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Influence of Strength Level on Performance Enhancement Using Resistance Priming

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Abstract

Nishioka, T and Okada, J. Influence of strength level on performance enhancement using resistance priming. *J Strength Cond Res* 36(1): 37–46, 2022—The current study aimed to investigate (a) whether resistance priming was effective in enhancing jump performance for both stronger and weaker individuals and (b) how resistance priming influences the lower-body force-velocity profile. A total of 20 resistance-trained men performed priming and control conditions 72–144 hours apart in a randomized and counterbalanced order. Jump performances (0 and 40% 1 repetition maximum [1RM] squat jump, 0 and 40% 1RM counter-movement jump [CMJ] and drop jump) were assessed before and 24 hours after the priming session, and before and 24 hours after rest (control). Priming session-induced percentage change in 0% 1RM CMJ height was positively correlated with the individual's relative half squat 1RM ($r = 0.612$, $p \leq 0.05$). Using the median split method, subjects were divided into stronger (relative half squat 1RM = 1.93–2.67 kg·kg^{-1}) and weaker (relative half squat 1RM = 1.37–1.92 kg·kg^{-1}) groups and subsequently analyzed. The stronger group showed specific improvement in 0% 1RM CMJ performance 24 hours after the priming session ($p \leq 0.05$), whereas the weaker group showed no improvement in any of their jump performances. Moreover, the priming session enhanced the theoretical maximum velocity ($p \leq 0.05$), but not the theoretical maximum force during CMJ in the stronger group; whereas none of the force-velocity profile variables were enhanced in the weaker group. These results suggest that stronger individuals are more likely to experience performance enhancement using resistance priming, which may be movement- and velocity-specific.

Key Words: delayed potentiation, ballistic performance, jumping, force, velocity, power

Introduction

Two approaches have been proposed for enhancing ballistic performance (e.g., jumping) required by many athletes using resistance exercises: one requires inducing chronic adaptation by implementing long-term training interventions (7,8), whereas others require taking advantage of the acute effects of exercise interventions (36). A typical mechanism by which acute effects promote improvement is through postactivation performance enhancement (PAPE) (27). This phenomenon indicates that performing maximal or near maximal muscle contractions (i.e., a conditioning activity) increases power production during subsequent exercises (36). For instance, previous studies (9,12,34) have reported improvement in the performance of biomechanically similar lighter load exercises (e.g., unloaded vertical jump) after performing high-load resistance exercise (e.g., back squat). Conditioning activities temporarily enhance subsequent ballistic performance for a period, typically lasting from 3 to 18.5 minutes (3,17,20,35). Given the small window of opportunity for

improving performance, many athletes may find it difficult to use PAPE, for instance, during warm-up before a competition (14).

Recent studies have shown that a range of ballistic performance may be enhanced for up to 48 hours following resistance exercise (14). This phenomenon is termed "delayed potentiation" (14), with resistance exercises performed for delayed potentiation being termed "resistance priming" (14). Previous studies (6,23,39) have suggested that delayed potentiation occurs over a relatively wide window of opportunity (1 hour and 45 minutes to 48 hours). Therefore, resistance priming can be a conditioning strategy that can overcome the aforementioned challenges of PAPE.

In both research and field settings (13), resistance priming has often been prescribed for high performance athletes who often have high strength levels (28,30). For instance, Raastad and Hallén (28) showed that performing a moderate intensity strength exercise (i.e., resistance priming) improved jump performance after 33 hours. Their subjects were considerably strong (body mass = 84.5 kg, 3RM [3 repetition maximum] squat = 169 kg). Furthermore, Saez Saez de Villarreal et al. (30) reported that resistance priming (e.g., low-volume, high-load half squat exercise) was effective in enhancing jump performance after 6 hours in strong subjects (body mass = 76.9 kg, half squat 1RM = 158.3 kg). As such, the aforementioned findings suggest that resistance priming could be an effective conditioning strategy for strong athletes. However, it remains unclear whether resistance priming is also effective for weaker individuals and whether strength level influences performance enhancement using resistance priming. From a practical perspective, such information can help practitioners make decisions regarding which individuals may or may not benefit from resistance priming.

Recently, the force-velocity profile, which provides information regarding theoretical maximum force ($\bar{F}_0$), velocity ($\bar{v}_0$), power ($\bar{P}_{max}$), and slope of linear force-velocity relationship (S_{Fv}), has been used as a method for evaluating ballistic performance (15,31,32). These parameters, which play an important role in maximizing jump performance, can be used to assess force output ability at various movement velocities (15,31,32). However, how resistance priming influences the force-velocity profile during vertical jump remains unclear. Findings concerning how force-velocity profiles change differently with resistance priming in stronger and weaker individuals would be valuable to practitioners.

Therefore, the current study aimed to (a) determine whether resistance priming was effective in enhancing jump performance in stronger and weaker individuals and (b) assess how resistance priming influences the force-velocity profile. Several previous PAPE studies (3,9,35) have suggested that stronger individuals have a greater performance enhancement using conditioning activities than weaker individuals. In addition, PAPE has been reported mostly for high-velocity performance (e.g., unloaded jumps) (36). Based on these findings, we hypothesized that (a) resistance priming would effectively enhance jump performance in stronger but not weaker individuals and (b) resistance priming would improve the theoretical maximum velocity (i.e., $\bar{v}_0$) but not theoretical maximum force (i.e., $\bar{F}_0$) in the force-velocity profile.

Methods

Experimental Approach to the Problem

A repeated measures design with a randomized and counter-balanced order was used to investigate the delayed potentiation effects of a resistance priming session on jumping performance after 24 hours. Subjects performed 2 different sessions (priming and control) 72–144 hours apart. To achieve the main purpose of the current study, which was to investigate the influence of strength level on performance enhancement using resistance priming, the priming condition consisted of a low-volume jump squat training session, which has been shown to be effective in improving jump performance (39), whereas the control condition consisted of rest. To evaluate the ballistic performances, the following jump performances were assessed before and 24 hours after the priming and control conditions: unloaded squat jump (SJ), unloaded countermovement jump (CMJ) performance, and reactive strength index (RSI) from drop jump (DJ). In addition, for the force-velocity profiling, loaded SJ and loaded CMJ were also performed. To examine the influence of strength level on performance enhancement using resistance priming, subjects were divided into stronger and weaker groups, followed by analyzing the performance outcomes of each group (34). The procedures for the priming and control conditions are provided in detail in Figure 1.

