



Does Static stretching and/or Muscle fatigue  
create a Cross-over effect?

An experimental study

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Bachelor thesis in Exercise Biomedicine, 15 credits

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## **Abstract**

**Background:** Extensive literature has described a decrease in force output performance in the local muscle groups after static stretching, and static stretching has therefore been recommended not to be performed during warm-ups. A recent study showed evidence of a cross-over effect in regard to static stretching, i.e. non-local muscles were also affected by static stretching. This result could however be due to fatigue in the muscle groups stretched, and a fatigued condition has previously shown cross-over effects in several studies.

**Aim:** The aim of the study was to (1) examine if upper-limb static stretching and muscle fatigue display a cross-over effect that show changes in force output in the lower limbs, and (2) if there was a difference between the effects of the static stretch protocol and the muscle fatigue protocol for the purpose of examining if fatigue is the larger factor for cross-over.

**Methods:** Concentric maximal jump height of 15 subjects with previous strength training experience of at least one year was measured and the subjects subsequently performed both intervention protocols in a random order. After each protocol concentric jump height was measured again. The static stretch protocol consisted of a static stretch for the shoulder at an intensity of “Very hard”, 10 repetitions of 30 second stretches with 15 seconds rest in between repetitions. The muscle fatigue protocol consisted of 10 repetitions of 30 seconds isometric muscle contraction in the same position with 15 seconds rest between repetitions at an intensity of “Very hard”. The data was collected on an infra-red contact mat and differences between the mean jump heights pre- and post each protocol and between the different protocols were analyzed with pair sample t-test.

**Result:** Mean concentric jump height ( $\pm$  standard deviation, SD) was 25.31 ( $\pm$ 9.4) cm for the baseline jumps, 23.66 ( $\pm$ 8.89) cm post static stretch intervention jumps and 24.13 ( $\pm$ 8.90) cm post muscle fatigue intervention jumps. This indicates a cross-over effect on force output in the legs post static stretching with a mean reduction of 1.65 cm ( $p=0.001$ ). Upper-limb muscle fatigue indicated a cross-over effect on force output in the legs with a mean reduction of 1.18 cm ( $p=0.032$ ). There was no statistical significance between the two protocols ( $p=0.146$ ).

**Conclusion:** The results presented a cross-over effect on both conditions. This is in line with previous research in the area. The results implicate that static stretching and muscle fatigue effects the central nervous system, which can lead to impairments in performance in non-local muscles. This can be considered in warm-up and exercise program design when force output is of great importance for performance.

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# 1 Introduction

Physical activity is a natural way to improve and preserve the health of our bodies. Aerobic activities first and foremost enhances the cardiovascular system while anaerobic activities such as strength training display changes in our muscles (Vinogradova et al., 2013). Strength training is an exercise form which is not only performed for health related reasons, but also commonly performed to increase performance in sport (Folland & Williams, 2007). Before exercising a warm up is usually performed to increase subsequent performance and reduce the risk of injury (Behm & Chaouachi, 2011). Static stretching has been a common part of a warm-up for decades and have been found to be an effective way of increasing range of motion around a joint, which enhances flexibility (Bandy, Irion, & Briggler, 1997). Several types of exercises, sports and athletes require a high flexibility for a high performance, including gymnasts, wrestlers, martial artists and ice hockey goaltenders (Behm & Chaouachi, 2011). Flexibility in strength training allows the muscles to work and improve through a greater range of motion, and a certain degree of flexibility is also sought to preform proper exercise technique, lowering the risk for injury (Jones, Christensen, & Young, 2000). But the effects of static stretching before exercise has been debated, due to its effect on strength and power performance. According to a review by Behm et al. (2011) a great number of studies now show significant local impairments in strength and power post stretching. Marchetti, de Oliveira Silva, Soares, Serpa, Nardi, Vilela & Behm (2014) however found that static stretching decreased the power output in muscles that are seemingly unrelated from the stretched muscles. This is one of the demonstrations of a phenomenon called the cross-over effect; when a trained limb effects a contralateral untrained limb (Farthing, 2009; Zhou, 2000). It has been reported for several conditions including force, power, fatigue and stretching (Marchetti et al., 2014). The research on cross-over on static stretching effects is very limited, and it is important to examine further so that warm-up and exercise routines can be adjusted accordingly to not impair performance.

## 2 Background

Many people around the world practice regular strength training for health benefits, recreational purposes, as a sport or as a complement to sport specific exercise to increase performance (Baechle & Earle, 2008). The benefits are many including improved strength, power, balance, coordination, metabolic and cardiovascular health, for adults, adolescents and the elderly (Harries, Lubans & Callister, 2015; Winett & Carpinelli, 2001). It has many health benefits such as stimulating and preserving volume and strength of the skeletal muscles and preventing conditions and disorders that are linked to decreases of these specific abilities (Harries et al., 2015; Vinogradova et al., 2013; Winett et al., 2001). It has also been proven that strength training can reduce the risk, and be an effective treatment, for metabolic syndrome and the associated obesity, hyperlipidemia and hypertension. Strength training can moreover slow the development of age related osteopenia and sarcopenia as well as different kinds of myopathy (Hurley, Hanson & Sheaff, 2011; Winett et al., 2001). If resistance training is performed regularly neural changes will occur as well as structural changes in the body, leading to an increase in strength i.e. maximal force output. The main structural changes include an increase in number and mass of the myofibrils inside the muscle fibers, which increases muscle size. Coordination and the learning of specific movements are a big part of the neural changes, containing improved agonist activation. A part of these changes could be due to increased neuron firing rate and stronger spinal reflexes, and these neural changes are thought to have a greater influence on the increased strength at the beginning of a resistance training regimen (Folland et al., 2007). For strength training to be performed a working system of neuromuscular function is needed, where the central nervous system including the brain and the spinal cord works together with the peripheral nervous system, neurons, proprioceptors and muscles to create these complex movements (McArdle, Katch & Katch, 2010).

Before any type of training a warm up is usually performed to increase performance and reduce the risk of injury. Static stretching (SS) has been a common part of a warm-up due to the belief that it prevents injury, reduces the risk for muscle soreness and improves performance (Behm et al., 2011). But according to a review paper by Behm et al. (2011) several studies now show significant local impairments in these abilities post stretching. Marchetti et al. (2014) also found a cross-over effect post static stretching, which means that non-local impairments in performance was also presented.

