# Effects of single- and multi joint ballistic resistance training upon vertical jump performance in well-trained sport science students.

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## Sammendrag

Hensikten med denne studien var å utforske to ulike treningsregimer med ballistisk styrketrening, med og uten mulighet til å utnytte koordinasjonen mellom kne- og ankelstrekker. Dette med hensyn til prestasjon i maksimalt vertikalt hopp. Endringer i 1 repetisjon maksimum (RM) i knebøy, i tillegg til endringer i ”power”, kraft og hastighet i vertikalt hopp, ble brukt for å predikere prestasjonene i maksimalt vertikalt hopp. Tretten godt trente idrettsstudenter ble delt i to grupper for en 5 ukers treningsintervensjon. En gruppe trente hofte-, kne- og ankelstrekker samtidig (MJG), mens den andre gruppen trente hofte- og knestrekker samtidig, men ankelstrekker isolert (SJG). Begge grupper trente tre ganger i uken. Etter trening i 5 uker hadde MJG en signifikant større økning i maksimalt vertikalt hopp enn SJG ($p<0.05$), selv om begge gruppene hadde økning i 1 RM knebøy (+21±14 kg, $p<0.0004$). Flerleddstrening i MJG og forandringer i topphastighet i hopptesten, var de to faktorene som predikerte 64 % av økningen i maksimalt vertikalt hopp ($p<0.003$). Ut fra resultatene i denne undersøkelsen konkluderes det med at MJG var overlegen SJG når det gjaldt økning i maksimalt vertikalt hopp etter 5 uker med ballistisk styrketrening.

**Nøkkelord:** Biartikulære muskler; hastighet; power; spesifikk trening; treningsintervensjon.

## Abstract

The intention of the present study was to explore the effects of two different ballistic resistance training regimes, with and without the possibility to utilize the proximal to distal coordination between knee and ankle, upon maximal vertical jump performance. Changes in 1 repetition maximum (RM) squat performance, as well as power, force and velocity variables during the vertical jump, were used to predict maximal vertical jump performance. Thirteen well-trained sport science students were divided into two groups for a 5 week training study. One group (MJG) exercised ballistic squat with plantar flexion in one movement, while the other group (SJG) exercised ballistic squat and plantar flexion separately, three times per week. After training in 5 weeks, the MJG improved maximal vertical jump performance significantly more than the SJG ($p<0.05$), although both groups increased 1 RM in squat (+21±14 kg, $p<0.0004$). Multi joint training and changes in peak velocity together explained 64% of changes in vertical jump height performance ($p<0.003$). Multi joint training was superior to single joint training in improving the maximal vertical jump performance after 5 weeks of ballistic training.

**Key words:** Biarticular; power; training intervention; training specificity; velocity.

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## Introduction

The ability to produce a high work rate (power) is important in various sports. In order to achieve this, resistance training has become an integral component of the physical preparation for enhancement of sports performance. A key issue for this type of training is to achieve the greatest gains in performance for a given amount of work effort. Thus, strength and conditioning exercises often are designed to mirror the duration, speed, intensity, resistance, and coordination pattern of the movements. Central to the concept of transfer of strength and power training is the well accepted training principle of specificity, which states that adaptations are specific to the nature of the training stress (Young, 2006). In sports movement the muscles are seldom required to generate force in isolation. Therefore, the amount of force that can be generated in a particular movement context is not only determined by the efficiency of single muscles, but also by the effectiveness of muscular coordination (Bobbert & van Soest, 1994; Carroll, Riek, & Carson, 2001; Nagano & Gerritsen, 2001; Rutherford & Jones, 1986). One way to enhance the effectiveness of muscle coordination is through motor learning, where individuals may learn to produce the specific pattern of muscle recruitment that is associated with optimal performance of the task.

Resistance training has been used as a way to augment muscular hypertrophy (Wernbom, Augustsson, & Thomeé, 2007), neural factors in strength (Sale, 1988), rate of force production, and velocity of movements (Behm & Sale, 1993; Hatfield, et al., 2006). One acknowledged characteristic of muscular performance is the force – velocity relationship, demonstrating the interactions between muscular contraction velocity and the magnitude of the muscles force of contraction. Most movements in sports occur to quickly for muscles to produce maximal force. Therefore, to achieve a more powerful muscular contraction in a shorter time, it is important to increase the muscles rate of force production. In the classic concentric force – velocity curve of Hill, the force decreases when the velocity increases. Since power is the product of force and velocity, power training is intimately related to the performance in sports tasks (Fleck & Kraemer, 2004). Power training is commonly performed by use of loads corresponding to 30 – 45% of 1 repetition maximum (RM), which is in the range of peak mechanical power (Fleck & Kraemer, 2004). Power in isolated plantar flexion is about 200 W, but increasing almost to 2000W in one-legged jump (van Soest, Roebroeck, Bobbert, Huijing, & van Ingen Schenau, 1985), and 2000 – 4000 W during a maximal vertical jump (Bobbert & van Ingen Schenau, 1988; van Soest, Roebroeck, Bobbert, Huijing, & van Ingen Schenau, 1985).

