INFLUENCE OF THE INTENSITY OF SQUAT EXERCISES ON THE SUBSEQUENT JUMP PERFORMANCE

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ABSTRACT

Fukutani, A, Takei, S, Hirata, K, Miyamoto, N, Kanehisa, H, and Kawakami, Y. Influence of the intensity of squat exercises on the subsequent jump performance. *J Strength Cond Res* 28 (8): 2236–2243, 2014—Jump performance can be enhanced after performing squat exercises, and this is thought to be because of the phenomenon of postactivation potentiation (PAP). However, the influence of the intensity of squat exercises on jump performance enhancement and its association to PAP have not been elucidated. Thus, we examined the influence of the intensity of squat exercises on the subsequent jump performance and the magnitude of PAP. Eight weightlifters (age, 19.8 ± 1.3 years; height, 1.67 ± 0.07 m; body mass, 77.1 ± 14.8 kg) were recruited as subjects. The intensity of squat exercises was set in 2 conditions: heavy condition (HC) (45% 1 repetition maximum [1RM] × 5 repetitions [reps], 60% 1RM × 5 reps, 75% 1RM × 3 reps, and 90% 1RM × 3 reps) and moderate condition (MC) (45% 1RM × 5 reps, 60% 1RM × 5 reps, and 75% 1RM × 3 reps). Before and after the squat exercises, the subjects performed countermovement jumps 3 times. In addition, a twitch contraction was concurrently elicited before and after the squat exercises. In both conditions, twitch torque and jump height recorded after the squat exercises increased significantly compared with those recorded beforehand. The extents of increase in both twitch torque and jump height were significantly larger in HC than in MC. We conclude therefore that a high-intensity squat exercise is better than a moderate-intensity squat exercise as a warm-up modality for enhancing subsequent jump performance.

KEY WORDS postactivation potentiation, twitch torque, electromyography

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28(8)/2236–2243

Journal of Strength and Conditioning Research

INTRODUCTION

Twitch torque is transiently increased after a high-intensity contraction. This phenomenon is referred to as postactivation potentiation (PAP) (7,10,19), and the high-intensity contraction for inducing PAP is called a conditioning contraction (21) (hereafter referred as "conditioning activity"). The primary mechanism of PAP is considered to be the myosin regulatory light chain phosphorylation in the activated muscle during a conditioning activity (5,20). Myosin regulatory light chain phosphorylation leads to the facilitation of actin-myosin interaction. As a result, force-generating capability of the muscle is enhanced.

Many studies have attempted to examine the effect of squat exercises as a conditioning activity on the subsequent dynamic performances such as jump or sprint. However, previous findings are still in controversy. Some studies found a positive effect of squat exercises on the subsequent jump height (4,13,17,24), but others did not (8,11,12). Because of this inconsistency, strength and conditioning professionals have not used the conditioning activity on the dairy resistance trainings or games.

Such discrepancy may be attributed to differences in how forcibly the squat exercises were performed as a conditioning activity. The intensity of squat exercises adopted differs among studies. Some studies that adopted heavy loads (i.e., 90% 1 repetition maximum [1RM] squat) in a conditioning activity reported the enhancement of jump performance (4,17). However, a study that reported an unchanged jump height (8) used a lower load (i.e., 40 or 80% 1RM squat) as a conditioning activity than those of the studies described above. Considering that the extent of PAP increases as a function of the intensity of the conditioning activity (23), there is a possibility that the extent of PAP induced by the squat exercises might have been different among studies described above. However, these studies did not measure the extent of increase in twitch torque to examine the extent of phosphorylation of the myosin regulatory light chain (15). Such drawbacks in the previous studies make it difficult to confirm whether or not the extent of enhancement in force-generating capability induced by the squat exercises was similar among studies. To clarify this, twitch torque should be measured simultaneously with the jump height to examine the influence of the intensity of squat exercises on the subsequent jump height, to ascribe the reason for its change to PAP. However, there has been only 1 study adopting twitch torque measurement simultaneously with jump height measurement to examine whether increase in jump performance was caused by PAP or not (14).

