SPORTS AND EXERCISE SCIENCE - HUMAN PEFRFORMANCE 60 ECTS

MASTER THESIS

Hip and trunk muscle electromyography differences between bilateral and unilateral bodyweight resistance exercises

Björn Frandsen

Master Thesis in Exercise Physiology
30 ECTS

Halmstad 2013-08-25

Hip and trunk muscle electromyography differences between bilateral and unilateral bodyweight resistance exercises

-A master's thesis in Sports and Exercise Science – Human Performance

Björn Frandsen

2013-June-03

Master Thesis (30 ECTS) in Sports and Exercise Science – Human Performance

Halmstad University

School of Business and Engineering

Thesis advisor: Charlotte Olsson, Department of Business and Engineering

Thesis examinator: Ann Bremander, Department of Business and Engineering

Abstract

Background. Force production and movement in sports are predominantly performed in a unilateral weight-bearing stance, therefore a resistance training program should closely resemble sport specific unilateral leg kinetics. Hip- and trunk-stabilizing muscle activity increases as the relative body weight balance changes from a bilateral to a unilateral stance, and these muscles are thought to play a central role in sports performance and injury prevention. Hip stabilizing muscles prevent internal rotation and medial adduction, therefore lacking strength in these muscles may well increase the quadriceps angle (QA). **Aim**. The aim of this study was (a) to examine the electromyographic (EMG) activity in hip and trunk muscles in three bodyweight exercises performed in a bilateral and a unilateral stance and, (b) to study the correlation between gluteus medius maximal voluntary contraction (MVC) activity and the QA in a drop-jump screening analysis. **Methods**. 14 healthy, young adults participated in a single session, single-group, observational study. Manual muscle testing was used to attain a MVC value for each specific muscle (gluteus medius (Gmed), gluteus maximus (Gmax), rectus abdominis (Rabd), and erector spinae (Espi)) and performed exercises were squat, bridge, and plank, both performed in a bilateral and a unilateral stance. A drop-jump screening analysis was performed to examine the correlation between Gmed MVC and the QA at the knee joint. **Results**. In all three exercises, there was a significant increase in EMG activity in the unilateral stance compared to the bilateral stance in both Gmed and Gmax ($p< 0.05$ for both muscles). Furthermore, in plank, there was a significant increase in trunk muscles (Rabd; $p< 0.05$, Espi; $p< 0.05$) in unilateral stance compared to the bilateral stance. In squat and bridge, no differences were identified in EMG activity for the trunk muscles (Rabd, Espi) between the bilateral and the unilateral stance. No correlation was found ($r= 0.34$) in the drop-jump screening analysis between Gmed MVC and the QA. **Conclusion**. Our results showed that all unilateral exercises activated (assessed by EMG) the hip muscles investigated (Gmed, Gmax) more than double compared to the same exercises performed bilaterally (except for Gmax in bridge). These results indicate that training performed on one leg activates hip stabilizing muscles to a greater degree than when the exercise is performed on two legs and, consequently, a unilateral training program might be beneficial for developing hip strength which is of great importance in sports performance as well as in injury prevention.

Table of content

Introduction

Resistance training, defined as static or dynamic muscle actions with various resistances, was once believed inappropriate for athletes that did not compete in weight-lifting or track and field events. At present, most athletes (including females who were traditionally excluded from such training) implement resistance training into weekly routines. In addition, resistance training is also considered as important for non-athletes who seek the health-related benefits associated with resistance training (Wilmore & Costill, 1999). Hip and trunk muscles stabilize the pelvis and trunk to maintain gait and posture control, as well as transfer force through the lower extremities during various movement patterns (Lanning, Uhl, Ingram, Mattacola, English, & Newsom, 2006). These muscles are believed to play a central role in maintaining proper technique and posture in resistance training, sports performance, injury prevention and many other activities of daily life (Behm, Leonard, Young, Bosney, & MacKinnon, 2005). Resistance training is traditionally performed on two legs (bilateral), however many sports are predominantly performed on one leg (unilateral) in an asymmetric, weight bearing stance. Thus it might be appropriate if a resistance training program should more closely resemble sport specific unilateral leg kinetics that include more unilateral resistance exercises.

A shift towards a unilateral stance in ground-based exercises would enhance the development of hip and trunk muscles compared to the conventional bilateral stance. The general aim of this study was to compare the magnitude of electromyographic (EMG) activity in four hip and trunk muscles (gluteus medius (Gmed), gluteus maximus (Gmax), rectus abdominis (Rabd), and erector spinae (Espi)) in three body weight exercises each performed bilaterally and unilaterally, and to correlate EMG activity in Gmed maximal voluntary contraction (MVC) and the quadriceps angle (QA) of the knee in a drop-jump screening test. In an exercise physiology viewpoint this study increases the knowledge regarding hip and trunk muscle EMG activation differences between bilateral and unilateral bodyweight resistance exercises, and whether unilateral resistance training may contribute to strengthen investigated muscles, which in turn may improve sports performance or/and avoid lower extremity dysfunction or injury.

Background

Resistance training

Resistance training induces adaptive changes in skeletal muscle that lead to improved neuromuscular functions. This contributes to an increase in maximal contractile muscle force and power, in trained and untrained, young and old, women and men. Therefore, resistance training in about every individual leads to improved mechanical muscle function which subsequently improves functional performance in sports and various activities in daily life (Cardinale, Newton, & Nosaka, 2011). One kind of resistance training is bodyweight exercises, with distal body segments carried by the body weight activates agonists and antagonists muscles around a joint. This is being considered more functional than traditional weight-lifting training where agonist and synergist often are activated simultaneously around a joint. Furthermore, greater antagonist activity appears to enhance power and force production, as well as injury prevention (Beachle & Earle, 2008).

The kinetic chain is defined as “the coordinated, sequenced activation of body segments that places the distal segment in optimum position at the optimum velocity with the optimum timing to produce the desired athletic task” (Kibler, Press, & Sciascia, 2006). In order to produce fast and powerful movements in sports, the kinetic chain transmits ground reaction forces (the reaction to the force the body exerts on the ground) through the lower body, and trunk and hip muscles. The ability to swiftly generate power is vital in competitive sports, and most ground-based sports often require asymmetric, single leg force production when jumping, running, bounding, or changing direction (Jones, Ambegaonkar, Nindl, Smith, & Headley, 2012). The hip and trunk muscles plays an important role within the kinetic chain to stabilize pelvis and trunk, to maintain gait and posture control, and to transfer force through the lower extremities towards the spine during various movements (Borghuis, Hof, & Lemmink, 2008).

Unilateral training

Exercises performed on one leg (unilateral) places greater demand on hip and trunk muscles compared to exercises performed on two legs (bilateral) due to a disruptive torque to the body, as well as the additional load placed on a smaller ground surface which further provide an unstable condition (Behm et al., 2005). Therefore, unilateral weight-bearing exercises are often used with the intention to train and strengthen muscles of the hip as well as the trunk. A well-designed, sport-specific unilateral resistance training program enhances the replication of the target sports with asymmetric kinetics in lower extremities by closely resemble the mechanics and forces required to perform the necessary, sport specific skills. Accordingly, unilateral resistance training may possibly elicit more sport-specific strength gains compared to traditional bilateral strength training benefits (Jones et al., 2012). One reason why unilateral exercises are seldom prioritized or implemented as assistance exercises could be due to the lack of scientific data investigating the potential strength and power differences between unilateral and bilateral resistance training. One study investigated unilateral and bilateral lower-body resistance training and found that they were equally effective for early phase improvement of leg strength and power in untrained individuals, however the unilaterally trained group significantly improved their vertical jump more than the bilateral group did (McCurdy K. , Langford, Doscher, Wiley, & Mallard, 2005).