When performing maximal vertical jump the initiation of joint movements has a proximal to distal sequence (Bobbert & van Ingen Schenau, 1988). These movements start with hip extension, followed by knee extension and at last a powerful plantar flexion in the ankle before toe off (Jacobs, Bobbert, & Ingen Schenau, 1993). Transportation of power from knee to ankle via the biarticular musculus (m.) gastrocnemius might explain some of the differences in ankle power in the isolated plantar flexion in proportion to ankle power in maximal vertical jump (Bobbert & van Ingen Schenau, 1988). The transportation of power mechanism ensures that energy liberated from hip- and knee extensors (from hip to knee via the biarticular m. rectus femoris, and from knee to ankle via m. gastrocnemius) is not used for further increase in rotational energy of upper and lower leg, but contributes to plantar flexion (Bobbert, Huijing, & Ingen Schenau, 1986; Gregoire, Veeger, Huijing, & van Ingen Schenau, 1984). The transfer action of m. gastrocnemius from knee to ankle joint was demonstrated for jumping (Bobbert, Huijing, & Ingen Schenau, 1986). As a consequence of this, they computed that 25% of the total amount of work done about the ankle is due to a transfer action by m. gastrocnemius from knee to ankle joint. Because the actual performance in vertical jumping also depends on the adjusting control to muscle properties, Bobbert and van Soest (1994) assume that the coordination between the knee extensors and plantar flexors might be one of the main reasons for improvement in maximal vertical jump. They found in simulation study that if muscles are strengthened while the muscle control remains unchanged, jump height rather decreases than increases. Several authors agree with the statement that the role of the biarticular m. gastrocnemius is important for performance in maximal vertical jump (Bobbert, Huijing, & Ingen Schenau, 1986; Gregoire, Veeger, Huijing, & van Ingen Schenau, 1984; Pandy & Zajac, 1991), but the muscular effects were only studied in simulation models. A recent study (Leirdal, Roeleveld, & Ettema, 2008) compared different training regimes with and without the possibility to exploit the biarticular role of m. gastrocnemius, but failed to find any improvement in vertical jumping. Thus, they hypothesized that the lack of improvement in vertical jump performance was caused by a long deceleration phase at the end of the training exercise, which is associated with that the high velocity when training with light loads makes the anatomical and geometrical constraints large (Fleck & Kraemer, 2004; Newton, Kraemer, Häkkinen, Humphries, & Murphy, 1996;

van Ingen Schenau, 1989). By search in literature we were not able to find any publication with a training intervention supporting the findings from the simulation studies.

Therefore, the purpose of this study was to explore the effects of two different ballistic training regimes upon maximal vertical jump performance. One group exercised ballistic squat with plantar flexion in one movement, while the other group exercised ballistic squat and plantar flexion separately. Also, we measured 1RM squat performance, as well as power, force and velocity variables during the vertical jump. Changes in these variables were used to predict maximal vertical jump performance. It is hypothesized that the group who exercise ballistic jump squat with plantar flexion in one movement will be superior compared to the group exercising ballistic jump squat and plantar flexion separately when looking into the improvement of vertical jump.

## Material and Methods

### Subjects

Seventeen well-trained sport science students (12 males, 5 females) aged 18 to 22 years, were recruited after local advertisement and volunteered to participate in the study. The subjects were allocated to either the multi joint (MJG) or the single joint (SJG) training group. The groups were matched in regard to their pretest performance in maximal vertical jump. Since the aim the study was to compare two different training regimes, there was no control group. At the start of the training period there were 9 subjects in the MJG and 8 subjects in the SJG. Four subjects withdraw from the study, two from each group, leaving 7 subjects in MJG, and 6 subjects in SJG. Therefore, data from 13 subjects were used for further analysis. The physical characteristics of the 13 subjects and results from the pretests are presented in Table 1. Full advice about possible risks and discomfort was given to the subjects and all the subjects gave their written informed consent to participate. The study was conducted according to declaration of Helsinki and approved by the Regional Ethics Committee for Medical Research Ethics.

**Table 1.** Physical characteristics of 13 sport science students before 5 week of either Multi joint or Single Joint resistance training (mean and SD).

| Variable | MJG (n = 7) | SJG (n = 6) |
|---|---|---|
| Age (years) | 20.5 ± 1.9 | 20.1 ± 1.4 |
| Body mass (kg) | 68.4 ± 14.1 | 71.8 ± 10.8 |
| Height (cm) | 173.4 ± 10.8 | 177.6 ± 9.3 |
| MVJ (cm) | 37.9 ± 5.6 | 41.1 ± 4.8 |
| 1 RM squat*(kg) | 119.3 ± 36.8 | 130.0 ± 30.0 |

There were no significant differences between the multi joint and the single joint group for the displayed characteristics at significance level 0.05. 1RM= One repetition maximum. MVJ = Maximal vertical jump. **Squat was performed with the lowest point at 90° knee angle.*

## Experimental design

The experimental design was a 5 week pre- to post design with two groups. The training period consisted of 5 week of ballistic resistance training with use of free weights, and 3 sessions per week. The subjects accepted the criteria of no resistance training of the legs besides the study related training during intervention. Guidance and instructions were given all participants before they entered into the training period, and once a week during the intervention period. All subjects kept their own training logs. If any of the subjects completed less than 10 of the planned 15 strength training sessions, or if they suffered from illness or injuries lasting more than 1 week during the intervention period, they were excluded from the statistical analyses.

## Training procedures

***Multi Joint group (MJG):*** The MJG exercised ballistic jump squat with plantar flexion in one movement. The load was 40% of the 1 RM measured at the pretest. The MJG protocol was 6 reps in 5 sets, with 3 minute rest period between each set. Subjects were instructed to have a controlled eccentric movement down to knee angle of 90°, followed by a maximal effort in the concentric movement (Figure 1). To avoid problem with a long deceleration phase the subjects were instructed to accelerate throughout the movement to the point of take off (end of plantar flexion).