In the present study, we conducted a detailed examination of the influence of the intensity of squat exercises as a conditioning activity on the subsequent jump performance, by measuring the change in twitch torque in different intensity conditions. We hypothesized that the squat exercises at higher intensity produces greater increase in not only twitch torque but also jump height, as compared with those at lower intensity. If the influence of intensity of the conditioning on the subsequent jump performances is clarified, strength and conditioning professionals can apply conditioning activity on the athletes by modulating intensity based on the scientific evidence as a new method for enhancing sport performances or training efficiency.

Methods

Experimental Approach to the Problem

To examine the influence of the intensity of the squat exercises on the subsequent jump performance, we set 2 conditions, that is, high-intensity condition (heavy condition [HC]) and moderate-intensity condition (moderate condition [MC]) were set. The experimental procedure is shown in Figure 1. The HC consisted of 4 sets of squat exercises, with the load and repetition of each set being 45% 1RM × 5 repetitions (reps), 60% 1RM × 5 reps, 75% 1RM × 3 reps, and 90% 1RM × 3 reps. However, MC consisted of 3 sets of squat exercises, at 45% 1RM × 5 reps, 60% 1RM × 5 reps, and 75% 1RM × 3 reps. A rest time of 2 minutes was provided between sets. Before and after each conditioning activity, a twitch contraction was evoked and a countermovement jump was performed without moving arms (Figure 2). To compare the differences in twitch torque and jump height between HC and MC, a 2-way analysis of variance (ANOVA) with repeated measures was performed.

Subjects

Eight healthy Olympic lifters (age, 19.8 ± 1.3 years; height, 1.67 ± 0.07 m; body mass, 77.1 ± 14.8 kg) were recruited for this study. All of them were university students and had attended national meetings of Olympic lifting, including national championship. They had been participating in a regular training program (5 times per week). None of them were in a weight reduction period. Their physical characteristics are listed in Table 1. Written informed consent was obtained from each participant in the present study. This study was approved by the Ethics Committee on Human Research of Waseda University.

Conditioning Activity (Squat Exercises)

A parallel squat (superior surface of the thigh became in parallel with ground at the bottom of squat) was used as a conditioning activity. The frequency of movement was dependent on the subject not to restrict their natural movement. In every squat motion, a spotter who had a license of Strength and Conditioning Specialist with Distinction (CSCS, D*) certified by the National Strength and Conditioning Association, was set behind the subjects and assisted them when the subjects could not execute the prescribed number of the lift (Figure 3).

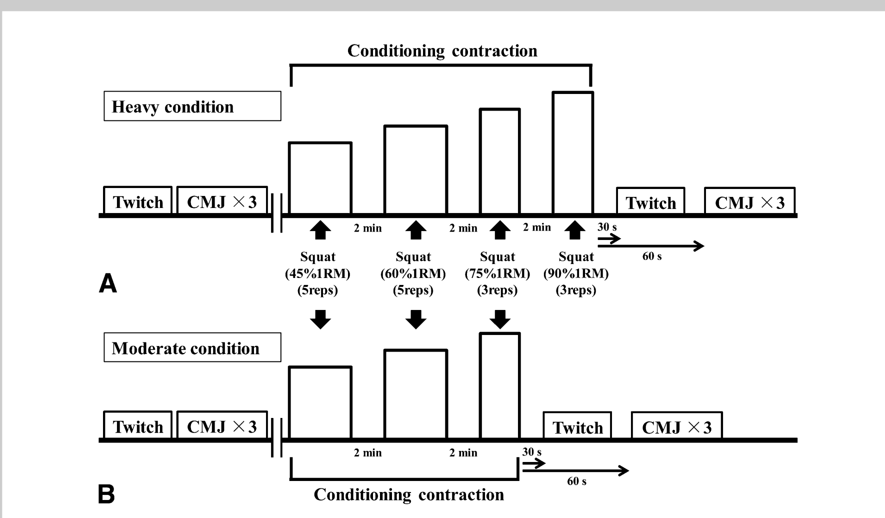

Figure 1. Experimental procedure. Panels A and B illustrate the sequence of the heavy condition and moderate condition, respectively. CMJ = countermovement jump.

