Muscle activity in bilateral and unilateral body weight squat

An electromyographic study

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Abstract

Hegnelius, M. - **Background.** It would be beneficial to the society to bring more awareness about the health benefits that comes with physical activity. Resistance training is a form of physical activity that has positive health benefits for athletes as well as for the average person. Squat is a resistance training exercise that can be performed on one (unilateral) or two (bilateral) legs. Both bilateral and unilateral squat are exercises that are similar to a wide range of different athletic as well as everyday movements. **Aim.** The aim of this study was to investigate if there is a difference in muscle activity, with electromyography (EMG), in gluteus maximus, gluteus medius, rectus femoris and biceps femoris between bilateral and unilateral body weight squat. **Method.** Fifteen healthy students (8 women and 7 men) volunteered to participate in the study. EMG signals were collected using surface electrodes with a collection frequency of 1000Hz. EMG data was processed through average root mean square. The values were normalized to maximum voluntary isometric contraction (MVIC) and expressed as percent (% MVIC). **Result.** The result of the present study showed that there was statistically significantly higher muscle activity in unilateral compared to the bilateral body weight squat in gluteus medius and rectus femoris (p<0.05), together with a trend for higher muscle activity in unilateral body weight squat in gluteus maximus and biceps femoris (p=0.07). The present study also showed that the highest muscle activity during a bilateral squat was found in rectus femoris which had significantly higher muscle activation compared to the other three muscles. Furthermore, for the unilateral squat, rectus femoris and gluteus medius had the highest muscle activity and had significantly higher muscle activity compared to gluteus maximus and biceps femoris. **Conclusion.** Practical implications from this study was that more muscle activity was required when performing unilateral body weight squat although the bilateral body weight squat is a more stable exercise. Further practical implication is that gluteus medius works significantly higher in unilateral compared to bilateral body weight squat which strengthen GM and by this develops a more stable lower body.
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1. Introduction

For the human body to function in an optimal way there is need for movement (Engström & Lindgärde, 2004). People that are over 18 years old should be active at least 150 minutes a week with an intensity that is at least moderate. If the intensity is high the recommendations say at least 75 minutes of training. Resistance training should be performed 2-3 times a week according to the recommendations (Ståhle, 2008). A study found that 40% of the adult population in Sweden performed a physical activity on one occasion a week (Ekblom-Bak, Engström, Ekblom & Ekblom (2011). Physical activity has been proven to reduce the risk of several diseases and injuries and above all improve quality of life. For injury prevention in addition to disease prevention, both resistance, strength, and flexibility are important to add to a training program (Kraemer, Ratamess & French, 2002). A common exercise in resistance training is the squat and it can be performed on two (bilateral) or one (unilateral) leg and with or without external weights (Schoenfeld, 2010). Body weight squat is an exercise that combines multiple muscle groups, bilateral body weight squat is a safe and stable exercise and unilateral body weight squat requires balance and coordination (Schoenfeld, 2010; Feger, Donovan, Hart, & Hertel, 2014). Unilateral body weight squat has the same load as bilateral body weight squat but have a smaller contact surface and therefore, a unilateral stance probably needs more muscles involved (Jones, Ambegaonkar, Nindl, Smith and Headly, 2012). There is a difference between the execution of the squat and also the body’s center of mass in bilateral and unilateral body weight squat which may affect which muscles that activates, and how much they activate in the different performances (Barton, Kennedy, Twycross-Lewis, Woledge, Malliaras, & Morrissey, 2014). To analyze how much activity it is in a specific muscle during a movement, a common method is electromyography (Konrad, 2005).

1.2 Background

1.2.1 Resistance training

It is widely accepted that resistance training is a beneficial physical activity that has positive health benefits for many people, for athletes as well as for the ordinary person. It is established that resistance training is for those who want to, need to or are interested in improving their health and quality of life (Fisher, Steele, Bruce-Low & Smith, 2011).
Resistance training reduces the injury risk in sports as well as everyday activities, due to for instance the strengthening effect resistance training has on muscles, bones, ligaments and tendons. To improve athletic performance the need for resistance training is apparent for example to strengthen the body, increase in speed and increase in explosiveness (Myer, Ford, Palumbo & Hewett, 2005).

Resistance training may be beneficial to be performed from prepubertal children to older adults (Myer & Wall, 2006; Hunter, McCarthy & Bamman, 2004). Some of the benefits of resistance training may be improved metabolism glucose, decreased blood pressure (in rest), improved aerobic capacity and increase in bone mineral density (Fisher et al., 2011). The human body is very adaptable to resistance training, a couple of months of resistance training can increase muscle strength significantly, from 10% to over 100% (Ståhle, 2008). The muscles adapt primarily by increase in muscles size and helps to strengthen joints and minimize the risk for injuries (Beachle & Earle, 2008). To increasing in muscle strength and size the neuromuscular system has to experience a non-familiar training stress and therefore, place the system into overload. Improvements made early on in a resistance training program most likely come from neurological adaptions (Coburn & Malek, 2012).