## **2.1 The cross-over effect**

The cross-over effect is a phenomenon where a trained limb can affect the contralateral untrained limb (Farthing, 2009; Zhou, 2000), and this effect has been reported for several exercise conditions such as fatigue, force and power (Marchetti et al., 2014). Marchetti et al. (2014) found that the propulsion duration and the peak force of a maximal concentric jump was adversely effected after an extensive static stretching (SS) protocol of the shoulder, while not showing significant reductions in muscle activation in the leg muscles gastrocnemius lateralis or vastus lateralis, indicating a cross-over effect after static stretching. It could be argued that it is uncertain if the cross-over effect seen in Marchetti et al.'s (2014) experiment is due to static stretching or muscle fatigue, since the method used in the study could possibly cause a fatiguing effect on the muscle groups in the shoulders, arms and trunk; and Kennedy, Hug, Sveistrup and Guével (2013) and McLean and Samorezov (2009) have previously found evidence of cross-over effects of muscle fatigue. Kennedy et al. (2013) investigated whether the neuromuscular fatigue created during an upper limb fatigue protocol would be transferred to an unrelated muscle group at the ankle. They found that fatigue created by contractions of muscles in the forearm decreased motor performance of the non-exercised and functionally unrelated ankle plantar-flexors (Kennedy et al., 2013). Kennedy et al. (2013) did not find peripheral fatigue in the ankle plantar-flexors and suggested that the effects were caused by central fatigue due to forearm muscle contractions. Peripheral fatigue in this case refers to local changes within the muscles while central fatigue refers to a reduction in central drive (Kennedy et al., 2013). McLean et al. (2009) conducted a study in which they researched cross-over of central fatigue through single leg squats. A cross-over effect was created which resulted in a less efficient landing strategy on the non-exercised leg. This lead McLean et al. (2009) to assume that central fatigue, presumably caused by inhibitory action of fatigued leg muscles, affected the CNS by altering decision-making and movement execution as well as lowering proprioceptive abilities (McLean et al., 2009), however the results could be due to fatigue in other working muscle groups in the trunk and back (Kennedy et al., 2013). For a greater understanding of the cross-over effect and its impact on strength training performance, more details of the mechanisms and structures involved in strength training, static stretching and muscle fatigue are of importance.

## 2.2 Static stretching

SS has been a common part of a warm-up for decades and have been found to be an effective way of increasing range of motion (ROM) around a joint both acute and long term (Van Gelder & Bartz, 2011). Other studies have however found the opposite; that an SS intervention four times a week did not increase ROM long term (Bazett-Jones, Gibson & McBride, 2008) and Worrell, Smith and Winegardner (1994) found that SS did not significantly increase ROM, even if an increase in ROM was indicated. SS has also been believed to increase performance, prevent injury and decrease muscle soreness following physical activity, however these beliefs are no longer fully supported, in fact the opposite are now supported in several studies (Behm et al.; 2011; Beckett, Schneiker, Wallman, Dawson & Guelfi, 2009; Donti, Tsolakis & Bogdanis, 2013; Thacker, Gilchrist, Stoup & Kimsey, 2003). A review article by Behm et al. (2011) concluded that a much greater number of studies reported significant impairments in measures of force and power, but not all. This, on the other hand, shows that there may be conditions where SS can improve force and power, or have no significant effect at all.

SS is usually performed by slowly lengthening the muscle in a controlled speed while keeping the muscle relaxed. The final stretch position is usually held for 30 seconds (Coburn & Malek, 2012), but scientists are divided in which duration for the static stretch that is optimal for increasing ROM. For example, one study by Madding, Wong, Hallum and Medeiros (1987) showed no significant difference between stretch durations, but all increased significantly from baseline. In another study by Bandy et al. (1997) the subjects performed a six week intervention to increase hamstring ROM and the outcome was that SS for 30 seconds was as efficient to increase ROM as SS for 60 seconds. The ROM in a joint can be restricted by muscle contractile activity (voluntary or generated by reflexes); the elasticity of the connective tissue in muscles and joints as well as structure of the joint and the bone; lack of strength or coordination; pain or subcutaneous tissue (Chalmers, 2004). The increase in ROM is thought to occur due to elastic changes in stiffness and length of the affected musculotendinous units and increased stretch tolerance (Behm et al., 2011). Muscle spindles reflexively assist muscle activation in a rapid stretch which is a phenomenon called the stretch reflex, but because SS is performed in a slow and careful manner the stretch reflex is not activated. A relaxed muscle allows for a deeper and more effective stretch, and therefore muscle activation should be avoided (Baechle & Earle, 2008).

Marchetti et al. (2014) means that SS affects the neuromuscular system through both central and peripheral mechanisms, and that this shows performance reductions in force and power that can persist for several hours. The researchers believe that these performance reductions can develop from several factors; neurophysiological, hormonal, cellular or mechanical. Donti et al. (2013) points to that the performance reductions are specifically due to neuromuscular inhibition and alterations of the viscoelastic properties of the musculotendinous units which causes a decrease in muscle stiffness. Chalmers (2004) means that muscle spindles could be in the center for the neurophysiological factors for reduced performance. Muscles and muscle spindles are made up of fibers, which contain contractile components, filaments proteins creating myofibrils; myosin at the center and actin peripherally (Sandri, 2010). The myosin in the filaments have heads that create cross bridges which interact with the actin filaments. This creates a filament “sliding” inwards which shortens the muscle fiber and creates a muscle contraction (Warshaw, 2004). According to Chalmers (2004) the muscle’s electrical activation and force production derived from the stretch reflex is very small when a muscle is completely relaxed and stretched slowly to a long length. The stretch sensitivity of the muscle spindles are reduced because the lengthening is believed to break the actin-myosin bonds within the spindles fibers. The lengthening is also linked to the Golgi tendon organs (GTOs) sending neural input to the CNS which in turn causes the muscle to reflexively relax (Chalmers, 2004). Since stretching effects muscle spindles which are connected to the CNS, it is important to further examine the impact on the non-local muscles so unnecessary performance reductions can be avoided.

The mechanical factor for reduced performance could be due to viscoelastic changes in the muscles. The muscles in our body show viscoelastic characteristics like a spring. If a force is applied it will lengthen, and when the force is removed it will return to its starting length. The stiffness of the muscle will decide the amount of force that is required to yield a certain change in length. These viscoelastic characteristics makes the muscles give a higher resistance to lengthening if a stretch is applied in a rapid manner, and therefore stretching to lengthen a muscle and decrease stiffness is recommended to be performed slowly (Chalmers, 2004). However, this decrease in stiffness can result in a performance reduction in directly following activities that require a high force output (Donti et al., 2013). Muscles with viscoelastic characteristics have shown a decrease in muscle force without demonstrating any significant decrease in electrical activity. This could indicate that stretch relaxation due to viscoelastic properties is the sole mechanism for a reduction in muscle force (Chalmers, 2004), however

this is a peripheral response and should technically not produce changes in muscle force in muscles that have not been stretched. The cross-over effect on static stretching indicates the opposite. The majority of the research on cross-over effect is done and displayed on muscle fatigue conditions, and further knowledge of the mechanisms behind muscle fatigue could give more understanding of the cross-over effect.

