Power Versus Strength–Power Jump Squat Training: Influence on the Load–Power Relationship

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ABSTRACT

CORMIE, P., G. O. McCAULLEY, and J. M. McBRIDE. Power Versus Strength–Power Jump Squat Training: Influence on the Load–Power Relationship. *Med. Sci. Sports Exerc.*, Vol. 39, No. 6, pp. 996–1003, 2007. **Purpose:** The purpose of this investigation was to compare the impact of power training and strength–power training on the load–power relationship in the jump squat. **Methods:** Twenty-six recreationally trained male subjects were randomly assigned to either a power training group (P; $N = 10$), a strength–power training group (SP; $N = 8$), or a control group (C; $N = 8$). The P group trained for 12 wk, performing seven sets of six jump squats with the optimal load for maximal power output (body mass only, no external load), whereas the SP group performed five sets of six jump squats with the optimal load for maximal power output (body mass only, no external load) and three sets of three squats with 90% of their one-repetition maximum (1RM). Work performed by the P and SP subjects was equivalent throughout the 12 wk of training. Peak power relative to body mass (PP), jump height (JH), peak force relative to body mass (PF), and peak velocity (PV) during the jump squat were examined across loads of body mass (BM) and 20, 40, 60, and 80 kg at week 0 (baseline) and after weeks 6 (midtest) and 12 (posttest). **Results:** After training, the P group significantly increased PP at BM and 20 kg, whereas the SP group significantly increased PP output across all loading conditions. Similarly, jump height was significantly increased by the P group at the lighter loads (BM, 20 kg, and 40 kg) and by the SP group at all loads. Whereas significant improvements in maximal power output and jump height at BM were observed in both P and SP groups, no difference in maximal power output or maximal jump height existed between the training groups. **Conclusion:** Combined lower-body strength–power training is effective as power training for improving maximum jump height and maximum power output in the jump squat, and it is more effective than power training at producing all-around (i.e., from BM to 80 kg) improvements in the load–power relationship of the jump squat. **Key Words:** JUMP HEIGHT, FORCE, VELOCITY, COMBINED TRAINING

Force and velocity share an inverse relationship and act concurrently in all muscular actions. As the velocity of a movement increases, so does the velocity of muscle shortening; as a result, the force that can be generated during that movement decreases (9). Similarly, as the resistance increases, the ability to generate force during concentric contraction is enhanced, with a simultaneous decrease in the velocity of muscle shortening. Because of this association, termed the force–velocity relationship, power output varies according to the load applied to a movement (9). The major emphasis of research focusing on muscular power has been to determine the most effective training intensity for maximizing adaptation and crossover to dynamic athletic performance (11,14,24–27). Kaneko et al. (11) examined four loading conditions (expressed as a percentage of maximum isometric strength (P_o)): 0% P_o, 30% P_o, 60% P_o, or 100% P_o. After 12 wk of training the elbow flexors, it was reported that the most efficient load for improving maximum velocity (V_{max}) was 0% P_o, whereas training with 100% P_o was the most effective load for improving maximum force output (F_{max}). Maximal power production was improved in the 30% P_o (the load that maximized power output; i.e., the optimal load) group to a greater extent than the other intensities (11). In a follow-up investigation, it was determined that training the elbow flexors using combined loads of 30 and 100% P_o improved maximal power output to a greater extent than training with 30 and 0% P_o (24). On the basis of these observations, three major theories have been developed regarding the type of training intensity that elicits the greatest improvement in muscular power: optimal-load training (power training), heavy-load training (strength training), and combined training (strength–power training).

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Performing lifts with the load that maximizes peak power output, the optimal load (approximately 30% of maximal dynamic strength (MDS = 1RM + body mass − shank mass) for the jump squat, which is equivalent to 0% of 1RM, or body mass only (13,22); shank mass equivalent to 12% of body mass (18)), permits individuals to train at velocities similar to those encountered in actual on-field movement. Power training with the optimal load has been shown to promote all-around improvements in the force–velocity relationship (i.e., increased V_{max} and F_{max}) that translate into increased maximal power output (11). Several investigations have indicated that training at the optimal load is more effective at improving maximal power production and dynamic athletic performance (various jumping, sprinting, and agility tests) than other loading conditions (7,14,27). Häkkinen et al. (7) report that explosive body-weight-jump training (equivalent to approximately 30% of MDS) resulted in a 21% increase in jump height after 6 months of training, whereas heavy resistance training (70–120% 1RM in the squat) resulted in a reduced improvement in jump height of 7%. Furthermore, the beneficial training effects of using light loads that elicit high movement velocity and rate of force development (RFD) to improve power output is an observation common throughout the literature (6–8,10,16,17). Thus, power training using the optimal load has been advised previously for maintaining specificity and maximizing improvements in peak power output (11,15,21).