Subjects

A total of 20 resistance-trained men between the ages of 20 to 25 volunteered to participate in this study (age: 22.4 ± 1.5 years, height: 172.2 ± 5.0 cm, body mass: 71.3 ± 7.4 kg, half squat 1RM: 142.5 ± 28.4 kg, mean ± *SD*). The included subjects had 11.6 ± 3.7 years of sports training background, had 4.3 ± 2.4 years of resistance training experience, and were free of musculoskeletal pain or injury that could compromise testing. After explaining the purpose, procedures, risks, and benefits of the study to potential subjects, written informed consent was obtained before participation. To minimize confounding factors, instructions related to diet and sleep were provided to the subjects before the experiment. On the night preceding each test session, the subjects were asked to keep their usual sleeping habits, with a minimum of 7 hours of sleep. During the period of investigation (in particular, immediately before the experimental session), the subjects were instructed to avoid any known stimulants (e.g., caffeine) or depressants (e.g., alcohol) that could possibly enhance or compromise wakefulness. Moreover, the subjects were requested to maintain their habitual physical activity and avoid strenuous activity the day before and throughout the study. This study was approved by the Ethics Review Committee on Human Research of Waseda University (Approval number: 2020-267).

Procedures

Familiarization and Preliminary Measurements. During the preliminary session i.e., 72–144 hours before the priming or control conditions, the subjects were familiarized with SJ (unloaded and loaded), CMJ (unloaded and loaded), DJ from 20, 40, and 60 cm heights and jump squat with 40% estimated 1RM. Furthermore, the subjects performed 3 repetitions of DJ from 20, 40, and 60 cm with adequate (60–90 seconds) rest to determine the optimum drop height for the main trials. The optimum drop height was defined as that, which had the greatest RSI (= DJ height/ground contact time). This approach was selected based on available literature, stressing the importance of identifying the individualized optimum drop height for maximizing neuromuscular adaptations (2). Accordingly, the average optimum drop height was 33.0 ± 9.5 cm. After 3 minutes of rest, the half squat 1RM of each subject was measured. Maximum strength of the lower body was measured using a knee angle of 90° because half squat strength is strongly correlated with jump performance (43). The half squat 1RM testing was performed by having the subjects complete a series of warm-up sets (5 repetitions at 30% estimated 1RM, 3 repetitions at 50% estimated 1RM, 2 repetitions at 70% estimated 1RM, and 1 repetition at 90% estimated 1RM) each separated by 3 minutes of recovery, after which a series of maximal lift attempts were performed until a 1RM was obtained. The subjects performed the downward movement of the half squat exercise until the lowest point, which was determined by a beep sound activated when photocell beam was interrupted by the posterior portion of the thigh at a knee angle of 90°. The knee angle was measured at the lowest point of movement of the half squat using a smart phone video camera at 240 Hz (iPhone 7, Apple Inc, Cupertino, CA). Two-dimensional motion analysis was performed on the data obtained using Kinovea Video Analysis Software (v. 0.8.15). The knee angle was calculated by digitizing using the reflection markers attached to the greater trochanter, lateral epicondyle of the femur, and lateral malleolus. The line connecting the greater trochanter with the lateral epicondyle of the femur, and the line connecting the lateral epicondyle of the femur with the lateral malleolus created an angle that was defined as the knee angle. Trials in which the subjects did not reach a knee angle of less than 90° of flexion were excluded from the analysis.

Measurement of Squat Jump, Countermovement Jump, and Drop Jump Performance. For the SJ and CMJ, the subjects held a 0.1-kg plastic bar for 0% 1RM and a 20-kg barbell loaded with the
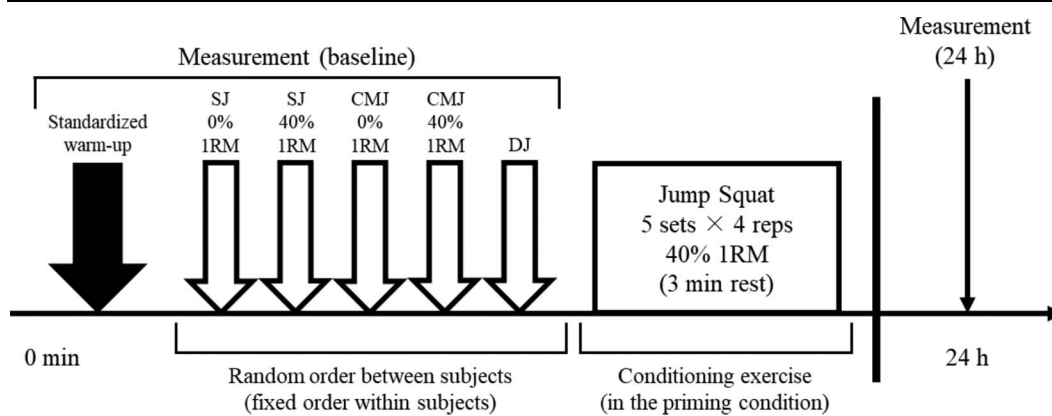
Figure 1. Procedures involved in the priming and control conditions. SJ = squat jump; CMJ = countermovement jump; DJ = drop jump; RM = repetition maximum.

appropriate weight plates for 40% 1RM. During the SJ, the subjects were instructed to lower into a half squat position at the desired knee angle, indicated by a beep sound as discussed earlier, and hold this position for 2 seconds. Upon instruction, they then jumped as high as possible while performing no previous countermovement. We checked the waveform data obtained from the force plate during the trial to confirm that no previous countermovement was used. Regarding the CMJ, the subjects were instructed to perform the downward movement as deep as SJ and countermovement as fast as possible and jump as high as possible. For the DJ, the subjects were asked to step off a wooden box at a set height without lifting their center of gravity and land on the force plate with both legs. In addition, they were instructed to rebound and immediately jump as high as possible after contact while minimizing ground contact time. Their hands were kept akimbo throughout the entire jump, while a straight body position during landing and take-off was encouraged. They were also required to land back on the force plate.

Priming and Control Conditions. The subjects performed a standardized warm-up that included 3 minutes of jogging, 10 minutes of dynamic stretching (40), and 2 repetitions each of SJ and CMJ at submaximal effort (approximately 80% of maximal effort) followed by 2 repetitions each of SJ and CMJ with 0% 1RM, 20 kg, 30% 1RM, and 40% 1RM with adequate (60–90 seconds) rest. After completing the standardized warm-up, the subjects performed 3 repetitions each of SJ and CMJ at 0% 1RM with 90 seconds of rest, 3 repetitions each of SJ and CMJ at 40% 1RM with 2 minutes of rest, and 3 repetitions of DJ with 90 seconds of rest. The order of these jump performance measurements was randomized between subjects and fixed within subjects. After an additional 2 minutes of rest, the subjects performed the conditioning exercise, which included 5 sets of jump squats at

continuous 4 repetitions (without stopping the movement) per set and 40% 1RM, with 3 minutes of rest (39). The subjects were instructed to perform the jump squat exercise with a countermovement to a knee angle of 90°. The subjects had a mean load of 57.0 ± 11.5 kg at 40% 1RM. In the priming condition, the subjects' jump performance was measured 24 hours after the intervention. In the control condition, jump performance was measured 24 hours after baseline measurements without performing the conditioning exercise. All jump performance measurements were made at the same time of day between 14:30 and 19:00 hours to avoid diurnal variations. To avoid dehydration, ad libitum drinking was permitted, with environmental conditions having been controlled (18–22°C and 20–60% humidity) during all testing sessions.

