Is there a sex difference in the bilateral deficit?

Jenny Häggblom

Bachelor's programme in Exercise Biomedicine, 180 credits

Bachelor thesis in Exercise Biomedicine, 15 credits

Halmstad 2015-08-25
Is there a sex difference in the bilateral deficit?

Jenny Häggblom
Abstract

The bilateral deficit can be described as when the sum of two unilateral movements exceeds the bilateral output. If the sum does not exceed the bilateral output, a bilateral facilitation is present. Little research has been done in males and females comparison of the bilateral deficit. The purpose of the current study was therefore to compare the bilateral deficit between sexes in a 1 repetition maximum (RM) leg press. Twenty participants, ten males and ten females, were recruited (23.4±2.1 years, 71.2±13.1 kg, 172.2±8.9 cm) and seventeen of them completed the study. The test consisted of two testing sessions (one unilateral with preferred leg, and one bilateral session) with seven days in between. The 1 RM was attained within six attempts, with a three minutes rest between every attempt. The current study showed a bilateral deficit of males (5.6±4.6%) and a bilateral facilitation of females (0.6±5.9%). There was a significant difference between sexes of p=0.031 (p<0.05). Previous studies have examined males and females separately, with different methods and protocols. This study used the same method and protocol in both sexes. Some suggestions of the mechanisms behind the deficit have been proposed and may explain the current findings, but further studies are needed. Future research needs to continue to explore and explain the sex difference in the bilateral strength deficit.
Index

ABSTRACT .................................................................................................................. III

1. BACKGROUND ........................................................................................................ 1
   1.1. SEX CHARACTERISTICS DIFFERENCES ......................................................... 1
       1.1.1. Anatomical differences ........................................................................... 1
       1.1.2. Physiological differences ....................................................................... 2
       1.1.3. Strength differences ................................................................................ 2
   1.2. BILATERAL DEFICIT ....................................................................................... 3
       1.2.1. Definition ................................................................................................. 3
       1.2.2. Mechanisms behind ................................................................................ 3
       1.2.3. Amount of the deficit in different tasks .................................................... 4
   1.3. AIM .................................................................................................................... 4
       1.3.2. Research questions .................................................................................. 4

2. METHOD .................................................................................................................... 4
   2.1. PARTICIPANTS .................................................................................................. 4
       2.1.1. Inclusion and exclusion criteria ............................................................... 5
   2.2. PROCEDURE .................................................................................................... 5
   2.3. ETHICAL AND SOCIAL CONSIDERATIONS ................................................... 7
   2.4. STATISTICAL ANALYSIS .............................................................................. 8

3. RESULTS ................................................................................................................... 8

4. DISCUSSION ............................................................................................................. 10
   4.1. RESULT DISCUSSION ...................................................................................... 10
   4.2. SEX DIFFERENCES ....................................................................................... 12
       4.2.1. Anatomical differences ........................................................................... 12
       4.2.2. Physiological differences ....................................................................... 12
       4.2.3. Strength differences ................................................................................ 13
   4.3. MECHANISMS BEHIND .................................................................................. 13
       4.3.1. Maximally activate relevant muscles ....................................................... 13
       4.3.2. Fast motor unit not being fully activated ............................................... 14
       4.3.3. Afferent feedback ................................................................................... 14
   4.4. METHOD DISCUSSION ................................................................................... 14
       4.4.1. Leg press versus squats .......................................................................... 14
       4.4.2. Sample .................................................................................................... 15

5. CONCLUSION ............................................................................................................ 15

6. REFERENCES ........................................................................................................... 16

7. APPENDIX 1 ............................................................................................................ 19
   7.1. CONSENT TO PARTICIPATE IN RESEARCH ............................................... 19

8. APPENDIX 2 ............................................................................................................ 20

9. APPENDIX 3 ............................................................................................................ 21
   9.1. GLOSSARY .................................................................................................... 21
1. Background
Strength training, especially heavy resistance training, is a performance enhancing method in all competitive sports (Cormie, McGuigan, & Newton, 2010). Some of the benefits from strength training is an increased muscular strength, increased fiber size in the working muscles, increased myofibrillar volume, increased storage of ATP (energy) in the muscles, as well as an increase of fat-free mass in the individual (Baechle & Earle, 2008). This leads to an increase in athletics performance (Young, 2006) in both inexperienced as well as experienced athletes. Many sports are reliant on the ability to generate force or power through the lower body and therefore strength training is an important method.