Strength training using heavy intensities (80–100% MDS) results in improvements in maximal force output (11). Through improving F_{max}, the force generated at any given velocity is increased after training, leading to enhanced power output throughout the loading spectrum (11). Although few studies have illustrated that heavy resistance training is more efficient at increasing maximum power output than explosive resistance training with light loads, ample research has highlighted the direct impact of increased strength levels on power production (7,14,16,27). Moss et al. (16) report significant improvements in peak power across the loading spectrum after training the elbow flexors with 90% of 1RM, in addition to a 15.2% improvement in 1RM. Furthermore, high correlations reported between strength and maximal power output support the theory that maximum force output plays a major role in the training adaptations involved with increasing the production of muscular power (1,16,22).

The premise of combined strength–power training incorporates high-velocity movements associated with power training to maximize improvements in V_{max} with heavy-load strength training to enhance F_{max}. Changes to the force–velocity relationship resulting from increasing both V_{max} and F_{max} are theorized to be additive and lead to a greater improvement in maximal power output than either strength or power training alone (23,24). In an examination of the elbow flexors, Toji et al. (24) have observed that combined strength–power training (100 and 30% of maximum isometric force) resulted in a significantly greater improvement in maximum power than combined velocity–power training (0 and 30% of maximum isometric force). The strength–power training was more effective because of a significant improvement in V_{max} and F_{max} in comparison with an improvement in V_{max} only for the velocity–power group (24). Harris et al. (8) compared the effects of high-force (strength; 80–85% of 1RM), high-power (power; 30% of max isometric force), and combined (strength–power) lower-body training programs on a variety of performance measures. Both the high-power and combined groups improved peak power and jump height during a vertical jump, whereas the combined strength–power group also improved 10- and 30-yd sprint performance and squat 1RM (8). It is important to note, however, that no evidence of work performed by the training groups was provided by either Toji et al. (24) or Harris et al. (8); thus, it is difficult to delineate whether the loading parameters or the work performed contributed to their observations. When comparing power and strength–power training programs in which equal work was performed, it is hypothesized that combined strength–power training may elicit a greater enhancement in maximal power output attributable to improvements in both V_{max} and F_{max}.

Previous studies comparing different types of power training are limited by the fact that the work performed during training is not equivalent between groups. Furthermore, although examinations of the elbow flexors have compared power versus strength–power training programs, no previous study has examined the impact on the load–power relationship in a movement commonly used by coaches to improve athletic performance (24). Thus, the purpose of this investigation was to address these limitations while comparing the effects of power training and strength–power training on maximal jump height and the load–power relationship in the jump squat.

METHODS

Subjects. Twenty-six recreationally trained male subjects completed all the requirements of this investigation. The subjects were recruited on the basis of their ability to perform a squat with proficient technique, and their previous training history. The subjects were randomly assigned to either a power training group ($N = 10$), a strength–power training group ($N = 8$), or a control group ($N = 8$). Subject characteristics for each of the groups are outlined in Table 1. The participants were notified about the potential risks involved and gave their written informed consent, approved by the institutional review board at Appalachian State University.

Study design. This investigation used a randomized, longitudinal design and was conducted over a period of 12 wk. Subjects were randomly assigned to one of three groups: 1) power (P), where training sessions involved jump

TABLE 1. Subject characteristics of the power, strength–power, and control groups.

