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EFFECT OF SINGLE VS. MULTI JOINT BALLISTIC RESISTANCE TRAINING UPON VERTICAL JUMP PERFORMANCE

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ABSTRACT

The present study aimed to examine the effects of two different ballistic resistance training regimens, 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 (1-RM) squat performance, as well as power, force and velocity variables during the vertical jump were used to predict maximal vertical jump performance. Thirteen sport science students divided into two groups performed a five week training study. The multi joint group (n=7) exercised ballistic squat with plantar flexion in one movement, while the single joint group (n=6) exercised ballistic squat and plantar flexion separately, three times per week. The main finding was that only the multi joint training group improved their maximal vertical jump performance and not the single joint training group. Both groups improved in 1-RM squat weight, but for the single joint training group this improvement was not associated with an increase in maximal vertical jump performance. It was concluded that to enhance vertical jump height by training ballistic squats one should train multi joints exercises to accomplish a transfer of power from proximal to distal joints.

Keywords: *coordination, specificity, biarticular, squat*

INTRODUCTION

The ability to produce a high work rate (power) is important in various sports, and resistance training has become an integral component of the physical preparation for enhancement of sports performance. 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 [22]. In sports movements 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 [4, 7, 14, 17]. Resistance training has been used as a way to augment muscular hypertrophy [21], neural factors in strength [18], rate of force production, and velocity of movements [1, 10]. Most movements in sports occur too fast for muscles to produce maximal force. Therefore, to achieve a more powerful muscular contraction in a shorter time, it is important to increase the muscle's rate of force production. Power in isolated plantar flexion is about 200 W, but increases to almost 2000 W in one-legged jump [20], and 2000–4000 W during a maximal vertical jump [3, 20].

Initiation of joint movements has a proximal to distal sequence when performing maximal vertical jumps [3, 6]. These movements start with hip extension, followed by knee extension and at last a powerful plantar flexion in the ankle before toe off [11]. The transportation of power mechanism ensures that energy liberated from hip and knee extensors is not used for further increase in rotational energy of upper and lower leg, but contributes to plantar flexion [2, 9]. A transfer action of *m. gastrocnemius* from knee to ankle joint was demonstrated for jumping [2]. As a consequence of this, Bobbert and van Soest [4] calculated that 25% of the total amount of work done by 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 [4] assumed 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 a simulation study that if muscles are strengthened while the muscle control remains unchanged, jump height decreases rather than increases [4]. Several authors agree with the statement that the role of the biarticular *m. gastrocnemius* is important for performance in maximal vertical jump [2, 9, 16], but the muscular effects were only studied in simulation models. A recent study compared different training regimens with and without the possibility to exploit the biarticular role of *m. gastrocnemius,* but failed to find any improvement in vertical jumping [12]. 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 and that the high velocity when training with light loads makes the anatomical and geometrical constraints large [8, 15, 19]. To our best knowledge, no other studies with training intervention supporting the findings from the simulation studies were found. Therefore, the purpose of this study was to compare the effect of a training regimen of ballistic squat with plantar flexion in one movement (multi joint movement) with training ballistic squat and plantar flexion separately (single joint movement) upon maximal vertical jump performance. It is hypothesized that the group who exercised ballistic jump squat with plantar flexion in one movement would be superior in improvement of maximal vertical jump compared to the group exercising ballistic jump squat and plantar flexion separately.

MATERIALS AND METHODS

Experimental approach to the problem

To examine the effect of ballistic squats with plantar flexion in one movement (multi joint movement) with training ballistic squat and plantar flexion separately (single joint movement) upon maximal vertical jump performance, a repeated-measures design was conducted with two groups of sports science students, matched on their pre-test performance in maximal vertical jumping. The first group, the multi joint training group (n=9) trained ballistic squats with plantar flexion in one movement, while the second group, the single joint group (n=8) trained ballistic squat and plantar flexion separately. All subjects carried out three exercise sessions per week and were tested for maximal vertical jump performance, one repetition maximum (1-RM) squat performance, peak values of power, force and velocity during the maximal vertical jump test before and after a 5-week resistance training intervention period.

