Muscle fatigue and neuromuscular knee valgus in strong versus weak young female athletes

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Abstract

Background. Knee injuries such as anterior cruciate ligament injuries (ACL) are common in young female athletes resulting in great medical and personal costs. Both knee valgus and muscle fatigue has been reported to increase the risk of injury, while strength training has been used to reduce the occurrence of knee valgus and injury. However, few data exist on the impact of muscle strength and fatigue on knee valgus. Aim. The study aimed at investigating whether muscle strength affects the presence of knee valgus and if fatigue affects knee valgus differently depending on the level of muscle strength in young female athletes. Methods. Twenty young female athletes, mean age 18,15 (±0,79) years, participated in this study. A unilateral drop jump, video analysed in 2-dimensional, was used to evaluate knee valgus and a one Repetition Maximum (1RM) in squat was used to determine the level of muscle strength. A fatigue protocol was used to achieve muscle fatigue before another unilateral drop jump was performed. The subjects were dichotomised, by the 1 RM according to the median, to analyse ‘weak’ versus ‘strong’ females. Both the right leg (RL) and the left leg (LL) were measured before and after fatigue. Results. No significant differences, in the degree of knee valgus, were found between strong and weak group before (RL, p=0.6, LL, p=0.11), or after (RL, p=0.97, LL p=0.36) fatigue. There was also no significant difference in how fatigue affected knee valgus between strong and weak group (RL, p=0.5, LL, p=0.38). Conclusion. The present study suggests that there is no difference in knee valgus between strong and weak female athletes. In addition, fatigue does not seem to have an impact on knee valgus in neither strong nor weak females. This study has limited number of subjects and further studies are needed.

Bakgrund. Knäskador såsom främre korsbandsskada (ACL) är vanliga hos unga idrottande kvinnor och bidrar till höga medicinska kostnader och personligt lidande. Knävalgus och muskeltummatning har var för sig visat sig öka risken för knäskador hos kvinnor, medan styrketräning har rapporterats kunna minska förekomsten av knävalgus och risken för skada. Emellertid finns få studier som undersöker effekterna av muskelstyrka och utmattnings på knävalgus. Syfte. Studien syftar till att undersöka huruvida styrka påverkar förekomsten av...
knävalgus och om muskulär trötthet påverkar knävalgus olika beroende på nivå av muskelstyrka hos unga idrottande kvinnor. **Metod.** Tjugo unga kvinnliga idrottare deltog i studien, ålder 18,15 (±0,79). Ett enbenshopp, vilket filmades med videokamera, användes för att utvärdera knävalgus och en repetition maximum (1RM) i knäböj för att bestämma maximal muskelstyrka. Ett utmattningsprotokoll användes för att åstadkomma muskeltrötthet. Genom att dela styrkevariabeln, 1 RM testet, vid medianen delades försökspersonerna in i två grupper; starka och svaga. Samtliga försökspersoner testade både höger och vänster ben innan och efter utmattning. **Resultat.** Resultaten visade ingen signifikant skillnad mellan stark och svag grupp gällande graden av knävalgus, i varken höger (p= 0,6) eller vänster (p= 0,97) ben före utmattning. Inte heller var det någon skillnad mellan stark och svag grupp efter utmattning (höger ben, p= 0,11, vänster ben, p= 0,36). Inte heller kunde någon signifikant skillnad konstateras angående utmattningens effekt på knävalgus beroende på styrka, stark/svag (höger ben, p= 0,5, vänster ben, p= 0,38). **Slutsats.** Sammanfattningsvis verkar det inte föreligga någon skillnad i förekomst av knävalgus mellan starka och svaga individer. Således verkar det som att muskelstyrka saknar betydelse för knävalgus hos unga kvinnliga idrottare. Vidare verkar inte heller utmattning påverka knävalgus hos varken starka eller svaga unga kvinnliga idrottare. Studien har begränsat antal deltagare och fler studier krävs.
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1. Background