	Power	Strength–Power	Control
Age (yr)	22.1 ± 3.2	20.5 ± 1.1	20.0 ± 2.9
Height (cm)	176.7 ± 8.4	174.8 ± 8.7	175.7 ± 4.5
Weight (kg)	81.6 ± 18.8	79.8 ± 15.4	85.5 ± 24.0
Body fat (%)	16.7 ± 8.1	15.2 ± 3.4	15.7 ± 7.3
Squat 1RM (kg)	107.5 ± 21.8	119.4 ± 25.0	116.3 ± 30.3
Squat-to-weight ratio	1.4 ± 0.3	1.5 ± 0.3	1.4 ± 0.3

Values expressed as mean ± standard deviation.

squats with the optimal load (body mass only (13,22)); 2) strength–power (SP), in which subjects were trained using heavy squats in addition to jump squats with the optimal load for maximal power output (body mass only (13,22)); or 3) control (C), which involved no training. Subjects completed three training sessions in 14 d during the first 6 wk, and they progressed to training twice per week after the midtesting session, in adherence with the overload principle (19). An average of 18.3 and 17.9 training sessions were completed by the P and SP training groups, respectively. All groups were tested before commencing training (baseline), after 6 wk of training (midtest), and after 12 wk of training (posttest). The testing sessions were conducted 4–7 d after the previous training session and assessed maximal strength (1RM and isometric squat) and power output in the jump squat across a variety of loads (body mass, and 20, 40, 60, and 80 kg).

Training programs. The training sessions involved a 5-min bicycle warm-up followed by two sets of six jump squats at approximately 70% of maximum jump height. Subjects in the P group then performed seven sets of six maximal-effort jump squats, separated by 3-min rests. Jump squats were performed at the load that maximized peak power output (body mass only; approximately 30% of maximal dynamic strength or 0% of 1RM) (13,22). Subjects were instructed to perform each repetition as explosively as they could, to maximize power output (2). Intensity was modified for each session so that an audible beep was heard by subjects during jumps that reached 98% of the maximal power output of their previous training or testing session. The SP subjects performed five sets of six maximal-effort jump squats under the same resting and loading conditions. The instructions provided and the manner in which intensity was adjusted were consistent with those of the P group. After the final set of jump squats, three sets of three squats were performed at 90% of 1RM and separated by 3 min of rest. The work during each training session was calculated as the product of displacement and force from the beginning of the eccentric phase to the point at which subjects returned to their standing position after the jump squat or squat. Eccentric, concentric, and total (i.e., eccentric plus concentric) work performed by the P and SP subjects was equivalent throughout the 12 wk of training (Table 2). As a limitation of the current investigation, it must be noted that through the equalization of work, these training programs may not have provided the optimal stimulus to maximize adaptations for both power and strength training.

Testing procedures. The testing protocol, which was consistent throughout the course of this investigation, was initiated by a 5-min bicycle warm-up. Maximal isometric strength was assessed by an isometric squat test performed at a 100° knee angle (test–retest reliability was consistently $r \geq 0.98$ in our laboratory) (3). After 10 min of rest, vertical jump performance was assessed, with adequate rest allocated between trials (2 min). Maximal dynamic strength was then examined using a squat 1RM in which the subject performed a series of warm-up sets and several maximal lift attempts until a 1RM was obtained. This protocol has been used extensively in our laboratory for assessment of maximal dynamic strength (4). Adequate recovery was permitted (20 min) before examination of power output in the jump squat across five different intensities: body mass (BM; i.e., no external load), and 20, 40, 60, and 80 kg. These absolute loads are equivalent to 0 ± 0, 19 ± 4, 38 ± 8, 58 ± 12, and 77 ± 16% of baseline 1RM in the P group; 0 ± 0, 17 ± 3, 35 ± 7, 52 ± 10, and 70 ± 14% of baseline 1RM in the SP group; and 0 ± 0, 18 ± 4, 36 ± 9, 55 ± 13, and 72 ± 17% of baseline 1RM in the C group (Table 3). No significant differences in the absolute loads and relative intensities existed between the groups; thus, the use of absolute loads did not distort any of the observed intergroup differences (Table 3). Participants set up for the vertical jump and jump squat in a standing position while holding a barbell across their shoulders. After instruction, subjects initiated the jump squat via a downward countermovement to a visually monitored knee angle of approximately 90°. Participants were instructed to keep constant downward pressure on the barbell throughout the jump and were encouraged to move the resistance as explosively as possible to achieve maximal power output with each trial (2). The bar was not to leave the shoulders of the subject. If these requirements were not met, the trial was repeated. A minimum of two trials at each load were completed, with additional trials performed if incorrect form or submaximal effort was used. Adequate rest was permitted between all trials (3 min). Anthropometric measures (height, weight, and body composition; three-site

TABLE 2. Comparison of eccentric, concentric, and total (total work = eccentric work + concentric work) work completed during weeks 1, 6, and 12.