Measurements

Electromyography. Surface electromyographic (EMG) signals were recorded from the rectus femoris (RF), vastus lateralis (VL), biceps femoris, and gluteus maximus of the right leg using bipolar electrodes (Ag/AgCl, diameter, 11 mm; Blue sensor, N-00-S; Ambu, Copenhagen, Denmark). The electrodes were placed on the muscle belly of each muscle, with their distance set to 20 mm. The ground electrode was located on the patella of the right leg. Before placing electrodes, an investigator abraded the skin with sand paper and cleaned it with alcohol to ensure that interelectrode resistance was <5 kΩ.

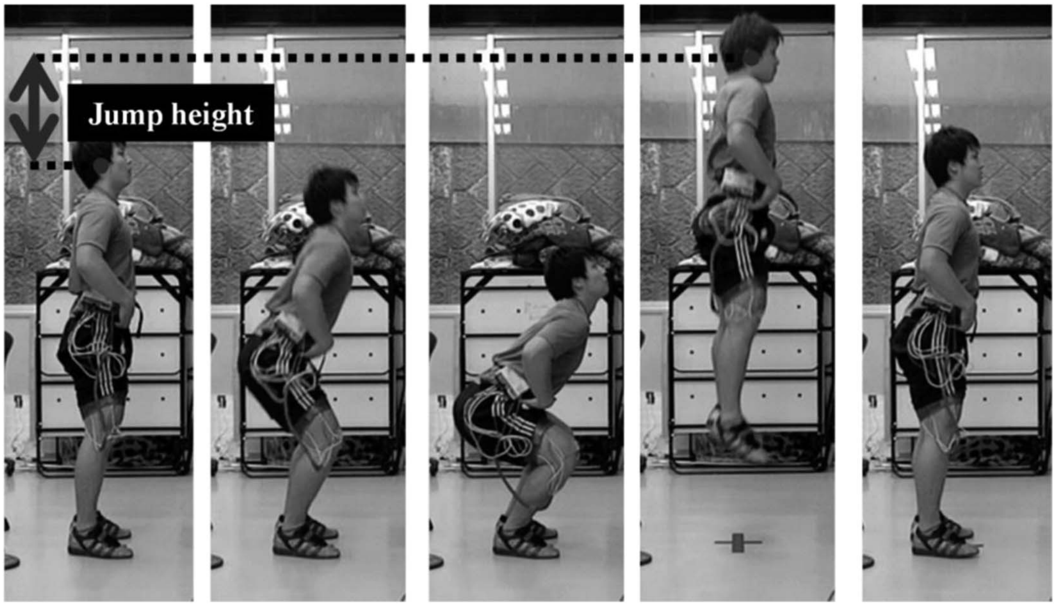

Figure 2. Experimental setting for the countermovement jump.

Electrical Stimulation. The twitch torque for knee extension was measured using a myometer (VTK-002; Vine, Tokyo, Japan). The subjects sat on the machine with their hip and knee joints of the right leg fixed at 90°. To evoke the twitch contractions of knee extensors, the anode (40 × 50 mm, VIASYS Healthcare, CA, USA) was placed on the great trochanter of the right leg, and the cathode (40 × 50 mm, VIASYS Healthcare) was placed over the femoral nerve at the inguinal area of the right leg. A single rectangular pulse of 500-μs duration was delivered by a high-voltage stimulator (SEN-3301; Nihon Kohden, Tokyo, Japan) with a specially modified isolator (SS-1963, Nihon Kohden). Stimulus intensity was determined before the experimental trial (after locating the EMG electrodes) by increasing the voltage until the corresponding torque for knee extension reached a plateau then setting the intensity at the value that was 20% higher than this.

Electromyographic Signal Processing. The EMG signals were recorded after being band-pass filtered between 5 and 1000 Hz (WEB-5000; Nihon Kohden). The torque signal was amplified using a strain amplifier (DPM-611B; Kyowa, Tokyo, Japan). The analog torque and EMG signals were converted to digital signals by using a 16-bit analog-to-digital converter (Power-lab/16SP; ADInstrument, Bella Vista, Australia). The sampling frequency was set at 4 kHz.