Studies report that female athletes are at a great risk of knee injuries in several sports, including soccer, team handball and basketball (Loës, Dahlstedt & Thomée, 2000; Myklebust, Maehlum, Engebretsen, Strand & Solheim, 1997). Studies also show that the medical costs of these injuries are high and that the most expensive medical treatment is for cruciate ligament injuries (Loës et al., 2000; Cumps, Verhagen, Annemans, Meeusen, 2008). In addition to the medical costs of knee injuries it has been observed that after two years, only 45% of anterior cruciate ligament (ACL) injury athletes are able to return to the same activity level than before (Spindler and Dunn, 2010). Knee valgus (Hewett et al., 2005) and muscle fatigue has been shown to increase injury risks in specifically female athletes (McLean, Fellin, Felin, Suedekum, Calabrese, Passerallo & Joy, 2007), while muscle strength is a factor that might improve knee valgus (Herrington, Munro & Comfort, 2015) and reduce the risk of knee injury (Augustsson & Ageberg, 2017).

1.2 Knee Valgus

The knee joint is positioned between two long lever arms (femur and tibia), which makes it very exposed to high forces and moments (Williams, Chmielewski, Rudolph, Buchanan, Snyder-Mackler, 2001). Ligaments, capsule and other soft tissue helps keep the knee stable during fast movements (Williams et al., 2001). If the knee stability is poor, the knee may lose its normally straight alignment with the hip and foot and fall medially or laterally to the femur caput, causing stress to the ligaments and other soft tissue (Williams et al., 2001; Cael, 2011).

Knee valgus is a term for when the knee is medial to the femur caput (Cael, 2011) which creates a quadriceps angle (Q angle) that is higher than in a knee with a straight line (Bojsen-Møller & Dyhre-Poulsen, 2000). Knee valgus is recognized in females even before puberty (Sigward, Pollard & Powers, 2012) and females have, already at young age, wider pelvis than men which leads to an increased medial rotation of the femur and therefore higher Q angle of the knee (Brukner et al., 2012). There can be different explanations for knee valgus to be expressed in an individual. One cause is an excessive internal rotation of the femur and tibia which can occur due to weak hip abductors (Powers, 2003). An impaired range of motion (Bell, Padua & Clark, 2008; Rabin & Kozol, 2010) and ankle pronation can also contribute to knee valgus (Bell et al., 2008). One study found that females muscle activation in hamstrings during pre-contact phase peaked early, leading to a decrease in the hamstring activation.
during the ground contact phase (Landry, McKean, Hubley-Kozey, Stanish & Deluzio, 2009). This early muscle activation peak might be another explanation to knee valgus in females. It has been shown that knee valgus is a key injury factor in specifically female athletes and that ACL injuries are higher in females with increased knee valgus (Hewett et al., 2005).

From this previous research, it seems that knee valgus creates an increased risk of knee injury in female athletes and can be influenced by several factors.

1.3 Muscle Fatigue
Another aspect of knee valgus is muscle fatigue. Muscle fatigue is a state where the muscles maximal force declines and possibly leads to inability to complete a task without declined performance (Enoka & Duchateau, 2008). There is three different ways for the muscle cell to produce energy, or more specifically ATP (adenosine triphosphate) (Baechle & Earle, 2008). The phosphagen system, glycolysis and the oxidative system (Baechle et al., 2008). The phosphagen system is for fast, short-term use and is active during the start of any exercise and is synthesizes ATP from creatine phosphate and ADP (Adenosine diphosphate) thru the enzyme creatine kinase (Baechle et al., 2008). Glycolysis is a group of reactions where glucose is converted to pyruvate. The pyruvate is then anaerobically converted to lactate, ATP and H2O or when oxygen is present the pyruvate is transported to the mitochondria to participate in Krebs cycle for ATP synthetisation (Baechle et al., 2008). The oxidative system is the only system that is fully aerobic and is primarily used during rest and for long-term, low-intensity activities (Baechle et al., 2008; McArdle, Katch, & Katch, 2009). The oxidative system uses fat and carbohydrates to produce ATP, starting with glycolysis and continuing with Krebs cycle (Baechle et al., 2008).