In most ground-based sports, for example during running, force production is usually generated by single-leg movements. Unilateral training, i.e. single-leg training, can be described as the contraction of one limb individually (Nijem & Galpin, 2014). The single-leg musculature, in unilateral training, works at high relative intensity and that is sufficient to improve strength (McCurdy et al., 2005). Because of more functional positions and lighter absolute weights, athletic careers will be prolonged and also enhance the athletic performance (Santana, 2001). Single leg training is also preferable due to the transferability and the increased strength in a bilateral exercise (McCurdy et al., 2005). Unilateral training is therefore an athletic performance enhancing method.

The aim of the current study it to investigate if (1) men and women exhibit a bilateral deficit, and (2) if there is an equal deficit between men and women.

1.1. Sex Characteristics Differences
1.1.1. Anatomical differences
There are some differences between men and women regarding the anatomy. For example, females have a different pelvis and hip complex compared to males. It has previously been suggested that females have a wider pelvis than men, but in more recent research, it’s seems like their pelvis is more anterior tilted. Women do have an increased quadriceps angle (Q-angle) (appendix 3) because of their pelvis position (Sernert, 2010). Because of the anatomical differences of the pelvis, females exhibit more hip adduction when performing a unilateral movement compared to men. When a hip adduction takes place, it could influence...
and reduce the strength of the working limb because of less muscle recruitment (Zeller et al., 2003).

1.1.2. Physiological differences
Men and women have an equal muscle fiber quality, no sex difference exists in muscle fiber distribution. A human skeletal muscle contains two different fiber types, type I (slow-twitch) and type II (fast-twitch). Type I fibers are predominantly used during prolonged aerobic exercise, while type II fibers are used during fast and forceful contractions. Type II fibers relies more on anaerobic energy metabolism, for example during strength or power tasks (McArdle, Katch, & Katch, 2010). According to Bishop et al. (1987) there appears to be no sex difference in muscle tissue quality and no difference between sexes in the muscles functioning.

Neuromuscular functioning
There is evidence to illuminate the differences in neuromuscular functioning between men and women. The “latency period between the preparatory and reactive muscle activation” (p.169), called the electromechanical delay (EMD), is shorter in males than females (Lephart et al., 2002; Blackburn et al., 2009). A longer EMD is also associated with a smaller rate of force production (RFP) (Blackburn et al., 2009). Females do also have an increased neuromuscular inhibition compared to males, and this reduces their strength capacity (McArdle, Katch, & Katch, 2010). The neuromuscular functioning therefore, give rise to the difference between sexes in a strength task.

1.1.3. Strength differences
Cross sectional area
A greater cross sectional area (CSA) is correlated with an increased muscular strength. Kirk et al. (1987) and Maughan et al. (1983) concluded that a difference in muscle size gives a difference in muscle strength. Men have somewhat larger muscles than women in the lower extremity, and thus a greater CSA (Beachle & Earle, 2008) and also strength (Miller et al., 1992). However, the strength per unit of CSA gives no difference between sexes (McArdle, Katch & Katch, 2010). Men have a greater CSA compared to women and therefore a greater muscular strength in the lower extremity muscles.

Absolute versus relative strength
The strength differs among sexes but when relative to body the strength is similar. Females are generally weaker than males (Hicks, 2001) on an absolute basis (McArdle, Katch, &
Katch, 2010). Females scores approximately 30% lower for a leg-strength task, in absolute terms, compared to males (McArdle, Katch, & Katch, 2010). When relative to body weight, the differences tend to disappear (Baechle & Earle, 2008), because females are generally smaller and lighter. Miller et al. (1992) though, reported higher relative muscle strength in males compared to females. Men scores higher on an absolute strength basis than women, but when expressed in relative strength the results may differ and be more equal.

Muscle recruitment
Men and women show muscle recruitment differences in the lower extremities. To be strong in any lower body motion, for example the squat or leg press, the quadriceps and the hamstrings should work together thru the movement to generate the maximal strength. Females are reported to be quadriceps dominant, meaning that the quadriceps is the first muscle group to be activated. Females tend to activate their hamstrings later in a movement compared to men (Lephart et al., 2002). With a longer EMD and RFP in females, there is a decreased muscle recruitment than in males (Blackburn et al., 2009). Males and females displays a strength recruitment in the recruited muscles in a lower body task and this may cause less strength in females.