Countermovement Jump. Jump height was recorded using a video camera (EXILIM, EX-F1; Casio, Tokyo, Japan). The sampling frequency was 30 Hz, and shutter speed was 1 per 1000 seconds. The movie and

Table 1. Characteristics of the subjects.*

Subject	Age (y)	Height (m)	Body mass (kg)	Squat 1RM (kg)	Squat/body mass
a	20	1.60	61	145	2.38
b	22	1.78	93	185	1.99
c	19	1.74	73	195	2.67
d	19	1.58	60	150	2.50
e	21	1.73	83	195	2.35
f	20	1.67	85	210	2.47
g	19	1.66	98	200	2.04
h	18	1.61	64	165	2.58
Mean	19.8	1.67	77.1	180.6	2.37
SD	1.3	0.07	14.8	24.3	0.24

*1RM = 1 repetition maximum.

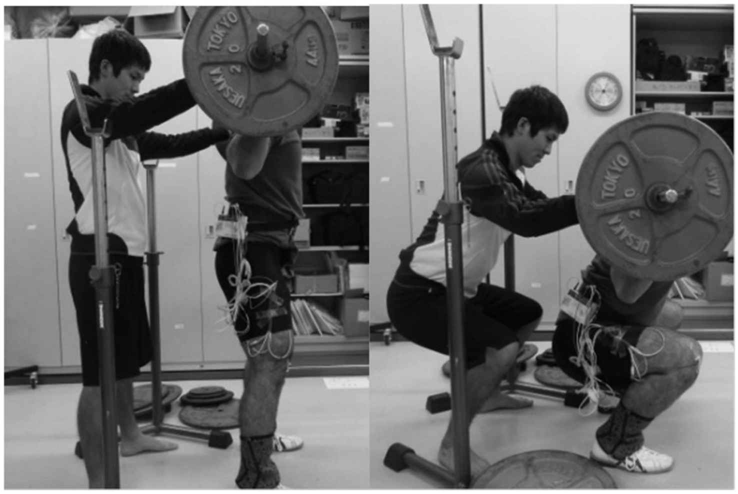

Figure 3. Experimental setting for the squat exercises, with the spotter assisting the subject.

EMG signals were synchronized (PH-100; DKH, Tokyo, Japan).

Procedures

First, the twitch torque for knee extension was recorded. After that, a countermovement jump with the maximal effort was performed 3 times. Jumps were performed successively. Then, the subjects performed squat exercises (HC or MC) as a conditioning activity. Thirty seconds after the last repetition of the squat exercises, the twitch torque was recorded, and 60 seconds after the last repetition of the squat exercises, a countermovement jump with the maximal effort was performed 3 times, similarly to that before the squat exercises. Thereafter, the subjects rested for at least 30 minutes to avoid the influence of muscle fatigue or PAP induced by the squat exercises and 3 countermovement jumps on the next intensity condition. The order of each condition was random.

Statistical Analyses

The peak torque obtained during twitch contraction was adopted as twitch torque. The peak-to-peak amplitudes of the M-wave obtained from the RF and VL were adopted as the M-wave amplitude value of each muscle. Because the twitch contraction could not be evoked at 2 subjects and skin resistance was high, data obtained from 6 of 8 subjects were adopted. Jump height was expressed as the displacement of the center of the ear recorded from the static posture to the instant when the center of the ear reached the highest position during a countermovement jump (Figure 2). The center of shoulder joint, greater trochanter, popliteal crease, lateral malleolus, and the head of the fifth metatarsal bone were digitized to measure the hip, knee, and ankle joint angles at the instance when the knee joint was flexed maximally during the countermovement jump to examine whether or not the kinematics of the countermovement jumps were identical using an image analysis software (Siliconcoach Pro7; 4Assist, Japan). The hip and knee joint angles in anatomical positions were defined as 0° (full extension). The ankle joint angle was defined as the angle composed by 2 straight lines, that is,

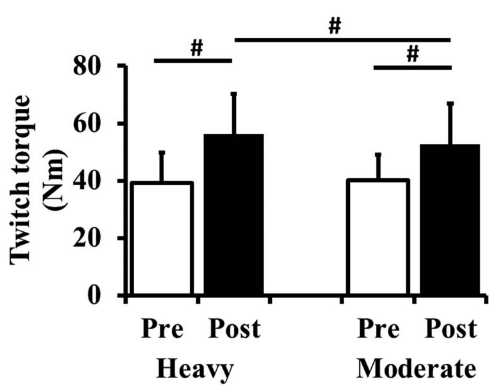

Figure 4. Twitch torque before and after squat exercises in the heavy condition and moderate condition. #Significant difference ($p \leq 0.05$). Pre = before squat exercises; Post = after squat exercises.

