A correlation study between one-repetition maximum in clean and maximal jump height in countermovement jump and squat jump in men and women

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Abstract

Background: A fundamental relationship between power and strength exist and is the foundation of power output. Vertical jump and weightlifting have many similarities including movement biomechanics. Both countermovement jump and weightlifting exercises uses stretch shortening cycle. Squat jump generally produce lower jump height then countermovement jump and do not include the stretch shortening cycle. Few studies have investigated if there is a correlation between one-repetition maximum in clean and maximal jump height in countermovement jump and squat jump and investigated if the result is equal in men and women. Aim: The purpose of this study was to investigate if there was a correlation between one-repetition maximum in clean and maximal jump height in countermovement jump and squat jump. The secondary purpose was to investigate if the correlation between one-repetition in clean and maximal jump height in countermovement jump and squat jump was equal in men and women. Method: Seventeen healthy subjects (n=17), nine males and eight women (age; 32.6 ± 9.4) completed the study. The study included two sessions, the first session was a one-repetition maximum test in clean and the second session was a vertical jump test including countermovement and squat jump. Both sessions included a dynamic warm up and the one-repetition maximum test also included a specific warm up. Result: The result showed a very strong significant correlation between one-repetition maximum in clean and maximal jump height in countermovement jump (r=0.77, p=0.000) and squat jump (r=0.72, p=0.001) in the combined group of men and women. When separating men and women the result showed no statistically significant moderate to strong correlations between one-repetition maximum in clean and maximal jump height in countermovement jump (men: r=0.45, p=0.229; women: r=0.59, p=0.121) and squat jump (men: r=0.40, p=0.320; women: r=0.46, p=0.209). Conclusion: Findings from this study show that there is a very strong significant correlation between one-repetition maximum in clean and maximal jump height in countermovement and squat jump in the combined group of men and women. When separating men and women the result was in the range of a moderate to strong correlation but not statistically significant. Therefore more research is needed in this area and a larger sample size is recommended to further investigate if the correlation is equal between one-repetition maximum in clean and
maximal jump height in countermovement and squat jump in men and women.

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Introduction

High ability to generate maximal power output result in improved athletic performance such as enhanced vertical jump performance. To be able to generate maximal power output strength is required. A fundamental relationship between power and strength exist and is the foundation of power output (Cormie, McGuican & Newton, 2011). Weightlifting is a dynamic strength and power sport that includes the exercises snatch and clean & jerk. These exercises have reported the highest peak power output in sports (Storey & Smith, 2012). Weightlifting exercises have grown to be very popular and used to improve power output and vertical jump performance (Cormie, McGuican & Newton, 2011; Chanell & Barfield, 2008; Tricoli, Lamas, Carnevale & Ugrinowitsch, 2005). Weightlifting is considered to have biomechanical similarities to vertical jump (Garhammer, 1993; Chanell & Barfield, 2008). Vertical jump and weightlifting exercises have more similarities such as using the same energy substrate and the use of the movement function called stretch shortening cycle (SSC) (Baechle & Earle, 2008; Storey & Smith, 2012). Countermovement jump (CMJ) indicates the eccentric-concentric strength in the lower extremity and squat jump (SJ) indicates the concentric strength in the lower extremity (Bellardini, Henriksson, & Tonkonogi, 2009). CMJ height is generally higher than SJ height and this is due to many factors such as the countermovement allowing the extensor muscles to create more force before the take off and concentric part of the jump (Maarten, Gerritsen, Litjens, & Van Soest, 1996). Previous research by Carlock et al (2004) investigated the relationship between vertical jump and weightlifting ability. The result showed a correlation of \( r=0.59 \) between CMJ height and one-repetition (1RM) estimated in clean & jerk in weightlifting men and women. The study by Carlock et al (2004) also correlated peak power from CMJ and 1RM estimated in clean & jerk and found a correlation of \( r=0.90 \) in men and \( r=0.76 \) in women. However, few studies have investigated if there is a correlation between 1RM in clean and maximal jump height in CMJ and SJ. Also, little research has been done to investigate if the result is equal in men and women.
Background

Power

Many sports, such as soccer, volleyball and American football require the ability to produce maximal muscle force in the shortest possible time. Power is defined as work divided by time (Baechle & Earle, 2008). Peak power is the highest value measured during a movement and is a very important factor for success in jumping and in weightlifting performance (Carlock, et al., 2004).

Coaches often use vertical jump test to evaluate jump height and power output (Borrás, Balius, Drobnic, & Galilea, 2011). To improve strength and power output resistance training need to be conducted (McArdle, Katch, & Katch, 2010) and are therefore described below.

The physiology of resistance training

Resistance training is an effective method for increasing strength and power (McArdle, Katch, & Katch, 2010). There are many physiological adaptations to resistance training such as neural and muscular adaptations. These neuromuscular adaptations can result in increased muscular strength, power output (McArdle, Katch, & Katch, 2010) and increased ability for vertical jump and weightlifting performance (Baechle & Earle, 2008) and is therefore described below.