Measurement Equipment and Data Analyses. All jumps (SJ, CMJ, and DJ) were performed on a single force platform (0625, ACP, AccuPower; AMTI, Watertown, MA) that sampled vertical ground reaction force (GRF) data at a frequency of 1,000 Hz using an analog-to-digital converter (EIRBZ22002369; CON-TEC Co Ltd, Osaka, Japan) and subsequently recorded them to a personal computer. Signals from the force plate were filtered by a 50-Hz low-pass, zero-phase-lag finite impulse response filter. Before each jump regarding SJ and CMJ, the subjects were weighed over 3 seconds with the external load laid on their shoulders to determine the total system weight (sum of body weight and external weight). The start of the jump was defined as the time point 30 ms before the vertical GRF exceeded the threshold (the total system weight ± 5 *SD*) (25). For each jump, the system's center of mass (COM) velocity was calculated through the trapezoid rule (22), whereas the net GRF was calculated as the amount of force exceeding the system weight divided by the system mass to determine acceleration. Acceleration

Table 1						
Summary of the descriptive statistics for the entire cohort, and those in stronger and weaker groups.*†						
	Age (y)	Height (cm)	BM (kg)	HSQ1RM/BM (kg·kg^{-1})	Sports training background (y)	Resistance training experience (y)
Entire cohort ($n = 20$)	22.4 ± 1.5	172.2 ± 5.0	71.3 ± 7.4	1.99 ± 0.30	11.6 ± 3.7	4.3 ± 2.4
Stronger group ($n = 10$)	22.4 ± 1.6	170.0 ± 3.9	73.2 ± 6.8	2.22 ± 0.23‡	12.2 ± 4.4	4.5 ± 2.7
Weaker group ($n = 10$)	22.4 ± 1.4	174.3 ± 5.1	69.4 ± 7.4	1.76 ± 0.16	11.0 ± 2.6	4.0 ± 1.9

*BM = body mass; HSQ1RM = half squat one-repetition maximum.
†Values are presented as mean $\pm$ *SD*.
‡Significantly ($p \leq 0.05$) different from the weaker group.

Table 2
Changes in performance variables during the SJ with 0% 1RM, CMJ with 0% 1RM, and DJ from the optimum drop height.*†

Jump	Variable	Stronger group (n = 10)						Weaker group (n = 10)					
		Priming			Control			Priming			Control		
		Baseline	24 h	d	Baseline	24 h	d	Baseline	24 h	d	Baseline	24 h	d
SJ	Jump height (m)	0.33 ± 0.02	0.32 ± 0.03	−0.04	0.33 ± 0.02	0.33 ± 0.02	−0.34	0.35 ± 0.04	0.34 ± 0.04	−0.11	0.34 ± 0.04	0.34 ± 0.05	0.01
	CON mean force (N·kg⁻¹)	16.86 ± 0.95	16.80 ± 0.76	−0.07	17.31 ± 0.55	16.93 ± 1.18	−0.41	17.11 ± 1.34	16.69 ± 1.26	−0.32	17.02 ± 1.14	17.13 ± 1.09	0.10
	CON mean velocity (m·s⁻¹)	1.05 ± 0.14	1.05 ± 0.10	−0.06	1.11 ± 0.10	1.05 ± 0.17	−0.39	1.09 ± 0.16	1.05 ± 0.14	−0.22	1.11 ± 0.13	1.11 ± 0.14	0.01
	CON mean power (W·kg⁻¹)	19.26 ± 2.70	19.09 ± 2.12	−0.07	20.46 ± 1.63	19.38 ± 3.38	−0.41	20.24 ± 3.53	19.31 ± 3.39	−0.27	20.24 ± 3.01	20.42 ± 3.19	0.06
CMJ	Jump height (m)	0.37 ± 0.04	0.39 ± 0.04‡§	0.45	0.38 ± 0.04	0.38 ± 0.04	−0.06	0.37 ± 0.03	0.37 ± 0.04	−0.10	0.36 ± 0.04	0.37 ± 0.04	0.05
	ECC RFD (N·kg⁻¹·s⁻¹)	60.53 ± 14.32	72.06 ± 12.78‡	0.85	68.49 ± 13.38	68.11 ± 11.64	−0.03	56.66 ± 15.46	55.18 ± 18.90	−0.09	55.30 ± 13.84	51.50 ± 19.51	−0.22
	ECC mean velocity (m·s⁻¹)	−0.68 ± 0.08	−0.74 ± 0.05‡	−0.98	−0.71 ± 0.05	−0.72 ± 0.04	−0.05	−0.67 ± 0.06	−0.67 ± 0.13	−0.05	−0.66 ± 0.11	−0.65 ± 0.11	0.06
	ECC mean power (W·kg⁻¹)	−6.68 ± 0.78	−7.30 ± 0.45‡	−0.98	−6.99 ± 0.47	−7.02 ± 0.39	−0.05	−6.54 ± 0.62	−6.59 ± 1.27	−0.05	−6.44 ± 1.04	−6.37 ± 1.13	0.06
	ECC peak displacement (m)	−0.36 ± 0.04	−0.36 ± 0.03	−0.20	−0.35 ± 0.03	−0.36 ± 0.02	−0.41	−0.35 ± 0.03	−0.36 ± 0.03	−0.11	−0.35 ± 0.03	−0.36 ± 0.03	−0.39
	CON mean force (N·kg⁻¹)	19.72 ± 1.22	20.07 ± 0.98‡§	0.32	19.94 ± 1.24	19.74 ± 1.01‖	−0.20	19.44 ± 1.24	19.18 ± 1.18	−0.21	19.26 ± 1.11	18.97 ± 1.06	−0.27
	CON mean velocity (m·s⁻¹)	1.61 ± 0.10	1.66 ± 0.09‡	0.52	1.64 ± 0.08	1.64 ± 0.07	−0.05	1.55 ± 0.10	1.54 ± 0.14	−0.11	1.55 ± 0.10	1.52 ± 0.12	−0.24
	CON mean power (W·kg⁻¹)	29.20 ± 3.13	30.50 ± 2.76‡§	0.44	29.91 ± 2.77	29.56 ± 2.55	−0.13	28.20 ± 3.00	27.68 ± 3.43	−0.16	27.79 ± 2.74	27.19 ± 2.91	−0.21
DJ	RSI (m·s⁻¹)	1.32 ± 0.29	1.31 ± 0.29	−0.04	1.37 ± 0.35	1.33 ± 0.29	−0.10	1.39 ± 0.18	1.29 ± 0.13	−0.62	1.35 ± 0.14	1.32 ± 0.14	−0.26

*SJ = squat jump; RM = repetition maximum; CMJ = countermovement jump; DJ = drop jump; d = Cohen's d effect size [(24 h − baseline)/SDboth]; CON = concentric; ECC = eccentric; RFD = rate of force development; RSI = reactive strength index (DJ height/ground contact time).