**Action potential**

To make the body move, a certain stimulus is required, it is the cerebral cortex in the brain that sends out a specific stimulus to make the body move accordingly (Beachle & Earle, 2008). Muscle tissue has the ability to react to a stimulus, such as the decision to move, by transmitting an electrical signal which is lead on from the nerve. The electrical signal in the motor neuron generates an action potential in the muscle and is the start of a muscle contraction (Cael, 2010). A motor neuron and the muscle fibers that it innervates are called a motor unit and if the motor unit experiences resistance training its coordinative ability improves (Coburn & Malek, 2012). At the start of a muscle contraction the action potential causes the release of acetylcholine from vesicles in the terminal axon of the nerve and leads to a depolarization of the T-tubuli which will cause a release of calcium from the sarcoplasmic reticulum. The calcium, by binding to the troponin-tropomyosin, releases the inhibition of the myosin-binding site of actin and myosin and actin links together in a so called cross-bridge. ATP binds to the myosin head and the cross-bridge cycle begins making the actin and myosin slide past each other causing muscle shortening.
When the electrical stimulation decreases the calcium will return to the sarcoplasmic reticulum, the myosin and actin is separated and the muscle activity ends (McArdle, Katch & Katch, 2010). To indirectly study the action potentials in a muscle it is common to use EMG, which gives information about muscle activity in a muscle during a specific movement (Konrad, 2005).

### 1.2.2 Electromyography

There is a close relationship between force generation in the muscle and electrical signals in... One way to examine the magnitude of neuromuscular activity is to use electromyography techniques where either an intramuscular needle or surface electrodes register the sarcolemma action potentials in the muscle and displays them as electrical signals (Uliam Kuriki, Mícolis de Azevedo, Sanae Ota Takahashi, Moraes Mello, de Faria Negrão Filho & Alves, 2012). Moreover, surface EMG is a non-invasive method that is safer and easier to operate compared to intramuscular EMG. Surface EMG records from a larger number of overlapping action potentials than the intramuscular EMG which may influence the results (Farina & Enoka, 2011). A restriction in surface EMG is that relatively few motor units can be detected. De Luca & Hostage (2010) discovered that with surface EMG the firing frequency was 20-30 motor unit action potentials per contraction. The total actual firing frequency in a contraction was according to Del Valle & Thomas (2005) 217 to 269 motor unit action potentials. Furthermore, Del Valle et al. (2005) discovered that the firing rate during a maximum concentric contraction was comparable to the firing rate during a maximum isometric contraction. The degree on which the firing rate compares to eccentric contractions was not established.

EMG is a method used to assess muscle activity in resistance training to analyze how much activity a specific muscle develops during a movement or a specific exercise. EMG measurement provides important information about the intensity of resistance training performed (if it’s low, submaximal or maximal in its demands). For example, a muscle needs to have an activity level of at least 40-60 % of the maximum voluntary isometric contraction (MVIC) to create an increase in strength (Konrad 2005).

### 1.2.3 Bodyweight resistance training

Bodyweight resistance training is an exercise mode that does not involve any external weight except the body as resistance, which makes it a safe and easy exercise model to perform for most people. Benefits with body weight resistance training are that there is
no need for equipment and it is effective when learning new techniques. For elite athletes progression with increasing loads for additional strength gains with body weight resistance training is difficult because of its limitation to only the body as resistance (Meyr et al., 2006). Yamauchi, Nakayama & Ishii (2009) conducted a study involving the effects of bodyweight resistance training in elderly individuals. They found that bodyweight exercises improved the muscle force and power in the subjects but did not show any effects on velocity in lower extremity multi-joint movements.

1.2.4 Open and closed kinetic chain exercises

Body weight resistance training is performed as either closed kinetic chain exercises or open kinetic chain exercises. A closed kinetic chain exercise is an exercise that is performed with restraints on the active part of the body's free motion (Beachle & Earle, 2008). Closed kinetic chain exercises for the lower extremity activates both the hamstrings and the quadriceps muscles and consists of multi-joint coordination. It strengthens the body in a more functional way instead of training a specific muscle group at a time (Adouni & Shirazi-Adl, 2009). The opposite of closed kinetic chain exercises is open kinetic chain exercise. An open kinetic chain exercise is when the terminal joint does not meet a resistance but is free in its motion but the proximal part is restrained (Beachle & Earle, 2008). Open kinetic chain exercises is often performed to isolate a specific muscle group (Kwon, Park, Jefferson & Kim, 2013).

Research has shown that closed kinetic chain exercises can improve the dynamic balance and neuromuscular activity of multiple muscle groups in healthy adults. The open kinetic chain had improvements but not as significant as the closed kinetic chained exercises (Kwon et al. 2013). Proprioceptive feedback, which is important for a correct execution of the movement, from the foot and lower extremity joints is higher in the closed kinetic chain exercises compared to open kinetic chain exercises, which may lead to an improved performance of the exercise (Kwon et al., 2013). A very common closed kinetic chain exercise is the squat. The squat can be performed on two legs (bilateral) and on one leg (unilateral). Depending on execution of the squat, bilateral or unilateral, it may lead to different demands on the body, such as muscle stress, balance or neuromuscular control (Beachle & Earle, 2008).
1.2.5 Bilateral and unilateral squat

The bilateral squat is one of the most common resistance exercise used in the training scene. It has the ability to activate multiple muscle groups in one movement and almost everything the human body does is a coordination of several muscle groups (Schoenfeld, 2010).