Neural and muscular adaptation

In the initial part of a resistance training program the neural adaptations account for the majority of the strength gained. After the initial part muscular adaptations occur (McArdle et al, 2010). The most important neural adaptation take places in the functional unit of the neuromuscular system called the motor unit. The motor unit consists of an alpha motor neuron and the associated muscle fibres it activates. When force is needed in a muscle the motor unit recruitment and the firing rate are influenced. Low muscle force actions activate few motor units and high muscle force actions activate many motor units, this phenomenon of motor unit recruitment is called the size principle. Motor units have different response to electrical stimulus and this is called twitch. There are three types of twitch characteristics, fast twitch (high force, fast
fatigue), fast twitch (moderate force, fatigue resistant) and slow twitch (low force and fatigue resistant). Fast twitch motor units are more readily activated when performing high force muscle activities where slow twitch motor units are mainly activated when performing low muscle force activities (McArdle et al, 2010). An important adaptation to resistance training is that twitch contraction time is decreased. Good synchronization and firing pattern of motor recruitment are a trainable factor and is important for success in sports. Weightlifters generally have a good synchronization and firing pattern of motor units during a lift. During a lift fast twitch motor units are recruited simultaneously and allow the weightlifter to generate force very quickly. Improved motor unit recruitment, firing pattern and decreased twitch contraction time is important neural adaptations gained from resistance training and can result in increase strength and power (McArdle et al, 2010).

Muscular adaptations that occur from resistance training are for example increases in skeletal muscles cross sectional area (CSA), strength and metabolic energy stores (McArdle et al, 2010). A strong relationship exists between CSA and strength. An increase in CSA is primary an effect of increased protein synthesis. Metabolic adaptation to resistance training is increased level of adenosine triphosphate (ATP), glycogen and creatine phosphate (PCr) stored intramuscular (McArdle et al, 2010). ATP and PCr is the most important energy substrate for activities that have short duration time, approximately 0-10 seconds such as vertical jump (McArdle, Katch, & Katch, 2010) and weightlifting exercises (Storey & Smith, 2012).

**Different types of resistance training affecting power output and vertical jump performance**

High ability to generate maximal power result in improved athletic performance such as enhanced vertical jump performance. Different types of resistance training are performed at different velocities and affect power output and vertical jump to a different extent (Cormie, McGuigan & Newton, 2011). Resistance training is the umbrella term for lifting and lowering external weight such as barbell, dumbbell or weight plates (Baechle & Earle, 2008). Traditional resistance training and weightlifting are well established methods for improving maximal power output. Traditional resistance training refers to exercises such as squat, bench press and deadlift. These types of exercises are good to
develop strength but are performed at slower velocities and therefore have a more markedly decelerating phase than weightlifting exercises (Garhammer, 1993; Cormie, McGuigan & Newton, 2011). Weightlifting exercises refers to clean & jerk, snatch and complementary exercises such as power clean, and hang clean (Storey & Smith, 2012). Weightlifting exercises has movement similarities with the vertical jump and requires high force and high velocity and is therefore incorporated in power training programs in many sports. Both high force and velocity are two important factors for high power output (Cormie, McGuigan, & Newton, 2011). Previous research by Garhammer (1993) shows that weightlifting exercises produce higher power output than squat, bench press and deadlift during 1RM.

**Weightlifting**

The principle of specificity refers to metabolic and physiological adaptations that are created by a specific type of training (McArdle, Katch, & Katch, 2010). Previous empirical observations have shown that weightlifting exercises are believed to have similar movement characteristics and joint angles like the vertical jump. Both vertical jump and weightlifting requires high velocity and accelerating throughout the whole movement (Chanell & Barfield, 2008; Cormia, McGuigan & Newton, 2011). Another similarity between vertical jump and weightlifting is the movement function SSC. SSC is used during the transition period and second pull were the knees are re-bent and the torso is moved under the barbell (Storey & Smith, 2012).

It is theorized that more explosive lift with lighter weight can be more effective to improve power output such as weightlifting exercises instead of traditional resistance exercises (Channell & Barfield, 2008). Chanell & Barfield (2008) investigated the effects of incorporating traditional resistance exercises (bench press, deadlift and squat) and weightlifting exercises (power clean) in vertical jump performance. The result showed that both traditional resistance training and weightlifting increased the vertical jump height but the weightlifting group showed larger effect on jump height (Channell & Barfield, 2008). Weightlifting exercises has also shown to increase CMJ and SJ height (Chanell & Barfield, 2008; Tricoli et al, 2005). Because of the high velocity and force weightlifting have potential to produce power in a variety of different loads of 1RM. The most frequently used loads during weightlifting ranges from 50-90 % of 1RM. Heavy
loads (exceeding 80 % of 1RM) are commonly used during weightlifting exercises to increase power output but adaptations are not well known (Cormie, McGuigan, & Newton, 2011). It is theorized that the increased power output is due to improved neural drive and a faster force production (Storey & Smith, 2012; Cormie et al, 2011). It is also theorized that training with high percentage of 1RM in weightlifting benefits power output in both experienced and inexperienced athletes (Cormie et al, 2011).