Subjects

Seventeen (12 males, 5 females) sport science students (age: 20.3±1.6 yrs, body mass: 70.0±10.7 kg, height: 1.74±0.09 m, 1-RM squat: 124.2±32.9 kg and maximal vertical jump: 39.4±5.2 cm), were recruited after local advertisement and volunteered to participate in the study. The subjects were randomly allocated either to the multi joint or to the single joint training group. The groups were matched in regard to their pre-test performance in maximal vertical jump. At the start of the training period, there were nine subjects in the multi joint group and eight subjects in the single joint group. However, four subjects withdrew from the study due to illness, two from each group, leaving seven subjects in multi joint group (5 men, 2 women), and six subjects in single joint group (5 men, 1 women). There were no statistical differences ($p \geq 0.29$) in anthropometrics, jump height and squat performance between groups. Therefore, data from thirteen subjects were used for further analysis. Full advice about possible risks and discomfort was given to the subjects, both orally and in writing, and all the subjects gave their written informed consent to participate. The study was conducted according to the declaration of Helsinki and approved by the regional ethics committee for medical research.

Procedures

The pre-test was done in one day for both groups, and the subjects were told not to carry out any resistance training or high-intensity endurance training the day prior to testing. Before testing **maximal vertical jumps**, 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 for approximately 15 min with an intensity of 70% of maximum heart rate (HR) the first 10 min and 80% of maximum HR the last 5 min. After warming up each participant had four test trials, with a rest period of 3 min between each test. 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 (Hultafors, Sweden). During the test, the participants were instructed to hold their hands on their hips and to sit for 2 s at knee joint angle of 90°. No counter movement was allowed. The average of the two highest vertical jumps was chosen to be the maximal vertical jump height. A linear encoder (ET-Enc-02, Ergotest Technology AS, Langesund, Norway) fastened to a power-lifting belt on the subjects measured the vertical jump height with a resolution of 0.075 mm and counts the pulses with 10 ms intervals. Force, velocity and power were calculated using Musclelab V8.13 software (Ergotest Technology AS, Langesund, Norway) The system has been validated, showing a maximal error less than 0.3%, 0.9% and 1.2% for force, velocity and power, respectively [5]. In addition, timing of the peak force, velocity and power was calculated.

Before **1-RM squat** testing, the subjects had a new warm up period of running or cycling of approximately 10 min with an intensity corresponding to 70% of maximum HR. The subjects tested out the exercises with light weights before testing began. Subjects performed multiple single repetitions with increasing load and with 3 min rest between each attempt. Maximum strength was determined by the highest weight the subjects were able to perform in 1-RM. In the post test the same procedure was used. When the same load was achieved as with the pre-test, the weights were increased with steps of 10-5-2.5 kg. The 1-RM was achieved within 3–5 attempts.

After the test the subjects were matched on their maximal jumping height and allocated to either the multi joint training group (n=7), or the single joint training group (n=6). **The multi joint training group** exercised ballistic jump squat with plantar flexion in one movement. The load was 40% of the 1-RM in squat measured at the pre-test. The protocol was five sets with six repetitions each, with 3-min 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 1A). To avoid any 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).

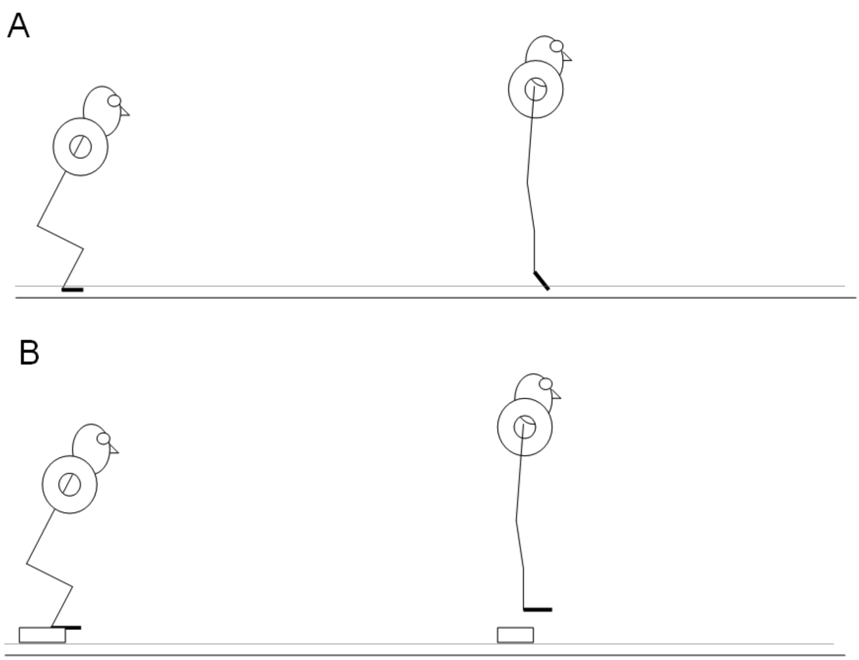

Figure 1. A) Illustration of squat training exercise for the multi joint training group and **B)** Squat training in single joint training group performed from a wooden board with a height of 5 cm above the floor, and half of each foot outside the wooden board and in the air.