	Eccentric Work (J)			Concentric Work (J)			Total Work (J)		
	Power	Strength–Power	*P*	Power	Strength–Power	*P*	Power	Strength–Power	*P*
Week 1	43,768 ± 12,573	38,384 ± 10,085	0.34	40,992 ± 10,802	38,964 ± 8475	0.40	84,760 ± 23,179	75,347 ± 18,549	0.40
Week 6	43,563 ± 13,887	40,755 ± 10,448	0.64	41,914 ± 11,130	38,121 ± 9073	0.45	85,478 ± 24,586	78,876 ± 19,250	0.54
Week 12	47,781 ± 14,250	44,575 ± 11,483	0.61	45,883 ± 10,898	41,545 ± 8847	0.38	93,664 ± 21,834	86,120 ± 20,257	0.46
Sum	135,112 ± 37,941	123,714 ± 31,491	0.51	128,790 ± 32,445	116,630 ± 26,017	0.40	263,902 ± 68,229	240,344 ± 57,306	0.45

Sum represents the cumulative work for week 1, week 6, and week 12. The *P* values from statistical tests comparing work between power and strength–power groups are included to indicate that no significant differences in work exist between the training programs.

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TABLE 3. The relative intensities of the absolute loads used during testing for each group.

Group	Relative Intensity of Absolute Testing Loads (% 1RM)				
	0 kg	20 kg	40 kg	60 kg	80 kg
Strength–power (SP)	0 ± 0	17 ± 3	35 ± 7	52 ± 10	70 ± 14
Power (P)	0 ± 0	19 ± 4	38 ± 8	58 ± 12	77 ± 16
P value for SP vs P	—	0.29	0.29	0.29	0.29
Control (C)	0 ± 0	18 ± 4	36 ± 9	55 ± 13	72 ± 17
P value for SP vs C	—	0.68	0.68	0.68	0.68
P value for P vs C	—	0.59	0.59	0.59	0.59

Values expressed as mean ± standard deviation. No significant differences existed between any of the groups.

skinfold: chest, abdomen, and thigh) were assessed at the end of each testing session.

All testing (baseline, mid, and post) was performed with the subjects standing on a force plate (AMTI, BP6001200, Watertown, MA) with the right side of the barbell attached to two linear position transducers (LPT) (Celesco Transducer Products. PT5A-150, Chatsworth, CA). The combined retraction tension of the LPT was 16.4 N; this was accounted for in all subsequent calculations. Analog signals from the force place and LPT were collected for every trial at 1000 Hz using a BNC-2010 interface box with an analog-to-digital card (National Instruments, NI PCI-6014, Austin, TX). LabVIEW (National Instruments, Version 7.1, Austin, TX) was used for recording and analyzing the data. Signals from the two LPT and the force plate underwent rectangular smoothing with a moving average half-width of 12. From laboratory calibrations, the LPT and force plate voltage outputs were converted into displacement and vertical ground-reaction force, respectively. Peak force, velocity, and power were determined as the maximal values achieved during the entirety of the concentric phase of the lift. This data-collection and analysis methodology has been validated previously (5), and test–retest reliability for maximal peak power output in the jump squat was consistently $r \geq 0.95$ in our laboratory. Results have been expressed relative to body mass to allow for comparison with previous literature and for application by coach practitioners.

Statistical analyses. A general linear model with repeated-measures multivariate analysis of variance was used to examine the training effect on performance variables and to determine whether differences existed between the P, SP, and C groups at baseline, mid-, and posttests. Analyses were followed by Bonferroni *post hoc* comparisons. An estimated effect size of $\eta^2 = 0.329$ at an observed power level of 0.749 existed for the comparison of 1RM at week 12 between the P and SP groups. Additionally, an estimated effect size of $\eta^2 = 0.315$ and 0.286 at an observed power level of 0.777 and 0.597 for maximum peak power relative to body mass after training existed for the P and SP groups, respectively.