The unilateral squat, also known as pistol squat, has been suggested an effective exercise in lower-body, ground-based resistance training. In a study that assessed surface EMG and testosterone concentrations in bilateral squat and unilateral squat, no significant difference were found between bilateral squat and unilateral squat EMG activity (vastus lateralis, biceps femoris, Gmax, Espi) or testosterone concentrations (Jones et al., 2012). However, it was concluded that the relative intensity in a unilateral squat may be greater than the bilateral squat and therefore enhance the force development and sport-specific strength gains of unilateral squat compared to bilateral squat.

The Gmed, which acts to stabilize the hip in both frontal and transverse planes, is often the primary muscle of interest in unilateral exercises, and by using EMG techniques several researchers have found that Gmed is recruited in unilateral lower-body resistance training (Homan, Norcross, Goerger, Prentice, & Blackburn, 2012; Krause, Jacobs, Pilger, Sather, Sibunka, & Hollman, 2009). A systematic review of observational studies conducted 2008 demonstrated that women with patellofemoral pain syndrome have weaker hip abductors, extensors, and external rotators on the affected side, compared to healthy subjects. (Prins & Van der Wurff, 2009). In another study, injury resistant athletes were compared to injury prone athletes, and results indicated that injury resistant athletes had significantly stronger hip abductors (mainly Gmed) compared to injury prone athletes who had weaker hip abductors (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004).

Exercises investigated in the present study (squat, bridge, and plank) were chosen to activate hip and trunk muscles and with the option to be performed both bilaterally and unilaterally without changing the structure of the movements. Squat, bridge, and plank are ground based, categorized as closed chain exercises, with several muscle groups as well as multiple joints work simultaneously. Squat is a full body exercise within resistance training practices that increase lower body strength as well as hip and trunk strength, and all exercises are common exercises within rehabilitation programs and core strength development programs (Ekstrom, Donatelli, & Carp, 2007).

Core stability in bilateral and unilateral resistance training

Decreased core stability has been suggested to contribute to the etiology of lower extremity injuries, as well as weakness and poor endurance in the lumbar extensors. Specific strengthening of core muscles may improve athletic performance and injury prevention (Ekstrom et al., 2007). The definition of "core stability" has become a term often being misunderstood, or confused with core strength. Core stability is defined as "the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in the integrated athletic activities" (Kibler et al., 2006). Core strength is defined as "the ability of the muscles to produce force via contractile forces and intra-abdominal pressure" (Faries & Greenwood, 2007). The definitions above have an intrinsic uniformity as there is a central relationship between core muscle strength and its ability to function as body component stabilizers.

The concept of "core training" refers to the four-sided muscular frame with abdominal muscles in the front, paraspinal and gluteal muscles in the back, the diaphragm at the top, and the pelvic floor and hip girdle muscles in the bottom (Enoka, 2008). The core include 29 muscles that cooperate to hold the trunk steady, and balance and stabilize the bony structures of the spine, pelvis, thorax and other kinetic chain structures of activated during most movements. Without adequate strength and balance in the core, these muscles would become mechanically unstable, and consequently disturbances would occur in force distribution, optimal control and efficiency of movements, and shearing forces on kinetic chain joints (McArdle, Katch, & Katch, 2010).

In a research report conducted year 2007, core muscle activity (assessed by EMG) were investigated in nine rehabilitation exercises, and results present the bridge and plank exercises well suited as specific exercises to enhance a core training program (Ekstrom et al., 2007). One study investigated trunk muscle EMG with unstable and unilateral exercises, and found an overall increase in lower-abdominal muscle EMG activity as a result of unstable exercises and greater trunk stabilizer muscle activation found in unilateral resistance exercises (Behm et al., 2005). Ekstrom et al., (2007) found that overall unilaterally performed exercises increased EMG activity levels in trunk and hip muscles compared to bilaterally performed exercises from a rehabilitation program. Another study investigated the muscle activity of the core during seated, standing and bilateral, unilateral resistance exercise. The exercise performed was dumbbell shoulder press, yet the conclusion was drawn that in to enhance muscular activity (assessed by EMG) of the superficial core muscles, standing exercises should be used instead of seated exercises, and unilateral exercises should be used instead of bilateral exercises (Saeterbakken, 2012). Behm et al., (2005) analyzed trunk muscle EMG activity (upper lumbar, lumbosacral erector spinae, and lower abdominal muscles) in unilateral and unstable exercises and found that an overall increase in trunk-stabilizing muscles were displayed in unstable exercises compared to stable exercises. Moreover, in unilateral resistance exercises using single arms also cause greater EMG activity of the contraleral side. The authors conclude that in order to strengthen the endurance of the trunk stabilizers for activities of daily life, sports performance or rehabilitation, resistance training exercises should include a destabilizing component. Consequently, resistance exercises performed in a unilateral stance with a destabilization component elicit greater muscle EMG activity of core and hip.

There are discrepancies regarding the importance of core stability in sport performance, low back pain rehabilitation, and injury prevention. One review article examining aspects of core stability and core strength program approaches (with the mindset that these types of programs are misconceived) concluded that athletes with low back pain most likely waste time by performing non-functional core specific training programs (Brooks, 2012). Rather, the investigators recommend that athletes with low back pain should withdraw from spine overload stressors, and focus on relearning correct movement techniques and use functional movements to correct muscular imbalance. Recommendations were made that non-athletes would benefit from gradual introduction to an overall physical fitness program to reach a physiological capacity required by activities of daily life (Brooks, 2012). A critical review published 2010 concluded that core stability programs are no more effective, and will not prevent injury or reduce lower back pain than any other form of exercise of physical therapy (Lederman, 2010). The author concluded that weak or dysfunctional abdominal muscles will not lead to lower back pain, rather continuous tension of trunk muscles during daily life or sport activities may potentially harm or damage the spine (Lederman, 2010).

Knee valgus and injury prevention

Knee valgus describes the medial knee displacement and may be used a predator for lower extremity dysfunction. During jumping and landing tasks knee motion and knee loading are predictors of knee anterior cruciate ligament injuries, along with other knee ligament injuries (Hewett, et al., 2005). Various musculoskeletal disorders such as iliotibial band syndrome, anterior cruciate ligament injuries, patellofemoral pain, low back pain, and hip joint pathology have been associated with abnormal hip kinematics and impaired hip muscle performance (Selkowitz, Beneck, & Powers, 2013). A way to measure the degree of knee valgus is by assessing the quadriceps angle (QA). The QA is the line of force from the quadriceps muscle, formed by a line drawn from the anterior superior iliaca spina (ASIS) to central patella and a second line drawn from central patella to tibial tubercle. Since it is not possible to measure the line of force clinically, it is commonly accepted that a line from the ASIS to the center of the patella acts as a substitute to measure the QA. The normal QA displayed in med are 14 degrees and the normal QA displayed in women are 17 degrees (Conley, 2007).