***Single joint group, (SJG):*** The SJG exercised ballistic jump squat and plantar flexion separately. After 6 repetitions of squats the subjects performed 6 plantar flexions with the same load before the 3 minutes rest period. The number of sets, load and repetitions equaled the MJGs training. However, the explosive squats in SJG were performed from a wooden board with a height of 4 – 5 cm above the floor, and half of the feet (from medial metatarsus to the toe) outside the wooden board and in the air (Figure 2). Thus, any load on the plantar flexors in this exercise was prevented. SJG were instructed to push hard from the heels in the squat movement. This group were instructed to accelerate throughout the movement to the point of take off (heels leaving the wooden board), and to land at the floor right in front of the wooden board.

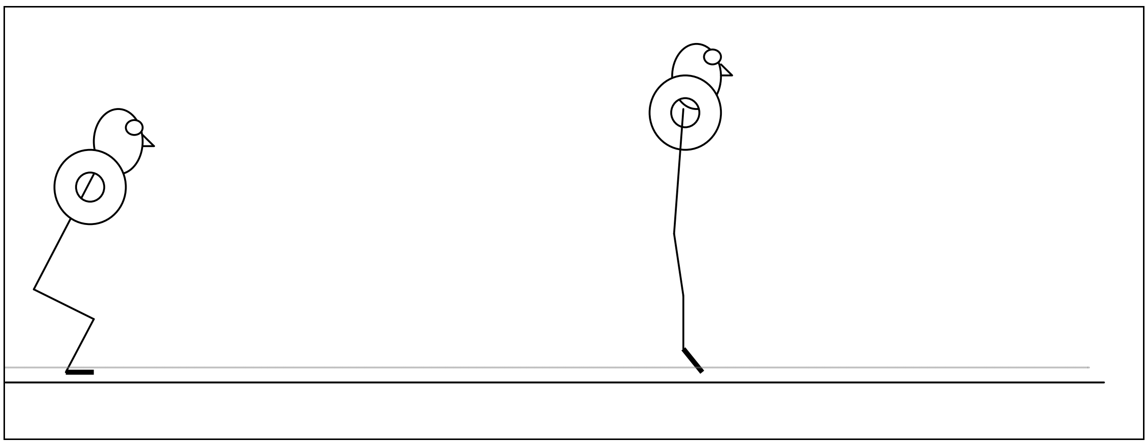

***Figure 1:*** *Illustration of squat training exercise for the MJG. Subjects were instructed to have a controlled eccentric movement down to knee angle of 90°, followed by a maximal effort in the concentric movement. The subjects were told to accelerate throughout the movement to the point of take off (end of plantar flexion).*

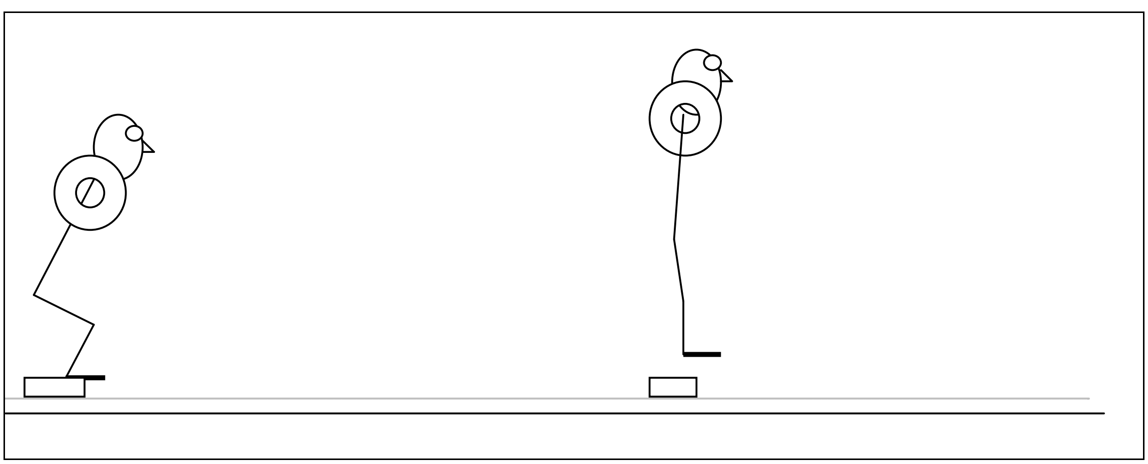

***Figure 2****: The explosive squats in SJG were performed from a wooden board with a height of 4 – 5 cm above the floor, and half of the feet outside the wooden board and in the air. Subjects were instructed to push hard from the heels in the squat movement. This group were also told to accelerate throughout the movement to the point of take off (heels leaving the wooden board), and to land at the floor right in front of the wooden board.*

**Testing procedures**

***Maximal vertical jump:*** Pretest was done in one day for both groups. Previous to testing, the participants were familiarized with the testing protocol, and performed practice jumps with the experimental equipment. Before testing, each participant had a warm up period of cycling or running in approximately 15 minutes with an intensity of 70% of maximum heart rate (HR) the first 10 minutes and 80% of maximum HR the last five minutes.