Performance of bilateral squat involves an estimated 200 muscles in the body, both muscles that primarily generate movement for example the quadriceps, hip abductors, hamstrings, gluteal muscles and muscle that primarily are involved in stability, such as the abdominals and erector spinae (Schoenfeld, 2010). Jones et al. (2012) found that in the bilateral squat, vastus lateralis was activated (%MVIC) the most, whereas gluteus maximus and biceps femoris were active but not to the same extent as the vastus lateralis. Squat is a very complex exercise (Schoenfeld, 2010) and a deeper knowledge than today’s regarding how and when the different muscles activates will help understand the best way to perform the squat, both on two legs (bilateral) and on one leg (unilateral). Both bilateral and unilateral stance are similar to a wide range of different athletic as well as everyday movements.

The unilateral squat is similar to the bilateral squat, but it requires better balance and coordination compared to the bilateral squat, and research has shown that by doing exercises of this nature the injury risk, particularly for ankle sprains, decreases (Feger, Donovan, Hart, & Hertel, 2014). The unilateral squat could indicate instability of the hip and to stabilize the hip, gluteus medius is an essential muscle (Zeller, McCrory, Kibler & Uhl, 2003).

A dominant quadriceps activity has been established when performing a unilateral squat. The involvement of the hamstrings muscles and its counteracting properties with the quadriceps is possible but not if the total muscle activity required in the movement is too low (Begalle, DiStefano, Blackburn & Padua, 2012). A study showed that when performing bilateral and pitcher squat (unilateral squat with support for the non-dominant foot) with an intensity of 10 repetition maximum there were no statistical significance between bilateral and unilateral stance (Jones et al., 2012). However, Barton et al. (2014) found that the muscle activity in bilateral and unilateral squat (with one foot supported by the wall to keep balance) were statistically significantly different in gluteus medius (GM) and gluteus maximus (GMA) and concludes that it may be because of the differences in the
mechanisms between bilateral and unilateral stance. The increase in muscle activity may be because of the movement of the body's center of mass which leads to a greater hip adduction and internal rotation of the torque during the unilateral squat (Barton et al., 2014).

The squat with bilateral stance has been shown to not strengthen GMA and GM muscles because the percentage of MVIC was too low (9-14% MVIC). In contrast, unilateral squat muscle activation of the gluteal muscles (GMA and GM) requires more muscle activity and therefore is more likely to succeed to strengthen the gluteal muscles (Barton et al., 2014).

In summary, previous research has investigated EMG differences in unilateral and bilateral resistance training exercises. Both the effects of the gluteal muscle activity during squat (Barton et al. 2014) and quadriceps and hamstrings muscle activity (Begalle et al. 2012) have been investigated separately. Jones et al. (2012) investigated the gluteal muscles, quadriceps and hamstring in exercises using external weights. However, further investigation of the gluteal activity (GMA and GM) together with quadriceps (RF) and hamstrings (BF) activity in both unilateral and bilateral body weight squat is appropriate to get a better understanding of the differences in muscle activity during different executions of the body weight squat. Studying the muscle activity and involvement of different muscles that are engaged during the squat is important in order to better understand the benefits and possible drawbacks involved when performing either a bilateral or unilateral body weight squat. This will help prevent injuries and provide knowledge about the different stance in the same exercise.

1.4 Aim

The aim of this study was to investigate if there is a difference in muscle activity in gluteus maximus, gluteus medius, rectus femoris and biceps femoris between bilateral and unilateral body weight squat.

Research question

1. Are there any differences in muscle activity in gluteus maximus, gluteus medius, rectus femoris and biceps femoris between bilateral and unilateral body weight squat?
2. Which muscles have the highest muscle activation during bilateral body weight squat, and does it differ compared to unilateral body weight squat?

2. Method

2.1 Subjects
Fifteen healthy students (8 women and 7 men) from Halmstad University were recruited to participate in the study. Anthropometric data were collected from each participant; age, height, shoulder width (acromion to acromion), body mass and body mass index (BMI). Inclusion criteria were that the subjects had to be recreational athletes who participated in regular resistance training at least four times a week and have experience of performing squat both bilaterally and unilaterally for at least two years. The subjects further had to be capable to perform bilateral and unilateral body weight squat to a 90 degree angle in the knee joint. Exclusion criterion was no previous major injuries or surgeries of the lower extremity. The subjects were informed to avoid endurance or weight training for the lower extremity two days before the test (Youdas, Hollman, Hitchcock, Hoyme & Johnsen, 2007). Study participation were voluntary and the subjects had the knowledge that they could drop out at any time without giving a reason (see 2.5 Ethical and social consideration).

2.2 Electromyography
EMG electrodes were used to assess the muscle activity in the following four muscles; GMA, GM, rectus femoris (RF) and BF. The EMG electrodes were placed on the dominant leg to a dry-shaved area that was cleaned with alcohol to minimize interference (Feger et al., 2014). Two measurement electrodes were placed on the muscle belly in the direction of the muscle fibers, about two centimeters apart and a third electrode, used as a reference, was attached perpendicular to the other two (Konrad 2005). The reference electrode is used to minimize electrode interferences that may occur which might influence the result. These interferences is called cross-talk; and cross talk is one of the reasons that surface EMG is a complex method to perform (Delsys, 2012; Hug, 2010).