The single joint training group exercised ballistic jump squat and plantar flexion separately. The load in each of the two exercises was 40% of the 1-RM in squat measured at the pre-test. After six repetitions of squats, the subjects performed six plantar flexions with the same load before the 3 min rest period. The number of sets, load and repetitions equalled the multi joint training group. However, the ballistic jump squats in single joint training group were performed from a wooden board with a height of 5 cm above the floor, and half of each foot (from medial metatarsus to the toe) outside the board and in the air (Figure 1B). Thus, any load on the plantar flexors in this exercise was prevented. The subjects were instructed to push hard from the heels in the squat movement, to accelerate throughout the movement to the point of take-off (heels leaving the board), and to land at the floor right in front of the board.

The subjects in both training groups were instructed not to take part in any additional resistance training of the legs during the intervention training period. Guidance and instructions in how to perform the exercises were given to all participants before they entered the training period. Each training group was monitored weekly by the investigators during the intervention training period, and all subjects kept their own training logs. If any of the subjects completed less than 10 of the planned 15 strength training sessions, they were excluded from the statistical analyses.

Statistical analysis

To show if anthropometrics, jump and squat performance were different between the two training groups at the start and thereby could be a confounding parameter, one-way ANOVA's were performed on these parameters at the pre-test. To compare the effects of the training protocols, a mixed repeated measures design 2 (test occasion: pre-post: repeated measures) × 2 (group: single joint training group and multi joint training group) ANOVA was used. Statistical analyses were performed using the SPSS software, version 18.0 (Statistical Package for Social Science, Chicago, IL, USA). The test-retest reliability (4 jumps at pre-test) as indicated by intra-class correlations (ICC) was 0.978 for maximal jumping height. The effect size and statistical power were also calculated. The level of significance was set at $p \leq 0.05$. Effect size was evaluated with η^2_p (Eta partial squared) where $0.01<\eta2<0.06$ constitutes a small effect, a medium effect when $0.06<\eta2<0.14$ and a large effect when $\eta2>0.14$ [3].

RESULTS

No significant effect from the pre- to post test was found for the vertical height, peak power, peak velocity and time to peak power ($F \leq 3.4$, $p \geq 0.091$; $\eta^2 \geq 0.14$, $1-ß \leq 0.23$). However, an interaction was found for the group factor in the vertical jump height ($F=6.5$, $p=0.026$; $\eta^2=0.37$, $1-ß=0.65$) indicating that there was a difference in jump height development between the groups after the intervention (Figure 2). Both groups showed a significant increase from the pre- to the post test for the 1-RM squat performance ($F=33.4$, $p \leq 0.001$; $\eta^2=0.75$, $1-ß=1.0$), peak force ($F=5.1$, $p=0.045$; $\eta^2=0.32$, $1-ß=0.54$) time to peak force ($F=4.9$, $p=0.049$; $\eta^2=0.31$, $1-ß=0.52$) and time to peak velocity ($F=7.5$, $p=0.019$; $\eta^2=0.41$, $1-ß=0.71$), with no differences between the groups. Furthermore, post hoc comparison per group showed that the multi joint training group had significant increases in all variables ($p \leq 0.047$; Table 1) except the peak velocity ($p=0.075$). The single joint training group had only a significant increase in 1-RM performance ($p=0.005$) after five weeks of intervention and no significant increases with the other variables ($p \geq 0.38$; Table 1).

Table 1. Performance variables at the pre- and post test for the multi and single joint training group (Mean±SD).

Group	Multi joint training group (n=7)		Single joint training group (n=6)	
	pre-test	post test	pre-test	post test
Jumping height (cm)	37.9±5.6	39.8±4.7*†	41.1±4.8	40.6±4.5
1-RM weight (kg)	119±36	136±36*	130±30	156±34*
Peak force (N)	1790±437	1924±442*	1983±348	2002±351
Peak velocity (m/s)	3.18±0.25	3.30±0.30	3.33±0.26	3.39±0.26
Peak power (W)	3197±933	3440±907*	3736±947	3818±985
Time to peak force (s)	0.137±0.047	0.159±0.022*	0.108±0.022	0.166±0.038
Time to peak velocity (s)	0.293±0.058	0.234±0.024*	0.254±0.042	0.243±0.030
Time to peak power (s)	0.204±0.048	0.087±0.016*	0.171±0.023	0.100±0.034

Note: *Significantly different from pre-test, p<0.05. †Significantly different from single joint training group, p<0.05.