In rehabilitation protocols there has been an increased focus on hip muscle strength development. The Gmed muscle plays a central role that prevents lower extremity kinetic malfunction, which with a lack of strength may give rise to several knee ligament injuries, and according to Comfort & Abrahamson, (2010) the “gluteus medius is critical for control of knee valgus via its ability to limit excessive femoral adduction and internal rotation”. Knee joint valgus is further linked to traumatic non-contact injury to the anterior cruciate ligament , medial collateral ligament, and lateral meniscus as well as non-traumatic gradual onset knee joint pain (Homan et al., 2012). Hip muscles strength influence knee valgus motion indirectly by determining neural drive requirements on biomechanical parameters thought to be associated with greater ACL loading and injury risk, along with its role to prevent pelvic drop and medially knee rotation (Homan et al., 2012). Thus, exercises for Gmed are important in knee injury prevention and rehabilitation programs.

By strengthen hip and trunk muscles, athletes may better protect the lumbar regions by spinal support and reduce lower extremity dysfunction kinetics, which might prevent the formation of knee ligament injuries (Ekstrom et al., 2007). Athletes should strive for sufficient strength in hip and trunk muscles to provide stability in all anatomical planes of motion in view of the broad diversity of movements athletes use (Lanning et al., 2006). Hip and trunk muscles play a crucial role in sports that involves swing moves such as golf or baseball where accuracy and maximal power is necessary, as well as injury prevention and enhance athletic performance (Leetun et al., 2004).

The most prevalent injuries incurred by athletes are musculoskeletal injuries, with lumbar spine and lower extremities being the most disabling. These injuries are often attributed to poor endurance or weakness in hip and trunk muscles (Lanning et al., 2006).
In order to assess the QA, the drop-jump screening analysis has commonly been used to screen lower extremity alignment and control in young athletes, and its reliability has been established moderate to high, as a result, the drop-jump screening test is a useful tool to help physiotherapists make clinical decisions about lower extremity dysfunction, and injurious movement patterns in young athletes (Whatman, Hume, & Hing, 2012). Consequently, the drop-jump screening analysis will be implemented in this study to evaluate the degrees of knee valgus assessed by the QA.

Aim

The aim of this study was to examine the difference between bilateral and unilateral EMG muscle activation in hip and trunk muscles (Gmed, Gmax, Rabd, Espi) in three bodyweight exercises (squat, bridge, plank) . In addition, this study aimed to investigate if there was a correlation between the degrees of muscle activation in Gmed and QA in a drop-jump screening test. Our hypothesizes were that (a) a higher EMG activity would be found in the unilateral stance compared to the bilateral stance in all exercises due to the additional load in the unilateral stance, and (b) a correlation would be found between Gmed MVC and the QA in a drop-jump screening analysis.

- Research question 1a; is there a difference between a unilateral and bilateral squat exercise in the muscles Gmed, Gmax, Rabd, and Espi?
- Research question 1b; is there a difference between unilateral and bilateral bridge exercise in the muscles Gmed, Gmax, Rabd, and Espi?
- Research question 1c; is there a difference between unilateral and bilateral plank exercise in the muscles Gmed, Gmax, Rabd, and Espi?
- Research question 2; is there a correlation between MVC EMG activity in Gmed (from the manual muscle test) and the QA in a drop jump screening analysis?

Methods

Subjects and experimental design

14 healthy, young adults (13 males, 1 female, BMI; 24,01 kg ± 1,51, age 23,69 years ± 2,29) participated in this single session, single-group, observational study. Inclusion criterions were that subjects were familiar with resistance training, and injury free at time of investigation. Subjects were thoroughly familiarized with the procedure guidelines, the exercises and the manual muscle testing which were being practiced until performance was in alignment with guidelines to attain a general standard (Hislop & Montgomery, 2007). Exercises, manual muscle testing, and the drop-jump tests were performed bare foot, to exclude a potential influence on stability from wearing shoes. Exercises performed were squat, bridge, and plank, performed with three repetitions bilaterally and unilaterally, respectively, and muscles assessed were Gmed, Gmax, Rabd, and Espi.

Standardization

In an attempt to standardize exercises and manual muscle testing, a wooden rod was used to achieve proper technique and desirable range of motion in exercises. In squat, the rod was held with shoulder-width grip and straight arms over the head, and a device (plastic binder) was used in squat to reach a depth that attained a 90˚ knee angle. In plank, the rod was held by the experiment leader between ankle joint and shoulder joint to achieve a straight line, and in bridge the wooden rod was held by the experiment leader between knee joint and shoulder joint to establish that the hip joint reached a position in align with the knee and shoulder joint at the end phase of the exercise. A metronome was used to pace proper speed of performance in exercises with two seconds in the eccentric phase and two seconds in the concentric phase. The right leg was used for unilateral exercises in all subjects, and consequently, electrode placement was made on the right side during the entire experiment. No concern was given in regard to exercises performed on the dominant versus the non-dominant leg, since unilateral strength is similar in dominant and non-dominant legs in healthy subjects (McCurdy & Langford, 2005).

Electromyography and manual muscle testing

EMG signals were collected with surface electrodes in “RAW free” mode and processed with an average root mean square algorithm for all conditions. Data was collected by a four channel EMG recorder (Muscle Tester 6000 Megawin, Kuopio, Finland) and frequency set to 1-1000Hz. EMG cross-talk was minimized by placing the electrodes within the border of the specific muscle, and with a center-to-center interelectrode distance of 22 mm (Criswell, 2011). Recordings were made in all three repetitions for both the bilateral and the unilateral squat and bridge, and in plank, recordings were collected for 12 seconds both bilaterally and unilaterally. EMG signals of average and peak EMG activity were collected from all exercises, whereof peak EMG activity was analyzed and evaluated in the study.

Electrodes were placed according to manufacturer's guidelines (Megawin Software manual, Kuopio, Finland). Electrodes for Gmed were placed anterosuperior to the Gmax muscle and just inferior to the iliac crest on the lateral side of the pelvis. For the Gmax muscle, electrodes were placed in the center of the muscle belly between the lateral edge of the sacrum and the posterosuperior edge of the greater trochanter. Rabd electrode placement were placed 3 cm lateral and 3 cm superior of the umbilicus, and Espi electrode placement were 4 cm lateral to the L1 spinous process (Criswell, 2011).

In order to determine the MVC for each muscle investigated a manual muscle test was implemented (Hislop & Montgomery, 2007). Manual resistance was applied by the experiment leader to increase the load and subsequently the MVC for the specific muscle. Three trials were performed for each muscle with one minute rest in between to avoid muscular fatigue. A mean value was calculated of peak value from each trial and set as the 100% MVC reference value. The manual muscle tests followed guidelines in accordance to Hislop & Montgomery (2007), and the test for Gmed was in a side-lying position while hip abducted to 45 degrees and resistance was applied just above the knee. Gmax was tested in a prone position with the knee flexed at 90 degrees with applied resistance at the lower part of the hamstrings. Rabd was tested in a 45 degree curl-up with feet on the floor with additional resistance on the shoulders, and Espi was tested in a prone position with additional resistance on shoulders (Hislop & Montgomery, 2007).