2.2.1 Maximum voluntary isometric contraction
Muscle strength cannot be measured with EMG (Uliam Kuriki et al., 2012) and therefore, data from one subject cannot be compare to another subjects without relating to a
reference value. Maximum voluntary isometric contraction (MVIC) is the most established reference used (Konrad 2005). Therefore, MVIC-values for each muscle were established by the performance of exercises that would enable the subjects to maximize the isometric contraction in each muscle. Three MVIC, with one minute rest between each contraction, were performed in each muscle before the actual tests started and EMG was recorded. Every contraction was held three seconds and an external resistance was applied to ensure that the contraction remained isometric. The MVIC-value contraction was performed in the middle of the range of motion in a fixed position to obtain accurate values (Konrad 2005). The MVIC-exercises was performed in accordance to Hislop & Montgomery (2007), see Appendix B.

All EMG data was collected by ME6000, 4 channels (Megawin Software, Kuopio, Finland) with a sampling frequency of 1000 Hz. MegaWin was used where the data was transmitted to a computer with the setting Raw Free. To process the EMG signals average root mean square (RMS) values were calculated during three repetitions, eccentric and concentric phase, repetition number 2-4 (number 1 and 5 were not calculated; see below).

### 2.3 Testing procedure

The dominant leg of the subjects were considered by the leg the subjects kicked a football with (Zeller et al., 2003; Youdas et al., 2007). Both bilateral and unilateral body weight squat were performed barefoot (Youdas et al., 2007) and in a specific pace of 48 beats per minute, first beat starting the repetition and fifth beat ending the repetition, making every repetition five seconds (Hale, Hausselle, & Gonzalez, 2014). All exercises were performed five times and had one minute rest between the trials to minimize potential risk of fatigue (Youdas et al., 2007). If any repetition was a failure the subject rested for three minutes after the test and then did the whole test procedure again. All the subjects got the same instructions for the warm-up, MVIC exercises and test exercises.

The average MVIC (AVEMVIC) was calculated in repetition number 2-4 and then used as a reference value to the muscle activity in the dynamic movements for each individual muscle. The data were converted to aveRMS to be able to calculate the mean average value of three (number 2-4) repetitions. The mean average value could then be converted to average % of MVIC (AVE%MVIC) for each muscle. To be able to compare different subjects to each other average EMG amplitude has to be presented as percent of MVIC (Uliam Kuriki et al., 2012).
2.3.1 Warm-up

After EMG electrode application and MVIC measurements, each subject performed a standardized warm-up with elements of preparing the body for the exercises in the test (table 1) (Elphinston, 2014). The warm-up was five minutes long (Konrad 2005) and to ensure that the test would be properly performed it also involved three practice trials of each exercise (Feger et al., 2014). The subjects then had three minutes rest to physiologically recover before the MVIC measurements were collected (Coburn & Malek, 2012).

TABLE 1. Standardized warm-up exercises before each subject’s electromyography measurement was made.

<table>
<thead>
<tr>
<th>EXERCISE</th>
<th>REPETITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee-pulls towards the stomach (alternate legs)</td>
<td>10/leg</td>
</tr>
<tr>
<td>Coordination jumps</td>
<td>10 /leg</td>
</tr>
<tr>
<td>Lunge-walk</td>
<td>10</td>
</tr>
<tr>
<td>Air-squat</td>
<td>10</td>
</tr>
<tr>
<td>One leg jumps</td>
<td>10/leg</td>
</tr>
<tr>
<td>Squat (practice trail)</td>
<td>3</td>
</tr>
<tr>
<td>Lunge (practice trail)</td>
<td>3/leg</td>
</tr>
<tr>
<td>SLS (practice trail)</td>
<td>3/leg</td>
</tr>
</tbody>
</table>

The exercises are described in more detail in appendix A.

2.3.2 Exercises

Bilateral body weight squat

During performance of bilateral body weight squat the subjects flexed the knees and hip until 90 degrees were reached in the knee joint and then rose up again to a 0 degree flexion. The feet were shoulder width apart, which were determined beforehand and marked on the floor. Instructions to subjects were to keep the torso straight while bending the knees and sit down back with the hands on the hips during the whole repetition (Hale et al., 2014).

Unilateral body weight squat

Subjects had the dominant foot in the ground and the other foot in front of the body
when performing unilateral body weight squat (Zeller et al., 2003). The subjects were instructed to bend the knee and reach a 90 degree angle in their knee joint and then ascend up to a 0 degree angle to make the unilateral body weight squat as equal as possible to the bilateral body weight squat. Similar to the bilateral body weight squat the subjects were instructed to keep the torso as straight as possible with hands on their hips throughout the repetition.

2.4 Ethical and social consideration

All subjects were given information about the study both in written and oral form. The information form was presented and enough time was given for the subjects to read and understand the contents. They could ask for clarifications from the study leader if anything was unclear. The information form included the risks and commitment of the study and that the data from this study would be submitted in a publication. At the end of the information form, an informed consent form was attached, (appendix C), to ensure the security of their integrity. Participation in the study and all personal information that was given was handled with discretion and respecting personuppgiftslagen (PUL). To be included in the study the subjects had to sign the informed consent form. The subjects could drop out of the study at any time without an explanation.