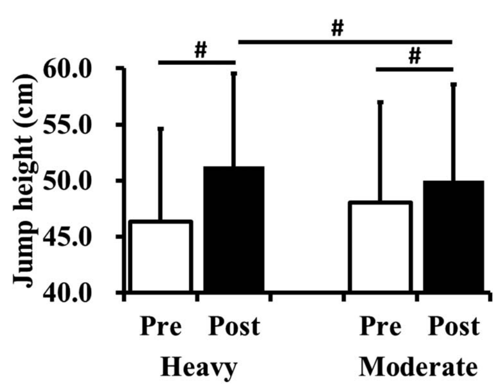

Figure 5. Jump height before and after squat exercises in the heavy condition and moderate condition. #Significant difference ($p \leq 0.05$). Pre = before squat exercises; Post = after squat exercises.

Table 2. M-wave amplitudes during twitch contraction in the HC and MC conditions.*†

	M-wave (mV)			
	Heavy		Light	
	Pre	Post	Pre	Post
Rectus femoris	2.5 ± 1.1	2.7 ± 1.4	2.6 ± 1.2	2.3 ± 1.0
Vastus lateralis	3.2 ± 1.8	3.3 ± 1.8	2.7 ± 1.0	3.4 ± 1.5

*HC = heavy condition; MC = moderate condition; Pre = before squat exercises; Post = after squat exercises.
†Values are presented as mean ± *SD*.

Table 3. RMS_{EMG} during countermovement jumps in the HC and MC conditions.*†

	RMS_{EMG} (mV)			
	Heavy		Light	
	Pre	Post	Pre	Post
Rectus femoris	0.65 ± 0.45	0.65 ± 0.39	0.68 ± 0.41	0.68 ± 0.37
Vastus lateralis	0.58 ± 0.29	0.60 ± 0.39	0.54 ± 0.28	0.60 ± 0.35
Biceps femoris	0.31 ± 0.17	0.33 ± 0.19	0.32 ± 0.18	0.29 ± 0.16
Gluteus maximus	0.26 ± 0.12	0.27 ± 0.15	0.44 ± 0.41	0.28 ± 0.13

*HC = heavy condition; MC = moderate condition; Pre = before squat exercises; Post = after squat exercises; RMS_{EMG} = root mean square value of electromyography.
†Values are presented as mean ± *SD*.

Table 4. Joint angles of the hip, knee, and ankle at the instance when the knee joint was flexed maximally during countermovement jumps in the HC and MC conditions.*†

	Joint angle (degree)			
	Heavy		Light	
Joint	Pre	Post	Pre	Post
Ankle	85.0 ± 9.8	85.0 ± 9.8	85.1 ± 9.3	86.3 ± 9.1
Knee	70.7 ± 17.5‡	66.9 ± 16.0§	69.3 ± 17.0	69.4 ± 15.3
Hip	71.0 ± 15.6	68.8 ± 15.3	69.8 ± 14.5	69.0 ± 14.9

*HC = heavy condition; MC = moderate condition; Pre = before squat exercises; Post = after squat exercises.
†Values are presented as mean ± *SD*.
‡Significant difference ($p \leq 0.05$) compared with Pre in moderate.
§Significant difference ($p \leq 0.05$) compared with Post in moderate.

1 from the popliteal crease to lateral malleolus and the other from the lateral malleolus to the head of the fifth metatarsal bone. In addition, the root mean square value of EMG (RMS_{EMG}) during the countermovement jump was calculated for each muscle. The duration of measurement of RMS_{EMG} was set from when the knee joint was flexed maximally to when the toe lifted off the ground. A 10–500 Hz band-pass filter was used to minimize the effect of motion artifacts on the RMS_{EMG} value during the countermovement jump. The jump height, joint angles, and RMS_{EMG} were calculated during 3 countermovement jumps, and averaged value over the 3 trials for each of the variables was adopted as the representative value. The coefficient of variability and intraclass correlation for the jump height among 3 trials were 2.8 ± 1.2% and 0.97, respectively.