If the energy substrates, such as phosphagen and glycogen, are decreasing, the muscles could experience fatigue (McArdle et al., 2009). Accumulation of phosphate in the muscles during contraction is also a contributory cause for muscle fatigue (Allen & Westerblad, 2001). Fatigue can also be caused from when the body’s VO2max is reached and an accumulation of CO2 occurs (Enoka et al., 2008). Another reason for muscle fatigue may be a decrease in the activation of the motor units activated from the voluntary nervous system during maximal or prolonged submaximal muscle contractions (Enoka et al., 2008).
Muscle fatigue reduces the capacity to reduce impact accelerations of tibia which may be an indication that fatigue increases the risk of injury (Moran & Marshall, 2006). It is also known that fatigue can increase the risk of knee injury in female athletes due to increased internal rotations and knee abduction during motion (McLean et al., 2007). In addition, fatigue might not only increase risk of injury it can also decrease an athletes performance during maximal and submaximal tasks (Enoka et al., 2008). Researchers observed that in previously ACL injured subjects, where none showed asymmetry during unilateral horizontal jumps before fatigue, as many as 68% showed asymmetry when fatigued (Augustsson, Thomee & Karlsson, 2004).

Based on this, muscle fatigue seems to be an important factor for knee injuries but it’s not clear if it can also contribute to knee valgus.

1.4 Impact of muscle strength on knee valgus
Muscle strength is the ability to exert force, and is often measured in how much an individual can lift (Baechle et al., 2008). Strength training has, except from improvement in muscle strength, been shown to improve knee valgus during unilateral squat and unilateral drop jump, while jump-landing training has been shown to improve unilateral drop jump and bilateral drop jump but not unilateral squat or muscle strength (Herrington et al., 2015). One study found that ten strength and ankle flexibility training sessions, over a two to three week period, significantly reduced knee valgus during squatting (Bell, Oates, Clark & Padua, 2013).

Strength training also leads to neural adaptions, including improvement of neuromuscular control (Beachle et al., 2008), which might also contribute to a reduced knee valgus. To investigate this, one study examined the presence of knee valgus in females during a unilateral step down test before and after a four weeks neuromuscular training program and found that, except from improved strength in hip abduction and hip external rotation, knee valgus were significantly reduced (p=0.001) (Olson, Chebny, Willson, Kernozek & Straker, 2011).

In addition to the fact that muscle strength has been shown to reduce the incidence of knee valgus in females, it has also been seen that weaker individuals are at greater risk of knee injuries (Augustsson & Ageberg, 2017; Khayambashi, Ghoddosi, Straub & Powers, 2016).
Taken together, muscle strength seems to be an important factor for neuromuscular control of the knee and might also predict the risk of knee injury in female athletes.

Knee injuries are common among female athletes (Loës et al., 2000; Myklebust et al., 1997). Knee valgus (Hewett et al., 2005) and fatigue is known to increase the risk of injury (McLean et al., 2007), while muscle strength might reduce the presence of knee valgus (Herrington et al., 2015) and risk of injury in female athletes (Augustsson et al., 2017; Khayambashi et al., 2016). Increased knowledge about these factors could be useful for injury prevention purposes. However, few studies have been done to investigate the impact of muscle strength in knee valgus before and after fatigue.

1.5 Aim

The aim of the present study was to examine the impact of muscle fatigue on knee valgus in strong versus weak young female athletes.

1.5.1 Research Questions
– Is there a difference in knee valgus in young female athletes depending on their level of muscle strength?
– Does muscle fatigue affect knee valgus differently in young female athletes depending on their level of muscle strength?

2. Methods

2.1 Subjects
In this study, 40 female subjects from Aspero Sports High School (soccer and floorball), Halmstad Centern Soccer team and Halmstad floorball club was asked to participate (soccer players n=30, floorball players n=10) (Figure 1). For the recruitment, the head trainers for the teams was contacted and presented with the study together with the team. Twenty-four subjects (soccer players n=18, floorball players n=6) agreed to participate in the study and of these, 4 subjects (floorball players) were excluded before testing (due to age <16, n=2; injury, n=2). The inclusion criterions was healthy female athletes, between16 to20 years of age, who were active in soccer or floorball (at least three days of practice/ week). Subjects with injury
problem within a six months period before the test session (e.g., fracture, knee surgery/ injury, disc hernia) or other physical problems that could affect the tests were excluded.