†Values are presented as mean ± SD.

‡Significantly different from baseline in the priming condition (p ≤ 0.05).

§Significantly different from 24 hours in the control condition (p ≤ 0.05).

‖Significantly different from baseline in the control condition (p ≤ 0.05).

was numerically integrated to provide instantaneous COM velocity, which was, in turn, numerically integrated to provide instantaneous COM displacement. COM power was calculated as the force multiplied by the system velocity at each time interval. The beginning of the eccentric (ECC) phase was defined as the instant at which the vertical COM velocity dropped below 0 m·s⁻¹. The end of ECC and the beginning of the concentric (CON) phase was identified as the instant at which the vertical COM velocity exceeded 0 m·s⁻¹ after the start of ECC phase. The end of the CON phase was identified as the instant at which the vertical GRF decreased below 20 N after the start of the CON phase. The ECC and CON mean forces, velocities, and powers were calculated during the ECC and CON phases, respectively. The rate of force development (RFD) was determined between the minimum and maximum force during the ECC phase. For the DJ, the contact and take-off of the DJ were defined as the time points, at which the vertical GRF exceeded or decreased below the threshold (i.e., 20 N), respectively. The DJ height was determined using the flight time method (39).

For the force-velocity profiling of SJ and CMJ, the mean vertical force developed by the lower limbs during push-off (i.e., CON phase) and the corresponding mean COM vertical velocity were determined using the equations validated by Samozino et al. (33) and Jiménez-Reyes et al. (16). The total system weight, push-off distance, and jump height data substituted for Samozino's equations (33) were derived from the vertical GRF. The push-off distance was identified as the distance of the vertical COM displacement from the start to the end of the CON phase. The jump height was calculated following the take-off velocity procedure (22). The force and velocity data obtained under 2 different loads (0 and 40% 1RM) were modeled using a least squares linear regression model to determine the force-velocity profile: $\bar{F}(\bar{v}) = \bar{F}_0 - a\bar{v}$, where $\bar{F}_0$ represents the theoretical maximum force (i.e., force-intercept) and $\bar{v}_0$ is the theoretical maximum velocity (i.e., velocity-intercept) corresponding to the slope of the linear force-velocity relationship ($S_{Fv} = -\bar{F}_0/\bar{v}_0$) (32,33). The average push-off distance during 0 and 40% 1RM was used in the analyses. The theoretical maximum power ($\bar{P}_{max}$) was calculated as $\bar{P}_{max} = \bar{F}_0 \cdot \bar{v}_0/4$. This two-point method was used to minimize stimuli and fatigue during performance testing based on distant loads validated by García-Ramos et al. (10) to be a quick and less fatigue-inducing procedure for testing the force-velocity profile.

Temporal phase analyses of the 0% 1RM CMJ were conducted through the following process (26). Force, velocity, and power values were normalized from the beginning of the ECC phase to the end of the CON phase in 1% intervals (from 0 to 100%). The values of force, velocity, and power attained at the closest time point (1 ms) to each percentage of the CMJ duration were individually determined for each subject. Afterward, the ensemble average of the CMJ values at baseline and after 24 hours were compared in the stronger and weaker groups at each time point (i.e., at each % of the CMJ duration) during the priming condition.

All force and power values were normalized to the subject's body mass. Average values over 3 jump repetitions were analyzed given that the average CMJ height provides better sensitivity for monitoring neuromuscular status compared with the highest CMJ height (4).

Visual Analog Scales. The subjects completed visual analog scales (VAS, 100-mm scale) to record perceptions of fatigue and muscle soreness during the priming and control sessions (38).
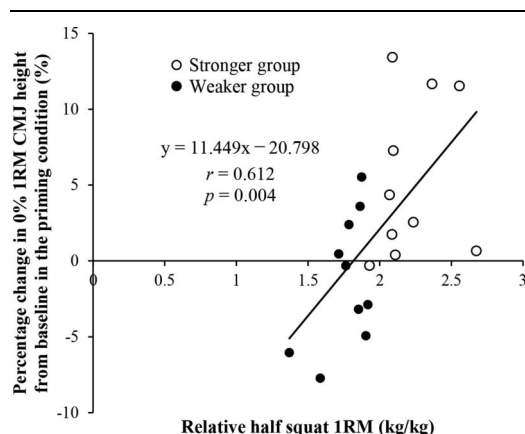
Figure 2. Relationship between the percentage change in 0% 1RM CMJ height after resistance priming and lower body strength (*n* = 20). RM = repetition maximum; CMJ = countermovement jump.

Table 3

Relationship between the percentage change (Δ) in jump height and Δ ECC phase variables during 0% 1RM CMJ in the priming condition (*n* = 20).*†

Correlation between:	*r*	*p*	Effect
Δ CMJ height and:			
Δ ECC RFD	0.561	0.010‡	Large
Δ ECC mean velocity	0.704	0.001‡	Large
Δ ECC mean power	0.704	0.001‡	Large

*ECC = eccentric; RM = repetition maximum; CMJ = countermovement jump; RFD = rate of force development.
†The statistical significance of the relationship (*p* value) and strength of the correlations (Effect) is displayed.
‡Significant (*p* ≤ 0.05) correlation.

Immediately after subjects arrived, the VAS for fatigue was anchored with verbal descriptors ranging from "not fatigued at all" to "extremely fatigued," on which subjects were asked to rate their general feeling of "fatigue and tiredness." The VAS for muscle soreness was anchored with verbal descriptors ranging from "no soreness" to "extremely sore," on which subjects were asked to rate their "muscle soreness and pain in the entire lower extremities during performing CMJ with bodyweight" immediately after they performed 2 repetitions of CMJ at 0% 1RM during the standardized warm-up.