**Using the stretch shortening cycle to improve vertical jump height and weightlifting performance**

The vertical jump height can be improved by making a countermovement and is a part of the movement function, SSC (Harrison & Gaffney, 2001). Weightlifting performance can also be improved to use the SSC between the transition phase and second pull by performing a double re-bend of the knees. The re-bending of the knees enables the lifter to use SSC in the second pull that requires maximal acceleration of the barbell (Storey & Smith, 2012).

McArdle et al, (2010) describes the SSC as a functional movement pattern that contains three different phases. The first phase is called the eccentric phase and using a pre stretch. The pre stretch is immediately followed by a shortening of the muscle (the concentric phase). The amortization phase is the transition phase between the eccentric and concentric phase (McArdle et al, 2010). The SSC uses tendons and some muscular components (musculotendinous units) that are called series elastic components (SEC). SEC is one of the most important factors in vertical jump and plyometrics. When musculotendinous units are stretched the SEC is acting like a spring and stores elastic energy. When musculotendinous units immediately are followed by the concentric phase the energy is released. Another component that contributes to the SSC is the stretch reflex. The stretch reflex includes muscles spindles, i.e. are proprioceptive organs that are sensitive for the magnitude and rate of a stretch. When a rapid stretch is conducted the muscle spindles are causing a reflexive response in muscle action. The reflexive muscle action increases the activity in the agonist muscle that results in increased force production (McArdle et al, 2010). However, previous research has investigated why CMJ is higher than SJ and the result shows that it is not primarily because of storage of elastic energy and SSC (Maarten, Gerritsen, Litjens, & Van Soest,
Difference between countermovement jump and squat jump

Jump height in CMJ indicates the eccentric and concentric (reactive) strength and jump height in SJ indicates the concentric strength in the lower extremity (Bellardini et al, 2009). Maarten et al (1993) investigated why CMJ height is higher than squat jump height and the result showed that a countermovement allowed the extensor muscles to create more force before the concentric part of the jump. In SJ the concentric part is started immediately and less force was produced (Maarten et al, 1996). Findings from the study also shows that CMJ allowed larger joint moments in the start of the push off and also the first part of joint extension in the CMJ that contributed that more work could be produced in contrast to SJ (Maarten et al, 1996). Previous research has investigated the relationship between weightlifting exercises and maximal vertical jump height in both CMJ and SJ and is presented in the following session.

Previous research investigating the relationship between clean and vertical jump

A previous study by Carlock et al (2004) investigated peak power in vertical jump and weightlifting ability in weightlifting men and women. The purpose of the study was to investigate if there was a correlation between peak power in vertical jump and weightlifting performance in the exercises clean & jerk, snatch and squat. The results indicated that peak power in CMJ and SJ are strongly associated with weightlifting ability. Carlock et al (2004) correlated CMJ height with estimated 1RM in clean & jerk and showed a strong correlation of r=0.59 in men and women. When estimated 1RM in clean was correlated with SJ the result showed a slightly higher correlation than a strong correlation of r=0.63 in men and women (Carlock et al, 2004). Another previous study investigated if there was a relationship between performance in hang power clean (a sub exercise to the exercise clean & jerk) and other variables such as CMJ height (Hori, Newton, Andrews, Kawamori, & McGuigan, 2008). The researchers correlated 1RM in hang power clean with CMJ height and the result was between a moderate and strong correlation r=0.41 in Australian rule football players (Hori et al, 2008).

An intervention study by Channell & Barfield (2008) investigated if two different
training programs could increase the vertical jump performance in high school boys. One training program included weightlifting exercises and the second training program included traditional strength training exercises such as squat and deadlift. The weightlifting group increased the vertical jump by 4.5 % and the group with traditionally strength exercises increased the vertical jump by 2.3 % (Channell & Barfield, 2008). A previous study investigated the effects of one weightlifting program, one plyometric program and one combined weightlifting and plyometric program on vertical jump performance (Arabatzi, Eleftherios, & Saez-Saez De Villarreal, 2010). The result showed similar increases in CMJ and SJ height in all three groups. However, the weightlifting group had a higher increase in eccentric and concentric power in contrast to the other groups (Arrabatzi et al, 2010). Another intervention study investigated if two different training programs could increase the vertical jump in male collage education students (Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005). One training program included weightlifting exercises together with the exercise squat and the other training program included vertical jump exercises and the exercise squat. The result showed similar magnitude of increase in vertical jump performance in both training groups (Tricoli et al, 2005). The majority of the research described earlier is done in male participants. In the study by Carlock et al (2004) they investigated both women and men and these results is therefore presented in following section.