Figure 1. Flow chart over subject recruitment. 40 subjects were invited to participate in the study. A total of 20 subjects were included.

2.2 Testing procedures
The study was a prospective experimental intervention. Data collection took place in a test lab at Halmstad University and the subjects were instructed and evaluated by three students at the Exercise Biomedicine program. Before the test session registration of the subject’s height and weight were conducted. The test session started with a five minute warm up on an Ergomedic Monark bike (894 E Peak, Vansbro, Sweden) with a load of 100 watt, the metronome (Korg MA30 Ultra Compact Digital) set at 50 bpm. One test leader kept track of the time using a stopwatch (Asaklitt) and notified the subjects after half of the five minutes passed and when ten seconds remained. Another test leader kept track of the rpm. After the warm up the subjects SIAS, middle of patella and big toe (on shoe) was marked with sports tape (yellow,
CureTape, Enschede, Netherlands) to facilitate later analysis. The subjects were asked to perform three unilateral drop jump directly followed by a maximum vertical jump on each leg. The subjects 1RM in back squat was then tested and registered followed by a fatigue protocol (Appendix 2) aimed for exhaustion. A second unilateral drop jump directly followed by a maximum vertical jump on each leg was performed. The jumps were recorded on a video for later analysis.

2.3 Measurements

2.3.1 Unilateral drop jump
The subjects performed three unilateral drop jump (figure 2) followed by a maximum vertical jump from a 15 centimetre step-up board (Reebok, Massachusetts, USA). All jumps and landings were recorded (Sony Xperia M4 Aqua). They started with three jumps on the right leg directly followed by three jumps on the left leg. Masking tape (24 millimetres, Reflekt, Upplands Väsby, Sweden) was taped as a T where the top of the T was 35 centimetres from the board. This was to help the subject to land at the same distance every time and to have the same distance from the camera for each subject. Because the jump height was not relevant to this study, the participants were allowed keep their arms where they felt most comfortable (swinging with the arms were also allowed).
2.3.2 1RM squat
Before the 1RM in squat, the subjects did a warm up consisting of 20 standing back extensions followed by 20 air squats. Further, ten repetitions of squats with a 20 kg barbell (Eleiko, Halmstad, Sweden) were performed. The barbell placement on the safety squat rack (Atlantis PRF1228 Multi-Rack 8’, Quebec, Canada) was adjusted to fit the subject’s height and the safety racks were set just below the height of the barbell when placed on the shoulders on the subjects while squatting. A board (2 cm thick) were placed under the heels to facilitate the depth of the squat and a weight belt was used to support the trunk. The foot placement was shoulder width apart, the upper body straight and the eyes fixed slightly upwards. The barbell was set high on the subject’s shoulders. The subject descended until the thighs were parallel with the floor and on test leaders verbal signal pushed back up to standing. Since no previous 1RM weight was available, a start weight of 30 kg was set for all subjects. Five to ten kg load (2.5- 25 kg weight plates, Eleiko, Halmstad Sweden), was added for each new lift until failure. The weight of the last approved squat was noted as the 1RM. The rest period between each successful lift was set to one minute. Each lift was monitored by the test leader to ensure proper form (as described above). Another test leader stood behind the subject with arm
around the waist of the subject to secure the lift. If the criteria’s for the lift were not met the lift was discarded.

2.3.3 Fatigue protocol
The fatigue protocol (appendix 2) involved quick step-up for 20 seconds on a 20 cm box starting with the right leg, horizontal agility ladder (6 metres, Select Indoor Agility Ladder, Kaunas, Lithuania) moving forward and sideways down and back one time each with both feet’s touching inside the space of the ladder, horizontal vertical jump with deep squat for five meters two ways, and another round of quick step-up on a 20 cm box for 20 seconds starting with the left leg.