## **2.3 Muscle fatigue**

Muscle fatigue is the equivalent of a drop in performance due to extensive muscle activity, and several properties of the muscle changes during fatigue which include action potential (Strojnik & Komi, 1998). A review article by Allen, Lamb and Westerblad (2008) means that the traditional explanation was that the function of the contractile proteins was impaired due to accumulation of lactate and hydrogen ions, but in recent years it has been shown that this accumulation does not correlate well with decreased force production. Alternatively the writers speculate that fatigue can be explained by effects brought on by changes in the action potential, various mechanisms that cause failure in the release of calcium ions, and effects of metabolites (Allen et al., 2008). The writers further explain that fatigue can arise at several different parts in the pathway between the brain and within the muscle itself, and it can therefore be useful to divide it. They continue with that it is collectively established that muscle fatigue can be examined in isolated muscle tissues, due to that a large amount of the fatigue arises in the muscle itself. Nevertheless they also point out that later studies suggest that during maximum muscle activation there is often a considerable central component (Allen et al., 2008). Gandevia (2001) describes neuromuscular fatigue as a reduction in the muscle's force output which is progressive and regardless of sustainability of the task performed. Central fatigue is a reduction of central drive to the motoneurons and significantly contributes to a decline in force production ability of an exercised muscle (Gandevia, 2001). The researchers are not unanimous if fatigue is more of a central response or a peripheral response specific to the exercised muscle. According to Marchetti et al. (2014) previous studies show proof of neural coupling between upper- and lower body neural networks. These networks may play a role in muscle coordination, activation and reflexes through a feedback loop from neurons connected to the muscles. This loop can have an inhibitory effect on the CNS which could lead to a decrease in the central drive to both exercised and non-exercised muscles. The central activation of both exercised and non-exercised distant muscles can be impacted by these reflex loops from muscle spindle neurons, skin and subcutaneous neurons (Marchetti et al., 2014). For the purpose of researching

if impairments on strength performance post static stretching and post muscle fatigue is a central response that cause a cross-over effect, a reliable and valid test for evaluating force output is needed. The squat jump (SJ) is a common method to evaluate strength in the leg extensor muscles which is particularly useful in the field (Sheppard & Doyle, 2008).

## **2.4 The squat jump**

Vertical jumping tasks are considered a valid measure of leg extensor power (Sheppard et al., 2008), and this attribute can be trained by exercise programs which incorporate strength training that creates a large power output and muscle tension (Markovic, Dizdar, Jukic & Cardinale, 2004). Research has shown a solid relationship between performance in vertical jump tests and performance in sports that have need of powerful leg extension (Sheppard et al., 2008). When evaluating athletes it is therefore important to have valid and reliable tests for power output, and Markovic et al. (2004) found while testing five different vertical jumps that the SJ and countermovement jump (CMJ) were the two most reliable and valid explosive power jump tests for leg extensors if used on a contact mat connected to a digital timer. Since the CMJ incorporates the stretch shortening cycle (SSC) (Strojnik et al., 1998), which is a process that involves a release of mechanical energy stored in the musculotendinous unit (Kallerud & Gleeson, 2013) and is therefore not a concentric-only contraction, this test is not of interest when the purpose is to examine concentric-only contractions. Concentric-only leg extensor power is commonly tested through squat jumps (SJ). By doing a brief isometric hold before performing the concentric jump it is believed that the influence from the SSC is minimized since it relies on a pre-stretch (Sheppard et al., 2008). Sheppard et al. (2008) found that out of 125 SJ trials, 89.6% of the trials had a countermovement but only 61.6% of these were spotted by observation. By strict definition a SJ with any margin of preceding countermovement should be rejected and cast-off from consideration. For the non-elite athlete population, it has been observed that a countermovement of 1-3 cm at the bottom of the jump, compared to no countermovement, does not significantly change SJ results. It is therefore deemed be a decent measure of concentric-only leg extensor power on non-elite athletes, even if a small countermovement is observed (Sheppard et al., 2008).

Many sports and exercise forms require powerful leg extension even though no jumping is essential to the activity itself (Sheppard et al., 2008). It is important to examine and learn more about the non-local effects of stretching and fatigue on subsequent power output so that warm-

up and exercise routines can be adjusted accordingly to not impair performance. Coaches and athletes that perform strength training and/or rely on high flexibility and strength attributes in their performance can benefit from this research on cross-over effects.

## **2.5 Aim**

The aim of the study was to examine if upper-limb static stretching and/or muscle fatigue display a cross-over effect that show changes in strength in the lower limbs.

- Is there a cross-over effect after a static stretching protocol for the shoulders showing impairments in strength performance in the lower limbs measured by squat jump?
- Is there a cross-over effect after a muscle fatigue protocol for the shoulders showing impairments in strength performance in the lower limbs measured by squat jump?
- Is there a difference between the effects of the SS protocol and the MF protocol?

## **3 Method**

The study was experimental including two interventions. A baseline evaluation was done before the interventions, and after each intervention a post-intervention test was made. The subjects were recruited at two different strength training facilities. Signs to raise interest were put up the same day at approximately 9:30 p.m. before the testing started. Individuals training at the facility were approached shortly after arrival by the test leader, the assistant or the facility employees; or individuals approached the test leader, the assistant or the facility employees if they were interested in participation and/or if they had questions about the study. The tests were done between 10 a.m. and 18 p.m. All participants were informed of test procedures and eventual risks before the study, and signed an informed consent (appendix 2) before the test procedure started.

### **3.1 Subjects**

The study included 15 healthy volunteering subjects between 19-39 years old. The criteria for participation in the study was at least one year of strength training experience. Exclusion criteria was no previous surgery on either upper and lower extremities and no history of injury with residual symptoms such as pain or “giving-away” sensations (Marchetti et al., 2014), surgery included back and neck and residual symptoms was limited to during the past four months.

### **3.2 Testing procedures**

#### **3.2.1 Warm-up**

The participants performed a standardized warm-up prior to the test consisting of a brief five minute jumping warm up with 20 jumps divided into five sets of four submaximal jumps, whichever jump they preferred, with 45 seconds rest between sets. Following the warm-up the subjects performed three submaximal SJ to get familiar with the jump (Marchetti et al., 2014). After the warm-up they had one minute of rest before the maximal SJs.

#### **3.2.2 Pilot test**

Before testing a pilot study was performed (n=8) to adjust any occurring faults or inconveniences. During the pilot study the muscle fatigue protocol was adjusted due to it being ineffective to produce enough fatigue. It was changed from a 30 second static hold above the head to a 30 second isometric muscle contraction hold of the hands together above the head. The Borg RPE (rate of perceived exertion) scale (appendix 1) was added to standardize the

stretch intensity and the work intensity during both protocols. The scale ranges from 6 (no exertion) to 20 (maximal exertion) and is an indicator of work intensity (Borg, 1982). The RPE scale has shown moderate to high correlation with heart rate and blood lactate level, and has been shown to be both reliable and valid (Levinger, Bronks, Cody, Linton & Davie, 2004). The protocols were also changed to be more time effective since it was believed that it would increase the number of volunteers. Therefore the second baseline jump after the rest proceeding the first intervention jumps was eliminated.

### **3.2.3 Testing**

The tests were performed barefoot on a wooden floor and the subjects were asked to use comfortable clothing so that they could use their full range of motion. During both the pilot study and the test procedure one leader and one assistant was present. The assistant controlled time table and RPE while the test leader completed the instructions, recorded jump height, assisted in the stretches and checked form and for countermeasures during the SJ. The test procedure took place during three days, the 13<sup>th</sup> – 14<sup>th</sup> of March 2015 at one facility and 15<sup>th</sup> of March 2015 at the other facility. Weight, height, age, sex and years of strength training experience of all the subjects was collected for descriptive purposes. Before the test procedure started a verbal introduction was performed in order to prepare the participants. The introduction followed a pre-written script and included a run through of the testing procedures, a demonstration of the Squat Jump (SJ), the stretching protocol and the muscle fatigue protocol. Any arising questions from the participants were answered.

