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Research article

Effects of warm-up on vertical jump performance and muscle electrical activity using half-squats at low and moderate intensity

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Abstract

The purpose of this study was to determine the effects of a specific warm-up using half-squats at low and moderate intensity on vertical jump performance and electromyographic activity of the thigh muscles. The subjects were 26 men who were divided into a low intensity group (LIG; n = 13) and a moderate intensity group (MIG; n = 13). The LIG performed a specific warm-up protocol that included the explosive execution of half-squats with loads 25 and 35% of the one repetition maximum (1RM) and the MIG with loads 45 and 65% of the 1RM. The two groups performed a countermovement jump (CMJ) before and three minutes after the specific warm-up protocols. During the concentric phase of the CMJ a linear encoder connected to an A/D converter interfaced to a PC with a software for data acquisition and analysis allowed the calculation of average mechanical power. The electromyographic (EMG) activity of the vastus lateralis (VL), vastus medialis (VM) and rectus femoris (RF) were recorded during the concentric phase of the jumps. The average quadriceps (Qc) activity (mean value of the VL, VM and RF) was also calculated. A two way ANOVA (protocols X time) with repeated measures on the second factor was used to analyze the data. Following the specific warm-up procedure both groups improved ($p \leq 0.05$) CMJ performance and mechanical power by 3.5% and 6.3%, respectively, with no differences observed between the two groups. EMG activity of the Qc and VL increased ($p \leq 0.05$) for both groups by 5.9% and 8.5%, respectively. It is concluded that the use of a specific warm-up that includes half-squats, performed explosively with low to moderate intensity, improves CMJ performance. This may be due to increased muscle activation as evaluated by the surface EMG.

Key words: EMG, contrast training, resistance exercise.

Introduction

Warm-up is considered to be a critical factor and is regularly used by athletes in order to avoid injuries and achieve high performance during training and competition. Warm-up consists of a general and a specific part. The general part focuses on the increase of the core and muscle temperature, cellular metabolism and the joint range of motion (Zentz et al., 1998). The specific part focuses on the reinforcement of the motor programs and mainly on the activity that, follows. When the activity is fast dynamic, there is high neuromuscular activation and optimal musculotendinus stiffness (Bishop, 2003; Burkett et al., 2005; Wilson et al., 1991; Wilson and Flanagan, 2008).

According to Verhoshansky (1986) exercise with submaximal loads activates the central nervous system creating a favourable environment for the performance of explosive activities with lower loads. The overwhelming majority of researchers (Clark et al., 2006; Comyns et al., 2006; Deutsch and Lloyd, 2008; Gourgoulis et al., 2003; Jensen and Eben 2003; Jones and Lees, 2003; Kilduff et al., 2007; Scott and Docherty, 2004; Weber et al., 2008; Young et al., 1998) mainly used heavy loads [80-95% of the 1 repetition maximum (RM) or 3-5 RM] during the warm-up exercise while limited data are available about the effectiveness of medium and light loads for increasing vertical jump performance. Smilios et al. (2005) found that jump-squats with loads of 30 and 60% of the 1RM increased countermovement jump height while the half-squat exercise had a positive effect only when the 60% load was applied. In conrast, other researchers did not observe any change in jump performance when loads 30-65% of the 1RM were used in the prior-exercise (Comyns et al., 2007; Hanson et al., 2007; Villareal et al., 2007). Considering that the use of low and moderate loads might be more feasible and easier to apply during a specific warm-up a purpose of this study was to futher examine whether use of this range of loads (≤65% of the 1RM) can acutely increase vertical jump performance. Furthermore, despite the fact that performance improvement is attributed mainly to neural factors, few researchers evaluated simultaneously the changes in performance with the changes in muscle activation using surface electromyography (EMG). Jones et al. (2003) found that 5 repetitions of parallel squats in a “Smith Machine” with a heavy load (85% of 1RM) had no effect on CMJ height and in the EMG activity of the rectus femoris, vastus lateralis and biceps femoris of the dominant leg. It appears that there are unanswered questions regarding the effects of specific warm-up protocols that contain resistance exercise with low or moderate loads on vertical jump performance and the electrical activity of the muscles involved. Therefore, the aim of this study was the investigation of the effects of a specific warm-up that included half-squats with low (25 and 35% of the 1RM) and moderate (45 and 65% of the 1RM) loads in the jumping ability and the electromyographic activity of the knee extensors muscles.