2.3.4 Validity and Reliability
The intra-class reliability of 1RM squat test has been reported as high and with no difference between genders (Seo et al., 2012). The unilateral drop jump, used in the present study, has also been shown to have a high reliability and validity to test knee valgus (Ortiz, Rosario-Canales, Rodríguez, Seda, Figueroa & Venegas-Ríos, 2016; Herrington & Munro, 2009). The fatigue protocol was based on previous general fatigue protocol used (McLean et al., 2007; Cortes, Quammen, Lucci, Greska & Onate, 2012; Quammen, Cortes, Van Lunen, Lucci, Ringleb & Onate, 2012; Cortes, Greska, Kollock, Ambegaonkar & Onate, 2013). The 1RM squat test was performed according to a protocol with high inter-rater, as well as a high test-retest reliability (Augustsson & Svantesson, 2013).

2.4 Statistical analyses
The video analysis was performed in Dartfish Software 6.0 (Windows, Fribourg, Schweiz) and Kinovea Software for Windows and the statistics data analysis with IBM SPSS Statistics 24 (Windows, New York, USA) and Microsoft Excel 2010 (Windows, Redmond, USA). Results were presented in mean ± SD. The 1RM squat result was measured in relative strength in proportion to body weight. Subjects were dichotomized according to the median of the relative 1RM strength value, into a strong and a weak group. The unilateral drop jumps were measured by degrees of knee valgus (figure 2) where the best jump (with the degree closest to 180) of each leg before and after fatigue was used in the statistical analyses. Valgus were scored when the degrees was below 0 when 180 was withdrawn from the knee angle (that is, when a value was negative). Both legs (RL and LL) were tested before and after fatigue in each group (strong and weak).
Shapiro-Wilks test was used to test if the data were normally distributed, the $p$ value $\alpha = 0.05$ was set to indicate statistical significance. For the data to be statistically tested as normally distributed both groups (strong and weak) needed to be normally distributed. Because the data was not normally distributed (Strong $p=0.26$, weak, $p=0.001$) the Mann-Whitney U test were used to compare the difference in knee valgus between strong and week group and to compare the difference in knee valgus before and after fatigue in strong and weak group.

2.5 Ethical and social considerations

According to section 18 of the Act (SFS 2003:460) concerning the ethical review of research involving humans, research on a person age 15 or over may take place only if the person concerned agrees and understands the meaning of participation in the study. Consent could be withdrawn at any time, however, the data collected was allowed for continued use in research (SFS 2003:460). This study included subjects between 16-20 years old which meant section 18 was addressed in those cases the subject was over 15 but fewer than 18 years of age. The subjects who were included in the study (n=20) were given a closer presentation and ethical informed consent document to sign. Registration of height and weight could be sensitive, it was therefore essential that the test leader kept professional and took this in to account. Furthermore, it was important that clear information were provided to the subjects regarding that participation in the study were voluntary, and that the subject at any time could withdraw its participation. It was important that the participants remain confidential during and after the study. To ensure confidentiality, all personal data was replaced by a serial number and no result can be pointed back to the subjects.

The aim of this study was to provide further information about knee valgus in young female athletes. This information can provide increased knowledge in the field and hopefully also increase understanding of knee injury and how these can be prevented.

3. Results

In total, 20 subjects (soccer players n=18, floorball players n=2), mean age 18,15 ($\pm0,79$) years, height 166 ($\pm3,97$) cm and weight 64,25 ($\pm5,96$) kg were included in this study. Collected data from all subjects (n=20) were included in the analysis. The subjects mean value of the 1RM squats, the relative strength value, degrees of knee valgus (RL and LL) and
degrees of difference in knee valgus before and after fatigue (RL and LL) are shown in Table 1.

3.1 Knee valgus in strong versus weak females

The subjects were divided in a strong vs. a weak group based on the median value of the 1RM relative strength: 0.94 (min 0.44 max 1.27) % of bodyweight. There was no significant difference on knee valgus between strong and weak group neither before (RL, p=0.6, LL, p=0.11) or after (RL, p=0.97, LL, 0.36) fatigue (table 1).

3.2 Influence of fatigue on knee valgus in strong versus weak females

No significant difference, in change values (knee valgus after fatigue minus knee valgus before fatigue), were found between strong and weak group (RL, p=0.5, LL, p=0.38) (table 1).

Table 1. Subjects (n=20) strength and valgus values together with the difference in valgus before and after fatigue for strong and weak group. All data presented in mean (±SD).