Muscles assessed in this study (Gmed, Gmax, Rabd, and Espi) constitute fundamental parts of the core, however, due to discrepancies regarding the core as a generally accepted definition these muscles will be referred to as parts of the hip and trunk muscles. The anatomical function of Gmed is to abduct the femur as well as to (a) the anterior portion internally rotates the hip and (b) the posterior portion extends and externally rotates the hip. Furthermore, Gmed holds pelvis secured in a horizontal plane over stance and therefore prevents pelvic drop on the opposite swing side during walking. The functions of Gmax is of a powerful extensor of a flexed femur at the hip joint, as well as to stabilize the hip and knee joint in a lateral plane and laterally rotates and abduct the thigh. The function of Rabd is to compress the abdominal content, flex vertebral column and tense the abdominal wall. The function of Espi (which is an umbrella term for a bundle of muscles and tendons running vertical along the back) is to extend the vertebral column. These muscles also straiten the back, returning it to an upright position from a flexed position and pull the head in a posterior direction. Furthermore, acting unilaterally Espi bend the vertebral column laterally (Drake, Wayne, Volg, & Mitchell, 2010; Behnke, 2006).

The drop jump screening analysis

The drop-jump screening protocol, to assess the QA, was being analyzed with a 2-Dimensional video assessment in frontal plane, filmed with a digital camera (Canon Ixus 220 HS) in super slow-motion mode. The digital camera was placed two meters from the box at 20 cm height. The drop-jump was performed with double legs from a 30 cm wooden box. Subjects were instructed to drop down of the box followed by a maximal vertical jump. The drop jumps were performed bilaterally with three repetitions. To identify the degrees of the QA, pieces of duct tape (2×2 cm) were placed on both legs at mid patellae, ASIS, and the talus bone at the foot joint similar to previous experimental study (Whatman et al., 2012). The drop-jump was assessed at landing phase, at turning point (deepest phase), and at take of phase. The jump that demonstrated the largest QA was used for analysis. The QA was analyzed in Kinovea (Kinovea Software v.8.15) between ASIS, mid-patellae, and the talus bone that represented the "straight" 180 degrees line. Knee movements in a medial direction from this "straight" line were calculated as degrees of QA (Hewett, et al., 2005).

Ethics and social considerations

Subjects were informed of the purpose of the study and were given a consent form (appendix) to read, understand, and sign. Requirements for the hip and lower trunk to be shaved could be a cause to discomfort, however, all subjects were well informed of the procedure before beginning the EMG preparation and were informed that they could terminate their participation at any time without having to explain why. Klorhexidin (Fresenius Kabi 0.5 mg/ml) was applied to increase skin conductance by cleaning the areas and in the endeavor to reduce itching. There were no identified risks by taking part in the study except the possibility for some muscle soreness during subsequent day(s). Instead, benefits could be an increased knowledge and experience in unilateral resistance training.

Statistical analysis

Data were collected with the Muscle Tester 6000 (Megawin Software, Kuopio, Finland), converted to Microsoft Office Excel, and copied to IBM SPSS Statistics v. 20.0 (IBM Business Analytics, U.S.) for statistical analysis. The p-value was set to $p < 0.05$ for statistical significance. In figures the symbol * was used to represent statistical significance and the symbol ** was used to represent clear statistical significance. All results are presented as sample means and standard deviations (SD). Pearson's correlation coefficient (r) was used to calculate the correlation between EMG µV activity in Gmed and QA since data was normally distributed. In SPSS, an analysis was run to assess data distribution of normality. Results from Shapiro-Wilks indicated that not all data followed a normal distribution, therefore paired-sample t-tests were performed between bilateral and unilateral exercises for each muscle (both % of MVC and as µV) in 38 dependent variables, and Wilcoxon two-related-samples tests were performed on the 10 variables that were not normally distributed to analyze significance.

Results

This study examined EMG activity in four hip and trunk muscles (Gmed, Gmax, Rabd, Espi) in squat, bridge, and plank performed both bilaterally and unilaterally (table 1-3) in 14 healthy, young adults during a single session, single group, observational study. The MVC activity for each specific muscle was set to 100% as the reference value. In addition, a drop-jump screening analysis was performed to study the correlation between Gmed EMG activity (MVC) and QA (table 4).

Squat

Figure 1 and table 1 shows that in the squat exercise, there was a significant increase in EMG activity in the unilateral stance compared to the bilateral stance in both Gmed and Gmax ($p < 0.01$ for both). No significant difference between bilateral and unilateral stance was found in the trunk muscles Rabd or Espi.

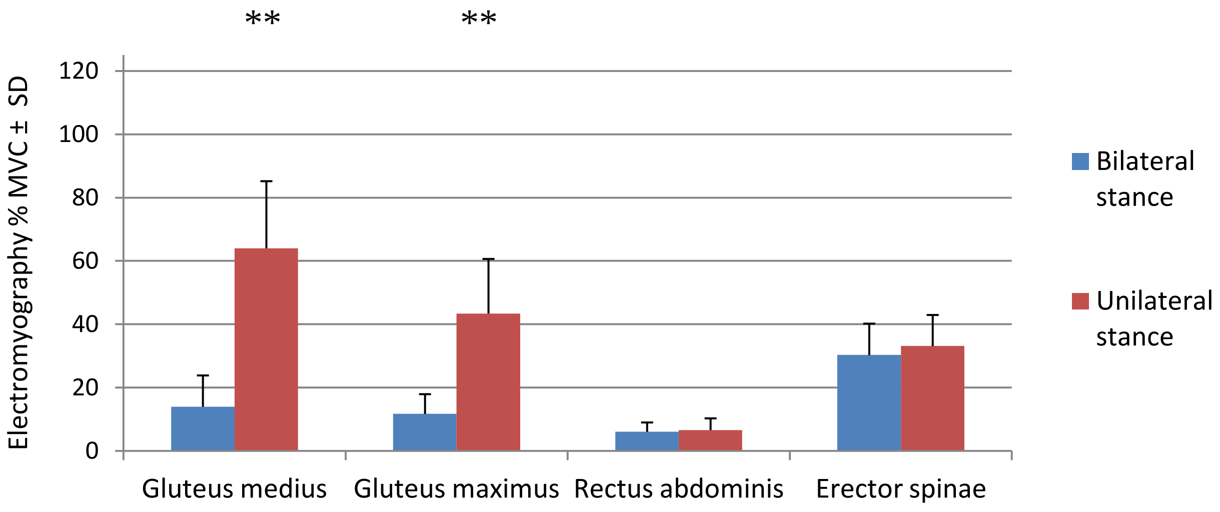

Figure 1. Sample mean + 1 standard deviation EMG activity as percent of maximal voluntary contraction (MVC) in four muscles in squat. ** indicates clear statistical significance muscle activity in unilateral compared to bilateral stance ($p < 0.01$).

A comparison of the degree of unilateral to bilateral muscle activity during the squat exercise showed that the Gmed demonstrated a 4.78 times greater activation in the unilateral compared to bilateral stance and the difference between Gmax muscle activation unilaterally compared to bilaterally was 3.71 times (table 1).