RESULTS

Strength and body composition. No differences existed between P, SP, and C groups in weight, body composition, 1RM, 1RM:body mass ratio, or isometric squat peak force at baseline testing. After the 12-wk training period, the SP group had significantly greater 1RM and 1RM:body mass ratio in comparison with the P group ($P = 0.01$ and $P = 0.01$ respectively) and 1RM:body mass ratio in comparison to C group ($P = 0.04$). Furthermore, the SP group significantly increased their 1RM ($P < 0.00$), 1RM:body mass ratio ($P < 0.00$), and isometric squat peak force ($P < 0.00$) between baseline and posttests (Table 4).

Power. Peak power relative to body mass (PP) increased from baseline to midtest in the P group at BM ($P = 0.01$) and in the SP group at BM, 40 kg, and 60 kg ($P = 0.01$, $P = 0.05$, and $P = 0.02$, respectively). Significant improvements were observed between baseline and posttests in the P group at the BM and 20-kg loads ($P < 0.00$ and $P = 0.01$,

TABLE 4. Comparison of weight, body composition, and measures of strength across baseline (no training sessions), midtest (week 6) and posttest (week 12) sessions.

	Baseline (Week 0)	Midtest (Week 6)	Posttest (Week 12)	Week 0 to Week 6 Change	Week 0 to Week 12 Change
Weight (kg)					
Power group	81.6 ± 18.8	81.0 ± 19.5	80.9 ± 19.1	−0.6 ± 1.8	−1.1 ± 2.1
Strength–power group	79.6 ± 15.4	79.3 ± 15.3	80.0 ± 14.4	−0.5 ± 1.1	0.2 ± 1.8
Control group	85.5 ± 24.0	—	85.7 ± 22.9	—	0.1 ± 4.3
Body composition (% fat)					
Power group	16.7 ± 8.1	15.6 ± 6.9	15.7 ± 8.2	−1.1 ± 3.4	−1.0 ± 4.0
Strength–power group	15.2 ± 3.4	14.8 ± 3.4	14.8 ± 3.8	−0.4 ± 1.9	−0.4 ± 2.7
Control group	15.7 ± 7.3	—	16.1 ± 8.1	—	0.4 ± 3.1
1RM (kg)					
Power group	107.5 ± 21.8	107.3 ± 22.0	109.3 ± 16.3	−0.3 ± 8.6	1.8 ± 10.5
Strength–power group	119.4 ± 25.0	128.8 ± 25.1	136.3 ± 24.5†‡	9.4 ± 3.2*†	16.9 ± 4.0*†‡
Control group	116.25 ± 30.3	—	117.5 ± 28.7	—	1.3 ± 3.5
1RM:body mass ratio					
Power group	1.4 ± 0.3	1.4 ± 0.3	1.4 ± 0.3	0.0 ± 0.1	0.0 ± 0.1
Strength–power group	1.5 ± 0.2	1.6 ± 0.3	1.7 ± 0.3†‡	0.1 ± 0.1*†	0.2 ± 0.1*†‡
Control group	1.4 ± 0.3	—	1.4 ± 0.3	—	0.0 ± 0.0
Isometric squat peak force (N)					
Power group	2201.8 ± 279.9	2195.6 ± 238.4	2151.5 ± 322.4	−6.2 ± 147.5	−49.3 ± 173.4
Strength–power group	2256.0 ± 585.0	2423.4 ± 439.2	2521.4 ± 524.5	167.3 ± 189.7†	256.3 ± 161.5†‡
Control group	2242.1 ± 516.3	—	2215.9 ± 464.8	—	−26.2 ± 185.6

Values expressed as mean ± standard deviation. * Significant difference from baseline ($P < 0.05$); † significant difference from power group ($P < 0.05$); ‡ significant difference from control group ($P < 0.05$).

