. October issue.	Observational study	An evident change in stride was observed immediately before injury occured		1			
Wragg et al (2000) Evaluation of the reliability and validity of a soccer specific field test of repeated sprint *European Journal of Applied Physiology*. 83, 77-83	Reliability study	The modified Bangsbo sprint test is a reliable test	C	7	CV, ANOVA, tukey post hoc	No	
Wiemann K, Tidow G (1995) Relative activity of hip and knee extensors in sprinting - implications for training. *New Studies in Athletics.* 1, 10, 29-49.	Experimental observational study	Among other: Hamstring muscles are active through the whole stance phase		12	Average of rectified EMG data from 12 sprinters	No	yes

Appendix 16

The bibliographic database MEDLINE was searched via Pubmed (up until 2011). The terms were searched as MESH terms and keywords. From the selected articles, reference lists were checked for further relevant studies.

A. Literature search matrix, MEDLINE via Pubmed; threshold level for analysis

	EMG	AND	Threshold level	AND	Analysis
OR	Electromyogram		Onset		Processing “data analysis”

B. Threshold level; articles selected

Title/ Author	Outcome	Level of recom-mendation	Aim/ type of research	Number of samples/ participants.	Fulfill recommendations from ISEK on procedure reported	Analysis procedure	Data exclusion criterias	Blinding procedure
Özgünen KT et al (2010) Determination of an optimal threshold value for muscle activity detection in EMG analysis. *Journal of Sports Science and Medicine*, 9, 620-628.	Different activity levels and different activities call for different threshold levels	d	Observational study to determine a proper threshold value in a constant speed incremental cycling exercise for accurate EMG signal analyses	9	yes	3 different threshold levels are analyzed: 25%, 35% and 45% of the mean RMS EMG value. The appropriateness of these threshold values was tested using two criteria: (1) significant correlation between the actual and estimated number of bursts and (2) proximity of the regression line of the actual and estimated number of bursts to the line of identity	no	no

Vaisman L et al (2010) Application of singular spectrum-based change-point analysis to EMG-onset detection. *Journal of Electromyography and Kinesiologi*, 20(4), 750-60.	the SSA-based change-point detection algorithm applied using a simple ‘‘maximum change event” detection algorithm is comparable to Hodges and Bui (1996) and has significant benefits in terms of automated real-time implementation.	c	The aim is to compare the results of the proposed SSA-based algorithm of detecting a threshold level To Hodges and Bui’s method, (1996) and Donoho’s wavelet-based denoising (1995)	< 30 subjects	yes	The proposed change-point detection algorithm was tested using existing EMG data from two different previous experiments. The first consisted of a wrist extension task, whereas the second involved recording trunk muscle activity during sitting. The error of the 3 algorithms was compared to the golden standard “expert visual inspection of signal”	no	
Johanson ME & Radtka SA (2006) Amplitude threshold criteria improve surface electrode specificity during walking and functional movements. *Gait Posture,* 24(4):429-34.	Threshold level above 15%MVC should be used in assessment of m *penoneus longu*s, mm. *tricpeps surae* and m. *tibialis anterio*r	c	Observational study The purpose of this study was to compare the duration of the EMG signal (within a movement or gait cycle) after removing 5%, 15%, and 18% of the normalized EMG signal.	19	no	Crosstalk was defined as out of phase, low amplitude EMG activity recorded by the surface electrode that was not present on the recording from the wire electrode from the same muscle.	Trials were excluded from the analysis if noise, motion artifact, or poor wire electrode signals were present.	no

Staude et al (2001) Onset Detection in Surface Electromyographic Signals: A Systematic Comparison of Methods; *EURASIP Journal on Applied Signal Processing,* 2, 67– 81	Threshold-based methods represent a trade off between detection precision and detection probability. A relatively low threshold level results in early onset detection but also causes more false alarms. High threshold levels usually lead to delayed or even missed onset detection	c	The aim of this paper is to objectively compare the performance of commonly used onset detection methods	1. 4000 trials of simulated tests. 2. 5 subjects each performing 120 responses to a visual stimulus.	yes	1. Simulated SEMG traces, each consisting of 4000 trials, were used for testing the onset detection algorithms. 2. EMG was recorded from the index finger performing a tap each time a visual stimulus was detected. The EMG data was analyzed using the different onset algorithms and compared for its error.	no	no

Hodges PW & Bui BH (1996) A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. *Electroencephalography and Clinical Neurophysiology*, 101, 551–519	Several methods accurately selected the time of onset of EMG activity and are recommended for future use	c	The aim of this study was to compare the relative accuracy of a range of computer-based techniques with respect to EMG onset determined visually by an experienced examiner	a random sample of recordings of EMG activity collected for another study (Hodges and Richardson, in preparation), involving 4 subjects	yes	All traces were evaluated both visually and by a series of computer-based onset determination methods. The examiner calculated the onset times for all traces to evaluate the repeatability of the visual recordings. The mean of the visually determined onset times between days was used for evaluation of the computer-based methods. A set of standard deviations (1-3) was used for each of the 27 different computer-models for evaluation of muscle onset.	If no onset signal was visible the data was recorded as missing data. If the signal showed artifacts etc it was eliminated from further analysis	Each muscle was displayed separately on the screen with no reference to the start of the movement to remove potential bias of the examiner.