The participants performed both protocols with a rest period of five minutes in between tests. Half of the participants began with the stretch protocol and the other half the fatigue protocol, the protocols proceeding each other. In order of participation, the subjects were given a number (1 – 15) and all odd numbers started with the SS protocol, while the even numbers started with the MF protocol. The height of the three jumps was recorded in centimeters (cm) including two decimals, and means were calculated after the procedure. The jumps were performed on an IR (infra-red) contact mat (IVAR TESTSYSTEM, fysprofilen Basic Clock, Mora, Sweden). The IR sensors were placed two meters apart and the power switch was set to record one millisecond (ms) and the input was 12 volts (V). Time was taken with the stop watch function of a smartphone (Sony Xperia Z3 Compact, Sony Mobile Communications).

### 3.2.4 Concentric Jump: Squat Jump

Each participant was given three SJ with a rest of one minute between jumps. The participants were asked to bend their knees to 90°, feet placed shoulder width apart, while holding their hands on their hips and torso upright to minimize upper body influence on the jump. They were instructed to stay in the bottom position for two seconds and then make a fast maximal vertical jump and land with the knees close to extended (Marchetti et al., 2014). The test leader observed the jumps for correct depth and for countermovement at the bottom of the jump position. If a countermovement was detected the jump was disqualified due to use of the SSC and another jump was performed.

Directly after the pre-jump the participants performed either the SS protocol or the MF protocol without rest. After each protocol was performed the participants continued with three maximal SJ with one minute rest between jumps. After the participant had performed one protocol and the post jumps, there was a five minute rest until the next protocol and proceeding post protocol jumps were performed (figure 1).

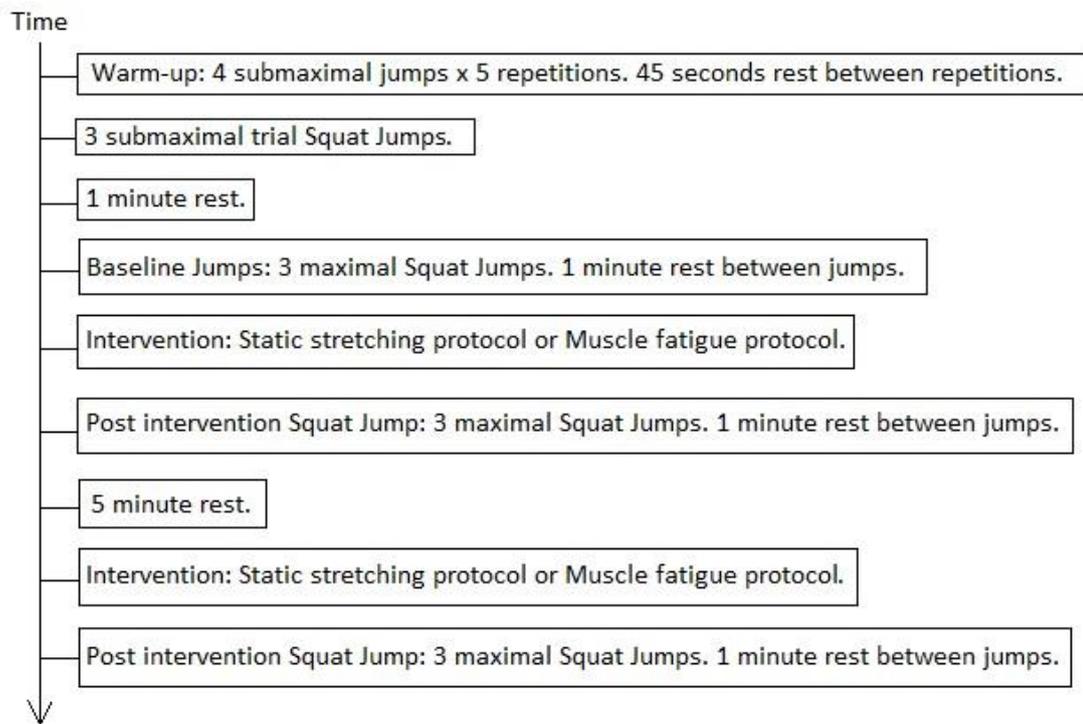


Figure 1: The study test procedure timeline.

### **3.2.5 Static Stretch protocol**

For the stretching protocol the participants sat on a chair with their hands behind their head while keeping the arms raised above the shoulder joint (glenohumeral joint) (Marchetti et al., 2014). The chair used in the trials measured a seat height from ground of 45 cm, a seat depth of 41.5 cm and a backrest height from the ground of 84 cm. All participants kept 90°, or close to 90°, in the hip and knee joints with the soles of both feet steadily on the ground. The torso was asked to be kept straight, resting against the back of the chair, with minimal curvature of the back. If the chair was too high, one weight plate (Eleiko XF Bumpers, width: 6 cm, diameter: 45 cm) was placed in the front of the chair so that the above mentioned position could be held. Both arms were moved by the test leader through the ROM of the horizontal abduction position. The elbows were passively pressed back reaching a passive stretch of the anterior part of the shoulder, particularly the anterior deltoid (appendix 3 nr 3). The passive stretch lasted for 30 seconds with 15 seconds rest between stretches. 10 stretches was done at an intensity equal to Borg scale RPE of 17 (Very Hard). The participants had a printed version of the Borg scale in front of them and were asked to inform the test leader when the RPE of 17 of the stretch was reached.

### **3.2.6 Muscle fatigue protocol**

To make the muscle fatigue protocol use the same structures and close to the same angles as the static stretch protocol, the subjects remained seated in an equal position on the same chair, arms abducted raised above the shoulder joint, with their hands approximately one to five cm above the head. The hands were pressed together at an intensity equal to Borg scale RPE of 17 (Very Hard). This position was upheld for 30 seconds followed by a 15 second rest. This was repeated 10 times. The torso was asked to be kept straight against the back of the chair, with minimal curvature of the back. The participants were allowed to use any wrist position that felt most comfortable to them, they could also change wrist position between sets (appendix 3 nr 1 & 2).

## **3.3 Ethical and social considerations**

This Bachelor Thesis study was ethically proved by the student supervisor and examiner before the beginning of the study.

Ethics is vital in every stage of a project. Researchers should consider if the research is worth doing, balancing harm and benefit, and if the research is explained clearly enough so that

individuals can make an informed decision about whether they want to consent. Mistakes may be made of presuming benefits such as enjoying participation, learning new skills and/or gain self-esteem, which cannot be promised. The people who benefit are individuals in the future, so balance is needed between the participants and future gain. This is why harm, risks, costs etc. should be kept as low as possible and no promising of benefits for the individuals involved should be made (Farrell, 2005). In this study considerations were made to keep the chance of harm minimal, by using exclusion criteria, and lower costs and inconvenience. It has been noted that some individuals may be deprived of the opportunity to participate in research due to factors as age, gender, disability, race, socioeconomic status, culture, lifestyle or sexual orientation. This is a social ethical problem. It is however up to the researcher to select which social factors that matters to the particular study (Gordon, Levine, Mazure, Rubin, Schaller & Young, 2011). Age and disability did deprive an individual to participate in this study, but it was for the purpose of decreasing the risk for harm during participation, to keep the group as homogenous as possible and to lessen inconvenience by using mature subjects. Individuals need clear and simple information to make an informed consent; including the aim of the study, who might benefit from the findings and what participants might gain. It will also include method and timetable, eventual risks, what will happen to the gathered data and how the researcher, supervisor and university can be contacted, and an explanation of the participants rights (Farrell, 2005). Based on this information and in line with Swedish law (SFS 2003:460) and the Helsinki declaration (World Medical Association, 2008), the informed consent with information handout was composed to be simple and clear and include all recommended and by law vital features (appendix 2).