Each test trial was performed from a standing start position, followed by a controlled descending phase to a knee angle of 90°. The initial angle was measured with a goniometer/ angle iron (Hultafors, Sweden). During the test, the participants were instructed to hold their hands on the hip and to sit for 2 seconds at knee joint angle of 90°. No counter movement was allowed with any body segment. Each participant had four test trials, with a rest period of three minutes between each test. The average of the two highest vertical jumps was chosen to be maximal vertical jump height. Jump height was measured from the vertical displacement of the linear encoder fastened to a power - lifting belt on the subjects. For this test MuscleLab 4010 with a linear encoder was used to measure motion in function of time (Ergo test Technology, Langesund, Norway), with a sampling rate at 100Hz. The system has been validated, showing a maximal error less than 0.3%, 0.9% and 1.2% for force, velocity and power, respectively (Bosco, et al., 1995). Thus, the system was found to be suitable for evaluation of athletes performing specific skills.

***1 RM squat performance:*** 1 RM was assessed by determining the maximum amount of weight that could be lifted in squat. Before testing the subjects had a warm up period of running or cycling of approximately 10 minutes with an intensity corresponding to 70 % of maximum HR. The subjects tested out the exercises with light weights before the testing began. Subjects performed multiple single repetitions with increasing load, and with 3 minutes rest between each attempt. Maximum strength was determined by the highest weight the subject’s were able to perform one single repetition. Post test was performed with the same weights as pretest until maximum pretest load was achieved, after this the load was increased to find the post test value of 1 RM.

## Data handling and calculations

Muscle Lab 4010 calculated velocity by equation $v = \Delta d/\Delta t$ *(m/s)*, acceleration by equation $a = \Delta v/\Delta t$ *(m/s²)*, force by equation $F = m*g + m*a$ *(N)* and power by equation $P = F * v$ *(W)* (Abbreviations: *v=velocity, d=distance, t=time, a=acceleration, F=force, P=power, g=gravity acceleration, m=meter, s=second, N=Newton and W=Watt).* Maximal vertical jump height was calculated as the difference between the maximum extension measured by the encoder during the jump and the extension of the encoder in standing position (Appendix 1). If there was a horizontal movement in the jump, the maximal jump height was calculated by trigonometry. Measurement of time to peak power, time to peak force and time to peak velocity was calculated from the position when the subjects had 90° knee angle during the maximal vertical jump test. Start of the measurements were considered to be when there were three successive increasing positive measurements of velocity higher than 0.010 m/s, followed by increase in measured position until maximum height was achieved (Appendix 2.). End of the measurements in time to peak power (P), force (F) and velocity (V) were the highest measured values in P, F and V in the concentric phase of the jump (Appendix 2.). Total body mass was used in the calculation of peak P and peak F in maximal vertical jump. MuscleLab 4010 (Ergo test Technology, Langesund, Norway) and Microsoft Excel (Version 2007; Microsoft Corporation, USA) were used in all calculations.

## Statistical analysis

Statistical analyses were performed using the SPSS software, version 15.0 (Statistical Package for Social Science, Chicago, IL, USA). Results are presented as mean ± SD unless otherwise stated. To compare pre- and post test results within groups, paired t-tests were used. For comparison between groups independent samples t-tests were used. In all cases, $p<0.05$ was used as the level of significance in two-tailed tests. The data were tested for normality using quantile–quantile plots and Shapiro-Wilks test of normality. Backward multiple linear regressions were applied to predict pre- to posttest changes in vertical jump height. Predictors to be included in the model were chosen on the basis of significant correlation towards delta vertical jump height. For continuous variables, correlations were calculated using the Pearson's correlation test after checking for linearity and outliers. Spearman's rho was applied for dichotomous variables, i.e. training group. Variables to be included in the final model were checked for co-linearity.

## Results

### Differences in maximal vertical jump

Maximal vertical jump did not differ significantly between the groups before the experiment. After training intervention, the improvement in maximal vertical jump height differed significantly between groups, with improvement in MJG and no improvement in SJG ($p<0.05$) (Figure 3 and Table 2).