<table>
<thead>
<tr>
<th></th>
<th>1RM (kg)</th>
<th>1RM, Relative strength (% of bodyweight)</th>
<th>Before fatigue (degrees)</th>
<th>After fatigue (degrees)</th>
<th>Fatigue valgus difference *² (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RL</td>
<td>LL</td>
<td>RL</td>
<td>LL</td>
<td></td>
</tr>
<tr>
<td>All (n=20)</td>
<td>62.5 (±13.83)</td>
<td>97 (±0.2)</td>
<td>-4.71 (±7.27)</td>
<td>-0.07 (±3.46)</td>
<td>-5.75 (±8.35)</td>
</tr>
<tr>
<td>Strong (n=10)</td>
<td>72 (±10.77)</td>
<td>113 (±0.11)</td>
<td>-4.24 (±8.25)</td>
<td>1.3 (±1.83)</td>
<td>-7.11 (±9.96)</td>
</tr>
<tr>
<td>Weak (n=10)</td>
<td>53 (±9.27)</td>
<td>82 (±0.14)</td>
<td>-5.18 (±6.09)</td>
<td>-1.44 (±4.1)</td>
<td>-4.38 (±6.04)</td>
</tr>
</tbody>
</table>

*¹ P-value calculated for strong versus weak
*² A higher value indicates greater knee valgus

4. Discussion

The aim in this study was to investigate if there was a difference in valgus appearance between strong and weak young females. The aim was also to investigate if fatigue affects knee valgus differently depending on the level of muscle strength. The results indicate that there is no significant difference in knee valgus between strong and weak individuals. The
results also indicate that fatigue does not have any significantly effect on knee valgus in neither strong nor weak females. This suggests that muscle strength does not have any major impact on knee valgus before or after fatigue.

4.1 Result discussion

4.1.1 Fatigue effect on knee valgus
The results from this study are in contrast to previous studies (Dickin, Johann, He & Popp, 2015; Ortiz, Olson, Etnyre, Trudelle-Jackson, Bartlett & Venegas-Rios, 2010). One former study, performed on active females (mean age 22.58 years), found that knee valgus significantly increased (p=0.05) after a fatigue protocol (Dickin et al., 2015). This study evaluated knee valgus during bilateral drop jumps from three different heights (30cm, 40cm, 50cm) (Dickin et al., 2015). In contrast to the mentioned study, the height of the unilateral drop jump in the present study was set to 15 cm due to the risk of injury. This may be one factor for the difference in the results between studies.

4.1.2 Strength effect on knee valgus
Previous studies that examined the influence of muscle strength on knee valgus and have reported a reduced knee valgus in subjects with greater muscle strength (Herrington et al., 2015; Bell et al., 2013), indicating that stronger individuals are less prone to knee valgus. Yet, the results in the current study found no significant difference between strong and weak individuals. Also, in contrast to our investigation, the study by Bell et al (2013) used knee valgus as an inclusion criteria. This might contribute to the different results.

As it’s been shown that strength training can improve neuromuscular control (Baechle et al., 2008), and an improved neuromuscular control can improve knee valgus (Olson et al., 2011), there could have been a reason to believe that the strong group in the present study would have been less prone to knee valgus, but no such evidence were found.

4.2 Methodological issues

4.2.1 Knee Valgus
The results in this study are limited to young female athletes where strength is determined with 1RM in squat. In the present study, we used the best attempt of the unilateral drop jump landings (the landing with least valgus) from all subjects. Previous studies have used average values from the performed drop jumps (Dickin et al, 2015; Moran et al., 2006) and it might
have been better to use the mean value of all three jumps in this present study as well, but due to technical problem with the video camera we could not receive the three jumps from all subjects. Another factor that may have influenced the presence of knee valgus during the unilateral drop jumps was that the subjects were free to keep their arms where they felt most comfortable, which led to that some subjects held their hands at their waist and some choose to swing their arms. If done again, we would have chosen to standardize how the arms would be held during the jumps.