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Methods

Subjects

Twenty-six men were recruited for this study. Their physical characteristics (mean±SD) were: age 22.4 ± 2.5 years, height 1.77 ± 0.06 m, body mass: 77.7 ± 8.1 kg, and 1RM at half-squat (knee angle 90°) 185 ± 30 kg. The subjects were athletes of martial arts and team sports (football, volleyball) and they were healthy without injuries of the muscle-skeleton system. All had experience of at least one year in weight training, including the half-squat. During the last 4 months they trained systematically 2-3 times a week with loads of 40-90% of the 1-RM aiming at power development. The Institutional Review Board for the Protection of Human Subjects approved this study and participants were consented prior to their enrollment.

Experimental design

The subjects were randomly separated in two groups. During the specific warm-up subjects in one group used light loads that corresponded at 25 and 35% of 1RM (LIG; n=13) while those in the other group used medium loads corresponding at 45 and 65% of 1RM (MIG; n=13). There were no differences between the two groups in age, height, weight and half-squat 1RM. Jumping height and power output were measured before and after the specific warm-up. The EMG activity of vastus lateralis,(VL) vastus medialis (VM) and rectus femoris (RF) was also recorded during the jumps.

Measurements

Maximum strength: Three days before the application of the specific warm-up protocols maximum strength in the half squat exercise (knee angle 90°) was determined with the 1RM method as it has already been described (Smilios et al., 2005).

Countermovement Jump height: The subjects performed a CMJ with the hands firmly grasping a light metal bar which was resting on the shoulders was performed. The height of the jump was calculated by the time of flight with the use of a resistive platform connected to a digital timer (Ergojump, Psion©CM, MAGICA, Rome, Italy) using the formula**:** Jump height (m) = 9.81m·s^{-2} X flight time $(\text{s})^2$ / 8 (Bosco et al., 1983). Subjects were instructed to keep their legs extended and beneath them during the jump performance because excessive bending at the knee coupled with landing in an exaggerated bent knee position could result in a false jump height calculation. Two jumps with a 30 sec inter-trial rest period were performed and the highest one was included in the statistical analysis. From a pilot study conducted in our laboratory intra-class correlation coefficient was found to be high for CMJ, r=0.949 (Smilios et al 2005).

Mechanical parameters: The distance of the vertical movement of the bar as a function of time during the CMJ was measured with a linear encoder (Ergotest Technology, Langesund, Norway) attached on a belt around the waist of the subjects. When the subjects were moving a signal was transmitted by the encoder, with a resolution of 0.075 mm, to an A/D converter (Muscle Lab, Model PFMA 3010e, Ergotest A.S, Langensund, Norway; sampling frequency 100 Hz; Bosco et al., 1995) interfaced to a PC with a software for data acquisition and analysis (Muscle Lab v6.07). This allowed the calculation of average velocity, average force and average power during the concentric phase (the moment power reversed from negative to positive values until power reached zero again) of each repetition.

Electromyographic activity: The EMG activity of RF, VL and VM was measured in the right thigh with bipolar silver surface electrodes (AE-131, NeuroDyne Medical Co., active area diameter 5mm, inter-electrode distance 20mm) that were placed on the muscles according to the indications of SENIAM (Freriks and Hermens, 1999). Before the placement of electrodes the skin was shaved and cleaned thoroughly with alcohol in order to reduce myoelectrical impedance. The raw EMG signals were amplified by a gain of 600 with a common-mode rejection ratio 100 db and filtered through a 6-1500 Hz band pass filter (Biochip, Grenoble, France). Next, the A/D converter unit converted the raw EMG signal to an average root mean square signal via its built in hardware circuit network (frequency response 450 kHz, averaging window 100 ms, total error±0.5%). Afterwards, the converted EMGrms signal was sampled at 100 Hz with the same A/D converter and simultaneously with the signals of the linear encoder or the force sensor. The electric activity (EMG activity) of quadriceps femoris (Qc) was measured as the average of the activity of RF, VL, VM. The EMG amplitude of the muscles during the concentric phase of the CMJs was normalized to the EMG recorded during a maximal isometric knee extension performed before exercise. Two maximal isometric contractions, lasting 4 sec, were performed using the right leg. The rest between trials was 90 sec. At the measurement of the knee extensors the angles at the hip and knee joints were selected to be 115° and 85°, respectively. During the measurements the upper limbs were crossed at the chest while the trunk, the pelvis and the thigh were immobilised using special Velcro belts. The EMG of the muscles was measured for an 1.5 sec period during the force plateau. Maximum isometric force was measured with a strain gauge sensor connected to the A/D converter.