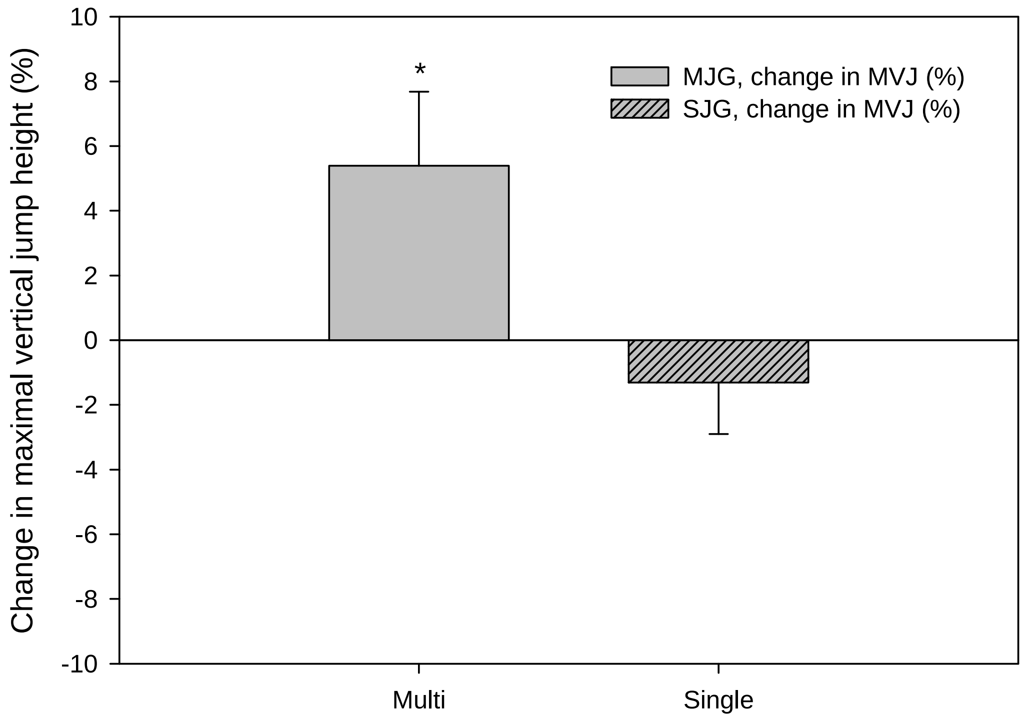


***Figure 3:*** *Percent change in maximal vertical jump performance in the two groups during 5weeks of ballistic resistance training (N = 13, mean and standard error). MVJ = maximal vertical jump; Multi = multi joint group (MJG); Single = single joint group (SJG).* * = Significant difference in change between groups; *p < 0.05.

Increased maximal vertical jump height performance during the training period, was significantly predicted by increased delta peak velocity (ß = 0.58, p = 0.008) and multi joint training (ß = -0.52, p = 0.014). These two predictors together explained 64% of change in vertical jump height performance (p = 0.002).

### 1RM squat performance

Pre- to post exercise results and characteristics for the subjects who completed the intervention period are displayed in table 2. Overall there was a 17% significant increase in the 1RM squat performance from pre- to posttest (+21±14 kg, p<0.0004). There was no change in 1RM squat performance between groups (p=0.27).

**Table 2.** Body mass, maximal vertical jump performance and 1RM squat performance in pre- and posttest for two groups of resistance trained subjects during 5 weeks of training (N = 13, mean and SD).

| Variable | SJG (n = 6) | | MJG (n = 7) | |
|---|---|---|---|---|
| | Pre | Post | Pre | Post |
| Body mass (kg) | 71.8 ± 10.8 | 71.6 ± 10.8 | 68.4 ± 14.1 | 68.7 ± 14.1 |
| [a]MVJ (cm) | 41.1 ± 4.8 | 40.6 ± 4.5 | 37.9 ± 5.6 | 39.8 ± 4.7[§*] |
| [b]1 RM squat(kg) | 130.0 ± 30.0 | 155.8 ± 34.4[§§] | 119.3 ± 36.8 | 136.4 ± 35.8[§] |

[a] = Maximal vertical jump performance.
[b] = 1repetition maximum in the squat exercise, performed with the lowest point at 90° knee angle.
[§] = Significant with-in group improvement from pre- to posttest; [§]p<0.05, [§§]p<0.01.
* = Significant difference in change between groups from pre- to posttest; *p<0.05.

### Force, power and velocity variables

Individual and groups mean pretest scores, as well as scores for changes from pre- to posttest, are displayed in Figure 4 for peak power (PP), time to peak power (TtPP), peak force (PF), time to peak force (TtPF), peak velocity (PV) and time to peak velocity (TtPV). In the MJG there was a mean increase of 243 W in PP (p = 0.04), 133 N in PF (p = 0.02) and 0.13 m/s in PV (p = 0.08). There were no significant changes in the corresponding values for the SJG. Time to peak power, time to peak force and time to peak velocity decreased in the MJG with 0.04 s (p = 0.05), 0.05 s (p = 0.03) and 0.06 s (p = 0.01), respectively. There were no significant changes in the corresponding values for the SJG. Pair wise comparisons between the MJG and SJG did not show statistical significant differences between groups from pre- to post tests in any of the 6 variables (Figure 4 A-F). However, there was a trend towards that MJG had a larger decrease in time to peak velocity (p=0.10).