### **3.4 Data collection and statistical analysis**

The results of all three pre- and post-test jumps were recorded as shown on the IVAR digital display and then calculated to means in Windows Excel 2013. The statistical analyses were performed in SPSS (IBM, SPSS Statistics, Version 20) software for windows. Normal distribution of the data was calculated with the Shapiro-Wilk test and histogram (Thomas, Nelson, & Silverman, 2011). Differences between the mean jump heights pre- and post-protocols was analyzed by paired sample t-tests. Difference between the mean jump heights post SS protocol and post MF protocol was also analyzed by a paired sample t-test (Thomas et al., 2011). Significance level was set to  $p \leq 0.05$ .

## 4 Results

15 subjects participated in the study, 9 females and 6 males, with the mean age ( $\pm$  standard deviation, SD) of 29 ( $\pm 7$ ) years old, mean height ( $\pm$ SD) of 173 ( $\pm 7$ ) cm, mean weight ( $\pm$ SD) of 71 ( $\pm 9$ ) kg and mean strength training experience ( $\pm$ SD) of 3 ( $\pm 3$ ) years (table 1). 24 individuals volunteered, three were excluded due to previous injury and six were excluded due to already being fatigued from a performed workout. There were no drop-outs in the study. The results of the Shapiro-Wilk test and histogram showed a normal distribution for the baseline jumps, the post SS protocol jumps and the post MF protocol jumps.

Table 1: Participant descriptives, n=15

	n	Mean ( $\pm$ SD)	Min	Max
Females	9			
Males	6			
Age (years)	15	29 ( $\pm 7$ )	19	39
Height (cm)	15	173 ( $\pm 7$ )	163	186
Weight (kg)	15	71 ( $\pm 9$ )	55	89
Training experience (years)	15	3 ( $\pm 3$ )	1	10

Cm=centimeters, kg=kilograms, Min=minimal, Max=maximal, SD=Standard deviation

Mean concentric jump height ( $\pm$ SD) was 25.31 ( $\pm 9.4$ ) cm for the baseline jumps, 23.66 ( $\pm 8.89$ ) cm post SS intervention jumps and 24.13 ( $\pm 8.90$ ) cm post MF intervention jumps (figure 2). A total of three jumps from three different participants were disqualified, all due to countermovement.

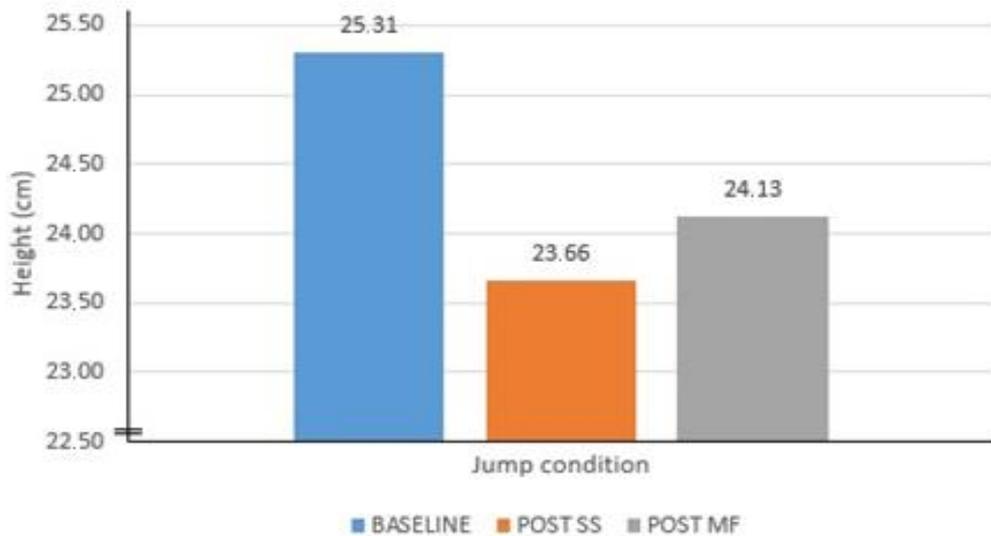


Figure 2: Mean height (cm=centimeters) of three squat jumps in baseline and post two different interventions, static stretch (SS) and muscular fatigue (MF) protocol.

Upper-limb static stretching indicated a cross-over effect on strength in the lower limbs with a mean reduction of 1.65 cm, p-value = 0.001. Upper-limb muscle fatigue indicated a cross-over effect on strength in the lower limbs with a mean reduction of 1.18 cm, p-value 0.032. The minimal jump height recorded was 11.8 cm and was post MF intervention. The maximal jump height recorded was 45.4 cm and was a baseline jump (table 2).

Table 2: Maximal, minimal and mean jump height including standard deviation for the three jump conditions and t-test value between baseline and post SS and baseline and post MF.

Jump condition	Max jump height (cm)	Min jump height (cm)	Mean jump height (cm)	± SD	Sig. (2-tailed)
Baseline	45.4	13.3	25.31	9.4	
Post SS	41.8	12.4	23.66	8.89	0.001
Post MF	41.4	11.8	24.13	8.9	0.032

SS=static stretch, MF=muscle fatigue, Max=maximal, Min=minimal, cm=centimeters, SD=standard deviation, Sig. (2-tailed)=t-test result

The largest difference measured between mean baseline jump height and mean post SS jump height was a reduction of 4 cm. One participant increased the mean jump height post SS intervention with 0.97 cm. Three participants increased their jump height post the MF intervention, the largest increase was 2.07 cm. The largest difference measured was a reduction of 4.84 cm between mean baseline jump height and mean jump height post MF intervention. (figure 3).