Experimental procedure

Before the application of the specific warm-up procedure the subjects of the experimental groups followed a similar general warm-up procedure that contained 5 min of cycling with a 60 W load, stretching of lower limbs muscles (gastrocnemious, quadriceps, hip flexors, hamstrings and gluteals) and 2 min of jumping exercises. The subjects performed the stretching exercises twice holding each stretch for 15 seconds and alternating between each leg in order to give adequate recovery before the next repetition. Jumping exercises included skipping (6 m), two foot ankle hops (6 reps), split squat jump (5 reps) and standing jump and reach (5 reps). Afterwards, surface electrodes were placed on the muscles and the maximum isometric contractions were performed. After a 3 min break, two counter movement jumps were performed. Then, after 2 min, the specific warm-up was executed that included 2 sets of 5 repetitions of the half-squat with loads that were different for each group. For the LIG the loads were 25% of 1RM for the 1st set and 35% of 1RM for the 2nd set. For the MIG the loads were 45% of 1-RM for the 1st set and 65% of 1RM for the 2nd set. Two sets with increamental loads were used for each group as usually the specific warm-up involves two or more exercise sets which are performed with a gradual increment of their intensity. We consider the loads sellected to be a low and a high one from the light and the moderate loads training zones, respectively. The subjects were instructed to perform each repetition with maximum velocity and particular attention was given to the fast transition from the descending phase of the exercise to the ascending one. The rest interval between the two sets was 3 min. After the specific warm-up a 3 min rest followed and two counter movement jumps were performed again.

Statistical analysis

A two way ANOVA (protocols x time) with repeated measures on the second factor was used to examine the effects of the two warm-up protocols on counter movement jump height and the EMG activity. Moreover, the power (P) of the analysis and the effect size (η^2) of the factors were calculated as suggested by Keppel (1991). For the examination of each protocol's effect a T-test for dependent samples was used. Significant differences between means were located with the Tukey HSD procedure. The significance level was set at $p \le 0.05$.

Results

Counter movement jump

In the total sample the CMJ height increased significantly by 3.45% ($p \le 0.05$, $\eta^2 = 0.56$, $p = 1$) after the specific warm-up. In the LIG the CMJ increased ($p \le 0.05$) by 3.95% while in the MIG increased by 3% ($p \le 0.05$). There were no significant differences among the groups ($p > 0.05$; Figure 1).

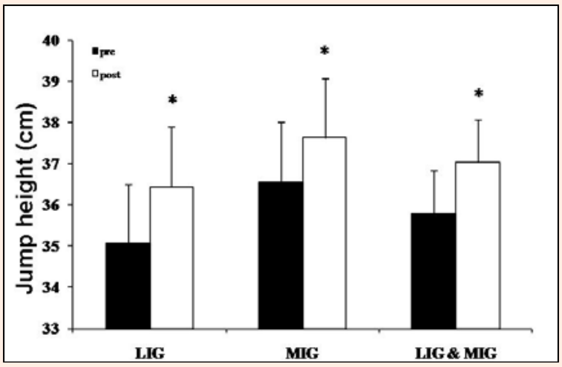

Figure 1. Countermovement jump height (mean±SE) changes after the execution of a warm up including half-squats with light (LIG) and medium loads (MIG). * $p \le 0.05$ from values before warm up.

Mechanical power

In the total sumple, mechanical power during the jump increased significantly by 6,8% ($p \le 0.05$, $\eta^2 = 0.26$, $p = 0.8$) after the specific warm-up. In the LIG power output increased by 6.3% ($p > 0.05$) while in the MIG increased by 7.3% ($p \le 0.05$). There were no significant differences among the groups ($p > 0.05$; Figure 2).

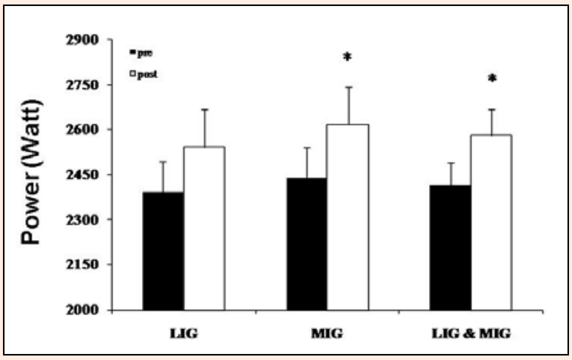

Figure 2. Power (mean±SE) changes after the execution of a warm up including half-squats with light (LIG) and medium loads (MIG). * $p \le 0.05$ from values before warm up.