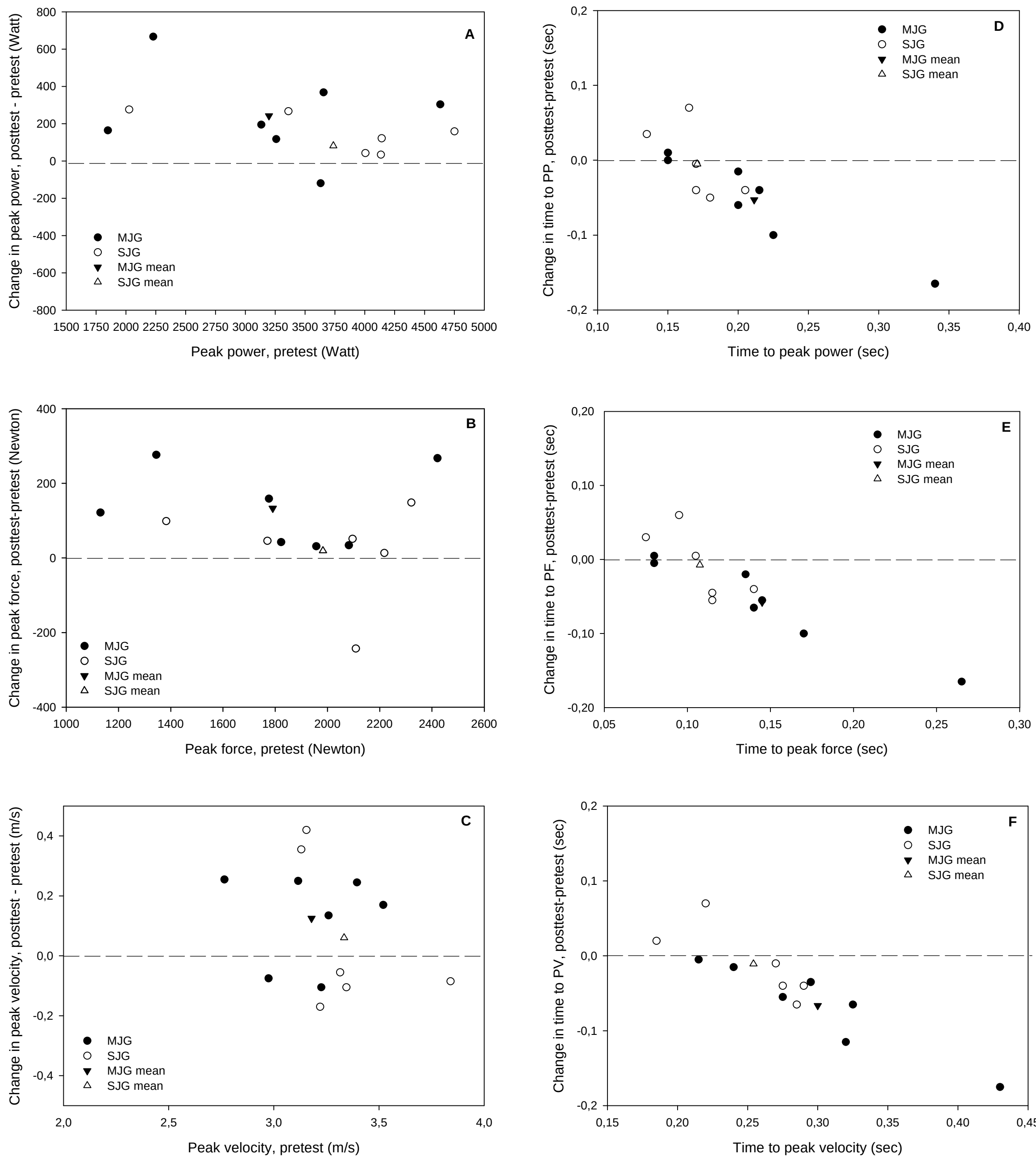


***Figure 4:*** Pretest and delta (post-pre) scores for two groups of resistance training subjects during 5 weeks of training (N = 13). The figure shows individual and group mean scores. (A) Peak power (SD = 942 ), (B) Time to peak power (SD = 0.04), (C) Peak force (SD = 395), (D) Time to peak force (SD = 0.04), (E) Peak velocity (SD = 0.26), (F) Time to peak velocity (SD = 0.05). PP= peak power, PF= peak force, PV= peak velocity.

## Discussion

The main finding in this study was that only the MJG, who trained squat jumps in combination with plantar flexion, improved their maximal vertical jump performance.

### Differences in maximal vertical jump

The present 5 weeks of ballistic resistance training resulted in significant improvement in maximal vertical jump for the MJG, but not for the SJG. Clearly, given the improvement in the training activities, the training period would have been long and intensive enough to provoke training effects in vertical jumping also for the SJG. Even though, the lack of improvement in maximal vertical jump height for the SJG are in line with findings in simulation studies who displayed that if muscles are strengthened while the control of them remains unchanged, jump height rather decreases than increases (Bobbert & van Soest, 1994; Nagano & Gerritsen, 2001). The improvement in maximal vertical jump performance for the MJG might be due to a shift in the coordination pattern, although no electromyographic measurements or movement analyses were done in order to support this suggestion. However, changes in coordination pattern were shown in a recent study (Leirdal, Roeleveld, & Ettema, 2008). Their findings indicated a more tightly coupled knee extension and plantar flexion in the multi joint group, whereas a more tightly coupled hip extension and knee extension, followed by a more isolated plantar flexion, were found in the single joint group.

In our study the SJG exercised the plantar flexors, but not the biarticular role of m. gastrocnemius with regards to the transfer of power from proximal to distal joints (Bobbert, Huijing, & Ingen Schenau, 1986; Jacobs, Bobbert, & Ingen Schenau, 1993; van Ingen Schenau, 1989) in the way MJG did. Therefore, the transfer of power from proximal to distal joints might be accomplished in the MJG, caused by a timely activation of rectus femoris and gastrocnemius before the end of push off.  The activation of gastrocnemius prior to the end of push off, may transfer power generated by the knee extensors (Jacobs, Bobbert, & Ingen Schenau, 1993). This was demonstrated in jumping by Bobbert et al. (1986). The SJG inability to exercise the coordination between the knee extensors and plantar flexors might be the main reason to the presented difference in the change in maximal vertical jump between the groups, because the actual performance in vertical jumping relies crucially on the tuning control to muscle properties (Bobbert & van Soest, 1994). This is also in line with other studies indicating that increases in maximal vertical jump performance are not exclusively dependent on the muscle - force - generating properties, and that coordination plays an important role (Bobbert & van Ingen Schenau, 1988; Gregoire, Veeger, Huijing, & van Ingen Schenau, 1984).