Statistical Analyses

Values are presented as mean ± *SD*. Statistical analyses were performed using SPSS (IBM SPSS Statistics Version 27), with *p* ≤ 0.05 indicating statistical significance. Normality was tested using the Shapiro-Wilk test. The reliability (intraclass correlation coefficient [ICC]) of each test was determined by comparing the test results achieved during the control condition at baseline to those achieved after 24 hours. The ICCs for performance variables ranged from 0.709 to 0.978 (see Table, Supplemental Digital Content 1, which demonstrates reliability of measurement for the performance variables, http://links.lww.com/JSCR/A293). Relationships between percentage changes in variables in the priming condition and relative half squat 1RM were calculated using the Pearson correlation coefficient (*r*). The strength of the correlation coefficient was determined based on the classifications outlined by Cohen (5), where *r* values of 0.10–0.29, 0.30–0.49, and ≥0.5 indicated a small, moderate, and large effect, respectively. After initial analysis of combining subject data and subsequent finding regarding the significantly positive relationship between the individual half squat 1 RM-to-body mass ratio (i.e., relative half squat 1RM) and percentage change in 0% 1RM CMJ height in the priming condition, the median split technique was used to separate subjects into 2 groups (9,34): the stronger group with the highest relative half squat 1RM (1.93–2.67 kg·kg^{-1}; *n* = 10) and the weaker group with the lowest relative half squat 1RM (1.37–1.92 kg·kg^{-1}; *n* = 10). Independent-sample *t*-tests were used for comparisons between the stronger and weaker groups. No differences in age, height, body mass, sports training background, and resistance training experience

were observed between the stronger and weaker groups (Table 1). Because the comparison of performance between the groups was not the purpose of the current study, a two-way (2 conditions × 2 time points) repeated measure analysis of variance (ANOVA) was used to examine the differences in performance outcomes for each group (34). When a significant main effect or interaction was observed (*p* ≤ 0.05), the least significant difference post-hoc tests were performed. Effect sizes were estimated by calculating the partial eta-squared (η^2) values (small: 0.01–0.059, moderate: 0.06–0.137, and large >0.138). For pairwise comparisons, effect size was determined by Cohen's *d* (small: >0.2, medium: >0.5, large: >0.8). After subsequent findings regarding the improvement in 0% 1RM CMJ performances in the priming condition, paired-samples *t*-tests were used to compare the force-, velocity-, and power-time curves at each time point (i.e., from 0 to 100%) between baseline and after 24 hours during 0% 1RM CMJ in the priming condition for each group.

Results

Jump Performance During Squat Jump With 0% 1 Repetition Maximum, Countermovement Jump With 0% 1 Repetition Maximum, and Drop Jump

No significant difference in SJ performance (jump height, CON mean force, CON mean velocity, and CON mean power), CMJ performance (jump height, ECC RFD, ECC mean velocity, ECC mean power, ECC peak displacement, CON mean force, CON mean velocity, and CON mean power) and DJ RSI at baseline was observed between the priming and control conditions for the stronger and weaker groups. Two-way ANOVA revealed a significant interaction (jump height: *p* = 0.015, η^2 = 0.501; ECC RFD: *p* = 0.044, η^2 = 0.379; CON mean force: *p* = 0.009, η^2 = 0.549; CON mean power: *p* = 0.009, η^2 = 0.553) and that time had a significant main effect (ECC mean velocity: *p* = 0.018, η^2 = 0.478; ECC mean power: *p* = 0.018, η^2 = 0.478; CON mean velocity: *p* = 0.044, η^2 = 0.379) on CMJ performance with 0% 1RM in the stronger group. Post-hoc comparisons showed that in the priming condition for the stronger group, CMJ performance after 24 hours was greater than that at baseline for jump height (+0.02 m, 95% confidence interval [CI]: 0.01–0.03 m, *p* = 0.010), ECC RFD (+11.53 N·kg^{-1}·s^{-1}, 95% CI: 1.84–21.22 N·kg^{-1}·s^{-1}, *p* = 0.025), ECC mean velocity (−0.06 m·s^{-1}, 95% CI: −0.11 to −0.02 m·s^{-1}, *p* = 0.009), ECC mean power (−0.62 W·kg^{-1}, 95% CI: −1.05 to −0.20 W·kg^{-1}, *p* = 0.009), CON mean force (+0.35 N·kg^{-1}, 95% CI: 0.02–0.69 N·kg^{-1}, *p* = 0.039),

CON mean velocity ($+0.05$ m·s^{-1}, 95% CI: 0.01–0.09 m·s^{-1}, $p = 0.017$), and CON mean power ($+1.30$ W·kg^{-1}, 95% CI: 0.41–2.19 W·kg^{-1}, $p = 0.009$). The same analysis showed that in the priming condition for the stronger group, CMJ performance after 24 hours was better than that after 24 hours in the control condition for jump height ($+0.01$ m, 95% CI: 0.00–0.03 m, $p = 0.042$), CON mean force ($+0.34$ N·kg^{-1}, 95% CI: 0.05–0.62 N·kg^{-1}, $p = 0.027$), and CON mean power ($+0.94$ W·kg^{-1}, 95% CI: 0.14–1.74 W·kg^{-1}, $p = 0.026$). In the control condition for the stronger group, CMJ CON mean force after 24 hours was lower than that at baseline (-0.34 N·kg^{-1}, 95% CI: -0.62 to -0.05 N·kg^{-1}, $p = 0.027$). No significant interaction or main effects for condition or time was observed on SJ performance (jump height, CON mean force, CON mean velocity, and CON mean power), CMJ performance (jump height, ECC RFD, ECC mean velocity, ECC mean power, ECC peak displacement, CON mean force, CON mean velocity, and CON mean power) and DJ RSI in the weaker group, and SJ performance (jump height, CON mean force, CON mean velocity, and CON mean power), CMJ ECC peak displacement, and DJ RSI in the stronger group (Table 2). Furthermore, the percentage change (Δ) in jump height was significantly correlated with Δ ECC phase variables during 0% 1RM CMJ in the priming condition and relative half squat 1RM (Table 3 and Figure 2).

Force-, Velocity-, and Power-Time Curves During 0% 1 Repetition Maximum Countermovement Jump in the Priming Condition

Significant differences in force from 12 to 30% and 42–64% of normalized time; velocity from 20 to 47% and 57–100% of normalized time; and power from 15 to 28%, 40–54%, and 61–93% of normalized time were observed between baseline and after 24 hours during 0% 1RM CMJ in the priming condition for the stronger group. No significant changes were observed in the force-, velocity-, and power-time curves during 0% 1RM CMJ for the weaker group in the priming condition (Figure 3).