Electromyographic activity

The EMG activity of RF and VM did not change significantly ($p > 0.05$) in any group while the activity of VL increased in the total sample ($p \le 0.05$, $\eta^2 = 0.36$, $p = 0.94$) by 8.5%. In the LIG increased ($p \le 0.05$) by 5.5% and in the MIG by 10.9%. No significant differences were found among the groups in VL activity ($p > 0.05$). In the total sample there was an increase ($p \le 0.05$, $\eta^2 = 0.37$, $p = 0.95$) of Qc EMG activity by 5.9%. In the LIG, Qc activity increased not significantly ($p > 0.05$) by 4.4% while in the MIG increased ($p \le 0.05$) by 7.2%. There were no significant differences ($p > 0.05$), however, among the two groups (Figure 3).

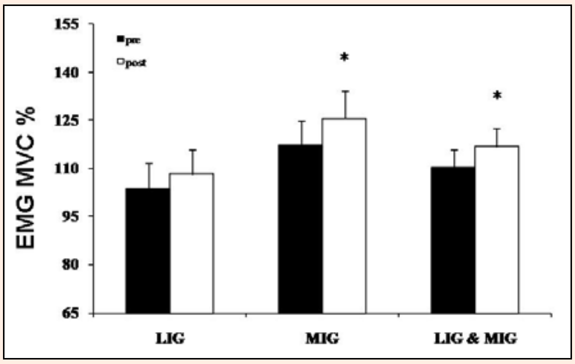

Figure 3. Changes of the Emg normalized values (mean±SE) of Qc during the concentric phase of the best CMJ performed after the execution of a warm up including half-squats with light and medium loads. * $p \le 0.05$ from values before warm up including half-squats.

Discussion

The present study examined the effect of a specific warm-up that included half-squats with low (25 and 35% 1RM) and moderate (45 and 65% 1RM) loads on the CMJ height, power and the electrical activity of knee extensors. The results showed that the counter movement jump height and power production increased regardless of the load used in the warm-up. More specifically, half-squats with low loads improved the counter movement jump height and power production at the same level as half-squats with medium loads (4% vs 3% and 6,3% vs 7,3%, respectively). The above increases in CMJ height and mechanical power were accompanied by an increase of the EMG activity of the knee extensors (VL & Qc) muscles.

The results of the present study show that the inclusion of a dynamic resistance exercise in the warm-up improve CMJ performance. This is in agreement with the results of several other studies which found increases in jump performance following the application of the half-squat exercise (Radcliffe and Radcliffe, 1996; Gourgoulis et al., 2003; Chiu et al., 2003; Villarreal et al., 2007; Rixon et al., 2007). Nevertheless, according to other researchers, dynamic exercise with weights is not always capable of stimulating the neuromuscular system and alter CMJ performance (Ebben et al., 2000; Hrysomallis and Kidgell, 2001; Jones et al., 2003). The differences between the studies in the training status and the strength level of the subjects, the length of the rest period between the conditioning exercise and the performance test and the form and the intensity of the conditioning exercise may contribute to the contrasting results. It should be mentioned that a limitation of the present study is the absence of a control group where the subjects would have rested quietly for an equivalent amount of time to which it took the other groups to complete their squat protocols, and then performed post vertical jumps. However, the results of previous studies show that when sitting instead of performing any intervention exercise has no potentiating effect on CMJ performance (Gilbert and Lees, 2005; Gonzalez-Rave et al., 2009).