During the test sessions the subjects wore their own sporting shoes. Some of the subjects are believed to have used shoes or soles that work to neutralize valgus. This was only observed by the test leaders during the test sessions and not was confirmed or further investigated due to time constraints. The issue of shoes may have influenced the result of knee valgus values and might be a matter to consider in future studies.

One subject had recently had a slightly sprained ankle but was allowed to participate as it stated that no pain or influence on movement was present. However, when we analysed the video of the subject, we saw that the movement during the unilateral drop jump looked somewhat affected. But after discussion, we chose to include the result in the study. In reconsideration, it may have been better to exclude this result.

4.2.2 Muscle Fatigue

We choose to put together a new fatigue protocol based on several similar fatigue protocols (McLean et al., 2007; Cortes et al., 2012; Quammen et al., 2012; Cortes et al., 2013) to fit the limited space in the laboratory and time during testing. One limitation in the present study was that we did not measure the level of fatigue. To ensure that subjects experienced de facto muscle fatigue a tool for evaluation would have been desirable. Previous studies have used a metronome to ensure the same speed in the fatigue protocol (Cortes et al., 2012; Quammen et al., 2012). In two studies the subjects heart rate were measured and a minimum of 85 % (Cortes et al., 2012) or 90 % (Cortes et al., 2013) of their estimated maximum was to be considered as being in a fatigued condition. Taken together we can’t ensure what level of muscle fatigue the subjects experienced in the present study and it would have been better to measure the subject’s heart rate to ensure fatigue. It would also have made it easier to compare the results with similar studies.
4.2.3 Muscle Strength
One methodological issue regarding the 1RM in squat were the subject’s limited experience with weight lifting, and more specifically back squatting with heavy weight. The overall 1RM might have been higher if the subjects were more experienced with squatting. The group division, with strong and weak divided by the median in terms of relative strength in proportion of the body weight gives little space between the strongest in the weak group versus the weakest in the strong group. To achieve a larger difference in the level of muscle strength between subjects, a larger sample could be used to dichotomize the strength variables to the highest and lowest quartile. However, due to the restricted sample size in the current study, we could not use the quartiles when dividing strong and weak athletes.

Interestingly, when looking at the degree of knee valgus in the unfatigued condition the LL shows the lowest degree of valgus. This might be due to the fact that the left leg, mostly are displayed as the non-dominant leg, and thus, is used to stabilize while kicking the ball. Hence, the left leg, when non-dominant, might possibly have greater knee stability.

5. Conclusions
The present study did not find any significant differences in neither knee valgus or change values (before and after fatigue), depending on strength in young female athletes. This might indicate that muscle strength does not affect knee valgus in young female athletes. In future studies, it would be desirable to have a larger test group which could be used to analyse the strength variable in the highest and lowest quartile, which would give a larger difference level of muscle strength between subjects. Although this study can contribute to knowledge about the impact of muscle strength on knee valgus, more research is required.
References


Appendices

Appendix 1
Informationsblankett – Hur knäkontroll förändras vid muskelutmattnings påverkan på starka jämfört med svaga individer.

Bakgrund

Syfte
Denna studie syftar till att ta reda på om knäkontrollen påverkas, om knät “faller in” i högre grad, vid utmattning och om det finns någon skillnad i hur knäkontroll påverkas av utmattning hos starka jämfört med svaga individer.

Tillfrågan om deltagande
Du är tillfrågad att delta i studien då du uppfyller våra kriterier gällande ålder, fysisk aktivitet och hälsa. Studien kommer inkludera 26 personer.

Hur går studien till?
Längd och vikt tas vid ankomst. Efter fem minuters uppvärmning på stationär cykel kommer du som deltagare få genomföra en enbens-hopp från 15 cm höjd med direktföljande hopp på höjden. Landningen görs tre gånger per ben. Landningarna kommer att filmas. Därefter kommer ett maximalt styrketest i knäböj (där du lyfter så tungt du kan en gång) genomföras. Därefter följer ett utmattningsprotokoll med fyra övningar. Övningarna består av uppklov på step-up bräda i 20 sekunder, hopp på höjden med djup knäböj, snabb förflyttning i agilitystege (en stege i tyg liggande på golvet, framåt och i sidled) samt ytterligare 20 sekunder uppklov på step-up bräda. Till sist utförs enbens-hopp igen på exakt samma vis som i början av testet. Även dessa landningar filmas.
**Tidsåtgång**
Testerna för studien sker under ett tillfälle och förväntas ta omkring 30 minuter per deltagare.