**Gender differences between vertical jump and clean**

Today women successfully participate and compete in different sports and research has shown that women also benefits from resistance training like men do (McArdle, Katch, & Katch, 2010). The study by Carlock et al (2004) correlated peak power in CMJ with the clean & jerk result and showed a nearly perfect correlation of $r=0.90$ in men and a very strong correlation $r=0.76$ in women. The correlation between clean & jerk and peak power from SJ was a nearly perfect correlation ($r=0.90$) in men and a very strong correlation ($r=0.76$) in women, identical to the correlation between clean & jerk and peak power from CMJ. The average jump height difference between CMJ and SJ was 11.8 % for the men and 5.4 % for the women and this data implies that men were more able to use the muscles contractile units more effectively by generate more power and better utilize the SSC then women (Carlock, et al., 2004). A study by Harrison & Gaffney (2001) investigated gender differences in SSC and showed that men were more effective
utilizing the SSC and performed higher CMJ than women.

To summarize, few studies have investigated the correlation between 1RM in clean and maximal jump height in CMJ and SJ in both men and women. Also, many previous studies have investigated the whole movement clean & jerk but what happens when the jerk is removed? More research is needed to investigate if the result is equal between men and women and also because the majority of the research is done in men. Today women compete successfully in sports as men do (McArdle, Katch, & Katch, 2010) and therefore research is needed on women’s performance as well. Therefore this study will try to investigate this opening to contribute with information in this area.

**Aim**

The purpose of this study was to investigate if there is a correlation between 1RM in clean and maximal jump height in CMJ and SJ. The secondary purpose was to investigate if the correlation between 1RM in clean and maximal jump height in CMJ and SJ was equal in men and women.

**Research questions**

- Is there a correlation between one-repetition maximum in clean and maximal jump height in countermovement jump and squat jump?
- Is the correlation between one-repetition maximum in clean and maximal jump height in countermovement jump and squat jump equal in men and women?

**Methods**

**Subjects**

Nineteen (n=19) injury free subjects were recruited from two Crossfit boxes and one gym in Halmstad. The inclusion criteria for participating in the study were six months of experienced with the clean, free of injuries and men and women from the same sport. Two subjects were excluded from participation in the study because of low experience with clean. The inclusion criteria men and women from the same sport were later not of biggest importance later abandoned. The remaining seventeen subjects (n=17; n=9 men and n=8 women) fit the inclusion criteria and completed the study.
Study design

This study is a correlation study that investigates the correlation between 1RM in clean and maximal jump height in CMJ and SJ in men and women. There were two test sessions, one 1RM test in clean and one test session for CMJ and SJ. Anthropometric data from the subject was collected at the first session at the 1RM test in clean.

Testing procedures

One-repetition maximum strength test in clean

The first session was a one-repetition maximum strength test 1RM-test in clean. First, the subjects performed a dynamic warm up that included ten body weight squats, lunge walks for ten meters, butt kicks for ten meters and five CMJ. The exercises in the warm up were performed two times (Moir, Shastri, & Connaboy, 2008). Ten meters was measured with a tape line to secure the distance. After the dynamic warm up a specific warm up was performed including four repetitions and three sets of clean (Comfort, Fletcher, & J, 2012) at 50 % of estimated 1RM (Faigenbaum, et al., 2012). Between each set was a rest period of one minute (Comfort, Fletcher, & J, 2012). The subjects had 3-5 trials to reach their 1RM load. The weight was increased by 2.5 kilograms up to 7 kilogram and between each trial there was a three minute rest period. If the subject failed one trial the load could be decreased with appropriate load in consultation with the researcher. If the subject failed but still had an appropriate technique another attempt at the same load was approved (Faigenbaum, et al., 2012). The clean started with the barbell on the floor and was pulled up with a shoulder width grip. The barbell was caught in the front of the shoulders in a deep squat in one whole movement. From the squatting position the athletes stood up still holding the barbell in front of the shoulders (Baechle & Earle, 2008; Storey & Smith, 2012).

Countermovement and squat jump test

The second session was performed one week after the 1RM test in clean and included CMJ and SJ. The subject first performed a warm up identical to the warm up of the 1RM test, i.e. a dynamic warm up that included ten body weight squats, lunge walks for ten meters, butt kicks for ten meters and five CMJ. The exercises in the dynamic warm up were performed two times (Moir, Shastri, & Connaboy, 2008). CMJ was performed three times with three minutes rest between each jump (Moir, Shastri, & Connaboy, 2008).
The CMJ was performed from an upright standing position and then down in a countermovement to a knee flexion of 90 degrees before jumping (Bellardini, Henriksson, & Tonkonogi, 2009). Between the CMJ and SJ test the subject had a rest of three minutes like they had in the 1RM test (Faigenbaum, et al., 2012). After the rest period the subjects performed three SJ with three minute rest between each jump based on the procedure by Moir, Shastri & Connaboy (2008). The SJ was performed from a static squat position with 90 degrees knee flexion (Bellardini et al, 2009). The subject had to hold the semi squat position for three seconds before jumping (Bellardini, Henriksson, & Tonkonogi, 2009). The hands were placed on the hips during the whole movement in both CMJ and SJ (Bellardini et al, 2009). The knee flexion was monitored by the same researcher to ensure consistency in the vertical jumps. All the values from CMJ and SJ were collected and the highest values were used in the analysis of the result (Moir, Shastri, & Connaboy, 2008).