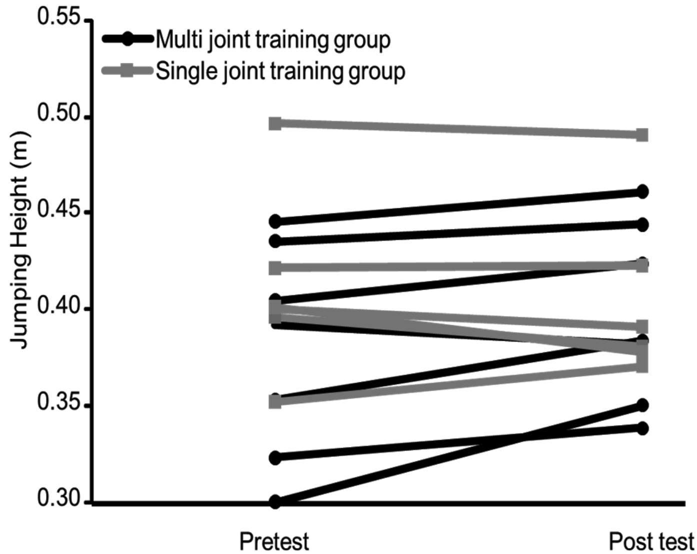

Figure 2. Jumping height at the pre- and post test for each subject in each group.

DISCUSSION

The main finding in this study was that only the multi joint training group improved their maximal vertical jump performance and not the single joint training group. Both groups improved in 1-RM squat weight, but for the single joint training group this improvement was not associated with an increase in maximal vertical jump performance. 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 single joint training group. Even though, the lack of improvement in maximal vertical jump height for the single joint training group is 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 [4, 14].

Improvement in maximal vertical jump performance for the multi joint training group might be due to a shift in the coordination pattern, although no kinematic or electromyographic measurements or movement analyses were done in order to support this suggestion. However, changes in coordination pattern were shown in a recent study [12]. 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. A significant decrease in time to peak force, velocity and power was found in the multi joint training group indicating a change in coordination pattern. It suggests that the training exercise was specific enough to make changes in the rate of force and power development for this group. In addition to an increased maximal vertical jump height for the multi joint training group, 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.

In our study, the single joint training group exercised the plantar flexors, but not the biarticular role of *m. gastrocnemius* with regard to the transfer of power from proximal to distal joints [2, 11, 19] in the way the multi joint training group did. Therefore, the transfer of power from proximal to distal joints might be accomplished in the multi joint training group, caused by a timely activation of *m. rectus femoris* and *m. gastrocnemius* before the end of push off. Activation of *m. gastrocnemius* prior to the end of push off may transfer power generated by the knee extensors [2, 11]. The single joint training group 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 [4]. 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 [3, 9]. 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, some authors have demonstrated that the neural factors dominate in strength development at the three first weeks of training [13]. 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 [17]. The movement in the 1-RM test situation is very similar to the training exercise for single joint training group with respect to coordination patterns, and could be one of the explanation of why single joint training group increased 1-RM, but not maximal vertical jump [4]. Therefore, the single joint training group 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.

A limitation of the present study was the low number of subjects in each group (n=7 and n=6) that completed the five weeks intervention period. This could influence the results. However, the jumping performances after five weeks intervention showed clear tendencies. In the multi joint training group, 6 of the 7 subjects showed an increase in jumping height, while in the single joint training group the opposite was shown; only one increased his jumping performance. There were four drop outs during the study period due to illness and, thus, this could potentially increase the chance of making a type II error. However, the effect size for the sample size used ranged between 0.14 and 0.75 and the corresponding power for the sample size used was 0.23–1.0. Nevertheless, a study with more subjects including kinematic or electromyographic measurement would have increased and strengthened the statement of enhanced effect of multi joint over single joint strength training on vertical jump height.

In conclusion, the multi joint training group was superior to the single joint group in improving maximal vertical jump performance after five weeks of ballistic squat training. This improvement was obtained without a corresponding greater increase in 1-RM squat performance for the multi joint group. Athletes performing squats, for another reason than the squat itself, should consider training of the biarticular role of *m. gastrocnemius*, i.e. finish the squats with plantar flexion. In practice, this may also be the easiest way to exercise the coordination between the knee extensors and plantar flexors in maximal vertical jump.

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