1.2. Bilateral deficit

1.2.1. Definition
Since the 1960s, when the bilateral deficit was first described (Costa, 2015), several studies have indicated that there is a phenomenon called the bilateral deficit. The bilateral deficit can be defined as when “the sum of two unilateral movements exceeds the bilateral output” (Challis, 1998; Nijem & Galphin, 2014). If the sum does not exceed the bilateral output, there is another phenomenon current, called the bilateral facilitation (Howard & Enoka, 1991). The deficit has been verified in different samples during the last decades (Costa, 2015), but still not in a males and females with the same protocol. Since males and females differ both anatomically and physiologically, it is interesting to examine if there is any difference between sexes. Based on the results in the previous findings, the suggestion is that a bilateral deficit or facilitation can be expected in every sample but with different magnitude.

1.2.2. Mechanisms behind
Research has previously suggested numerous reasons why the bilateral deficit is present.
Three of the most common theories are (1) an inability to maximally activate relevant muscles
during the bilateral motion (Challis, 1998), (2) that the fast motor units cannot be fully activated during a bilateral task (Oda & Moritani, 1994), and (3) the influence of afferent feedback mechanisms from muscles in the working limbs (Howard & Enoka, 1991). Even though the proposals are widely recognized in research, there is a lack of evidence explaining their contribution to the phenomenon.

1.2.3. Amount of the deficit in different tasks
It has been proposed that there is a general bilateral deficit of 3-25% in different tasks. For example, Challis (1998) and Van Soest et al. (1985) found a deficit of 8.8% (in females) and 8.5% (in males) in vertical jumps in two different samples. Jakobi & Cafarelli (1998), on the other hand, found facilitation in males of 3.2% in a leg extension. Even greater deficits has been found, for example Hay et al. (2006) used the leg press in a power-study of males, and found a deficit ranging from 6.1-20.9%. Different tasks seem to result in different amounts of deficits (table 4). Only a few studies have used a sample from both males and females, but no results indicates if the amount is equal between sexes. Based on the previous studies, there is no clear amount of the deficit, and seems to depend on both sample and task used.

1.3. Aim
The aim of the current study is to investigate if (1) men and women exhibit a bilateral deficit, and (2) if there is an equal bilateral deficit between men and women.

1.3.2. Research questions
1. Do both men and women exhibit a bilateral deficit?
2. Is there an equal bilateral deficit between men and women?

2. Method
2.1. Participants
Students from Halmstad University Sweden were approached to participate in the current study. 20 participants volunteered in the present study, and they were placed in gender-heterogeneous groups for the statistical analyses, one female (n=10) and one male (n=10) group. The participants signed an informed consent (appendix 1) during the initial meeting, under approval of the current supervisors. The initial meeting was held approximately 24-48 h before the first test occasion, and consisted of a questionnaire (appendix 2), a familiarization session with the leg press, the technique and the testing procedure.
2.1.1. Inclusion and exclusion criteria
A crossover design was used with two test occasions occurring, one unilateral and one bilateral. There were 7 days in between test occasions to avoid fatigue. The inclusion criteria in the study were no lower extremity injury that would have occurred in the previous last 6 months and no heavy (less than 8 repetitions) leg-workout 24 hours prior testing. Participants were asked to do normal daily routines prior testing. If the participant used performance-enhancing substances (in this case amino acids, creatine or caffeine), the participant was asked to use the same dosage prior or during both test-occasions. Three participants were excluded from the study, this because of improper technique, withdrawal, and medication that might have influenced the result negatively and therefore their results is not included at all. Final number of participants in the study was 9 females and 8 males.

2.2. Procedure
This study used a standard hip sled machine (Atlantis LegPress C-401) to examine the 1 repetition maximum (1RM) strength difference between unilateral and bilateral strength movements. The leg-press’s (figure 1A) sled weighed 50 kg and additional weights (Eleiko 2.5,5,10,15,20,25 kg) were then added to reach the participants 1RM. During the single-legged presses, the participants’ used their preferred leg throughout the whole study, and this had previously been done by Challis (1998).

The warming consisted of a general warm up to increase overall body temperature, and consisted of 5 minutes of aerobic exercise (row, bicycle, or treadmill). The participants were able to talk unstrained during the general warm up (no specific heart rate percent was used). A specific warm up, in the leg press, consisted of 1 set of 8 repetitions, 1 set of 3 repetitions (Barosso et al., 2013) and 1 set of 2 repetitions (added during pilot-study) at 50, 70 and 80% of the estimated 1RM values (based on the pre-meeting questionnaire). The specific warm up sets were separated with 2-minutes rest periods. After the specific warm up, participants rested for 3 minutes and then the test started. A 3-minute rest period was given between each trial and no more than 6 attempts occurred. Strong verbal encouragement from the investigator was given during each press. The amount of weight added between trials was at least 2.5 kg. If a participant did not manage a to press a weight, some weight was removed and another attempt occurred after 3 minutes of rest, if there was attempts left. The sixth
attempt was recorded as their 1RM, even if the participant had more strength left and could have continued.