**1RM squat performance**

The increase in 1 RM squat for the subjects shows a clear effect for the squat training exercise during the study. Admittedly, our study does not answer whether these improvements are due to changes within the muscles and its force – velocity characteristics or within the nervous system and the altering of the recruitment pattern. However, Moritani and deVries (1979) have demonstrated that the neural factors dominate in strength development at the three first weeks of training. At least a part of the 1 RM increase might be due to an increased ability to coordinate other muscle groups involved in the movement, such as those used to stabilize the body (Rutherford & Jones, 1986). The movement in the 1 RM test situation is very similar to the training exercise for SJG with reflection to coordination patterns, and could be one of the explanation of why SJG increased 1 RM, but not maximal vertical jump (Bobbert & van Soest, 1994). Therefore, the SJG in the current study may have increased their muscle strength in their training exercise, but require further movement specific training in jumping to transfer the improvement in strength to enhanced vertical jump performance.

Not surprisingly there was no difference in body weight during the training period. The time of muscle activation is usually so short, although neural activation of the trained muscle is very high during explosive type of strength training, that training induced muscular hypertrophy takes place to a slighter degree than during typical heavy resistance training (Paavolainen, Häkkinen, Hämäläinen, Nummela, & Rusko, 1999). This training period was so short that it classically is associated with neural adaptations, more than muscular hypertrophy (Fleck & Kraemer, 2004; Sale, 1988).

The exclusion criteria were not completing an average of two training sessions per week, which is considered sufficient by for not previously strength-trained subjects to significantly increase strength (Kraemer & Ratamess, 2004). The training load of 40% of 1RM is in the range classically associated with peak mechanical power (Fleck and Kraemer, 2004). The high velocity when training with this load makes the anatomical and geometrical constraints in the knee joint large (van Ingen Schenau, 1989; Fleck and Kraemer, 2004), and it is theorized that to protect the joint from sudden deceleration at the end of the range of motion, with a decrease in agonist activation and a increase in antagonist activation, the power decreased during approximately the last 50% of the range of motion (Newton et al., 1996). This deceleration phase can be avoided in squat when performing jump squat in a ballistic manner, if the individuals accelerate throughout the motion to the point of load projection (feet leaving the ground). A study of volleyball players showed that with ballistic training, maximal force production and rate of force development are the main contributors to improved vertical jumping (Newton, Kraemer, & Häkkinen, 1999). To prevent the problem of a long deceleration phase in the training exercises, all subjects were told to jump with the weight.

**Force, power and velocity variables**

Because power during muscle actions in many sports activities is limited by time, it is advantageous to exert as much force as possible in a short period. The significant decrease in time to peak force and time to peak power during jumping for the MJG, might suggest that the training exercise was specific enough to make changes in the rate of force and power development for this group (the MJG, but not for SJG). In addition to an increased maximal vertical jump height for the MJG, the decrease in time to peak velocity indicates a faster jumping movement. It remains to elucidate whether these improvements are due to changes within the muscles and its force – velocity characteristics or within the nervous system and the altering of the recruitment pattern.

Power training has been shown to cause shifts in force–velocity curves simultaneously with quantitative changes of the neuronal input to the muscle (Komi, 1986). The improved relationship between force and velocity in MJG are shown with a higher peak power for this group. Even though it only was a trend towards higher peak velocity for MJG, velocity is also apparent in the power variable which was significant. Increased peak velocity and multi joint training was the only significant predictors of the improvement in maximal vertical jump performance. Given that both group trained in a ballistic way, but MJG with a more movement specific exercise according to maximal vertical jump, could strengthen the importance of neural adaptations and learning of coordination patterns in resistance training (Bobbert & van Soest, 1994).

### Limitations

It is not easy to confirm how the subjects exercised the times without supervisor. However, careful instructions were given how to perform the training and not to perform any strength training on the legs besides the training in the study. The development in squat strength also indicate that the subjects have taken the training seriously.

A higher percentage of females in MJG after exclusion of subjects disturbed the pretest results according to the matching based on maximal vertical jump. However, there were no significant differences between the groups after the exclusion. Additionally, a metastudy (Folland & Williams, 2007) have failed to show any difference between males and females with regard to improvements both in terms of hypertrophic and strength adaptations after heavy resistance training. Thus, it is suggested that improvement of strength training is not different between genders.

### Conclusion

The multi joint group was superior to the single joint group in improving maximal vertical jump performance after 5 weeks of ballistic training. It was hypothesized that the multi joint training in MJG would be more movement specific for vertical jumping than the isolated actions of plantar flexors in SJG. The improvement in maximal vertical jump for MJG does support this hypothesis. Type of strength training (i.e. MJG) and changes in peak velocity substantially explained changes in maximal vertical jump in this study.