The present study contains all the results that has been found. The author has not distorted or excluded facts obtained during the study. The design of the study was to get a better understanding about muscle activity patterns and the results will benefit people interested in optimizing their training. World Health Organization (2015) describes that all structured measures that prevent disease, promotes health and prolong life in the population is a public health matter. Their main focus is to see to the public and not to one individual and focus should be on staying or becoming healthy and increase quality of life. This study promotes a healthy activity such as resistance training (WHO, 2015) and gives a better understanding of the benefits of this type of training. The results can reach a lot of people because it investigates an exercise with well documented disease and injury prevention benefits (Schoenfeld, 2010). Strength training prevents a number of diseases, for example, coronary heart disease, hypertension and obesity. Consequently, strength training does not only make the individual healthier in the sense of not get a disease related to inactivity but also make the well-being of the individual better, both mentally and physically (Ewing Garber et al., 2011).
2.5 Statistical analysis

Data was analyzed with IBM Statistical Package for the Social Sciences (SPSS) version 20. Data was not normally distributed, after exploring the data, and therefore non-parametric tests were required. Wilcoxon signed-rank test was used to see if any statistical differences existed between bilateral and unilateral squat in muscle activity in each of the muscles, GMA, GM, RF and BF, separately. Friedman test and post-hoc testing (pairwise comparison) was used to compare differences in muscle activity between all the four muscles, GMA, GM, RF and BF, during either the bilateral or unilateral body weight squat. Statistical significance was set at $\alpha = 0.05$ for all analysis, however, for clarity all probability values are reported. Data are presented as mean ± standard deviation (SD).

3. Result

All subjects completed bilateral and unilateral body weight squat tests without complications and did not report any difficulties performing the exercises. The anthropometric data of the subjects is shown in table 2. One subject was left foot dominant and 14 subjects were right foot dominant.

<table>
<thead>
<tr>
<th></th>
<th>Mean (n=15)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>23.53</td>
<td>±1.96</td>
</tr>
<tr>
<td>Length (m)</td>
<td>1.74</td>
<td>±0.09</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.13</td>
<td>±10.58</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.71</td>
<td>±2.17</td>
</tr>
<tr>
<td>Shoulder width (cm)</td>
<td>41.80</td>
<td>±2.93</td>
</tr>
</tbody>
</table>

SD= Standard deviation; BMI = body mass index; cm = centimeter; kg = kilogram.

3.1 Muscle activity in bilateral versus unilateral squat

Result from body weight squat performed bilaterally and unilaterally indicated that unilateral body weight squat had a statistical significant higher muscle activity in GM ($p=0.001$) and RF ($p=0.003$) compared to bilateral body weight squat (figure 1, table 3). For BF and GMA no statistical significant difference was found in muscle activity between unilateral and bilateral body weight squat, however, in both muscles a trend was found.
that unilateral body weight squat produced higher muscle activity compared to bilateral body weight squat (GMA p= 0.069 and BF p= 0.061) as shown in table 3.

![Bilateral and unilateral squats (+/- 1 SD)](image)

**FIGURE 1.** Mean (±SD) normalized EMG activity expressed as percentage of "maximum voluntary isometric contraction" (MVIC) during bilateral (BS) and unilateral body weight squat (US). Gluteus maximus (GMA), gluteus medius (GM), rectus femoris (RF) and biceps femoris (BF).

### 3.2 The level of muscle activity in the different muscles

**TABLE 3.** Muscle activity in bilateral (BS) and unilateral (US) squat.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>MVIC (µV)</th>
<th>BS (µV)</th>
<th>BS (%MVIC)</th>
<th>US (µV)</th>
<th>US (%MVIC)</th>
<th>Ratio BS:US</th>
<th>p-value of % MVIC in BS vs US</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMA</td>
<td>943.5</td>
<td>164.1</td>
<td>9.5(±13.3)</td>
<td>92.9</td>
<td>16.9(±8.6)</td>
<td>1:1.8</td>
<td>0.069</td>
</tr>
<tr>
<td>GM</td>
<td>334.2</td>
<td>18.9(±7.7)</td>
<td>7.0(±4.2)</td>
<td>125.3</td>
<td>40.0(±11.2)</td>
<td>1:5.7</td>
<td>0.001</td>
</tr>
<tr>
<td>RF</td>
<td>316.2</td>
<td>90.8(±52.6)</td>
<td>47.0(±27.3)</td>
<td>128.7</td>
<td>70.0(±42.8)</td>
<td>1:1.5</td>
<td>0.003</td>
</tr>
<tr>
<td>BF</td>
<td>734.1</td>
<td>51.1</td>
<td>6.9(±7.4)</td>
<td>86.1</td>
<td>12.4(±7.2)</td>
<td>1:1.8</td>
<td>0.061</td>
</tr>
</tbody>
</table>

GM had the largest ratio between bilateral and unilateral stance, with 5.7 times higher activation in unilateral then bilateral body weight squat. GMA and BF had nearly the same ratio with 1.8 times larger muscle activation in unilateral then bilateral body weight squat. RF had a muscle activation of 1.5 times higher in unilateral stance compared to bilateral stance.
TABLE 4. Pairwise comparisons after Friedman test between gluteus maximus (GMA), gluteus medius (GM), rectus femoris (RF) and biceps femoris (BF) in bilateral and unilateral body weight squat.