The settings for the bilateral leg press were the following, the toes of the participants were placed 10 cm from the top of the plate and the feet were hip-width apart. During the unilateral leg press, the toes were 10 cm from the top, the foot under the hip (again hip-width apart) where it felt most natural for the participant. The feet were slightly pointed out in both exercises (Hay et al., 2006). The support for the back was set at the lowest possible to the ground (figure 1B). The participant was asked to hold the handles during the whole testing procedure, including the warm-up.

Figure 1. A. The Atlantis LegPress C-401 (Atlantis Strength, 2015), B. The support for the backs settings during the testing procedure

In the starting position, the participant had their leg extended (knees not locked) and then they flexed their knees to a 90° angle (Benton et al., 2013). By a command from the observer, the participant then extended their knees from 90° back to the starting position (Shaner et al., 2014), again knees not locked. A pre-test to set the 90° angle was done at both of the test- occasions. The 90° angle were set and recorded using only sled-weight (50 kg).

A pilot study was conducted a few weeks before the current study started. The pilot study was used to evaluate the method beforehand, as well as for preparing the investigator to possible obstacles with regard to the testing procedure. Some modifications occurred during the pilot study but this did not influence any of the participants, nor their results, and the pilot is not included in the results at all.
2.3. Ethical and social considerations
Participants were recruited through social media networks, in this case Facebook, and all of them participated voluntarily in the current study. None of the participants were forced or paid to enter the study. If any of the participants would like to withdraw from the study, they had the right to do so at any time (World Medical Association, 2013).

Before this study began, at the initial meeting, every participant signed an informed consent (appendix 1). An informed consent is needed in a study like this, when involving human beings, according to the Nürnberg Codex of 1947 (Codex, 2015). The informed consent was in line with the Declaration of Helsinki (World Medical Association, 2013) and was approved from supervisors prior testing. The informed consent where then handed over to the supervisors for archiving.

During the initial meeting, all information about the study was given to the participants. The aim of the study and the study’s procedure were clearly explained during this meeting (Vetenskapsrådet). This information included the awareness of compensation if they were harmed during the study, details about confidentially aspects of the data, details of methods as well as inclusion and exclusion criteria (Drummond, 2009) were presented. Every attendant was surely understood about the study’s aim and method before the first test-occasion and had the right to withdraw before the study began.

All participants were experienced and used the exercise modalities on a normal basis. Since the participants were used to the exercises there was no increased injury risk for them. All participants received their individual results after testing was completed. Results will be made public through DiVA, where a larger population can access the results.

This study did not affect the environment negatively, all research was made at the same place with local participants so the stress on the environment were kept to a minimum. The informed consent as well as the contents of the consent was kept in line with the Act of Ethical Review of Research Involving Humans (SFS 2003:460).
2.4. Statistical Analysis
When exploring the results from the tests, two formulas were used to estimate the difference and then to explore the bilateral deficit or facilitation. The deficit were calculated based on these formulas:

\[
\text{Difference} = \frac{\text{Unilateral strength (kg)}}{\text{Bilateral strength (kg)}} \times 100
\]

\[
\text{Difference} - 50 = \text{Bilateral deficit \%}
\]

A positive value (> 0%) indicates a bilateral deficit, the weight moved with one leg is more than half the weight moved with two legs. A negative value (< 0%) indicates that there is a bilateral facilitation (Howard & Enoka, 1991), the weight moved with one leg is less than half the weight moved with two legs. The results will be presented as a bilateral deficit or facilitation.

A test for significant outliers were done by using the Grubbs’ test where the significance level were set to p<0.05. The results, after the Grubbs’ test, in the current study were then compared using an independent t-test to test for the significance between samples, i.e. males versus females, with a 5% risk (p<0.05). All data were controlled for normal distribution (Shapiro-Wilk, with a significance of 0.263) before the independent t-test occurred. During the independent t-test, the study used the 2-tailed test for significance. The IBM SPSS software, version 20.0 (SPSS Inc. Chicago, IL, USA) was used for the analysis.