Table 1. Results for electromyography activity mean ± standard deviation (SD) and significance levels in bilateral and unilateral squat in four muscles.

Muscles	MVC µV ± SD	Stance	% of MVC ± SD	µV ± SD	Ratio BiS: UnS (% of MVC)	p-value BiS:UnS (% of MVC)	p-value BiS:UnS (µV)
Gluteus medius	539.93 ± 302.21	BiS	13.97 ± 9.19	66.79 ± 32.61	1: 4.78	p< 0.01	p< 0.01
		UnS	64.03 ± 21.23	323.14 ± 135.77			
Gluteus maximus	490.64 ± 163.27	BiS	11.70 ± 6.26	60.00 ± 41.39	1: 3.71	p< 0.01	p< 0.01
		UnS	43.40 ± 17.30	206.64 ± 100.32			
Rectus abdominis	912.68 ± 545.69	BiS	6.05 ± 2.97	43.21 ± 17.13	1: 1.09	p= 0.23	p= 0.89
		UnS	6.57 ± 3.76	43.71 ± 13.22			
Erector spinae	623.79 ± 249.81	BiS	30.28 ± 9.96	180.21 ± 64.85	1: 1.10	p= 0.28	p= 0.29
		UnS	33.16 ± 9.84	198.71 ± 81.77			

Explanations of abbreviations: MVC = Maximal voluntary contraction, % of MVC = electromyographic (EMG) activity reported as percent of MVC, µV = average EMG activity in absolute µV, BiS = Bilateral stance, UnS = Unilateral stance, and p-values (between bilateral and unilateral stance given both as % of MVC and as absolute µV levels) in squat.

Bridge

Similar to the findings in the squat exercise, performing the bridge resulted in a statistically significant increase in the unilateral compared to the bilateral stance in both the Gmed and the Gmax muscle activity ($p < 0.01$ for both), however, no significant difference existed in Rabd or Espi muscle activity (figure 2, table 2).

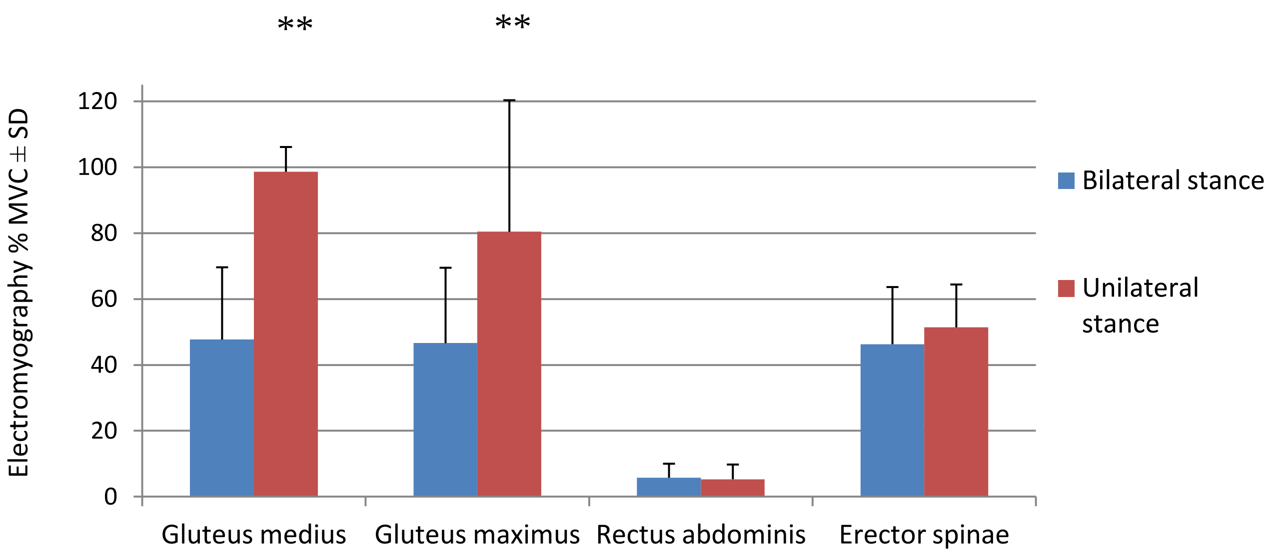

Figure 2. Sample mean + 1 standard deviation EMG activity as percent of maximal voluntary contraction (MVC) in four muscles in bridge. ** indicates clear statistical significance muscle activity in unilateral compared to bilateral stance ($p < 0.01$).

In the bridge exercise there was a 2.04 times greater activation in Gmed and a 1.72 times greater activation in Gmax when unilateral stance was compared to bilateral stance (table 2).

Table 2. Results for electromyography activity mean ± standard deviation (SD) and significance levels in bilateral and unilateral bridge in four muscles.

Muscles	MVC µV ± SD	Stance	% of MVC ± SD	µV± SD	Ratio BiS: UnS (% of MVC)	p-value BiS:UnS (% of MVC)	p-value BiS:UnS (µV)
Gluteus medius	539.93 ± 302.21	BiS	47.68 ± 21.97	257.43 ± 100.63	1: 2.04	p< 0.01	p< 0.01
		UnS	98.61 ± 7.54	532.43 ± 183.78			
Gluteus maximus	490.64 ± 163.27	BiS	46,63 ± 22.89	232.14 ± 148.28	1: 1.72	p< 0.01	p< 0.01
		UnS	80,43 ± 39.93	406.29 ± 203.35			

Rectus abdominis	912.68 ± 545.69	BiS	5,78 ± 4.27	52.71 ± 60.19	1: 1.05	p= 0.23	p= 0.67 (Wilcoxon)
		UnS	5,33 ± 4.47	48.64 ± 34.37			
Erector spinae	623.79 ± 249.81	BiS	46,29 ± 17.36	274.64 ± 128.28	1: 1.11	p= 0.28	p= 0.25
		UnS	51,42 ± 13.02	309.93 ± 123.00			

Explanations of abbreviations: MVC = Maximal voluntary contraction, % of MVC = electromyographic (EMG) activity reported as percent of MVC, µV = average EMG activity in absolute µV, BiS = Bilateral stance, UnS = Unilateral stance, and p-values (between bilateral and unilateral stance given both as % of MVC and as absolute µV levels) in squat.

Plank

In the plank exercise all muscles investigated showed a statistically higher degree of muscle activation during the unilateral compared to the bilateral stance as shown in figure 3 and table 3.