Force-Velocity Profile

No significant difference in the force-velocity profile ($\bar{F}_0$, $\bar{v}_0$, $\bar{P}_{max}$, and S_{Fv}) during SJ and CMJ at baseline was observed between the priming and control conditions for the stronger and weaker groups. Two-way ANOVA revealed a significant interaction (CMJ $\bar{P}_{max}$: $p < 0.001$, $\eta^2 = 0.727$) and that time had a significant main effect (CMJ $\bar{v}_0$: $p = 0.026$, $\eta^2 = 0.442$; CMJ S_{Fv}: $p = 0.021$, $\eta^2 = 0.466$) on CMJ performance in the stronger group. Post-hoc comparisons showed that CMJ $\bar{v}_0$ ($+0.32$ m·s^{-1}, 95% CI: 0.12–0.52 m·s^{-1}, $p = 0.006$) and CMJ $\bar{P}_{max}$ ($+1.55$ W·kg^{-1}, 95% CI: 0.74–2.37 W·kg^{-1}, $p = 0.002$) were greater but CMJ S_{Fv}
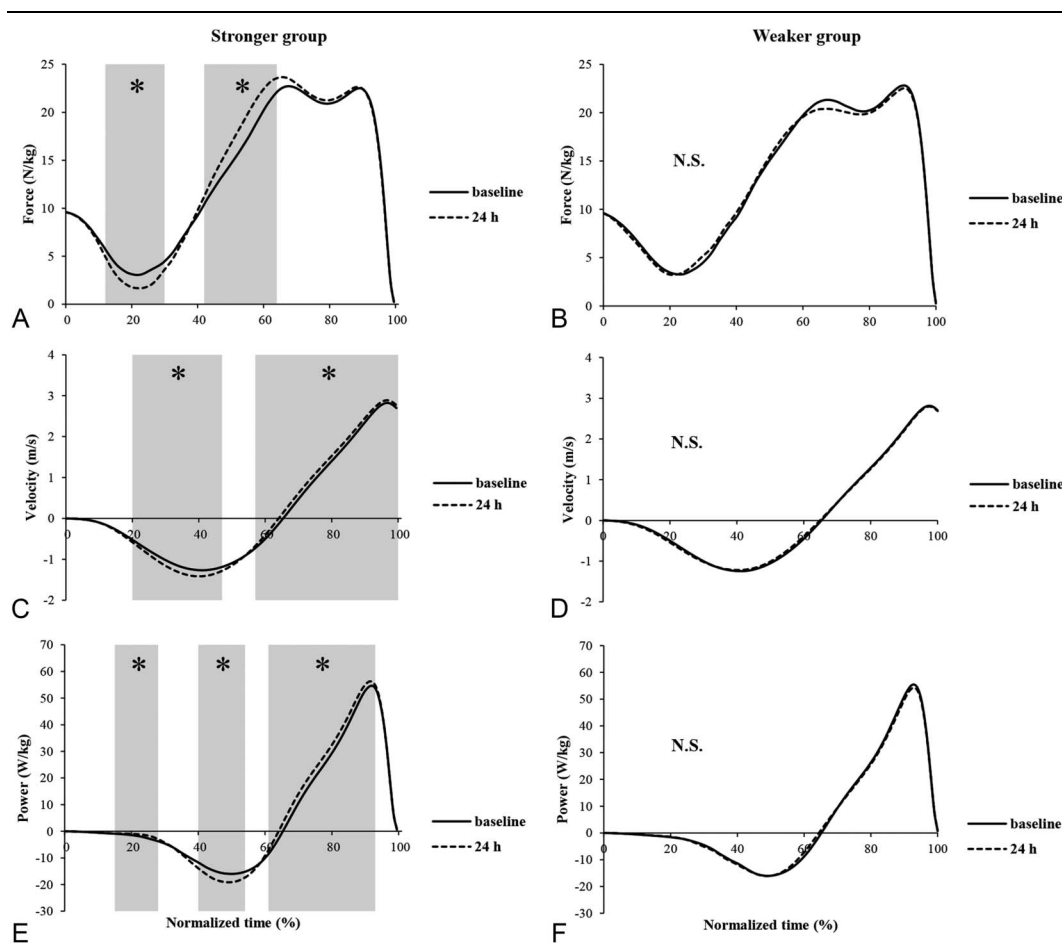

Figure 3. Changes in the force-time (A and B), velocity-time (C and D), and power-time (E and F) curves during 0% 1RM CMJ in the priming condition (A, C, and E = stronger group; B, D, and F = weaker group). *Significant ($p \leq 0.05$) difference between baseline and 24 hours in (A) force from 12 to 30% and 42–64%; (C) velocity from 20 to 47% and 57–100%; (E) power from 15 to 28%, 40–54%, and 61–93%. N.S. = not significant; RM, repetition maximum; CMJ, countermovement jump.

Table 4
Changes in the force-velocity profile variables during SJ and CMJ.*†

Jump	Variable	Stronger group (n = 10)						Weaker group (n = 10)					
		Priming			Control			Priming			Control		
		Baseline	24 h	d	Baseline	24 h	d	Baseline	24 h	d	Baseline	24 h	d
SJ	$\bar{F}_0$ (N·kg⁻¹)	34.81 ± 5.83	36.13 ± 5.03	0.24	36.13 ± 3.66	36.07 ± 5.69	−0.01	33.83 ± 4.08	32.71 ± 4.00	−0.28	34.12 ± 5.10	34.17 ± 2.86	0.01
	$\bar{v}_0$ (m·s⁻¹)	2.72 ± 0.50	2.58 ± 0.40	−0.31	2.58 ± 0.23	2.62 ± 0.37	0.11	2.98 ± 0.67	3.04 ± 0.70	0.09	2.84 ± 0.44	2.77 ± 0.29	−0.19
	$\bar{P}_{max}$ (W·kg⁻¹)	23.05 ± 1.64	22.87 ± 1.47	−0.12	23.15 ± 1.12	23.11 ± 1.23	−0.03	24.68 ± 3.45	24.43 ± 3.83	−0.07	23.81 ± 2.04	23.62 ± 2.56	−0.08
	S_{Fv} (N·s⁻¹·kg⁻¹·m⁻¹)	−13.65 ± 5.03	−14.64 ± 4.34	−0.21	−14.21 ± 2.61	−14.42 ± 4.62	−0.06	−12.14 ± 3.84	−11.42 ± 3.37	0.20	−12.52 ± 3.71	−12.49 ± 1.99	0.01
CMJ	$\bar{F}_0$ (N·kg⁻¹)	34.99 ± 3.20	33.63 ± 3.67	−0.40	35.44 ± 4.74	34.70 ± 3.90	−0.17	35.04 ± 3.87	33.42 ± 4.00	−0.41	34.04 ± 4.16	33.97 ± 4.20	−0.02
	$\bar{v}_0$ (m·s⁻¹)	2.80 ± 0.25	3.12 ± 0.42‡	0.92	2.90 ± 0.50	2.90 ± 0.48	−0.02	2.82 ± 0.28	2.97 ± 0.39	0.43	2.84 ± 0.26	2.87 ± 0.35	0.11
	$\bar{P}_{max}$ (W·kg⁻¹)	24.40 ± 2.47	25.95 ± 2.71‡§	0.60	25.32 ± 2.92	24.85 ± 2.86	−0.16	24.55 ± 2.13	24.54 ± 2.54	0.00	24.01 ± 2.27	24.15 ± 2.29	0.06
	S_{Fv} (N·s⁻¹·kg⁻¹·m⁻¹)	−12.65 ± 1.93	−11.10 ± 2.47‡§	0.70	−12.77 ± 3.57	−12.36 ± 2.67	0.13	−12.65 ± 2.63	−11.58 ± 2.70	0.40	−12.21 ± 2.80	−12.17 ± 3.24	0.01