3. Results
20 participants started the study, three of them were excluded during the study so results from 17 participants is presented. There is a difference in the anthropometry between sexes, regarding weight and length (table 1). The participants’ age is similar between groups, woman 23.8 (±1.7) years and men 22.7 (±2.4) years. All of the volunteered participants had more than 1-year experience of leg press as an exercise.

| Table 1. Participants’ anthropometry. Values are means (± SD) |
|-----------------|-----------------|-----------------|
|                 | Female (n=10)   | Male (n=10)     | Total (n=20)    |
| Age             | 23.8 (±1.7)     | 22.7 (±2.4)     | 23.4 (±2.1)     |
| Weight (kg)     | 61.3 (±7.7)     | 78.2 (±9.5)     | 71.2 (±13.1)    |
| Length (cm)     | 164.9 (±5.3)    | 176.9 (±5.7)    | 172.2 (±8.9)    |
The average 1RM (repetition maximum) in the unilateral and bilateral leg press, expressed in kilograms, is seen in table 2 and figure 2. Men exhibited a greater absolute strength in both unilateral (210.9±59.9 kg) as well as bilateral (379.4±109.6 kg) modality compared to the females (112.2±19.5 kg and 227.8±36.4 kg respectively). The bilateral deficits, both within and between sexes, are also presented in table 2. The average bilateral deficit in the current study for the females was -0.6±5.9%, which equals a bilateral facilitation of 0.6±5.9%, and the corresponding results for the males were a bilateral deficit 5.6±4.6%.

**Table 2.** Average strength, unilateral and bilateral 1RM (kg), and the average bilateral deficit (above + or under - 50) percent in males and females (±SD), p<0.05

<table>
<thead>
<tr>
<th></th>
<th>Female (n=9)</th>
<th>Male (n=8)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilateral 1RM (kg)</td>
<td>112.2 (±19.5)</td>
<td>210.9 (±59.9)</td>
<td>-</td>
</tr>
<tr>
<td>Bilateral 1RM (kg)</td>
<td>227.8 (±36.4)</td>
<td>379.4 (±109.6)</td>
<td>-</td>
</tr>
<tr>
<td>Bilateral deficit %</td>
<td>-0.6 (±5.9)</td>
<td>5.6 (±4.6)</td>
<td>0.031*</td>
</tr>
</tbody>
</table>

* Bilateral facilitation of 0.6±5.9%  
* Significant difference between females and males bilateral deficit (p<0.05)

**Figure 3.** Average strength, unilateral and bilateral 1RM (kg) for females and males

The results from the current study partly support the research question, there is a bilateral deficit for the males (5.6±4.6%). But, there was not a bilateral deficit of the female sample in this study, and instead a bilateral facilitation (0.06±5.9%) was achieved. There was significant difference between males and females results with a p-value of 0.031 (p<0.05).
Males in the current study had a higher absolute strength than females, but they also showed a higher relative muscular strength (when expressed in relation to body mass) (table 3). Female had a relative strength of 1.9±0.2 in the unilateral and 3.8±0.2 in the bilateral. The corresponding results for males were 2.5±0.5 and 4.7±0.8 respectively.

**Table 3.** Strength in relation to body mass in females and males (weight pressed in kilograms divided by bodyweight [BW] in general)

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilateral (kg/BW)</td>
<td>1.9 (±0.2)</td>
<td>2.5 (±0.5)</td>
</tr>
<tr>
<td>Bilateral (kg/BW)</td>
<td>3.8 (±0.2)</td>
<td>4.7 (±0.8)</td>
</tr>
</tbody>
</table>

A test for outliers (Grubb’s test) was done after conducting the results. The test for outliers revealed that some participants were somewhat away from the rest but not a significant outlier (p>0.05) so no exclusions of results were made based on this statistical analysis.

**4. Discussion**

The current paper has investigated the sex differences in the bilateral deficit in a strength task, the leg press. The result from the present paper shows a bilateral deficit in males of 5.6 ±6.0% and a bilateral facilitation in females of 0.6 ±5.9% (table 2). The result shows that women do not exhibit a bilateral deficit but males do, even though the results barely indicated a facilitation nor deficit. There is a significant difference p = 0.031 (p<0.05) between men and women in the current study.

**4.1. Result discussion**

A bilateral deficit occurs when the sum of two unilateral movements exceeds the bilateral output, and the opposite, the facilitation is when the sum does not exceed the bilateral output (Howard & Enoka, 1991). The current result shows that men actually display an increased strength in one leg compared to when two legs are used, a bilateral deficit (5.6 ±6.0%). This does not happen in the female sample of the current study, instead they had a bilateral facilitation of 0.6 ±5.9%. Females, though, barely showed facilitation with such a high standard deviation. However, based on the results from the current paper, women are generally stronger with both legs instead of one leg at a time.