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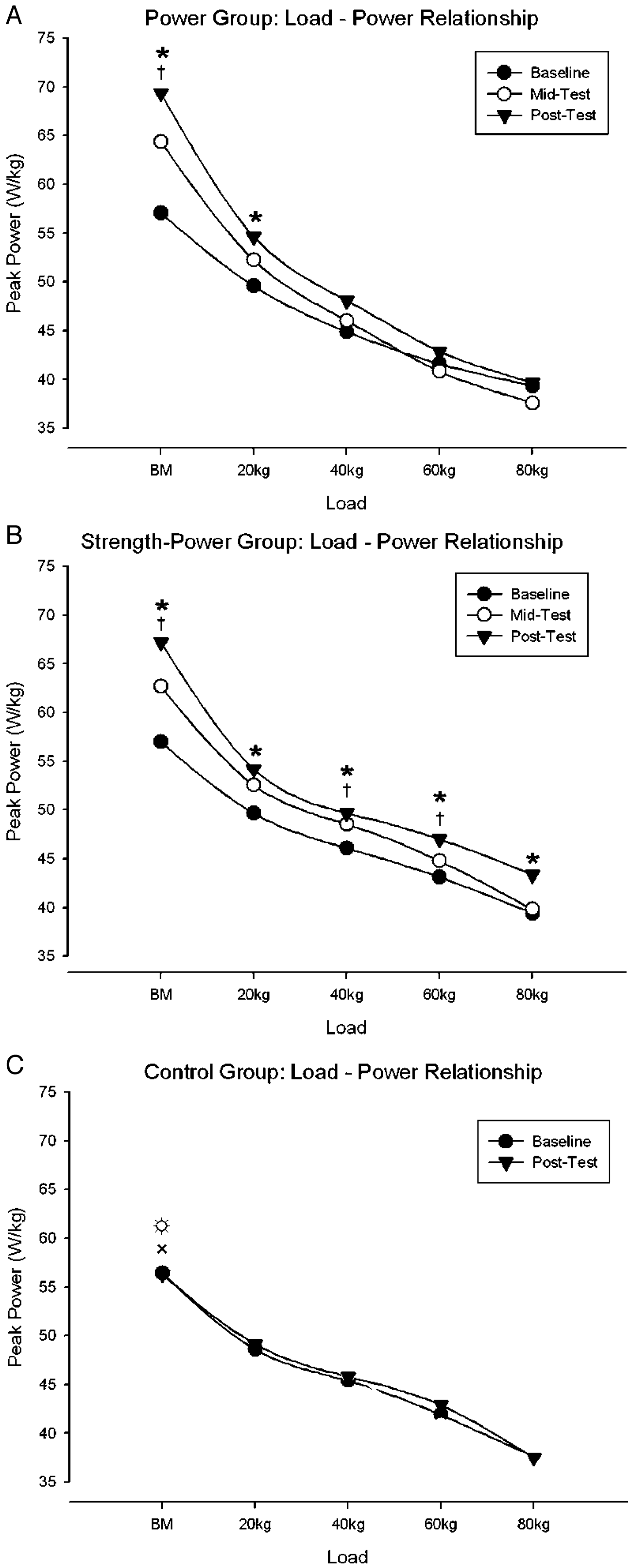

FIGURE 1—The load–power relationship of the power (*A*), strength–power (*B*), and control (*C*) groups at baseline, mid-, and posttests. Peak power expressed relative to body mass. * Significant difference between baseline and posttesting; † significant difference between baseline and midtesting; × significant difference between power and control groups at posttest; ☼ significant difference between strength–power and control groups at posttest.

respectively), whereas the SP group displayed improvements under all loading conditions (BM, and 20, 40, 60, and 80 kg; P = 0.03, P = 0.03, P = 0.01, P = 0.01, and P = 0.01, respectively). No changes in PP were observed in the C group. PP across all intensities was equivalent for all three groups at baseline testing, but significant differences existed at BM after 12 wk of training between the C group and both P (P = 0.02) and SP (P = 0.02) groups (Fig. 1). Similar results occurred for jump height (Fig. 2; C vs P groups: BM P < 0.00, 20 kg P = 0.01, and 40 kg P = 0.03; C vs SP groups: BM P = 0.02, 20 kg P = 0.02, and 40 kg P = 0.05).

Force. Peak force relative to body mass (PF) increased significantly from baseline to posttests in the SP group only at intensities of 60 and 80 kg (Fig. 3; P < 0.00 and P = 0.04, respectively). Whereas no intergroup differences existed in PF at baseline, PF at posttesting was significantly different between P and C groups at BM (P = 0.02) and between SP and C groups at BM, 20 kg, and 80 kg (Fig. 3; P = 0.05, P = 0.04, and P = 0.01, respectively).