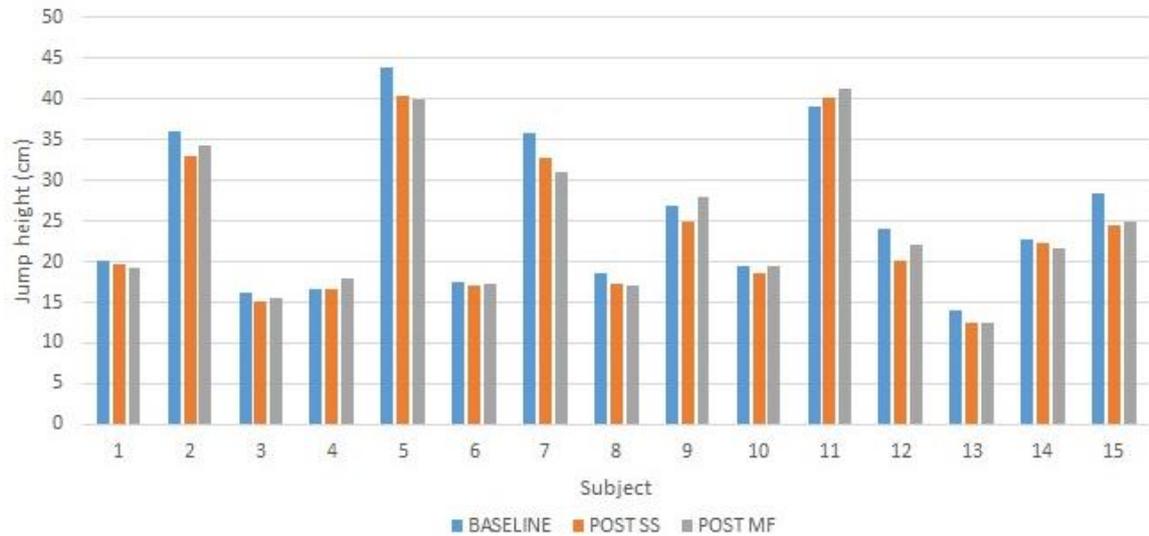


Figure 3: Mean jump height (cm=centimeters) for baseline, post static stretch (SS) intervention and post muscle fatigue (MF) intervention for all 15 subjects.

A cross-over effect was indicated post both protocols. The paired t-test showed that there was a statistical significant decrease in mean concentric jump height after the SS protocol with a reduction of 1.65 cm ( $p=0.001$ ) and the MF protocol with a reduction of 1.18 cm ( $p=0.032$ ). The difference between the two protocols was not statistically significant ( $p=0.146$ ).

## 5 Discussion

The aim of this study was to investigate if upper-limb static stretching and/or muscle fatigue display a cross-over effect that show changes in strength in the lower limbs. A cross-over effect which decreased performance was seen on strength in the lower limbs after static stretching and after muscle fatigue. Even if there were no significant change found between the two test protocols, these results are in line with earlier research suggesting that static stretching as well as muscle fatigue causes a cross-over effect (Marchetti et al., 2014; Kennedy et al., 2013; McLean et al., 2009). This indicates that static stretching and muscle fatigue give rise to mechanisms that effect the CNS.

### 5.1 Result discussions

It is difficult to compare the actual numbers in these results to other studies in the area since they have used different methods to measure performance. Kennedy et al. (2013) measured changes in maximum voluntary contraction (MVC) of the plantar flexors using surface electromyography after a maximal and a submaximal fatiguing intervention for the forearms. A decrease in plantar flexor MVC was seen from 100% to  $77 \pm 8.3\%$  after the maximal fatigue intervention and from 100% to  $92.4 \pm 6.2\%$  after the submaximal intervention. They further conclude that their study demonstrates a cross-over effect and that the results increases understanding central fatigue and its effects on unrelated none exercised muscles. In Kennedy et al.'s (2013) study there were only 14 participants, a relatively low number, and they are humble in their conclusion stating that more research is acquired. McLean et al. (2009) had a total of 20 subjects but is still not more appropriate to make comparisons to due to their methods. They measured cross-over changes through a 3-dimensional analysis of the biomechanics in a one-legged landing after 100%, 75%, 50% and 25% fatigue in the other leg. Their results show that 50%, 75% and 100% fatigue significantly ( $p=0.01$ ) decreased landing biomechanics in the other leg. McLean et al. (2009) therefore conclude that a cross-over is induced and that central fatigue seems to be a critical factor concerning one-legged landing injury risk, thereby stating it clinically significant in their opinion. Marchetti et al. (2014) measured vertical ground reaction force (peak force and propulsion duration) on a force plate. The researchers saw a decrease in mean peak force from about 860 Newtons (N) to 630 N, which was a significant reduction ( $p=0.021$ ). The control group in their study had a non-significant mean reduction of 10 N. Note that there are no exact peak force number values in

the article, these numbers are interpreted from a graph. The difference between the test group and the control group was statistically significant ( $p=0.045$ ). The researchers also noted an increased propulsion duration for the stretched group ( $p=0.024$ ), however the difference between the test group and the control group were not statistically significant. Marchetti et al. (2014) used 25 subjects in their study, 15 in the stretch group and only 10 in their control group, which are few for both groups; but still they draw the conclusion that these effects should be taken into account by coaches and athletes, thereby stating it clinically significant in their opinion. The p-value after the SS intervention in the current study's result ( $p=0.001$ ) indicates an even smaller risk for the result to be due to chance, and since the number of participants is the same ( $n=15$ ) the same conclusion as Marchetti et al. (2014) made could be proposed. However, it is more interesting to discuss how much difference a decrease of 1.65 cm or 1.18 cm, respectively, in concentric jump height makes. Due to the fact that the time variable, i.e. jump flight time, was not recorded in the study the results cannot be calculated to N. Measurements in N could be easier to translate to how much power that is needed to move actual loads a certain distance, as for example during the squat exercise. This could be useful in determining how this loss of power output equals in loss of load an athlete is able to lift, to make a more clinical interpretation of the result. Even though the subject number in this study was limited, the margins in elite sports can be very small and therefore the author of this study consider these results relevant and of importance for the elite athlete population, but more research on this population is needed.

As earlier mentioned, the reason for static stretching's effect on the CNS could be due to inhibitory inputs from muscle sensory neurons and inhibitory neural input from the GTOs. Activation of the local and non-local muscles could be effected by long loop reflexes originating from muscle spindles, skin and subcutaneous neurons (Marchetti et al., 2014). However, Miller and Burne (2014) found no significant changes in GTO reflex inhibition at any time during 30 minutes preceding an acute bout of static stretching, and the GTO's electrical response returned to initial value as soon as the muscle returned to its resting length. Nevertheless, they did not examine changes in concentric contraction and did not quantify stretch intensity, which means that all GTO's may not have been activated (Miller & Burne, 2014).

Reductions in neuron excitability due to static stretching could negatively affect muscle force. The arm's and leg's neurological representations overlap in the brain, which means that the decline in supraspinal drive might originate from mechanisms in this area (Marchetti et al.,

2014). This loop and overlap may be the reason for both protocols showing cross-over effects. Gandevia (2001) mean that central fatigue is a reduction of central drive to the motor neurons, and that this significantly contributes to a decline in force production ability of an exercised muscle, but because of this overlap it may also effect remote non-exercised muscles. Halperin, Aboodarda and Behm (2014) stated however that different muscles were effected differently to non-local fatigue; suggesting that leg extensors, unrelatedly of the fatigued muscle group, were more vulnerable than the elbow flexors to cross-over fatigue (Halperin et al., 2014). In future studies it would be interesting to further examine if static stretching has the same effect on upper body performance if the lower body was stretched.