*SJ = squat jump; CMJ = countermovement jump; d = Cohen's d effect size [(24 h − baseline)/SD both]; $\bar{F}_0$ = theoretical maximum force; $\bar{v}_0$ = theoretical maximum velocity; $\bar{P}_{max}$ = theoretical maximum power ($\bar{F}_0 \cdot \bar{v}_0 / 4$); S_{Fv} = slope of linear force-velocity relationship ($-\bar{F}_0/\bar{v}_0$).

†Values are presented as mean ± SD.

‡Significantly different from baseline in the priming condition ($p \leq 0.05$).

§Significantly different from 24 hours in the control condition ($p \leq 0.05$).

($+1.56$ N·s⁻¹·kg⁻¹·m⁻¹, 95% CI: 0.38–2.73 N·s⁻¹·kg⁻¹·m⁻¹, $p = 0.015$) was lower after 24 hours compared to those at baseline in the priming condition for the stronger group. The same analysis showed that in the priming condition for the stronger group, CMJ $\bar{P}_{max}$ ($+1.10$ W·kg⁻¹, 95% CI: 0.32–1.88 W·kg⁻¹, $p = 0.011$) was greater but CMJ S_{Fv} ($+1.26$ N·s⁻¹·kg⁻¹·m⁻¹, 95% CI: 0.00–0.52 N·s⁻¹·kg⁻¹·m⁻¹, $p = 0.050$) was lower after 24 hours than those after 24 hours in the control condition. No significant interaction or main effects for condition or time was observed for the force-velocity profile during SJ for the stronger and weaker groups, for CMJ $\bar{F}_0$ for the stronger group (Table 4).

Visual Analog Scales

No significant difference in perceptions of fatigue and muscle soreness at baseline was observed between the priming and control conditions for the stronger and weaker groups. Two-way ANOVA revealed that time had a significant main effect on fatigue and muscle soreness in the weaker (fatigue: $p = 0.028$, $\eta^2 = 0.433$; muscle soreness: $p = 0.003$, $\eta^2 = 0.639$) and stronger groups (muscle soreness: $p = 0.029$, $\eta^2 = 0.426$). Post-hoc comparisons showed that fatigue after 24 hours was greater than that at baseline in the priming condition for the weaker group ($+10.60$ mm, 95% CI: 3.25–17.95 mm, $p = 0.010$). Muscle soreness after 24 hours was significantly greater than that at baseline in the priming condition: for the stronger group ($+10.10$ mm, 95% CI: 1.37–18.83 mm, $p = 0.028$) and for the weaker group ($+9.70$ mm, 95% CI: 3.93–15.47 mm, $p = 0.004$). In the control condition, muscle soreness after 24 hours was also significantly greater than that at baseline: for the stronger group ($+7.70$ mm, 95% CI: 0.39–15.01 mm, $p = 0.041$) and for the weaker group ($+9.70$ mm, 95% CI: 2.11–17.29 mm, $p = 0.018$). No significant interaction or main effects for condition or time was observed for fatigue in the stronger group (Table 5).

Discussion

The current study primarily aimed to examine whether resistance priming was effective in enhancing jump performance in both stronger and weaker individuals and determine its effect on the force-velocity profile. As hypothesized, the main findings of this study suggested that the CMJ performances in the stronger individuals specifically improved 24 hours after the priming session, whereas none of jump performances in the weaker individuals showed improvement. Moreover, the priming session enhanced the theoretical maximum velocity (i.e., $\bar{v}_0$) during the CMJ, but not the theoretical maximum force (i.e., $\bar{F}_0$) in the stronger individuals, whereas none of the force-velocity profile variables in the weaker individuals exhibited enhancement.

The present study showed that resistance priming using jump squat exercise improved CMJ performance in strong individuals after 24 hours (Table 2), a finding consistent with that previous research (39). The study by Tsoukos et al. (39) study involved relatively strong subjects (body mass: 80.7 ± 8.6 kg, half squat 1RM: 163 ± 29 kg) also found that a low-volume power-type training session, exactly the same as the conditioning exercise used herein, improved CMJ height after 24 hours. Therefore, resistance priming using low-load jump squat exercise seems to be effective in enhancing CMJ performance after a day among strong athletes.

In addition, the percentage change in CMJ height induced by resistance priming was positively correlated with the individual's relative half squat strength (Figure 2), which can be attributed to

Table 5

Changes in the perceptions of fatigue and muscle soreness measured using visual analog scales (100-mm scale).*†

	Stronger group (n = 10)						Weaker group (n = 10)					
	Priming			Control			Priming			Control		
	Baseline	24 h	d	Baseline	24 h	d	Baseline	24 h	d	Baseline	24 h	d
Fatigue (mm)	12.30 ± 11.44	18.50 ± 13.79	0.49	12.00 ± 9.82	13.80 ± 10.16	0.18	12.70 ± 6.94	23.30 ± 11.57‡	1.11	13.30 ± 12.81	16.00 ± 9.95	0.24
Muscle soreness (mm)	9.70 ± 13.34	19.80 ± 17.44‡	0.65	9.20 ± 13.49	16.90 ± 15.41§	0.53	9.00 ± 8.59	18.70 ± 13.55‡	0.86	8.00 ± 6.88	17.70 ± 13.55§	0.90

*d = Cohen's d effect size [(24 h − baseline)/SD both].
†Values are presented as mean ± SD.
‡Significantly different from baseline in the priming condition ($p \leq 0.05$).
§Significantly different from baseline in the control condition ($p \leq 0.05$).

fatigue resistance. Harrison et al. (14) proposed that the difference between potentiation and fatigue can determine performance improvements associated with resistance priming. Although potentiation is considered a positive factor for neuromuscular performance enhancement, fatigue is considered a negative factor (29). Several previous studies (3,9,35) have suggested that strong individuals have a more developed fatigue resistance compared to weak individuals. In fact, the current study showed that the stronger group did not experience a significant increase in fatigue perception with resistance priming (Table 5). The aforementioned findings therefore suggest that strong individuals may experience less fatigue from resistance priming and are thus more likely to show improved neuromuscular performance.