Descriptive data are presented as mean ± *SD*. A 2-way ANOVA with repeated measures was used to assess the effects of condition (HC and MC) and time (before and after) and their interaction on jump height, twitch torque, M-wave amplitude, RMS_{EMG}, and joint angles measured during a countermovement jump. If the interaction was significant, then paired *t*-tests were used to examine the differences between 2 intensity conditions and between before and after the squat exercises. Effect size for ANOVA was calculated as the partial η^2. In addition, effect size for paired *t*-test was calculated the as the Cohen's *d*. The level of significance was set at $p \leq 0.05$. All statistical analyses were conducted by using IBM SPSS Statistics 20.0.

Results

A significant interaction between conditions × time was found for twitch torque ($F = 11.398$, $p = 0.02$, effect size = 0.70). Additional analyses showed that the twitch torque increased significantly in both HC ($p < 0.001$, effect size = 1.37) and MC ($p = 0.005$, effect size = 1.07). Although the twitch torque recorded before squat exercises did not differ between the 2 conditions ($p = 0.283$, effect size = 0.06), that recorded after squat exercises was significantly larger in HC than in MC ($p = 0.021$, effect size = 0.25) (Figure 4).

A significant interaction was also found for the jump height ($F = 31.071$, $p = 0.005$, effect size = 0.70). Additional analyses revealed that the jump height increased significantly in both HC ($p = 0.012$, effect size = 0.59) and MC ($p = 0.001$, effect size = 0.22). Jump height before squat exercises did not differ significantly between 2 conditions ($p = 0.126$, effect size = 0.20) (Figure 5). However, jump height after squat exercises was significantly larger in HC than in MC ($p = 0.039$, effect size = 0.14).

No significant interactions and no main effects were found for M-wave amplitudes during a twitch contraction and for RMS_{EMG} during a countermovement jump for any of the muscles (Tables 2 and 3).

For the joint angle, a significant interaction was found in the knee joint ($F = 9.67$, $p = 0.017$, effect size = 0.58). Significant differences were found between HC and MC both before ($p = 0.046$, effect size = 0.08) and after ($p = 0.027$, effect size = −0.16) the squat exercises. However, no significant differences between before and after the squat exercises were found either in MC ($p = 0.053$, effect size = −0.23) or HC ($p = 0.873$. effect size = 0.01) (Table 4). There were no significant interactions or main effects in hip or ankle joints.

Discussion

The main purpose of this study was to examine whether jump performance is enhanced by conditioning activity through the simultaneous measurement of twitch torque. The jump height significantly increased both in HC and MC, but the extent of increase in jump height was significantly larger in HC than in MC. In addition, the extent of increase in twitch torque was significantly larger in HC than in MC. These results support our hypothesis that the increase in the jump height was larger in high-intensity squat exercises, and that this larger increase was associated with a larger increase in twitch torque. Considering the lack of significant difference in RMS_{EMG} and significant but small difference in kinematics (only in knee joint angle with the extent of difference 3.8°) between 2 conditions, the significant difference in the increase in jump height after the squat exercises may be associated with the enhancement of the force-generating capability of muscle due to PAP, as reflected in a significant increase of twitch torque after the squat exercises.

The extent of increase in twitch torque was significantly larger in HC than in MC. It is known that phosphorylation of the myosin regulatory light chain in the activated muscle during a conditioning activity makes the actin-myosin interaction more sensitive to the given Ca^{2+}, which is a proposed mechanism of PAP (19,20). To make the most of this mechanism, it is important to activate all muscle fibers during the conditioning activity because only activated muscle fibers are phosphorylated. In addition, the extent of PAP is larger in fast-twitch than in slow-twitch fibers (15). Fast-twitch fibers are recruited in the later phase of force-increment in accordance with the size principle (9). Taken together, high-intensity squat exercises should be better as a conditioning activity to attain the large extent of PAP than moderate intensity squat exercises.