Even though the groups in this study were too small to make adequate comparisons between the years of strength training experience and the sexes, tendencies could be interesting to look at. Years of strength training experience did not show a large difference in the results which could be speculated to be due to that the individuals participating in the study performed different types of strength training. Nonetheless, there was one mentionable difference during one condition between the sexes. The mean reduction post the SS intervention for all participants was 6.5%, however the females had a mean reduction in jump height of 6% while the males had a mean reduction in jump height of 7% post the SS intervention; a small indication that the males were more affected by the SS intervention than the females, but nothing concrete can be stated due to the small groups. Generally in the study the males found the stretching the most uncomfortable, and they could have been “fighting” the stretch with static muscle contraction which simultaneously could create a higher fatiguing response or a higher exertion, but this could just as well have happened amongst the females. The feeling of discomfort could also have affected them psychologically, but this is just speculation.

It cannot be excluded that other psychological factors could influence the results; some individuals may be more or less motivated to perform at maximal or high intensities, and some may also have expected or wished for a certain result and this could have influenced their performance.

One natural question arises while reading literature on the subject of static stretching, is if it is needed at all during warm-ups. Behm et al. (2011) mentions that a number of researchers have found that stretching has no effect on injury prevention and that the individuals who are most likely to get injuries are the ones who are the most flexible, in comparison with moderately

flexible individuals; and this is apart from the fact that it seems pretty clear that it impairs strength and power performance (Behm et al., 2011). They do not state though which type of injuries, and there is a possibility that these flexible individuals who are more likely to get injured are high-end or elite athletes who could be prone to injuries due to their high training volume or their sport. Static stretching does however increase flexibility, which is needed in several sports and in exercise-specific situations. It is important to not discard studies that don't find post static stretching impairments since these may find ways to implement static stretching before performance which could enhance acute flexibility for individuals who need it. Worrel et al. (1994) reported an increased hamstring eccentric and concentric torque after four hamstring stretches of 15-20 seconds each, but they did not find a significant increase in ROM. According to the review by Behm et al. (2011) an overwhelming number of studies in comparison do show impairments, so depending on the goal of the exercise, coaches and athletes, elite and recreational, should be thoughtful and tactical while designing a warm-up. If subsequent performance require a high force output, static stretching of any body part should be avoided or minimized before performance. It is also advisable to keep the warm-up intensity relatively low so that central fatigue doesn't impair performance. Due to this knowledge it is also logical to schedule heavy strength/power exercises early in the workout when creating a strength training program

## **5.2 Method discussion**

The tests could affect population groups differently, which would have made a more homogenous group, in regards to age, strength training experience and sex, required for a more applicable result. Test conditions is also a factor which can affect results i.e. participants' previous training, food and fluid intake, caffeine, nicotine etc. and should be more controlled. A control group helps to account for factors that could have affected performance, for example psychological influences or local fatigue in the lower extremities. It would be preferable to include a control group or control test session to minimize the influence of these factors in the result.

Due to a faulty screw that was stuck in one of the IR sensors they could not be placed directly on the floor and stay steady and keep contact, so each sensor was placed on top of two blocks, one cm high. This does not serve a problem looking at result in differences between the two test protocols in this study, but it is an issue when comparing to other studies; particularly if

one would look at actual jump height of the subjects, since the jump height was not measured from floor level.

The same stretch technique and duration was used as in Marchetti et al. (2014) study since it was easy to standardize and stated as the most extensive protocol used in previous literature. However this duration or the stretch itself can be speculated not be the most used stretch during warm-ups to increase shoulder ROM. Some participants mentioned that it was an uncomfortable stretch, and if the study was conducted again another stretch would be used, a stretch and a duration which is more commonly used during warm-ups. For the purpose of standardization, the same warm-up as the one Marchetti et al. (2014) used in their study was also used. It is questionable whether this warm-up was adequate to get the participants properly warmed up for the task, and a warm-up including the whole body would also be used if the study was conducted again.

In most studies in the literature on stretching, point of discomfort is used (Behm et al., 2011). In this study the Borg RPE scale was used to standardize intensity. This choice was made to give the participants an equal reference point during the two different protocols. It should however be noted that the Borg RPE scale is subjective and the individuals perception could be influenced by emotional state, but this is also the case with point of discomfort. The Borg scale does not provide any direct levels of interindividual comparison (Borg, 1982), but in the used protocols the metric properties are not of importance, and no comparison between individuals were made. It is possible that since an RPE of 17 for the “stretch feeling” was used and the participants were not used to follow directions of the Borg scale, they could have misunderstood and have created muscle fatigue by isometrically pushing back during the stretch. To minimize this risk, they were reminded to stay relaxed in the shoulder area.

To ensure that an increase in ROM in the shoulder joint was achieved, it would have been relevant to measure ROM pre- and post the SS intervention. This factor similarly applies to fatigue, which could be tested through electromyography measures of MVC pre-and post the MF intervention. It was not possible to take these measures due to time factor and in the field, and from taking into account previous research in the area it was assumed that an increase in ROM and a rise of fatigue was created, even if it is not certain.

Sheppard et al. (2008) ran into a problem while testing the SJ; it requires extensive experience of performing the jump to decrease or eliminate small countermovement before the concentric action, and it is also difficult to detect every countermovement by observation only. This could have been avoided by recording the jumps and checking in slow motion right after the jump for countermovement, but there was neither equipment nor personnel involved in this study to include this aspect; and since non-elite individuals were used in this study it should not significantly influence the result if the observation missed a countermovement of 1-3 cm. Nevertheless it is possible that a greater countermovement was missed and that this affected the jump results.

Enoka and Dechateau (2008) concluded that the expression central fatigue had is very task specific, so neuromuscular fatigue is vastly reliant on the type of exercise performed. This also makes it important to distinguish the type of fatigue that different exercises produce before evaluating how it alters motor performance. Gandevia (2008) mean that central and peripheral alterations occur during both maximal and submaximal contractions, while Place, Bruton and Westerblad (2008) claims that central fatigue is more associated with low intensity submaximal conditions contra maximal contractions that associate more with peripheral failure. However Kennedy et al. (2013) concluded that maximal isometric contractions of the forearm muscles lead to a greater decrease in performance both in the forearms but also a greater cross-over effect decrease in plantar flexors. The muscle's peripheral maximal muscle voluntary contraction performance recovered more slowly after the maximal protocol used. Kennedy et al. (2012) used 100% maximal contraction and 30% submaximal contraction while in this study a Borg of 17 was used. A significant cross-over decrease in concentric performance was shown but more studies of different intensities are needed to determine what effects they have on performance as another result may have been seen if the intensity was different. Future studies could examine cross-over on various intensities, this could lead to more accurate recommendations in regards to warm-up intensity.

## **6 Conclusion**

This study presented a cross-over effect after an extensive static stretching protocol and after a muscle fatigue protocol. More directly the results show that concentric jump performance significantly decreased after static stretching and after muscle fatigue in the shoulders. This is in line with previous research in the area. No significant difference was seen between the protocols. The results implicate that static stretching and muscle fatigue effects the CNS, which leads to impairments in performance in non-local muscles. Future studies can focus on different stretching intensity; if performance reductions are seen at a lower intensity and if not may be useful for athletes that require a high degree of flexibility. Studies on different intensities during fatiguing exercises can also be useful in recommendations for warm-up intensities. It would further be interesting to see if the same cross-over effects are seen on upper-body performance after lower-body stretching, and how different sexes, ages and individuals with higher or lower training statuses are affected.