Another possible factor for the improved performance of the stronger group in the current study may be explained using muscle fiber composition. Tesch and Karlsson (37) reported that those with greater maximal isometric one-leg strength tended to have a greater percentage of fast twitch fibers. Therefore, it is likely that subjects in the stronger group had a higher percentage of fast twitch fibers (37). In addition, Hamada et al. (11) suggested that human muscles with a higher percentage of type II fibers exhibit greater potentiation. Consequently, it is possible that the performance enhancement identified in the stronger group was because of greater potentiation caused by a higher percentage of fast twitch fibers. However, because the muscle fiber composition of the subjects was not assessed in the current study, any relationship involving muscle fiber composition and performance enhancement using resistance priming needs to be directly investigated in future studies.

Our findings showed that resistance priming using loaded jump squats improved CMJ performance but not the SJ and DJ performance, which could be attributed to the different biomechanics of each jump. Accordingly, the CMJ uses the stretch-shortening cycle (SSC), whereas SJ uses the CON-only movement (41). Regarding CMJ and DJ, Bobbert et al. (1) revealed that knee and ankle joint moments and power output showed larger values during DJ than during CMJ and that hip joints moments exhibited larger values during CMJ than during DJ. Furthermore, as CMJ uses slower SSC (41) and DJ uses faster SSC (1), the speed of SSC also differs between CMJ and DJ. Loaded jump squat, the conditioning exercise used herein, is more biomechanically similar to CMJ than to SJ and DJ (1,24). Harrison et al. (14) suggested that the priming activity must be specific to the neuromuscular pathway of the subsequent performance to maximize potentiation of performance. These findings suggest that resistance priming has the potential to improve subsequent neuromuscular performance in a movement-specific manner.

The specific improvement in CMJ performance may also be attributed to the force-, velocity-, and power-time curves (Figure 3). Given that stronger individuals exhibited increased unloading and rapid force development during the ECC phase of the CMJ following resistance priming, they experienced enhancement in ECC RFD, ECC velocity, and ECC power (Figure 3 and Table 2), which may be associated with improvements in CMJ performance (8,21). Laffaye and Wagner (21) reported that ECC RFD was positively and primarily correlated ($r = 0.50$, $p = 0.001$) with vertical jump performance (i.e., CMJ height). Furthermore, Cormie et al. (8) found that changes in ECC variables (e.g., average ECC power) were significantly correlated with changes in a variety of CON

performance variables (e.g., average CON power) after 10 weeks of jump squat training. The current study showed no enhancement in SJ performance, which is CON-only, whereas CMJ performances during the CON phase (i.e., CON mean force, velocity, and power) were enhanced as the ECC phase variables improved (Table 2). Moreover, the percentage change (Δ) in CMJ height was significantly correlated with Δ ECC phase variables in the priming condition (Table 3), which could have been attributed to improvements in SSC function, such as muscle-tendon interactions (18). Assuming that muscle-tendon interactions were optimized during the ECC phase in the CMJ, less fascicle lengthening and greater tendon lengthening would have likely occurred (18). These alterations may contribute to increased force generation of muscle fibers by maintaining the state close to the optimal length (18), which would consequently promote greater force development and translation of the greater negative momentum (i.e., ECC velocity) into higher forces during the ECC phase. Furthermore, the smaller lengthening of fascicles would also allow muscle fibers to work at a relatively slow velocity, which would cause higher force generation during the CON phase because of length-tension and force-velocity relationship (18,42). Although the shortening velocity of the muscle-tendon unit would be increased, this may largely depend on the increased shortening velocity of the tendon (18). These changes may improve the CON phase variables (i.e., mean force, velocity, and power) in the CMJ (Figure 3 and Table 2). Incidentally, given the lack of a significant change in the ECC peak displacement observed in the current study (Table 2), it is unlikely that the length of muscle-tendon unit would have changed at the end of the ECC phase. In summary, our results suggested that improvements in SSC function during the ECC phase mainly contributed to the enhancement in CMJ performance after resistance priming. Furthermore, considering this suggestion and the aforementioned study (1) showing that CMJ is a hip-dominant exercise, greater improvement in SSC function can also be expected to occur around the hip than around the knees and ankles. Such specific adaptation may explain the lack of improvement in SJ and DJ performances, although future research is needed to directly investigate this matter.

Regarding the force-velocity profile during the CMJ in the strong individuals, resistance priming using low-load (40% 1RM) jump squats enhanced the ability of force output at high (i.e., $\bar{v}_0$), but not low velocity (i.e., $\bar{F}_0$), subsequently causing an improvement in $\bar{P}_{max}$ and reduction in S_{Fv} (Table 4). This finding is similar to that presented in a previous study using the same priming exercise (39). Accordingly, Tsoukos et al. (39) reported that resistance priming using low-load jump squats elicited improvements in no-load CMJ height (i.e., performance at high velocity) but not maximum leg press isometric force (i.e., performance at null velocity), which could have been attributed to velocity specificity of resistance training (19). Kawamori and Newton (19) suggested that both the intention to move explosively and actual movement velocity are important and crucial stimuli that elicit high-velocity-specific neuromuscular adaptations to resistance training. The light-load jump squat used herein was performed at maximal intended velocity and relatively high movement velocity (24). Therefore, resistance priming performed in the current study would have more strongly stimulated the ability of force output at high rather than low velocity. In other words, resistance priming using low-load

ballistic exercise seems to improve neuromuscular performance specifically at high velocity.

Practical Applications

The current study suggested that resistance priming using low-load ballistic exercise (i.e., jump squats) specifically enhanced ballistic performance after 24 hours in stronger individuals, but not in weaker individuals. In addition, this effect was only observed in force output capacity at high-movement velocity during CMJ, suggesting that performance enhancement using resistance priming is influenced by an individual's strength level and is movement- and velocity-specific. These findings indicated that (a) stronger individuals seem to benefit substantially from resistance priming, whereas weaker individuals may not experience performance enhancement and (b) practitioners should prescribe resistance priming using light-load jump squats 24 hours before the competition for athletes required to produce higher force outputs at higher velocity (e.g., jumpers) rather than those required to produce higher force outputs at lower velocity (e.g., powerlifters and football linemen).

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