The present result indicates that high-intensity squat exercises are better than moderate-intensity squat exercises for enhancing jump performances. At the same time, this suggests that previous findings in which the positive effect of condition activities on jump performances was not found may be because of the intensity of condition activities, that is, low- or moderate-intensity squat exercises. Chiu et al. (1), however, adopted 90% 1RM squat as a conditioning activity but did not find improvement of jump performance. This result indicates that there are other factors than intensity that can affect the change in jump performance induced by the conditioning activity. One of the possible factors might include physical characteristics (training status) of the subjects, which is known to affect the increase in twitch torque after a conditioning activity (16). Chiu et al. (1) tested both recreationally trained men and athletes requiring explosive strength as subjects and reported that there was no significant increase in jump height after a conditioning activity, but when the subjects were divided into 2 groups (athletes and recreationally trained men groups), the extent of increase in jump height before and after the conditioning activity was significantly larger in the athletes than in recreationally trained men. The present study reports an increase in jump height, and we used highly trained weightlifters as subjects (squat/body mass ratio: 2.37 ± 0.24), and they might have been sensitive to the potentiation effect of conditioning activity (16). This could explain the conflicting results of Chiu et al. (1) and present study.

The performance of voluntary movement such as jumping is affected by the neural excitability and force-generating capability of the muscle (i.e., PAP) (2). In addition, some studies reported that spinal excitability (e.g., H-reflex) was changed (decreased immediately after the conditioning activity but increased after depression) by the conditioning activity (6,22). Thus, we have to also consider the neural factor that has possibly affected jump performance. In our current protocol, however, the M-wave during a twitch contraction and RMS_{EMG} during 3 countermovement jumps for each muscle were not different significantly between 2 conditions or between before and after the sequence of squat exercises (Tables 2 and 3). These results preclude the possibility of intervention of neural factors in the present study.

Another factor that could have affected our results is the duration of the squat exercises. Because it is not practical to conduct squat exercises at an intensity of >75% load without some warm-up exercises, the load of squat exercises were gradually increased in the present study. As a result, the total duration of the squat exercises was longer in HC (4 sets) than in MC (3 sets). However, because we set a rest interval of 2 minutes between squat exercises (Figure 1), the countermovement jump was performed after >3 minutes of the second last session of squat exercises. The extent of PAP decreases in an exponential fashion, and a large part of PAP disappears in 5 minutes (23). Taken together, factors affecting the jump performance conducted after the squat exercises would be mainly because of the final set of squat exercises. Thus, the significant difference in the change in jump height between 2 conditions would be attributable to the intensity not to the total duration of the squat exercises.

In conclusion, high-intensity squat exercises would be better than moderate intensity squat exercises as a conditioning activity for enhancing subsequent jump performance although jump performance increased in both intensity conditions. This can be explained by the larger increase in twitch torque an index of enhancement of force-generating capability, which was more pronounced in the squat exercises with high intensity rather than moderate intensity.

Practical Applications

The results of the current study indicate that squat exercises with a heavy load can enhance subsequent dynamic performances. In some case, moderate-intensity squat exercises as a warm-up would be better because the occurrence of muscle fatigue or injury is low. As a warming-up exercise, however, high-intensity squat exercise may be better for enhancing training efficiency when power clean or snatch which require high-intensity contraction are performed in the dairy resistance training. This notion has been introduced as a "complex training" (3,18). For instance, performing high-intensity squat exercise before doing sprint or agility training may be useful because force-generating capability is temporarily enhanced by squat exercise, that is, PAP. Once the force-generating capability is enhanced, training performances will be augmented, thereby increasing the training efficiency. Thus, conditioning activities have a possibility to be a new strategy to enhance training efficiency. Future study that adopts training intervention with and without conditioning activity is required to elucidate the above hypothesis.

Acknowledgments

The authors gratefully thank the subjects for their time and dedication to our study. This study was partly supported by the Waseda University Global Centre of Excellence (GCOE) program, Sport Sciences for the Promotion for Active Life, Grant-in-Aid for JSPS Fellows, and partly by the Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture of Japan (no. 24300209).

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