<table>
<thead>
<tr>
<th></th>
<th>Bilateral body weight squat p-value</th>
<th>Unilateral body weight squat p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF - GMA</td>
<td>1.000</td>
<td>0.994</td>
</tr>
<tr>
<td>BF - GM</td>
<td>1.000</td>
<td>0.000</td>
</tr>
<tr>
<td>RF - BF</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>GM - GMA</td>
<td>1.000</td>
<td>0.028</td>
</tr>
<tr>
<td>GM - RF</td>
<td>0.001</td>
<td>1.000</td>
</tr>
<tr>
<td>GMA - RF</td>
<td>0.043</td>
<td>0.004</td>
</tr>
</tbody>
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Differences in muscle activity were compared for all four muscles measured (GMA, GM, RF and BF) in order to investigate which muscle(s) had the highest muscle activity during either bilateral or unilateral stance. Statistical investigation revealed that for unilateral squat, muscle activity in RF was statistically significantly higher than in both GMA (p=0.004) and BF (p=0.000), but not compared to GM (p=1.000). BF and GMA were not statistically significantly different from each other (p=0.994). In bilateral squat, only RF had a statistically significantly higher muscle activation compared to all the other three muscles, whereas no other differences in muscle activity was found for the bilateral squat (table 4).

4. Discussion

4.1 Result discussion

The result of the present study showed that there were statistically significantly higher muscle activity in unilateral compared to the bilateral body weight squat in GM and RF (p<0.05), together with a trend for higher muscle activity in unilateral body weight squat in GMA and BF (p<0.07). The largest difference in muscle activity between the stances was found in GM which had a muscle activity of approximately 7%MVIC in bilateral stance and 40%MVIC in unilateral stance. This difference made the muscle activity approximately five times higher in unilateral compared to bilateral stance, however, the ratio were calculated using mean%MVIC from each stance and not from every subject individually. Therefore, it should be taken in consideration that standard deviation...
probably would have been rather high if calculations were done for each subject. The present study further showed that the highest muscle activity during a bilateral squat was found in RF which had significantly higher muscle activation compared to the other three muscles. Furthermore, for the unilateral squat, the RF and GM had the highest muscle activity and had significantly higher muscle activity compared to GMA and BF.

4.1.1 Muscle activity in bilateral versus unilateral squat

A possible explanation to the statistical significant difference in GM and RF, and the trend in GMA and BF during bilateral and unilateral body weight squat is that unilateral body weight squat may be a more difficult exercise with need for more muscle activity in the overall lower body, both the back and front of the body, compared to bilateral body weight squat. Contradictory a study by Jones et al. (2012) found that the intensity when performing unilateral exercises may be equal to bilateral exercises. They studied bilateral and pitcher squat when performing a 10 repetition maximum load and found that there were no statistical difference in bilateral and pitcher squat in vastus lateralis, GMA and BS during this load. Therefore, the trend of a higher muscle activity seen in the present study may be only when performing bilateral and unilateral body weight squats and not applicable to squats with external weights. Although, Jones et al. (2012) found that vastus lateralis was significantly more activated than GM and BS as the present study also found. Jones et al (2012) suggests that unilateral stance might be beneficial for more sport specific gains compared to bilateral body weight squat because unilateral stance is more common in many sports for example when running. In the present study, performance of unilateral body weight squat showed a trend of higher muscle activity in all four muscles measured and therefore makes it relevant to take unilateral body weight squat in consideration when training for a specific sport that involves movements with unilateral stance.

GM had the highest difference (%MVIC) between bilateral (7 %MVIC) and unilateral (40 %MVIC) body weight squat which is in accordance with Barton et al. (2014) who found that the muscle activity in bilateral squat was 9 %MVIC and 42 %MVIC in unilateral squat. These results together could indicate that a unilateral squat is a far more effective exercise to strengthen GM than bilateral squat. This occurrence may be because performance of unilateral squat is less stable then performance of bilateral squat because unilateral squat involves a smaller contact surface. The load on the dominant leg in unilateral squat is
higher compared to bilateral squat because it endures the same load on a smaller surface. Further, it also has a movement of the body's center of mass, against the outside of the hip, compared to a squat performed on two legs, which leads to hip adduction and rotation of the torque to keep stable and thus the higher muscle activity in GM.

There was no statistical significant difference in muscle activity in GMA during bilateral and unilateral body weight squat in the present study. However, Barton et al. (2014) found that to produce strength in GMA the unilateral squat was preferred compared to the bilateral squat. In the present study we cannot argue with confidence that a unilateral body weight squat will activate GMA more than a bilateral body weight squat, since only a trend for this was found (p=0.07), but it would be interesting to extend the present study with more subjects in order to get a clearer picture about the GMA muscle activation in unilateral and bilateral body weight squats.

### 4.1.2 The level of muscle activation in the different muscles

The present study showed that RF had a statistically significantly higher muscle activity in bilateral body weight squat compared to the other three muscles and similarly, the unilateral body weight squat activates the RF and GM significantly higher compared to GMA and BF. Like the present study, Begalle et al. (2012) reported a higher quadriceps activity (the present study measured RF, one of the four quadriceps muscles) compared to the hamstring muscles (the present study measured BF, one of the three hamstring muscles) involvement in unilateral body weight squat. This may occur due to the fact that neither bilateral or unilateral body weight squat requires a high muscle activity in BF since RF muscle activity is rather high, and does not need to involve the hamstrings muscles for support. Therefore, RF had a significantly higher muscle activity than BF in both bilateral and unilateral stance.

GM had a statistical significant higher muscle activity in unilateral body weight squat compared to GMA. Jones et al. (2012) found that GM muscle activity was significantly higher compared to the lower back (near the location of GMA) and therefore, has a similar result to the present study. This may be the case because GMA is placed in the middle section of the buttock and the GM is placed further out on the hip (Vigué & Martín Orte, 2012). While unilateral body weight squat is performed the center of mass moves to the side of the body which make GM more active than GMA. When performing unilateral body weight squat it is harder for the body to keep stable and cannot utilize the GMA in the
same way as in bilateral body weight squat and therefore the muscle activity is higher in GM in unilateral body weight squat and GMA is higher in the bilateral body weight squat. These findings are in agreement with Barton et al. (2014) that demonstrated that it may be the larger hip adduction and rotation of torque that makes the muscle activity differ from the bilateral stance to unilateral stance.