Data collection

The CMJ and SJ were measured by an infra red Mat (IVAR, LN Sportkonsulent, Mora, Sweden). Weight plates and barbell from Eleiko were used for the clean (Eleiko, Halmstad, Sweden). The result from CMJ, SJ and 1RM in clean was documented in Excel (Microsoft Office Excel 2007, Microsoft) and was saved at an external USB.

Ethical and social considerations

When working with humans it is the researcher's responsibility to protect the subjects from harm and informed the subject their rights when participating in research studies (Thomas, Nelson, & Silverman, 2011). It is important to always treat the subject with respect and be sensitive to human dignity. In the present study an informed consent was made (appendices 1 & 2) to explain the rights and protect the subjects. Initially the purpose of the study was explained and time was given to ask questions. The subject participated voluntarily in the study but had the right to end the participation in any time without any further questions from the researcher. It is also the subjects’ right to remain private and confidential. No unnecessary and personal information not concerning the research was asked by the researcher. It is impossible of tracking a subject in the study. All subject got an ID number instead of their name when collected the data. All result is presented in mean values on group level in the result (Thomas,
Nelson, & Silverman, 2011). The subject was informed which the test leader was and that the test leader together with Halmstad University was responsible for the study and that the study also would be stored and published at Halmstad University.

Physical activity is important to create and maintain health. Resistance training have many positive health benefits such improved body composition, stronger tendon and ligaments and improved mineral content and density in bones in both athletes and non athletes (McArdle et al, 2010). Based on the principle of specificity it is of importance to understand how to train to reach specific adaptations (McArdle et al, 2010). It is important for coaches, strength and condition specialist to evaluate sport specific performance in athletes. An athletic profile can be made by testing different physical qualities to monitor athlete’s performance over time (Baechle & Earle, 2008). The present study contributed with information in this area by investigated the relationship between three popular strength and power exercises.

**Statistical analysis**

The result was transferred from Excel (Microsoft Office Excel 2007, Microsoft Corporation, Redmond, USA) to SPSS (SPSS Version 20, IBM, New York, USA) for analyzing the result. The Shapiro Wilks test was conducted to investigate if the data was normally distributed. (Shapiro & Wilk, 1965). The majority of the data was normally distributed and the result was presented in mean value ± standard deviation. Due to the data was normally distributed Pearson's correlation coefficient (r) was used to calculate the correlation between CMJ height and 1RM in clean in men and women (Thomas et al, 2011). An independent T-test was conducted to compare if the result was equal in men and women (Thomas et al, 2011). Thomas et al (2011) describes the coefficient of correlation as a quantitative value that explains the value of the relationship between two (or more) variables. The correlation coefficient can range from 0.0 to either + 1.0 or – 1.0 (both positive and negative). A perfect correlation is 1.0 or minus 1.0 and no correlation at all is defined as 0.0 (Thomas et al, 2011). Carlock et al (2004) used the definitions 0.10 for a small correlation, 0.30 as a moderate correlation, a strong correlation at 0.50, very strong correlation at 0.70, nearly a perfect correlation at 0.90 and a perfect correlation at 1.0. The definitions used in the study by Carlock et al (2004) were also used in the present study. Thomas et al (2011) describes how to interpret the
meaningfulness of the correlation by using the coefficient of determination \(r^2\). \(R^2\) indicates the level of common associations’ factors that influence the two investigated variables (Thomas et al., 2001). A level of probability \(p\) is set by the researcher and this level is also called alpha \((\alpha)\). The level of probability is usually set at either 0.01 or 0.05 and is used to control for a type I or type II error (Thomas, Nelson, & Silverman, 2011). In the present study the level of probability was set to 0.05.

**Results**

The present study investigated if there is a correlation between CMJ height and 1RM in clean and also investigated if the correlation was equal between men and women. Seventeen healthy subjects \((n=17)\), nine males and eight women \((\text{age}; 32.6 \pm 9.4, \text{height}; 177.2 \pm 8.3, \text{weight}; 76.0 \pm 9.9, \text{years of experience with clean}; 1.6 \pm 1.2)\) completed the study and were included in the analysis of the result (table 1).

Table 1. Subject characteristics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>All, n=17 Mean ± SD</th>
<th>Men, n=9 Mean ± SD</th>
<th>Women, n=8 Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years.</td>
<td>32.6 ± 9.4</td>
<td>35.0 ± 10.1</td>
<td>30.0 ± 8.2</td>
</tr>
<tr>
<td>Height, cm.</td>
<td>177.2 ± 8.3</td>
<td>183.4 ± 3.3</td>
<td>170.1 ± 6.2</td>
</tr>
<tr>
<td>Weight, kg.</td>
<td>76.0 ± 9.9</td>
<td>83.4 ± 5.7</td>
<td>67.7 ± 6.2</td>
</tr>
<tr>
<td>Experience clean, years.</td>
<td>1.6 ± 1.2</td>
<td>1.8 ± 1.6</td>
<td>1.3 ± 0.5</td>
</tr>
</tbody>
</table>