The overwhelming majority of the studies that have been conducted up to date have used heavy loads (>80% 1RM) for the execution of the half-squat exercise. However, from the results of the present study as well as that of Smilios et al. (2005), it appears that the use of heavy loads is not the only mean to achieve higher performance. We found a 3% increase in countermovement jump height after half-squats with moderate loads (45 and 65% of 1RM). Similarly, Smilios et al. (2005) found that after half-squats (2 sets of 5 repetitions) with a load of 60% of 1RM the counter movement jump increased by 2.84%. Furthermore, in the present study, we used even lower loads (25 and 35% of 1RM) and again we observed an increase of the jumping ability (3.95%). Conversely, other studies did not find a change in jump performance after squats with loads 30-65% of the 1RM (Comyns et al., 2007; Hanson et al., 2007; Koch et al., 2003; Villarreal et al., 2007). This can be due to differences in the type of the jump executed to examine performance enhancement as well as to the exercise performed to improve performance. In the present study, the subjects were tested with a CMJ while in other studies the drop jump, the CMJ with arm swing and the standing broad jump were used for testing (Comyns et al., 2007; Hanson et al., 2007; Koch et al., 2003). The drop jump is a fast stetch shortening cycle activity while the CMJ a slow one. Therefore, a different stimulus which involve loaded fast stretch shortening cycle movements may be needed to potentiate performance in these type of activities.

Furthermore, in the study of Hanson et al. (2007), the squat exercise was performed using a Smith machine where the movement pattern is not as specific to the vertical jump movement as the performance of a half-squat with a free barbell. Future studies should examine more thoroughly the effectiveness of light to moderate loads, as a part of a warm-up routine, on the increament of explosive performance and how the movement pattern specificity between the loading exercise and the performance task determines the efficacy of this routines.

In the present study we also observed that the increases in CMJ height and power output were accompanied by a greater EMG activity of the knee extensors muscles as well. This may indicate that increased neural activation of the muscles, among other mechanisms, may have contributed to the improvement of jump performance. However a limitation of the present study is that we did not use electrical stimulation techniques to obtain the M wave and normalize the EMG data with this value. This would have helped us to draw a safer conclusion about the contribution of the central nervous system in the enhancement of jump performance. In contrast to our results, Jones et al. (2003) reported no increases in EMG activity after a bout of lower limb (5 reps of squats with a load 85% of 1RM and 3 successive blocks of plyometric exercises) complex training pair. It should be noted, however, that they did not find an improvent in the performance tests, as well, whereas in the present study CMJ performance increased. Probably, the absence of performance change justifies the lack of EMG changes or vice versa. A possible reason for the lack of changes in the results of Jones et al. (2003) could be the movement pattern specificity of the preloading exercise. According to Hanson et al. (2007), during Smith Machine squats the torso is vertically oriented increasing stress on the knee extensors away from low back and hip extensors. Also the shift of the feet forward decreases the amount of ankle dorsi-flexion. Consequently, the increased stress may have led the knee extensors in a fatigued state while the reduced stress may have led the hip extensors and ankle dorsi-flexors in an unpotentiated state. Besides, Jones et al. (2003) explained the trend for the EMG activity to reduce with time, as a possible result of fatigue. Furthermore, in the present study the intensity of the exercise was low or medium and the EMG activity of VL and Qc increased 8,5% and 5%, respectively. Taking into account the lower intensity of the exercise, it may be hypothesized that the factor which caused the increase of muscle activity was the performing speed. According to Duchateau (2006) the speed of a dynamic contraction for the generation of a specific force determines motor unit recruitment which are mobilized without breaking the size principle. Thus, in a rapid muscular action up to three times the motor units are activated relative to a slow one, which is attributed to the decrease of the recruitment threshold because of the movement speed. The emphasis on the explosive execution of the exercise performed in the present study may have have contributed to the increased activation of the muscles involved. In conclusion, the present study shows that the explosive performance of half-squats with low or medium loads in the specific part of a warm-up of medium trained individuals, increases the activation of the knee extensor muscles and the CMJ performance. Further research regarding the effect of the training status, the form of the exercise (isometric, dynamic, ballistic) and the interaction of load and rest period on the performance of the activity that follows will help the proper planning of a specific warm-up routine.

Conclusion

The results of this study indicate that acute power performance and EMG activity of the lower limbs is enhanced when preceded by two sets of half-squats with low to medium intensity. This may be attributed to the explosive execution of the warm-up sets and the similarity of the movement pattern of the tasks. It appears that the inclusion of two sets of half-squats with low to medium loads in a warm-up may result in improved performance in activities requiring high power output by the lower limbs.

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Key points

- The inclusion of two sets of explosively performed half squats with low to moderate loads in the warm up procedure elicited an acute performance enhancement.
- The performance was enhanced regardless of the load used in the warm-up.
- The performance enhancement is accompanied by a greater electromyographic activity of the knee extensors muscles.

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