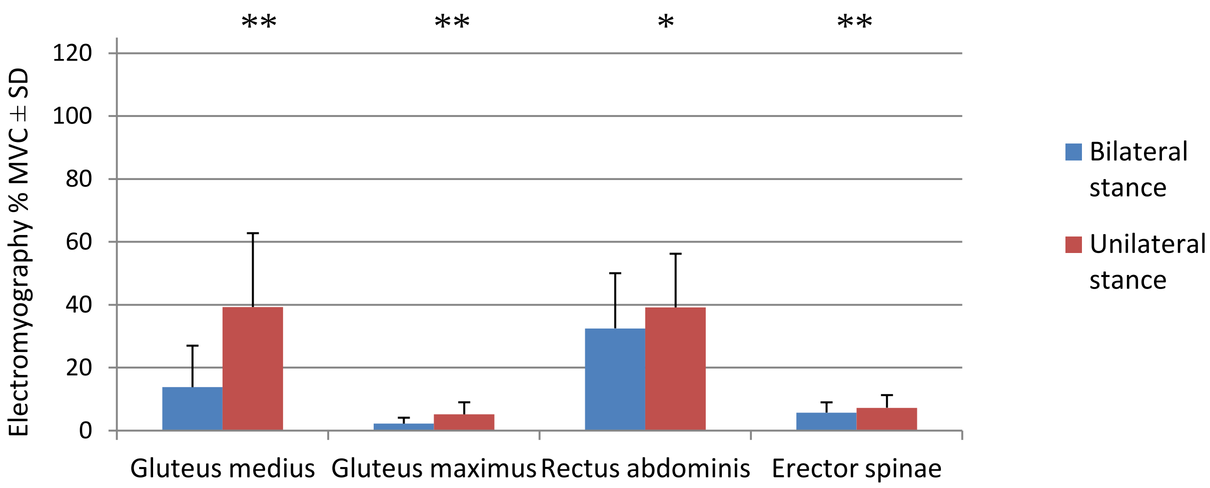

Figure 3. Sample mean + 1 standard deviation EMG activity as percent of maximal voluntary contraction (MVC) in four muscles in plank. * indicate statistically significance muscle activity in unilateral compared to bilateral stance ($p < 0.05$), and ** indicates clear statistical significance in muscle activity in unilateral compared to bilateral stance ($p < 0.01$).

A comparison of the degree of unilateral to bilateral muscle activity during the plank exercise showed that Gmed demonstrated a 2.85 times greater activation in the unilateral stance in contrast to the bilateral stance and the difference between Gmax muscle activation unilaterally compared to bilaterally was 2.33 (table 3).

Table 3. Results for electromyography activity mean ± standard deviation (SD) and significance levels in bilateral and unilateral plank in four muscles.

Muscles	MVC µV ± SD	Stance	% of MVC ± SD	µV ± SD	Ratio BiS: UnS (% of MVC)	p-value BiS:UnS (% of MVC)	p-value BiS:UnS (µV)
Gluteus medius	539.93 ± 302.21	BiS	13.79 ± 13.19	57.21 ± 47.82	1: 2.85	p< 0.01 (Wilcoxon)	p< 0.01 (Wilcoxon)
		UnS	39.31 ± 23.47	194.00 ± 140.50			
Gluteus maximus	490.64 ± 163.27	BiS	2.22 ± 1.94	9.79 ± 8.01	1: 2.33	p< 0.01 (Wilcoxon)	p< 0.01 (Wilcoxon)
		UnS	5.17 ± 3.84	22.85 ± 18.58			
Rectus abdominis	912.68 ± 545.69	BiS	32.51 ± 17.52	273.35 ± 166.79	1: 1.20	p< 0.05	p= 0.23
		UnS	39.17 ± 17.06	329.00 ± 181.42			
Erector spinae	623.79 ± 249.81	BiS	5.71 ± 3.27	30.35 ± 9.47	1: 1.27	p< 0.01	p< 0.01
		UnS	7.24 ± 4.04	38.50 ± 12.17			

Explanations of abbreviations: MVC = Maximal voluntary contraction, % of MVC = electromyographic (EMG) activity reported as percent of MVC, µV = average EMG activity in absolute µV, BiS = Bilateral stance, UnS = Unilateral stance, and p-values (between bilateral and unilateral stance given both as % of MVC and as absolute µV levels) in squat.

Taken together, a significantly higher EMG muscle activity was found in the hip muscles Gmed and Gmax for all exercises compared to bilateral muscle activity for the same bodyweight exercises. For trunk muscle (Rabd, Espi) only the plank exercise displayed a significant increase in EMG activity in unilateral compared to the bilateral stance.

The drop-jump screening analysis

The drop-jump screening analysis was used to assess the degrees of QA in a drop-jump test. Of the 14 subjects included in the squat, bridge and plank exercises, 12 male subjects performed the drop-jump test. Seven subjects did not demonstrate any QA, and five subjects demonstrated a QA in between five and 20 degrees in the drop-jumps (table 4). No correlation was found (r= 0.34) as assessed by Pearson's correlation test between peak EMG activity (µV) in Gmed (MVC) and the degrees of QA (only including subjects displaying knee valgus). Each subject's individual EMG activity (MVC) and degrees of the QA is presented in table 4.

Table 4. Electromyographic muscle activity (MVC) in gluteus medius and degrees of quadriceps angle (QA) in 12 male subjects. Normal QA demonstrated in males is 14 degrees (Corley et al., 2007).

Subject #	Gmed EMG activity (μV)	Degrees of QA
1	339	0
2	281	0
3	366	0
4	830	0
5	1360	0
6	720	0
7	388	0
8	469	10
9	472	15
10	164	5
11	666	12
12	364	20

Discussion

Results discussion

Results from the present study showed that statistically significant increases in muscle activity was found in the unilateral stance compared to the bilateral stance in the hip muscles gluteus medius and gluteus maximus in all exercises ($p< 0.01$). The trunk muscles rectus abdominis and erector spinae did not change their level of muscle activation comparing unilateral to bilateral stance, except for a significant increase in activity in both muscles in the plank exercise (Rabd; $p< 0.05$, Espi; $p< 0.01$). Noticeable from this study was that Gmed displayed the highest degree of EMG activation difference when comparing the unilateral to the bilateral stance, followed by Gmax. A higher EMG activity in unilaterally performed bodyweight exercises would be expected due to the greater absolute load placed on the muscle during exercises (the body weight), however in the present study the magnitude of increase in EMG activity in the Gmed and Gmax in the squat was higher than would be expected if it was attributed to increase in body weight load alone.

Squat

The results of this study show statistically significant increases in muscle activity in the unilateral stance compared to the bilateral stance in the hip muscles (Gmed, Gmax) in all exercises ($p< 0.01$), which agree with results from Jones et al., (2012), who found higher EMG activity in Gmed and Gmax in unilateral squat compared to bilateral squat .

However, their methodology involved a 10 repetition maximum (RM) test to assess maximum strength. By doing so, the relative load was calculated of 1RM in both bilateral and unilateral squat which may make their comparison a direct 1:1 comparison between the unilateral and bilateral movement. In our study a fixed load as percent of 1RM was not calculated, but EMG was measured while bilateral and unilateral exercises were performed simply with body weight. We can assume that greater load was placed on the subjects in the present study during unilateral exercises, which must be taken into consideration when EMG activity results are evaluated. For Gmed, the EMG activity between bilateral and unilateral exercises was 4.78 times larger (% MVC), and Gmax EMG activity between bilateral and unilateral exercises was 3.71 times larger (% MVC) in squat. Therefore, conclusions can be drawn that unilateral squat results more than double EMG activity levels in Gmed and Gmax and thus, these muscles are activated to a higher degree during unilateral compared to bilateral squat, even though the relative load was not calculated in the present study.