Table 2 shows the result in 1RM in clean, maximal jump height in CMJ and SJ and the difference in mean (independent t-test) between men and women. The result showed that men lifted 91.8±17.8 kg and women lifted 60.6±11.3 kg in clean which represent a mean difference of 31.2kg \((p=0.001)\). Maximal jump height in CMJ was 42.2±5.7 cm in men and 31.3±4.7 cm in women that represent a mean difference of 10.9cm \((p=0.001)\). Maximal jump height in SJ was 37.5±4.2 cm in men and 29.9±4.2 cm in women that represent a mean difference of 7.6 cm \((p=0.002)\).
Table 2. Result in 1RM in clean, maximal jump height in CMJ, SJ and comparison of means (independent t-test) between men and women.

<table>
<thead>
<tr>
<th>Variable</th>
<th>All, n=17 Mean ± SD</th>
<th>Men, n=9 Mean ± SD</th>
<th>Women, n=8 Mean ± SD</th>
<th>Mean difference</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM in clean, kg.</td>
<td>77.2 ± 21.6</td>
<td>91.8 ± 17.8</td>
<td>60.6 ± 11.3</td>
<td>31.2</td>
<td>0.001</td>
</tr>
<tr>
<td>CMJ, cm.</td>
<td>37.1 ± 7.6</td>
<td>42.2 ± 5.7</td>
<td>31.3 ± 4.7</td>
<td>10.9</td>
<td>0.001</td>
</tr>
<tr>
<td>SJ, cm.</td>
<td>33.9 ± 5.7</td>
<td>37.5 ± 4.2</td>
<td>29.9 ± 4.2</td>
<td>7.6</td>
<td>0.002</td>
</tr>
</tbody>
</table>

The result showed a very strong significant correlation ($r=0.77$, $r^2=0.59$ and $p=0.000$) between CMJ height and 1RM in clean in the combined group of men and women (figure 1). Between 1RM in clean and maximal jump height in SJ the result also shows a very strong significant correlation ($r=0.72$, $r^2=0.52$ and $p=0.001$) in the combined group of men and women (figure 2). In figure three the result are in the range of a moderate to strong non-significant correlation between 1RM in clean and maximal jump height in CMJ in men ($r=0.45$, $r^2=0.20$ and $p=0.23$) and women ($r=0.59$, $r^2=0.35$ and $p=0.12$). In figure four the result also is in the range between a moderate and strong non significant correlation between 1RM in clean and maximal jump height in SJ in men ($r=0.40$, $r^2=0.16$ and $p=0.320$) and women ($r=0.46$, $r^2=0.22$ and $p=0.209$).
Figure 1. Pearson's correlation between 1RM in clean and maximal CMJ height in the combined group of men and women. The result showed a very strong significant correlation ($r=0.77$, $r^2=0.59$ and $p=0.000$).

Figure 2. Pearson's correlation between 1RM in clean and maximal jump height in clean in men and women. The result showed a very strong significant correlation ($r=0.72$, $r^2=0.52$ and $p=0.001$).
Figure 3. Pearson's correlation between 1 RM in clean and maximal CMJ height separately in men and women. The result shows non-significant moderate to strong correlations between 1RM in clean and maximal jump height in CMJ in men ($r=0.45$, $r^2=0.20$ and $p=0.23$) and women ($r=0.59$, $r^2=0.35$ and $p=0.12$).

Figure 4. Pearson's correlation between 1RM in clean and maximal jump height in SJ separately in men and women. The result shows non-significant correlations in the range between moderate and strong correlation between 1RM in clean and maximal
jump height in SJ in men \( (r=0.40, r^2=0.16\) and \( p=0.320 \)\) and women \( (r=0.46, r^2=0.22\) and \( p=0.209 \)\).

**Discussion**

The result shows that there was a very strong significant correlation between 1RM in clean and maximal jump height in CMJ and SJ in the combined group of men and women (figure 1 and 2). When separating men and women the result was in the range between a moderate to strong non-significant correlation between 1RM in clean and maximal jump height in CMJ and SJ (figure 3 and 4).

**Result discussion**

**Pearson’s correlation between 1RM in clean and vertical jump height**

The present study shows a very strong statistically significant correlation between 1RM in clean and maximal jump height in CMJ \( (r=0.77, p=0.000) \) and SJ \( (r=0.72, p=0.001) \) in the combined group of men and women. Previous research by Carlock et al (2004) investigated the relationship between vertical jump height and weightlifting ability in weightlifting men and women. The researchers found a strong correlation between 1RM in clean with CMJ height \( (r=0.59) \) and a slightly stronger correlation between clean & jerk and SJ height \( (r=0.64) \). The previous correlations was done in a combined group of men and women with a large sample size \( (n=64) \). In the study by Carlock et al (2004) the correlation between clean & jerk and SJ \( (r=0.64) \) was higher than the correlation found between clean & jerk and CMJ \( (r=0.59) \). In the present study the result was opposite and the correlation between 1RM in clean and maximal CMJ height \( (r=077) \) was higher than the correlation found in maximal SJ height \( (r=0.72) \).