The results from this paper are in line with previous reports when looking at the males’ results. Previous reports have displayed a bilateral deficit in most of the tasks investigated (table 4). For example, Howard & Enoka (1991) found a bilateral deficit in weightlifters but
neither in cyclists nor in untrained individuals, all participants were men in their study. Kawakami et al. (1998) showed a bilateral deficit of men in two modalities of plantar flexion. A power produced leg extension conducted by Dickin et al. (2011) showed a bilateral deficit in general of 19.7%, which is more than the current study’s result.

Challis (1998) found a deficit of 8.8% in females and this is completely different from the current facilitation of 0.6%. This conflicting result could depend on the modality used, because Challis (1998) used the countermovement jumps and the leg press was used in the current. The countermovement jump requires both power and stability of the core (Shaner et al., 2014) and the leg press requires pure strength and no core or balance (Brown, 2001). Future studies should investigate further if these results are trustworthy, especially since these results are based on a pure strength task.

Table 4. Anthropometrics, bilateral deficit or facilitation of previous studies and the current

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilateral deficit %:</td>
<td>+8.5%</td>
<td>+5.2 ±4.7</td>
<td>-6.6 ±7.1</td>
<td>-9.5 ±6.8</td>
<td>+6.6 ±2.3%</td>
<td>+13.9 ±6.0%</td>
<td>+13.5%</td>
<td>+17.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+5.6 ±6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.6 ±5.9</td>
</tr>
<tr>
<td>Participants:</td>
<td>10 males</td>
<td>22 males</td>
<td>6 males</td>
<td>7 females</td>
<td>20 males</td>
<td>5 males</td>
<td>12 males</td>
<td>20 males and females</td>
</tr>
<tr>
<td>Age (y):</td>
<td>23.0 ±4.0</td>
<td>22.7 ±3.0</td>
<td>33.1 ±6.6</td>
<td>29.0 ±3.2</td>
<td>27.5 ±1.78</td>
<td>27.8 ±3.5</td>
<td>22.41 ±3.39</td>
<td>23.8 ±1.9</td>
</tr>
<tr>
<td>Weight (kg):</td>
<td>83.5 ±10.0</td>
<td>76.8 ±10.4</td>
<td>64.39 ±6.93</td>
<td>77.48 ±2.0</td>
<td>72.2 ±4.7</td>
<td>74.92 ±5.23</td>
<td>69.7 ±12.3</td>
<td></td>
</tr>
<tr>
<td>Height (cm):</td>
<td>193.0 ± 6.0</td>
<td>177.6 ±4.6</td>
<td>178.2 ±5.4</td>
<td>175.7 ±4.9</td>
<td>176.8 ±5.4</td>
<td>168 ±3.0</td>
<td>176 ±3.0</td>
<td>177.58 ±6.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>171.9 ±8.9</td>
</tr>
</tbody>
</table>

Notes: 1 weightlifters, 2 cyclists, 3 untrained, 4 knee joint at 0°, 5 knee joint at 90°, 6 dominant leg, 7 non-dominant leg, 8 males, 9 females

The men in the current study, in absolute terms, were taller, heavier and stronger than the females. The anthropometries though were relatively equal to previous studies, as well as the
age of the participants (table 3). A similarity between the previous studies and the current is that most of the participants were students at university level.

4.2. Sex Differences
Men in the current study experienced a bilateral deficit of $5.6 \pm 6.0\%$ while the females experienced a bilateral facilitation of $0.6 \pm 5.9\%$. The sex differences between men and women might partly explain the present results but there could be other, not investigated in this study, explanations as well. Therefore, future studies should continue to investigate the sex aspects and compare the deficit among sexes.

4.2.1. Anatomical differences
Men and women differ anatomically, especially in their pelvis and hip complex. Females’ exhibits more hip adduction than men, this is partly because of their wider and more anterior tilted pelvis (Sernert, 2010). This adduction influences and reduces the strength of the working limb because of less muscle requirement. When females tested unilaterally in the current study, their hips might have adducted and therefore influenced the results. This was the case in the study of Zeller et al. (2003), and could therefore be an explanation. No attention was paid at this in the current study, so upcoming studies should examine this further.