In harmony with our results, Krause et al., (2009) demonstrated a significant difference ($p < 0.01$) in EMG activation for the Gmed muscle in unilateral squat compared to bilateral squat, with approximately a five times greater EMG activity in the unilaterally performed squat . The squats were performed unilaterally and bilaterally with no regard to relative load calculations which was similar to our own design.

Bridge

Comparing EMG activity in bilateral and unilateral bridge, Ekstrom et al., (2007) found approximately the double EMG activity in Gmed and Gmax, which corresponds roughly with our results between bilateral and unilateral bridge (Gmed 1:1.72, Gmax 1:2.04). Moreover, Ekstrom et al., (2007) did not find any statistical significance in bilateral and unilateral bridge for Espi and Rabd, similar to the present outcome. Gmed EMG activity in bridge further correspond with Krause et al., (2009) which established greater EMG activity for Gmed in unilateral weight-bearing exercises. An interesting observation among our results are the elevated EMG activation in bridge, both bilaterally and unilaterally performed, with EMG levels (Gmed, Gmax, Espi) about 50% of MVC up to values exceeding the value obtained in MVC. This implies that bridge performed with bodyweight both bilaterally and unilaterally, places greater demands on hip muscles, and to some extent trunk muscles compared to the recommended manual muscle test (Hislop & Montgomery, 2007).

Plank

In the plank exercise, all muscles investigated showed a statistically higher degree of muscle activation during the unilateral compared to the bilateral stance. In agreement with Ekstrom et al., (2007) our results display similar EMG activation during the bilateral plank with marginal differences, however no comparison can be made in the unilateral stance of plank since they performed a different type of unilateral plank. Plank is a generally accepted rehabilitation exercise (McArdle et al., 2010), therefore, conclusions can be drawn that by performing plank in a unilateral stance, EMG activity will be significantly enhanced in hip and trunk muscles investigated.

The drop-jump screening analysis

In answering research question two; is there a correlation between EMG activity in Gmed and the degrees of QA in a drop-jump test? Our conclusion was that no correlation was found between EMG activity in Gmed and the degree of QA in the drop-jump screening analysis test (r= 0. 34). Twelve subjects (all males) participated in the drop-jump test, whereof five subjects displayed a QA between five and 20. Only two subjects displayed a greater QA than the normal values demonstrated in males; 14 degrees (Corley, 2007). Our expectations were that Gmed MVC would correlate with the medial knee displacement assessed by QA, however, no such correlation was found during the drop-jump screening test.

One study investigated the influence of hip strength on gluteal activity (Gmed, Gmax) and lower extremity kinematics (Homan et al., 2012). They found that hip muscle strength indirectly influence knee valgus motion by determine neural drive requirements because weaker individuals compensate their lack of force production by a heightened neural drive.
In the same study, hip abduction and external rotation were assessed with maximal isometric contractions via a dynamometer and EMG activity was recorded during two-legged landing tasks from a height representing 50% of subject's height. Subjects were separated into two groups based on their strength in hip abduction and external rotation (dynamometer) and results showed that those that were weaker in external rotation and hip abduction displayed greater EMG activity (% MVC) compared to those with stronger external rotators and hip abductors during landing tasks. The results from their study are in conflict with our hypothesis that greater EMG activity is a sign of more force produced by the muscle which would lead to lesser QA.

Method discussion

In manual muscle testing, the grading system was used to assess specific muscles available range of motion, exertion at top range of the test, and resistance applied, with a scale that run from zero to five where zero indicate “no activity” and five indicate “normal or best possible activity”. All subjects in the present study scored between a four (4) and a five (5), probably because all subjects were injury free at time of investigation. Manual muscle testing is a generally accepted testing methodology within physical therapy, however for clinical use reliability and validity are considered “satisfactory” and can never be "perfect" due to the subjectivity of the experience of the experiment leader (Criswell, 2011). Reliability was increased by adhering to the same setup procedure for each subject by providing clear instructions for the performance of the manual muscle tests, which were also being practiced before EMG signals were recorded. Electrode placement was also performed in a standardized manner, with manufacturer’s guidelines as reference. Electrode placement is complicated to judge because the structure of the body may vary from subject to subject. This may have interfered with various EMG activity in subjects, however using MVC as a reference some of the possible errors due to faulty electrode placements would be eliminated.

No regard was taken to relative load in the present study which affects the way our results can be interpreted and the way muscle activity from unilateral and bilateral exercises compare. Previous researches have used both methods and the choice depend on the aim of the study (Krause et al., 2009; Ekstrom et al., 2007; Jones et al., 2012; McCurdy et al., 2005). Relative load can be assessed by performing 1 RM, which would have been easy to do in squat, however assessing 1 RM in bridge and plank would have been problematic concerning the placement of additional load or the excessive load of the vertebrae in plank. No concern was made to higher muscle activation in bilateral compared to unilateral stance because that was not the aim of the present study.

In the drop-jump screening test subjects did not display an abnormally high QA which may be due to several reasons. Subjects were experienced within jumping technique and squat stance which may have influenced their QA consequently resulting in improved (expressed as a minimal QA) landing and jumping technique. In addition, subjects received information that the drop jump screening test was measuring the QA which may have subconsciously influenced their jumping technique.

Conclusion

In conclusion, our results showed that all unilateral exercises activated (assessed by EMG) the hip muscles investigated (Gmed, Gmax) more than double compared to the same exercises performed bilaterally (except for Gmax in bridge). In contrast, activation of the trunk muscles (Rabd, Espi) did not show any difference in activation between bilateral and unilateral bodyweight resistance exercises in the squat and bridge, however, in plank an increase in EMG activity was showed in Rabd and Espi in unilateral stance compared to the bilateral stance. Gmed displayed the largest difference unilaterally to bilaterally in all exercises, which implies that a greater demand is placed on Gmed when performing exercises in the unilateral stance, and thus unilaterally performed bodyweight exercises may well be implemented with the aim to strengthen Gmed. No correlation was found between EMG activity (MVC) and QA in the drop-jump screening analysis. In an exercise physiology viewpoint this study enhanced the knowledge regarding hip and trunk muscle EMG activity differences between bilateral and unilateral bodyweight exercises. Practicing unilateral bodyweight resistance exercises may well develop strength in Gmed that, consequently, may protect against lower extremity dysfunction or injury for athletes as well as for the general population.

References

Beachle, T. R., & Earle, R. W. (2008). *Essentials of Strength Training and Conditioning.* Champaign: Human Kinetics.

Behm, D. G., Leonard, A. M., Young, W. B., Bosney, A. W., & MacKinnon, S. N. (2005). Trunk muscle electromyographic activity with unstable and unilateral exercises. *Journal of strength and conditioning research* , 19, 193-201.

Behnke, S. Robert. (2006). *Kinetic Anatomy* (2 ed.). Champaign: Human Kinetics.

Borghuis, J., Hof, A. L., & Lemmink, K. (2008). The importance of sensory-motor control in providing core stability. Implications for measurement and training. *Sports Medicine , 38*, 893-916.

Brooks, C. M. (2012). On rethinking core stability exercise programs. *Australasian Musculoskeletal Medicine* , 17, 9-14.