The present study investigated if the result was equal in men and women and the result showed moderate to strong correlations between 1RM in clean and maximal jump height in CMJ in men \( (r=0.45) \) and in women \( (r=0.59) \). Findings from the present study shows a result in the range between a moderate to a strong correlation between 1RM in clean and maximal jump height in SJ in men \( (r=0.40) \) and women \( (r=0.46) \). However, Carlock et al (2004) also separated men and women and correlated peak power from vertical jump with clean & jerk. The result showed a much stronger correlation (a nearly
perfect correlation in men and a very strong correlation in women) between clean & jerk and peak power from CMJ in men (r=0.90) and in women (r=0.76). The correlation between clean & jerk with peak power from SJ was nearly perfect in men (r=0.90) and very strong in women (r=0.76) and were identical to correlation found between clean & jerk and peak power from CMJ (Carlock et al, 2004).

Clean & jerk is one of the two competitive exercises in weightlifting but exercises such as power clean and hang clean are used as a complementary exercises (Storey & Smith, 2012). Previous research by Hori et al (2008) investigated the relationship between hang power clean and CMJ height. The relationship between 1RM in hang power clean and CMJ showed a correlation between moderate and strong (r=0.41) in Australian rule football players (Hori et al, 2008). In the present study the result showed a moderate to strong correlation between 1RM in clean and maximal jump height in CMJ in men (r=0.46) and women (r=0.59). The result in women is in the higher range of a strong correlation meanwhile the correlation for men is lower (between moderate and strong) and similar to the result found in the study by Hori et al (2008).

The present study removed the jerk and correlated maximal jump height in CMJ and SJ with 1RM in clean in contrast to the study by Carlock et al (2004) who investigated the whole movement clean & jerk with maximal jump height and peak power from vertical jump height. Storey & Smith (2012) describes that the jerk requires the lifter to dip down by making flexion in hip and knee and then accelerate the barbell vertically over the head on straight arms. The vertically displacement of the barbell exposes the lifter to downward forces equivalent to 17 times body weight (Storey & Smith, 2012). Removing the jerk from clean probably allowed heavier load because the barbell did not have to be lifted over the athletes' head and supported on straight arms. Clean could therefore give a better indication of maximal strength and power in the lower extremity. Removing the jerk could therefore be a factor affecting the result in the present study compared to the result found in the study by Carlock et al (2004). Another factor that could have affected the result in the present study is the influence of SSC. In Weightlifting the SSC is used before the jerk is conducted (Storey & Smith, 2012) and could therefore have had a greater impact on clean performance when removing the jerk.
Difference between countermovement and squat jump

CMJ height is usually higher than SJ height and can depend on many factors (Maarten et al, 1996). One explanation could be that SJ is not used very often and are therefore hard to control. A second explanation is that the muscles are not able to produce enough force before the concentric phase starts. A third explanation could be that SJ do not store as much elastic energy compared to CMJ (Maarten et al, 1996). Either one of these factors described could possibly help explain the result found in the present study. In the present study the correlation between 1RM in clean and maximal jump height in CMJ was higher than the correlation found between 1RM in clean and maximal jump height in SJ in both the combined group and men and women separately (figure 1, 2, 3 and 4). However, Carlock et al (2004) found the opposite result that clean & jerk had a stronger correlation with SJ then clean & jerk and CMJ height in the combined group of men and women. Another factor that could have affected the result in the present study is that one woman performed a higher SJ than CMJ and this probably affected the strength of the correlation between 1RM in clean and maximal jump height in CMJ and SJ.

Method discussion

Subjects

Crossfit athletes were chosen because they incorporate weightlifting and clean in their training (Smith, Sommer, Starkoff, & Devor, 2013) and were therefore experienced with clean and also because they were available. The original thought was to only recruit Crossfit athletes and therefore have inclusion criteria to recruit men and women from the same sport. However, because of low number of subject the recruitment was extended to athletes who were experienced with the exercise clean. A larger sample size was more valuable than a homogenous group only including crossfit athletes. The main purpose with the study was to investigate if there was a correlation between two variables and not investigate the performance in Crossfit athletes.

One factor that could have influenced the significant level is the number of participants (Thomas et al, 2011). Thomas et al (2011) describes that a low sample size requires a high correlation coefficient to be significant. The combined group of men and women included nine med and eight women (n=17) and when separating this group the sample
size was lowered and the correlation coefficient would therefore needed to be higher to get an statistical significance.

**1RM test in clean**

The procedure of the 1RM test is from a previous study by Faigenbaum et al (2012) who investigate the reliability of the 1RM test in power clean. The result showed an intra class correlation coefficient (ICC) of 98 % that indicate a high reliability between the two test sessions (Faigenbaum, et al., 2012). Another reason for choosing the procedure by Faigenbaum et al (2012) is that the test was made for weightlifting exercises. There a many 1RM test described in the literature but the procedure is often applied to exercises such as bench press and squat (Baechle & Earle, 2008). Power clean does not include jerk in the movement (Faigenbaum, et al., 2012) and therefore similar to clean in the execution. Therefore the procedure of 1RM test by Faigenbaum et al (2012) was considered appropriate for 1RM test in clean.