Velocity. Peak velocity (PV) significantly increased from baseline to midtesting in the P group at BM and 20 kg loads (P < 0.00 and P = 0.01, respectively) and in the SP group at BM (P < 0.00). Improvements from baseline to posttesting were observed in the P group at BM, 20 kg, and 40 kg (P < 0.00, P < 0.00, and P < 0.01, respectively) and in the SP group at BM and at 20, 40, and 60 kg (P < 0.00, P = 0.01, P = 0.02, and P = 0.03, respectively). No differences in PV existed between P, SP, and C groups at baseline testing; however, the posttest revealed significant differences between the C and P groups and between the SP and C groups at BM (C vs P groups: P < 0.00; C vs SP groups: P = 0.01) and 20 kg (C vs P groups: P = 0.01; C vs SP groups: P = 0.01) intensities (Fig. 4).

DISCUSSION

The results of this investigation yielded to two primary conclusions: 1) SP training was as effective as power training at improving maximum jump height and maximum power output in the jump squat; and 2) SP training elicited greater improvements in jump height and power output through a wide range of loads in the jump squat. These conclusions stem from the specificity of adaptations to the load–power relationship of power and strength–power training.

After training, the P and SP groups both improved maximal power output in the jump squat, but no intergroup differences in maximal power output were evident. This is a common observation throughout the literature (8,24,25). The P group displayed an improvement in peak velocity under light-load conditions similar to previous investigations (11,24). While velocity was not assessed under a zero-loading condition, because the subject always had to accelerate the mass of his body, this adaptation is indicative of an increased V_{max} (11,24). The improved ability to generate high velocities at BM, 20-kg, and 40-kg loads

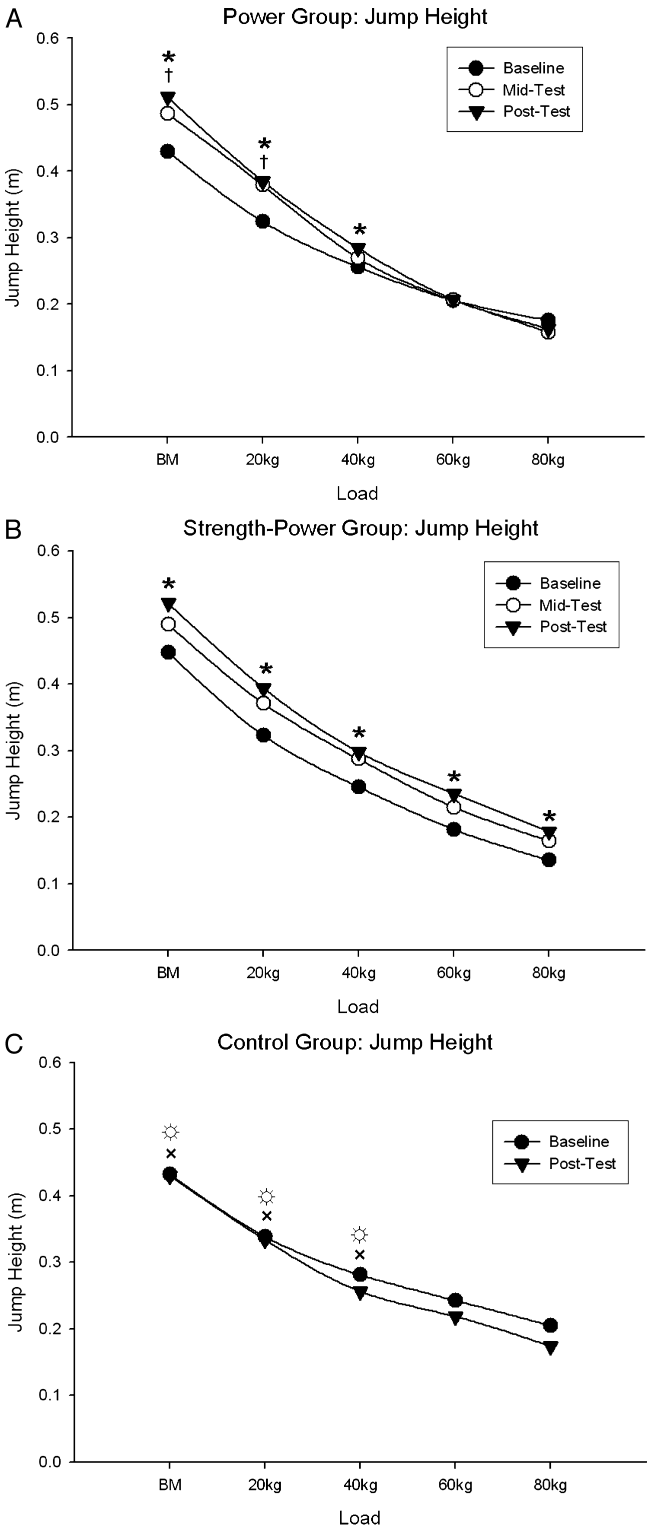

FIGURE 2—Maximal jump height achieved by the power (*A*), strength–power (*B*), and control (*C*) groups across the loading spectrum at baseline, mid-, and posttests. * Significant difference between baseline and posttesting; † significant difference between baseline and midtesting; × significant difference between power and control groups at posttest; ☼ significant difference between strength–power and control groups at posttest.