4.2.2. Physiological differences
There is no difference in muscle tissue quality or functioning between men and women (McArdle, Katch, & Katch, 2010). Men however, have somewhat larger muscles than women and thus a greater CSA (Beachle & Earle, 2008). The muscle size gives an increase in CSA and also an increase in muscle strength (Maughan et al., 1983). Lower extremity muscles are bigger in males than females, which in turn gives a greater muscular strength. This may explain the difference in men and females’ maximal strength, but it does not explain the bilateral deficit differences in the current study.

Since there is evidence for different neuromuscular functioning between men and women, the results in the present study might be explained by this. The electromechanical delay (EMD) in males is shorter than in females (Lephant et al., 2002) and this gives rise to the smaller rate of force production (RFP) in women (Blackburn et al., 2009). Because of the longer latency
period between preparatory and muscle activation in females (Lephart et al., 2002), the strength reduces and this could partly explain the current results.

### 4.2.3. Strength differences
In relative to body weight, the strength should equal each other (Beachle & Earle, 2008) but in the current study the relative strength differed. Women in the current study were lighter than males, and when the strength in average was divided by the average bodyweight of the sample, the relative strength was smaller in women (unilateral 1.9±0.2 and bilateral 3.8±0.4 times bodyweight) than men (unilateral 2.5±0.5 and bilateral 4.7±0.8 times bodyweight) (table 3). These results, higher relative muscle strength in males, are in line with previous results of Miller et al. (1992).

The differences of relative strength, in the current study may have been because of different lean body mass distribution between sexes. Miller et al. (1992) could see that more fat mass is distributed in the lower extremities of females, compared to men. A larger amount of intramuscular fat does not contribute to force production (Miller et al., 1992) and this could theoretically explain the current results of the relative muscle strength difference. Future studies should continue and evaluate this aspect.

### 4.3. Mechanisms behind

#### 4.3.1. Maximally activate relevant muscles
Challis (1998) suggested that one of the mechanisms that explain the bilateral deficit was the inability to maximally activate the relevant muscles during the bilateral motion. As previously mentioned, women have a prolonged latency period between the preparatory and the reactive muscle activation (Lephart et al., 2002) which gives a smaller rate of force production (Blackburn et al., 2009). Women also have an increased ability to faster maximally activate the quadriceps muscles (Lephart et al., 2002) compared to men. During the current study females may have activated the quadriceps to a greater extent in the bilateral modality than the unilateral. For example, they could have activated the quadriceps to the same extent in both unilateral and bilateral modality, and since only one leg worked during the unilateral aspect, they had a reduced strength in the unilateral leg press. This could therefore have given rise to an increased bilateral strength compared to the unilateral strength. Future studies should use electromyography to evaluate this aspect further.
4.3.2. Fast motor unit not being fully activated
Oda & Moritani (1994) proposed a mechanism that might explain the current study’s results. They proposed that fast motor units couldn’t be fully activated during a bilateral task (Oda & Moritani, 1994) compared to a unilateral task. Men in the current study may have activated the fast motor units to a greater extent in the unilateral test compared to the bilateral test. Previously it has been mentioned that no difference exists between men and women in muscle fiber distribution. But Miller et al. (1992) displayed that men have larger type II muscle fibers in the vastus lateralis (quadriceps muscle) compared to women. The current study could have had participants of whom type II muscle fibers were dominant. Muscle biopsies could be used to determine if this is a realistic explanation.

4.3.3. Afferent feedback
Afferent feedback, feedback from the working muscles to the central nervous system (Coburn & Malek, 2012) could be a third aspect of the mechanisms behind the bilateral deficit. Howard & Enoka (1991) suggested that the afferent feedback mechanisms from muscles in the working limb could influence the amount of the deficit. Since females have an increased neuromuscular inhibition (McArdle, Katch, & Katch, 2010) and an increased electromechanical delay (Lephart et al., 2002), their afferent feedback during the unilateral movement may not have worked as properly as in the males. It is hard to investigate this, and this study did not examine this at all, but still it could be a possible explanation.

4.4. Method discussion
4.4.1. Leg press versus squats
Leg press is a more safe exercise than the squats, although they are similar in muscle recruitment. An increased balance demand is present during the squats compared to the leg press (Shaner et al., 2014) and an improper balance could result in a severe injury (Brown, 2001). When external load is placed on the axial skeleton, the torso-muscles require a proper position (Coburn & Malek, 2012) and this aspect is removed during the leg press. A female does also, during squats, have an increase risk of hip adduction and more reliance on the knee extensors than males (McCurdy et al., 2005). To equal the differences between men and women, the leg press is a preferable exercise.