### **6.1 Practical applications**

The above mentioned implications means that coaches and athletes, depending on the goal of their exercise, should consider avoiding static stretching of any body part in a warm-up if they wish for highest possible force output in subsequent performance. The intensity of the warm-up should also be kept relatively low so that subsequent performance is not impaired by central fatigue. When creating a strength training program heavy strength/power exercises should be scheduled early in the workout.

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## 8 Appendices

### 8.1 Appendix 1: Borg RPE Scale

rating	description
6	NO EXERTION AT ALL
7	EXTREMELY LIGHT
8	
9	VERY LIGHT
10	
11	LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD (HEAVY)
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

For more information on this document, please contact the author at [info@openstax.org](mailto:info@openstax.org).

## 8.2 Appendix 2: Informed consent

### Studieinformation

Hej! Jag heter Michelle Nordin och håller på att skriva mitt examensarbete. Du tillfrågas att delta i studien därför att du frivilligt har anmält dig.

Det finns studier som har påvisat ett fenomen kallat *cross-over effekt* där en kroppsdel påverkas utav arbete som utförts i annan del av kroppen. Syftet med studien är att se om stretching eller muskulär uttrötning i överkroppen påverkar styrkan i benen. Resultatet ökar förståelsen kring fenomenet, vilket är av intresse för dig som håller på med styrketräning för att få ökade kunskaper om stretching för ett pass.

För att delta behöver du vara fullt frisk (ej förkyld eller dylikt) och inte ha genomgått operation i armar, ben och rygg eller haft annan skada senaste fyra månaderna som lämnat kvarstående besvär.

Testet inleds med en kort genomgång av proceduren där du har möjlighet att ställa frågor. Därefter utförs hopptest barfota, ett statiskt stretch-program och ett uttröttningsprogram. Proceduren beräknas ta ca 30 minuter.

Följs testprotokollet innebär testerna ingen hög skaderisk men det finns alltid en risk för skador vid maxhopp. Vissa individer kan även tycka att stretching kan vara obehagligt.

All insamlad data kommer att sparas på ett USB-minne som endast studieledare och handledare på högskolan har tillgång till, för att inte obehöriga ska kunna ta del av resultatet. Studien kommer att presenteras i ett examensarbete. Ingen information som kan kopplas till din identitet kommer att presenteras.

Ditt deltagande i studien är helt frivilligt. Du kan när som helst, utan förvarning eller särskild förklaring, välja att avsluta studien utan att det kommer få några konsekvenser för dig. Dina testresultat kommer i detta fall tas bort och kommer inte gå att spåra till dig.

Tack på förhand!

#### Ansvariga

Studieansvarig/forskare

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Handledare

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### Skriftligt samtycke

I studien kommer personuppgifter om Dig att behandlas datoriserat. Högskolan i Halmstad (Box 823, 301 18 Halmstad, tel. 035-16 71 00) är personuppgiftsansvarig för behandling av personuppgifter. Kontaktperson för projektet är studieledare Michelle Nordin, 0736212524, [michelle.nordin@live.se](mailto:michelle.nordin@live.se) samt handledare Emma Haglund [emma.haglund@hh.se](mailto:emma.haglund@hh.se)

- Jag har informerats om studieprocessen och fått möjlighet att ställa frågor och fått dessa besvarade.
- Jag är medveten om att deltagande är frivilligt och att jag närsomhelst kan avbryta.
- Jag är medveten om att det finns en viss skaderisk och att deltagande sker på egen risk.
- Jag samtycker till att Högskolan i Halmstad behandlar personuppgifter om mig i enlighet med vad som beskrivits ovan.
- Jag samtycker till att delta i studien.

.....

Datum och ort

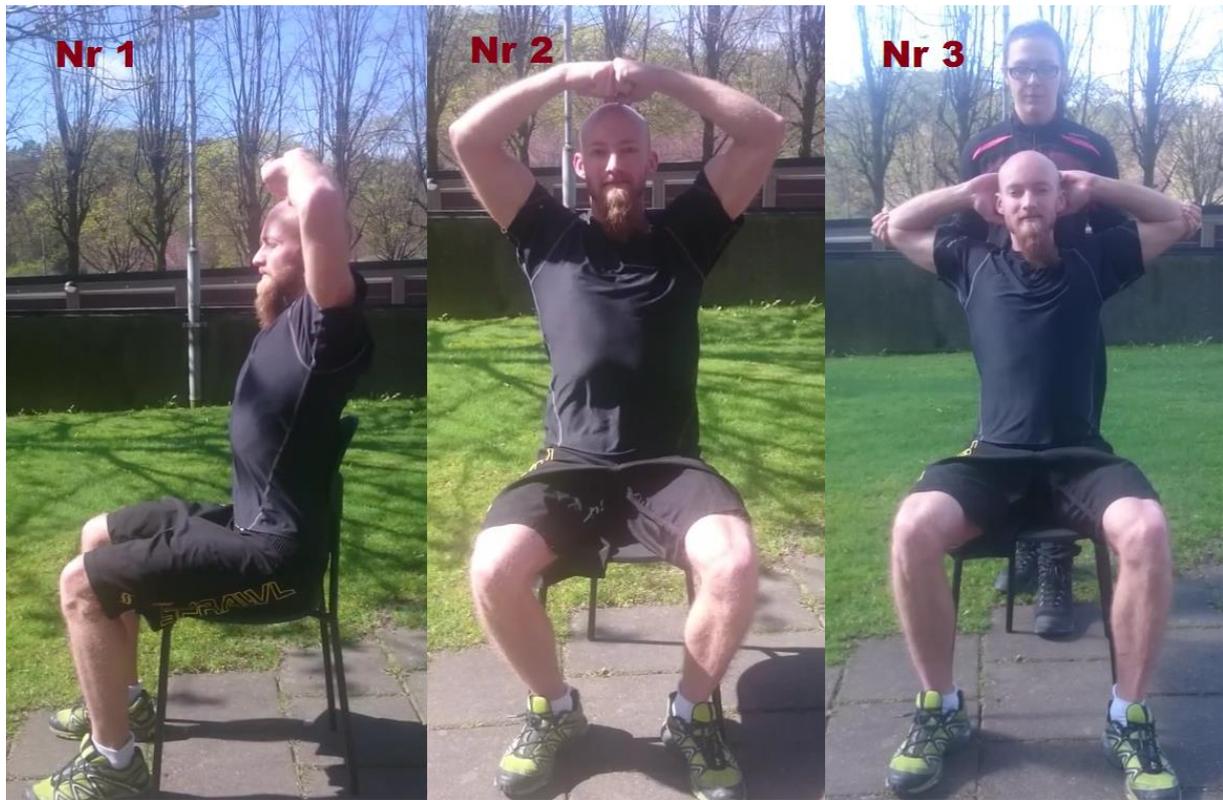
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Namn

.....

Namnförtydligande

### 8.3 Appendix 3: Muscle fatigue protocol and static stretching protocol



Nr 1: Muscle fatigue position from lateral view.

Nr 2: Muscle fatigue position from anterior view.

Nr 3: Static stretching position from anterior view.

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