4.2 Method discussion

In the present study a selection of four lower body muscles, which activates in bilateral and unilateral body weight squat, was made to limit the measurements. The selection was based on the muscle characteristics with superficial features (Vigué & Martín Orte, 2012). Inclusion and exclusion criteria were chosen to minimize potential injury risk for subjects and to avoid misleading results. A previous injury in a muscle structure could have a weakening effect on the muscle hence influencing the EMG result by producing a higher muscle activity to compensate for the weak muscle. To enhance the capacity for valid results the subjects had to know beforehand that a 90 degree angle could be reached in bilateral body weight squat as well as in unilateral body weight squat.

The electrodes were placed on the muscle belly and were identified by manual palpation in accordance with Konrad (2005) with reference electrode placed perpendicular to the measurement electrodes. Research showed that most of the studies used an unaffected bony structure when placing the reference electrode. In EMG studies this method is more acknowledged (Delsys, 2002; Youdas et al., 2007). Due to equipment limitations the reference electrode was placed perpendicular to the measurement electrodes.

The subjects reported difficulties exerting forces on the MVIC for RF, which may reflect on the low MVIC values for RF. This might have influences the %MVIC by incorrectly increasing the calculated %MVIC, and might have affected the results when the different muscles were compared to each other. However, the MVIC was carried out by the same supervisor for all subjects and all MVIC exercises that were performed to find MVIC values during the test were in accordance to Hislop & Montgomery (2007) in order to minimize the measurement bias in the study. Moreover, any differences found between unilateral and bilateral stance would not be influenced by this type of measurement error. To minimize the potential risk of fatigue the subjects had to perform resistance training frequently and were encouraged to not engage in any lower extremity training two days before the test occasion. The subjects rested for one minute between the testing exercises.
to avoid fatigue accordingly Youdas et al. (2007). Coburn and Malek (2012) declares that resting period to physically recover should be between one and three minutes. Resting period was three minutes between warm-up to MVIC and MVIC to test and one minute between the bilateral body weight squat test and unilateral body weight squat test. In body weight resistance training the rest does not have to be as long as when training with external weights and with the training background of the subject this should mean that they did not need longer than one minute to recover. Therefore, the rest periods did not appear to be problematic for the subjects and therefore, probably did not influence the results in the present study. If the subjects were tired the muscle activity would have been higher than if they were well rested.

The present study represented both sexes to reach the general public. Zeller et al. (2003) found that women may have difficulties in controlling the hip and therefore have an increased hip adduction which leads to that the knee moves to a valgus position when performing the unilateral body weight squat. This can induce misleading results by making GM muscle activity higher and may be one of two reason, that GM is one of the two muscles in this study that show a significant difference between bilateral and unilateral body weight squat. The valgus should have been measured and standardized to get a more reliable result.

The present study has a small sample size and has little reliability to draw proper conclusions. A higher number of participants would have been desirable to increase the credibility. Further studies are encouraged to examine the difference in muscle activity of the lower extremity during bilateral and unilateral body weight squat.

4.3 Conclusion

In conclusion, all muscles (GMA, GM, RF and BF) investigated in this study were either significantly higher (RF, GM), or showed tendencies of higher (GMA, BF) muscle activity in unilateral body weight squat compared to bilateral body weight squat, assessed with EMG. The largest difference was found in GM which had a muscle activity of 40%MVIC in unilateral stance compared to 7%MVIC in bilateral stance. In bilateral squat, the highest muscle activity was seen in RF compared to all the other muscles whereas in the unilateral squat both RF and GM had significantly higher muscle activation compared to GMA and BF. Practical applications from the present results is that, to strengthen the front of the leg both bilateral and unilateral body weight squat is appropriate due to the fact of the
high muscle activation found in RF during both stances. Unilateral body weight squat requires more muscle activity, especially in RF and GM, in lower body muscles than bilateral body weight squat. Therefore, unilateral stance is more compatible to strengthen the body than bilateral body weight squat and by this possibly prevent injuries and diseases that can be prevented by resistance training. However, to strengthen GMA and BF a different exercise or an addition of external weights may be of interest because of the low muscle activity reached during body weight squat in the present study. Further on, GM works significantly higher in unilateral compared to bilateral body weight squat which strengthen GM and by this improve the dynamic balance of an individual and by this strengthen the stability in every movement of the day such as walking and running
5. References


Appendix A
The exercises in more detailed description so the execution is the same for all the participants.

Warm-up

Knee-pulls towards the stomach (alternate legs)
Stand on one leg and bend the other leg at the same time as you pull it towards your stomach, keeping the balance on the leg that is still on the floor. Pull the knee as close and high as you can and then slowly, still keeping your balance, place it next to the leg on the floor. The placements of the hands should be on the hips, if the balance is lost just take a second and then continue the exercise.