**Finns det några fördelar?**
Som deltagare i vår studie kommer du få kunskap om din knävinkel samt hur det påverkar dig vid utmattning. Du kommer också få testa din maximala styrkekapacitet. Studien medför kunskap om knäkontrollens påverkan vid utmattning samt som kan bidra till att ge kunskap om hur tränare och idrottare kan förebygga knäskador och då också bidra till en medicinsk kostnadsvinst. Kunskap om sambandet mellan höftstyrka och knäkontroll kan vara värdefull vid rehabilitering och förebyggande arbete av knäskador.

**Vilka är riskerna?**
Deltagande i studien kan innebära en risk för skada då testerna utförs med maximal prestation. Som deltagare kan du också känna dig fysiskt och mentalt utmattad efter testerna. Genomgång samt standardisering av alla delar i testerna kommer ges innan start för att minska risk för skador.

**Hantering av data och sekretess**
All sammanställd data sker konfidentiellt på så sätt att personuppgifter har ersatts med löpnummer och alla publicerade resultat sker med gruppresultat. All data kommer förvaras på skyddat USB på Högskolan i Halmstad. Du kommer få tillgång till ditt enskilda resultat, för allmänheten kommer resultatet presenteras i gruppformat.

**Frivillighet och rätten att avbryta**
Deltagandet är frivilligt och kan när som helst återtas utan vidare förklaring. Vid önskan om att avbryta sitt deltagande i studien kontaktas någon av nedanstående projektledare.
Projektledare
Josefin Forsberg
Student
Högskolan i Halmstad

Carolina Lundh
Student
Högskolan i Halmstad

Mona Emadeldin
Student
Högskolan i Halmstad
Samtyckesblankett – Hur knäkontroll förändras vid muskelutmatning hos unga idrottande kvinnor samt skillnaden av utmattningens påverkan på starka jämfört med svaga individer. Tillsammans med korrelationen av höftstyrkans påverkan på knäkontroll vid utmattning

Jag medgiver att jag tagit del av den skriftliga samt muntliga informationen angående studien och fått möjlighet att ställa frågor. Jag deltar frivilligt och förstår varför jag har blivit tillfrågad. Jag godkänner att mina personuppgifter samlas in.

Jag samtycker att deltaga i studien och jag förstår att jag när som helst utan vidare förklaring kan avsluta mitt deltagande. Jag förstår vad deltagande i studien innebär och ställer upp frivilligt.

__________
Ort och datum

Födelsedatum (XXXX-XX-XX)

__________
Namnteckning

__________
Namnförtydligande

Telefonnummer

__________
Email

Undertecknad har gått igenom informationsblanketten och erhållit ovanstående persons samtycke.

__________
Ort och datum

__________
Namnteckning

Namnförtydligande
Appendix 2
Fatigue protocol
The exercises were done in the same order they are listed below. No rest between the exercises.

Step-up
Step-up and down as quickly as possible on a step up box. Right foot first.
Duration: 20 s
Box height: 20 cm

Agility ladder
Quick running steps down and back on a horizontal agility ladder. One round running forward directly followed by one round running sideways. Both feet steps in each gap.
Length: 6 metres (one way)

Plyometric vertical jump with deep squat sequence
Vertical jump with deep squat landing immediately followed by another vertical jump sequence. One metre horizontal movement with each jump. Ten jumps in total, five jumps each way.
Length: 5 metres (one way)

Step-up
Step-up and down as quickly as possible on a step up box. Left foot first.
Duration: 20 s
Box height: 20 cm
Appendix 3

Test protocol

Nr:______

Date:______________

Name_________________________________________ Birth date____________________
Height________________ Weight______________
Activity level (days/w)_______________ Injury history (what/when)____________________
1RM________________

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<th>Finished</th>
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<th>Vertical jumps</th>
<th>Agility ladder</th>
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<td>1RM</td>
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