## Acknowledgements

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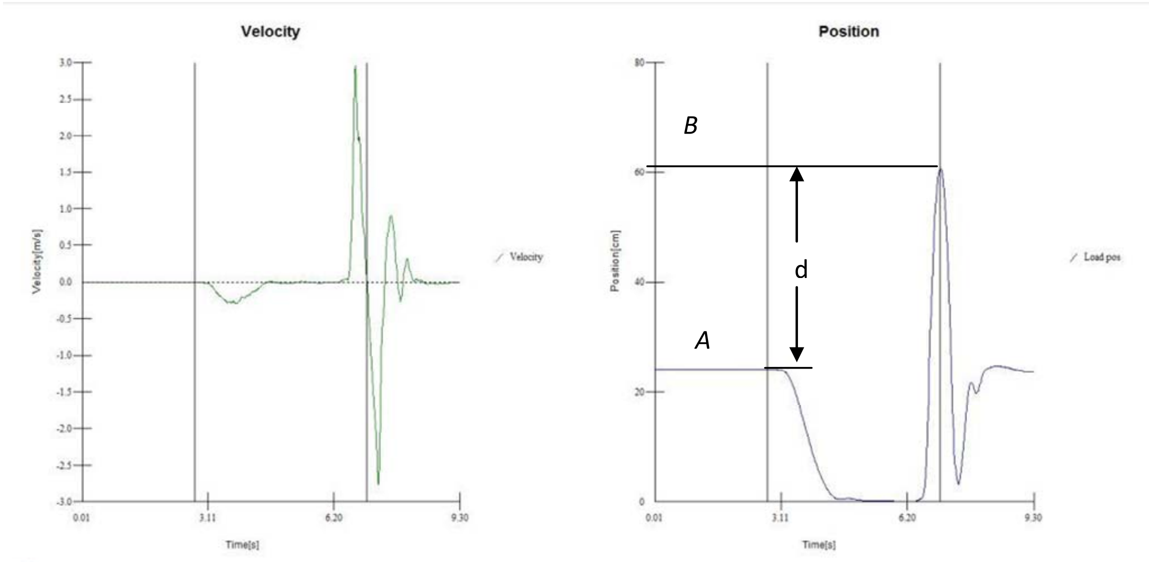
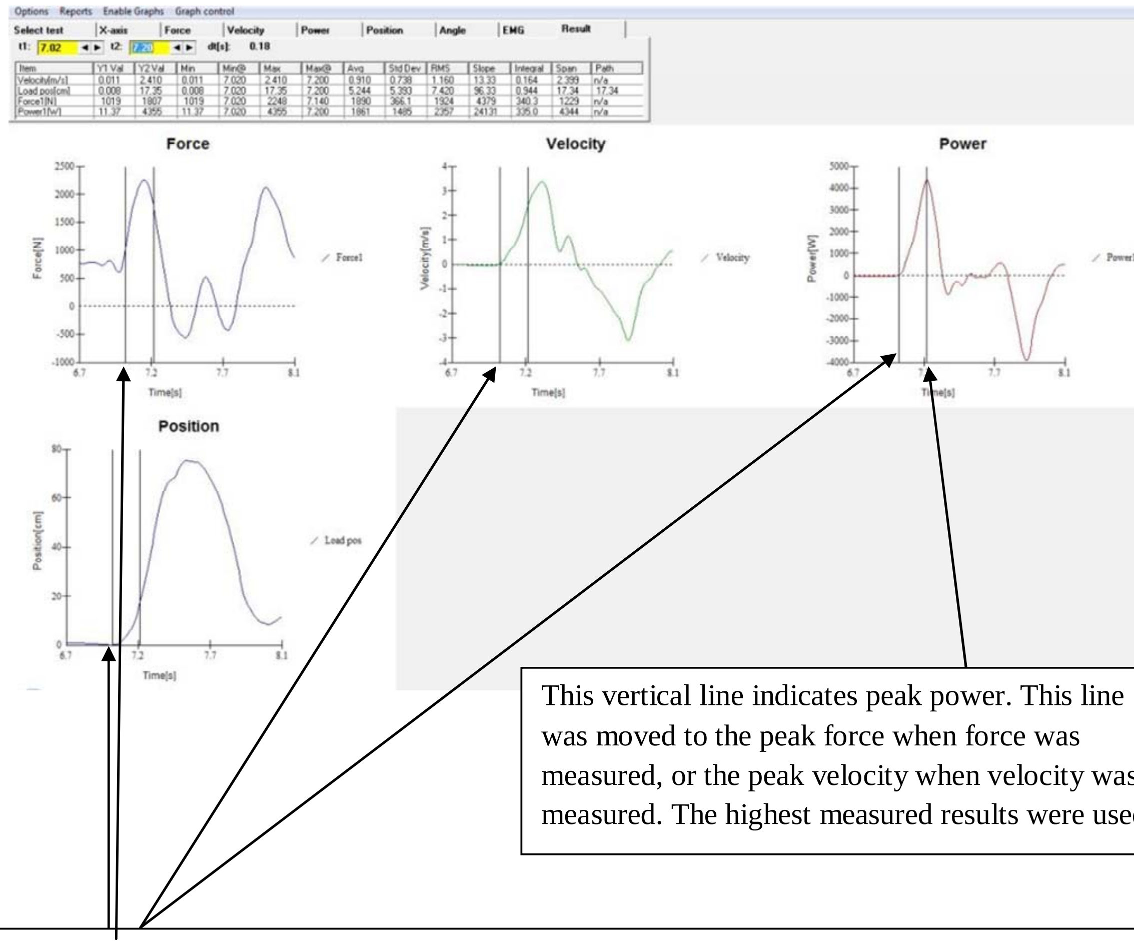
## Appendix 1:




d = maximal vertical jump measured by the difference between the maximum extension measured by the encoder during the jump and the extension of the encoder in standing position (d = *B – A)*.

# Appendix 2:




This vertical line indicates peak power. This line was moved to the peak force when force was measured, or the peak velocity when velocity was measured. The highest measured results were used.

All these vertical lines indicate start of the movement when the subjects sit in a position with 90 degree knee joint angle. Start of the measurements were considered to be when there were three successive increasing positive measurements of velocity higher than 0.010 m/s, followed by increase in measured position until maximum height was achieved.