Coordination jumps (alternate legs)
One legged jump where you use your arms to get more movement in the body and a coordination factor. You jump on one leg and at the same time pull the other knee towards the stomach. At the same time, you swing the opposite arm forward whilst having the elbow joint in a 90 degree angle. The other arm follows the rest of the body, with the hand direction towards the ground.
**Lunge-walk**

Take a big step forward and bend the knees until the rear knee almost touches the floor, reaching approximately 90 degree angle in both knees, than push the body up on the front leg. Now use the rear leg to take another big step forward and keep it going until all repetitions is complete.

![Lunge-walk images](image1.jpg) ![Lunge-walk images](image2.jpg) ![Lunge-walk images](image3.jpg)

**Air-squat**

Sit down backward, bending your knees and hip, to a comfortable position and then ascend up again. You don’t have to worry about the depth in these repetitions. Keep your hands on your hips during the exercise.

![Air-squat images](image4.jpg) ![Air-squat images](image5.jpg) ![Air-squat images](image6.jpg)

**One leg jumps**

Lift one leg a couple of centimeters over the floor and then jump on the leg that is still on the floor by bending the knee. Do all repetitions on one leg then change to the other. The hands should be on the hips.

![One leg jumps images](image7.jpg) ![One leg jumps images](image8.jpg) ![One leg jumps images](image9.jpg)
**Squat (practice trail)**

Bend the knees and hip until 90 degrees in the knee joint and then ascend up to straight legs. The feet should be shoulder wide apart and the torso straight while the arms is crossed over the chest. This is a more specific air-squat that is also involved in the actual test.

**Single Leg Squat (practice trail)**

Stand with one leg on the ground and the other leg in front of the body a couple of centimeters of the floor. Bend the knee on the leg that is still on the floor to a 90 degree angle in the knee joint and then ascend up to standing.
Appendix B

The manual muscle testing procedures to get the MVIC values.

**Gluteus maximus**
The subject lay on the stomach with the non-dominant leg straight in line with the body and the dominant leg is bent to a 90 degree flexion in the knee joint. The subject will lift the foot of the bent leg, whilst keeping it bent, towards the ceiling until it meets a resistance, weights on top of a chair, and then keep on pushing the foot upwards although the leg’s not moving, this contraction is held for three seconds. The resistance for the subject is placed in the middle of the range of motion for the gluteus maximus (Hislop & Montgomery, 2007).

**Gluteus medius**
The subject lay on the side with the dominant leg upper most. The pelvis is slightly rotated forward and the dominant leg is a bit extended beyond the midline. The non-dominant leg is flexed for stability. The subject should then lift the upper leg without flexing or rotating the hip in either direction whilst meeting a resistance in the middle of range of motion for the gluteus medius (Hislop & Montgomery, 2007). The resistance used was a weighted chair frame that the subject lay under and pressed the leg up towards during the MVIC exercise.

**Rectus femoris**
The subjects is positioned in a sitting position on a table with the legs bent at the knees and the feet is pointing towards the floor. The subject will try to straighten out the dominant leg and meet a resistance in the middle of the range of motion for the rectus femoris. As resistance a strap is used to fixate the subjects ankle and when the subject try’s to straighten the leg the strap will hold it still, making the contraction isometric The butt should be on the table at all times (Hislop & Montgomery, 2007).

**Biceps femoris**
The subject lay on the stomach with one leg straight in line with the body. The dominant leg is externally rotated with the toes pointing laterally (the toes toward the wall and heel toward the other leg). The subjects lay under a chair and try’s to push the chair towards the head by bending the knee, and not move the upper leg from the floor, without success and therefore making the contraction isometric (Hislop & Montgomery, 2007).
Appendix C

Information and informed consent form that all participants have to sign before entering the study.

You are invited to participate in a research study, *Muscle activity during bilateral and unilateral body weight squat*. The aim of this study is to analyze the muscle activity in gluteus maximus, gluteus medius, rectus femoris and biceps femoris (these muscles are located on the buttocks and legs) during bilateral and unilateral body weight squat. Please read this information carefully and in the end you will be asked to sign if you agree to participate in this study.

"Maja Hegnelius, a third year student at Biomedicine- athletic training, will be conducting this research study.

You will be performing two different forms of squat; bilateral and unilateral. In the test you will do the exercises five times each to a 90 degree angle in the knee joint. Before you do this there will be electrodes placed on your skin. The area were the electrodes are placed will be dry-shaved and washed with alcohol. It is possible that the markings from the electrodes will be irritated a while after the test.

The study will provide information about the muscle activity patterns in specific muscles during the bilateral and unilateral body weight squat. It is interesting to know how much more you activate a specific muscle depending on if it is bilateral or unilateral.

The result data will be coded with numbers instead of your name and the author will protect the participants’ privacy. The study is confidential and the recordings will be after demolished after the study. When the result of the study is published, all participants will be numbers and no names will be in the publication.

Best Regards//

Maja Hegnelius

Phone number; 0707 424755
E-mail address; majahegnelius@gmail.com
**Consent form**

The acceptance to participate is completely optional. If you choose not to participate you will not be treated any differently. If you decide to participate you have the right to withdraw from the study at any time.

I have read and understood the consent form and had the opportunity to ask questions about the study. I am over 18 years old and agree to participate in this study.

_____________________________  ___________________________  ___
Name of participant              Signature of participant              Date

_____________________________
Person receiving the consent
My name is Maja Hegnelius and I am 23 years old.
I moved from my home town Malmö to Halmstad three years ago and started at Halmstad University. I had a lot of good times during my time as a student and now I proudly present my bachelor thesis.