Cardinale, M., Newton, R., & Nosaka, K. (2011). *Strength and Conditioning; Biological Principles and Practical Applications.* Oxford: Wiley-Blackwell.

Comfort, P., & Abrahamson, E. (2010). *Sports Rehabilitation and Injury Prevention.* Chichester: Wiley-Blackwell.

Conley, S. (2007). The Female Knee: Anatomic Variations. *Journal of American Academy Orthopaedic Surgeons,* 15, 31-36.

Criswell, E. (2011). *Cram's introduction to surface electromyography* (2 ed.). London: Jones and Bartless Publishers.

Drake, R. L., Wayne Vogl, A., & Mitchell, A. W. (2010). *GRAY´S ANATOMY for students* (2 ed.). Philadelphia: Churchill Livingstone Elsevier.

Ekstrom, R. A., Donatelli, R. A., & Carp, K. C. (2007). Electromyographic Analysis of Core Trunk, Hip, and Thigh Muscles During 9 Rehabilitation Exercises. *Journal of orthopaedic sports physical therapy , 37*, 754-762.

Enoka, R. (2008). *Neuromechanics of human movement* (4 ed.). Champaign: Human Kinetics.

Faries, M. D., & Greenwood, M. (2007). Core training: Stabilizing the confusion. *Strength and conditioning journal , 2*, 10-25.

Ford, K., Myer, G., & Hewett, T. (2003). Reliability of dynamic knee motion in female athletes. *Paper presented at: American Society of Biomechanics Annual Meeting;* , 25-27.

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. R., Colosimo, A. J., LcLean, S. G., et al. (2005). Biomechanical Measures of Neuromucular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes. *American Journal of Sports Medicine* , 39, 492-501.

Hislop, H., & Montgomery, J. (2007). *Muscle Testing: Techniques of Manual Examination.* London: W.B. Saunders Company.

Homan, K. J., Norcross, M. F., Goerger, B. M., Prentice, W. E., & Blackburn, T. J. (2013). The influence of hip strength on gluteal activity and lower extremity kinematics. *Journal of Electromyography and Kinesiology , 23, 411-415.*

Jones, M. T., Ambegaonkar, J., Nindl, B. C., Smith, J. A., & Headley, S. A. (2012). Effects of unilateral and bilateral lower-body heavy resistance exercise on muscle activity and testosterone responses. *the Journal of Strength and Conditioning Research* , 1094-1100.

Kibler, B., Press, J., & Sciascia, A. (2006). The role of core stability in athletic function. *Sports medicine , 36*, 189-198.

Krause, D. A., Jacobs, R. J., Pilger, K. E., Sather, B. R., Sibunka, S. P., & Hollman, J. H. (2009). Electromyographic analysis of the gluteus medius in five weight-bearing exercises. *Journal of strength and conditioning research , 23*, 2689-2694.

Lanning, C. L., Uhl, T. L., Ingram, C. L., Mattacola, C. G., English, T., & Newsom, S. (2006). Baseline values of trunk endurance and hip strength in collegiate athletes. *Journal of athletic training* , 41, 427-434.

Lederman, E. (2010). The myth of core stability. *Journal of Bodywork & Movement Therapies* , 14, 84-98.

Leetun, D. T., Ireland, M. L., Willson, J. D., Ballantyne, B. T., & Davis, L. M. (2004). Core stability measures as risk factors for lower extremity injury in athletes. *Medicine & Science in Sports & Exercise , 36*, 926-934.

Lidgren, L. (2003). *The Bone and Joint Decade and the Global Economic and Healthcare Burden of Musculoskeletal Disease.* The Journal of Rheumatology , 30, 4-5.

McArdle, W. D., Katch, F. I., & Katch, V. L. (2010). *Exercise physiology; nutrition, energy, and human performance* (7:th edition ed.). Baltimore: Lippincott Williams & Wilcins.

McCurdy, K., & Langford, G. (2005). Comparison of unilateral squat strength between the dominant and non-dominant leg in men and women. *Journal of Sports Science and Medicine* , 4, 153-159.

McCurdy, K., Langford, G. A., Doscher, M. W., Wiley, L. P., & Mallard, K. G. (2005). The effects of short-term unilateral and bilateral lower-body resistance training on measures ofstrength and power. *Journal of Strength and Conditioning Research* , 19, 9-15.

Noyes, F. R., Barber-Westin, S. D., Fleckenstein, C., Walsh, C., & West, J. (2005). The drop-jump screening test; difference in lower limb control by gender and effect of neuromuscular training in female athletes. *The Americal Journal of Sports Medicine* , 33, 197-207.

Prins, M. R., & Van der Wurff, P. (2009). Females with patellofemoral pain syndrome have weak hip muscles: a systematic review. *Australian journal of physiotheraphy* , 55, 9-15.

Saeterbakken, A. H. (2012). Muscle activity of the core during bilateral, unilateral, seated and standing resistance exercise. *European Journal of Applied Physiology,* 112, 1671-1678.

Selkowitz, D. M., Beneck, G. J., & Powers, C. M. (2013). Which exercises target the gluteal muscles while minimizing activation of the tensor fascia lata? electromyographic assessment using fine-wire electrodes. *Journal of Orthopaedic & sports physical therapy* , 43, 54-64.

Whatman, C., Hume, P., & Hing, W. (2012). Kinematics during lower extremity functional screening tests in young athletes; Are they reliable and valid? *Physical Therapy in Sport*, 14, 77-86.

Wilmore, J. H., & Costil, D. L. (1999). *Physiology of Sport and Exercise*. Champaign: Human Kinetics.

Appendix

Welcome to a research project assessing hip and trunk muscle electromyographic activity in unilateral and bilateral body-weight exercises

My name is Björn Frandsen and I study the master's program in Sports and Exercise Science – Human Performance. I hereby inquire subjects between the age of 18 and 30, injury free and familiar with fundamental resistance training to participate in this single session, single-group, observational study. Participation will take about an hour and personal information and data will be treated anonymously in agreement with "personskyddslagen" §10. The aim of this study is to examine the difference between bilateral and unilateral electromyography muscle activation in hip and trunk muscles in three bodyweight exercises as well as to examine the correlation between hip strength and the quadriceps angle in a drop-jump screening test. A presentation of the study will be held in summer year 2013 and the complete study can be collected via the database of Halmstad University (DiVA).

- Inclusion criterions; 18-30 years, injury free, and familiar with resistance training
- Date; Week 10-12
- Location; Biomedicine laboratory, Q building, Halmstad University
- Equipment; Sportswear, loose shorts
- Requirements; Shaving parts of hip and lower trunk
- Risks; Sore muscles
- Benefits; Increased knowledge and experience in unilateral resistance training

If you would be interested in participating in this study please contact me (Björn Frandsen) before Monday the 4: th of Match.

Best regards//

Björn Frandsen, Master's program, Sports and Exercise Science – Human Performance

Phone number; 073 6197726

E-mail address; mr_frandsen@hotmail.com

Consent form

I hereby approve to participate in this study, its procedures and leave my full consent. I have read and understood information and aim of the research project and I have had opportunity to ask various questions. Data will be treated anonymously and I am aware of the eventual publication of the paper in Halmstad University's database. I consent to participate in this study.

Date and place *Signature and full name of participant*