**CMJ and SJ test**

The procedure of CMJ test was taken from Moir et al (2008) that investigated the intersession reliability in maximal CMJ height during four sessions. The result showed an ICC between 0.87-0.94 between the different sessions and indicates good reliability. The dynamic warm up was also by Moir et al (2008) and was therefore suited for the CMJ and SJ test in the present study. However, Moir et al (2008) did not describe the appropriate knee angle during the CMJ and where to place hands during the jumps. Complementary information about appropriate hand placement and knee angles was found in the book by Bellardini et al (2009). Hands were placed on the hips and a knee flexion of 90 degrees during both CMJ and SJ and this procedure was therefore used in the present study (Bellardini, Henriksson, & Tonkonogi, 2009). Knee flexion was observed by the same researcher to achieve as high consistency as possible. However, to achieve higher consistency in knee flexion during jump performance a 2D video camera could have recorded the jump. Then an analysis could have been done to calculate the exact knee angles during the CMJ and SJ test. In future research a 2D analysis program is recommended to be able to analyze and achieve high consistency in knee flexion in vertical jump performance.

The test sessions was performed at three different locations, two Crossfit boxes and one
gym. The subjects did both test at their Crossfit box and gym they trained at. This method was chosen because the subject should be used to the environment.

**Conclusion**

Findings from this study show that there is a very strong significant correlation between 1RM in clean and maximal jump height in CMJ and SJ in the combined group of men and women. When separating men and women the result was in the range of a moderate to strong correlation but not statistically significant. More research is therefore needed in this area and a larger sample size is recommended to further investigate if the correlation is equal between 1RM in clean and maximal jump height in CMJ and SJ in men and women.
References


Appendices

1. Informerat samtycke

Bakgrund och syfte

Hej!


Inklusionskriterier

- Ha tränat frivändningar minst 6 månader.
- Skadefri dem senaste 6 månaderna.
- Kvinnor och män från samma idrott.

Förfrågan om deltagande

Du som läser detta är tillfrågad om du vill vara deltagare i studien.

Studiens upplägg

Studien kommer bestå av två stycken tillfällen. Första tillfället kommer vara ett 1RM-test i frivändning. Vid andra testtillfället kommer vertikal hopptest att genomföras.

Risker

- Träningsvärk.
- Ömhet vid främre delen av axlarna och nyckelbenet från frivändningarna.
- Om testpersonen känner obehag eller smärta vid vertikalhoppen eller frivändningarna ska detta meddelas till testledaren och mätningarna genast avbrytas.

Fördelar

- Få reda på sitt 1RM i frivändning.
- Få reda på sin maximala hopphöjd.
- Få en indikation på om frivändning och hopphöjd har ett starkt samband.

Etiska och sociala aspekter

Testpersonerna har alltid möjlighet att ställa frågor om studien. Alla deltagare kommer
att behandlas anonymt. Alla resultat kommer att presenteras i form av medelvärde på gruppnivå och det finns inga möjligheter att spåra individer utifrån det presenterade resultatet. Testpersonerna har alla rättigheter att avbryta deltagandet i studien och all information kommer då att uteslutas och tas bort från. All insamlad data kommer att sparas på ett externt USB och ingen information kommer att sparas på testledarens personliga dator. När studien är klar och godkänd kommer den att publiceras på databasen DiVa på Halmstad Högskola.

Med vänliga hälsningar

Frida Elmdahl

Ansvariga
Forskningshuvudman: Halmstad Högskolan
Handledare: Hanneke Boon.
E-post: hanneke.boon@hh.se

Testledare och författare till studien:
Frida Elmdahl
Telefonnummer: 073-420 35 65.
E-post: fridaelmdahl@gmail.com
2. Samtycke till deltagande i forskningsstudie
Nedan ger du ditt samtycke till att medverka i forskningsstudien där jag undersöker sambandet mellan 1RM i clean med maximal vertikal hopphöjd. Läs igenom dokumentet noggrant och ge ditt samtycke genom att skriva dig namnteckning i slutet av dokumentet.

- Jag har tagit del av syftet och upplägget av studien.
- Jag har fått ställa frågor om studien och fått mina frågor besvarade.
- Jag vet vem som genomför och är ansvarig för studien.
- Jag deltar frivilligt i studien.
- Jag är medveten om att jag när som helst kan avbryta deltagandet i studien utan att behöva förklara situationen.
- Jag är medveten om att all information kommer att behandlas anonymt.
- Jag ger mitt medgivande till Halmstad Högskola att bearbeta och lagra information som är insamlad vid studien.

_________________________  _________________________
Deltagarens underskrift             Ort & Datum

_________________________
Deltagarens namnteckning

Tack för ditt deltagande!
Frida Elmdahl