The current study used the leg press over the squats because of its reduced injury risks (Brown, 2001) and because it is easier to standardize. The squats though, are more functional
(Shaner et al., 2014) and have a greater correlation with jumping tasks than the leg press (Nuzzo et al., 2008). The results from the current study could have been easier to compare to previous results if the squats was tested, instead of the leg press. But due to limited time and sample size, the leg press was a more familiar exercise to the participants. Future studies however, should use the squats instead of the leg press to search for the bilateral deficit.

4.4.2. Sample
The current study recruited students from Halmstad University. All of the participants were familiar with the leg press. The sample was heterogeneous in two aspects, firstly they were of different sexes and secondly they were from different athletic backgrounds. Previous studies have used single-sex samples and participants from one to three different sports, only a few have used mixed sexes. Howard & Enoka (1991) had participants of whom six where either weightlifters, cyclists or untrained, but all were men. The greatest study with female participants to my knowledge, before the current, was made by Challis (1998) were he had 7 females. This study recruited 10 females and 10 males but only 17 results were used (9 females and 8 males).

5. Conclusion
The bilateral deficit is a well-known phenomenon and has been researched during the last 50 years. Men in the current study, showed a bilateral deficit of 5.6 ±5.9% compared to women that achieve a bilateral facilitation 0.6 ±4.6%.

The greatest benefit from this study was that both males and females were tested for the bilateral deficit with the same protocol. Only a few previous studies have used both sexes in the test for the bilateral deficit. The second benefit from the current study was to see if the unilateral strength was greater than the bilateral strength. Since unilateral training is more functional than bilateral training, the results from a study on the bilateral deficit, coaches can see if their athletes are strong enough at one leg compared with two legs. No conclusions can be made based on the findings in this study and future studies should continue to focus on the bilateral strength deficit and compare men and women.
6. References


Hamill, J., & Knutzen, KM. (2009). Biomechanical Basis of Human Movement, 3rd edition. Lippincott Williams & Wilkins, USA.


7. Appendix 1

7.1. Consent to Participate in Research

Halmstad University
Sweden

You have been asked to participate in a research study for my Bachelor’s thesis. The title of the study and research questions is:

Because of the lack in previous research regarding a true strength task when investigating the bilateral deficit and the lack of gender-heterogeneous groups participating in the same study. The aim of the current paper is to study the difference between unilateral and bilateral 1 repetition maximum (1RM) strength in a 40° leg press machine and to compare the results between sexes.

The research questions of the current study was:

1. Is there a bilateral deficit in the leg press exercise, which has been seen in previous force- and explosive studies?
2. Is the bilateral deficit equal between sexes?

Before you agree, the investigator must tell you about
1) the purposes, procedures, and duration if the research;
2) any procedure which are experimental;
3) any reasonably foreseeable risk, discomforts, and benefits of the research; and
4) how confidentiality will be maintained.

Where applicable, the investigator must also tell you about
1) any available compensation or medical treatment if injury occurs;
2) the possibility of unforeseeable risks;
3) any added costs for you;
4) what happens if you stop participating;
5) when you will be told about new findings which may affect your willingness to participate; and 6) how many people will be in the study.

If you have any questions, concerns or complaints about this research study, its procedures, risk and benefits, or alternative courses of treatment, you should ask: Investigator Jenny Häggbloom
You may contact her now or later at given e-mail to participants

Your participation in this research is voluntary, and you will not be penalized or lose benefits if you refuse to participate or decide to stop.

Signing this document means that the research study, including above information, has been described to you orally, and that you voluntarily agree to participate.

____________________  ___________________________  ___________________________
Signature of participant     Date     Signature of investigator     Date
8. Appendix 2

8.1. Questionnaire
Asked at pre-meeting approximately 48h pre-testing

Age: _________________

Sex:  
- Female  
- Male

Leg press Experience:  
- At least 3 months  
- 1-3 years  
- More than 3 years

Right-footed  
Left-footed

Any lower body injuries during last 6 months  
- Yes  
- No

Weight usually used during leg press workouts? ________ reps @ __________ kg

Length: _____________ cm

Weight: _____________ kg
9. Appendix 3

9.1. Glossary

*Bilateral* = Both left and right limbs are working together

*Unilateral* = Only left or right limb are working at a time

*Q-angle* = The angle from SIAS through the mid patella and tuberositas tibiae

*Bilateral deficit* = When the sum of two unilateral movements exceeds the bilateral output

*Bilateral facilitation* = When the sum of two unilateral movements does not exceed the bilateral output

*Afferent feedback* = Feedback from the working muscles to the central nervous system
Current student at Halmstad University