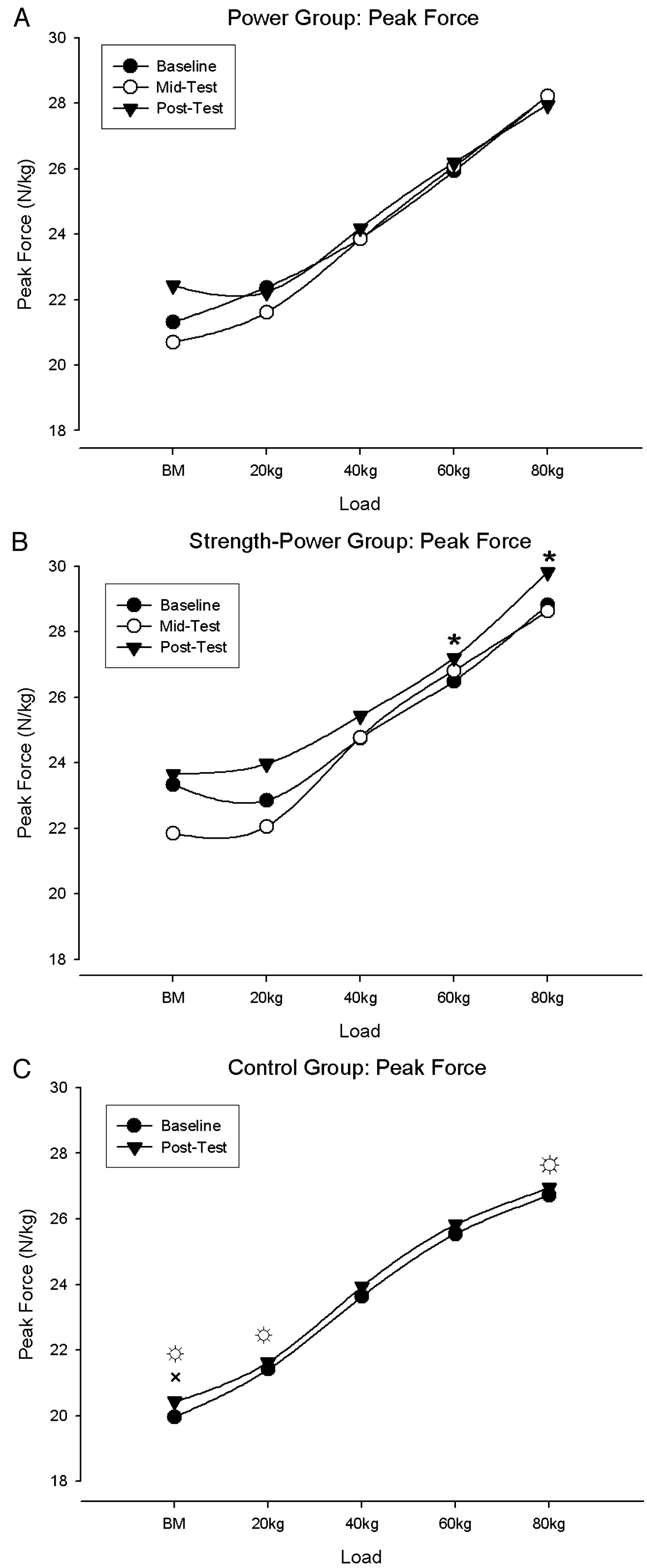

FIGURE 3—Peak force achieved by the power (*A*), strength–power (*B*), and control (*C*) groups across the loading spectrum at baseline, mid-, and posttests. Peak force expressed relative to body mass. * Significant difference between baseline and posttesting; × significant difference between power and control groups at posttest; ☼ significant difference between strength–power and control groups at posttest.

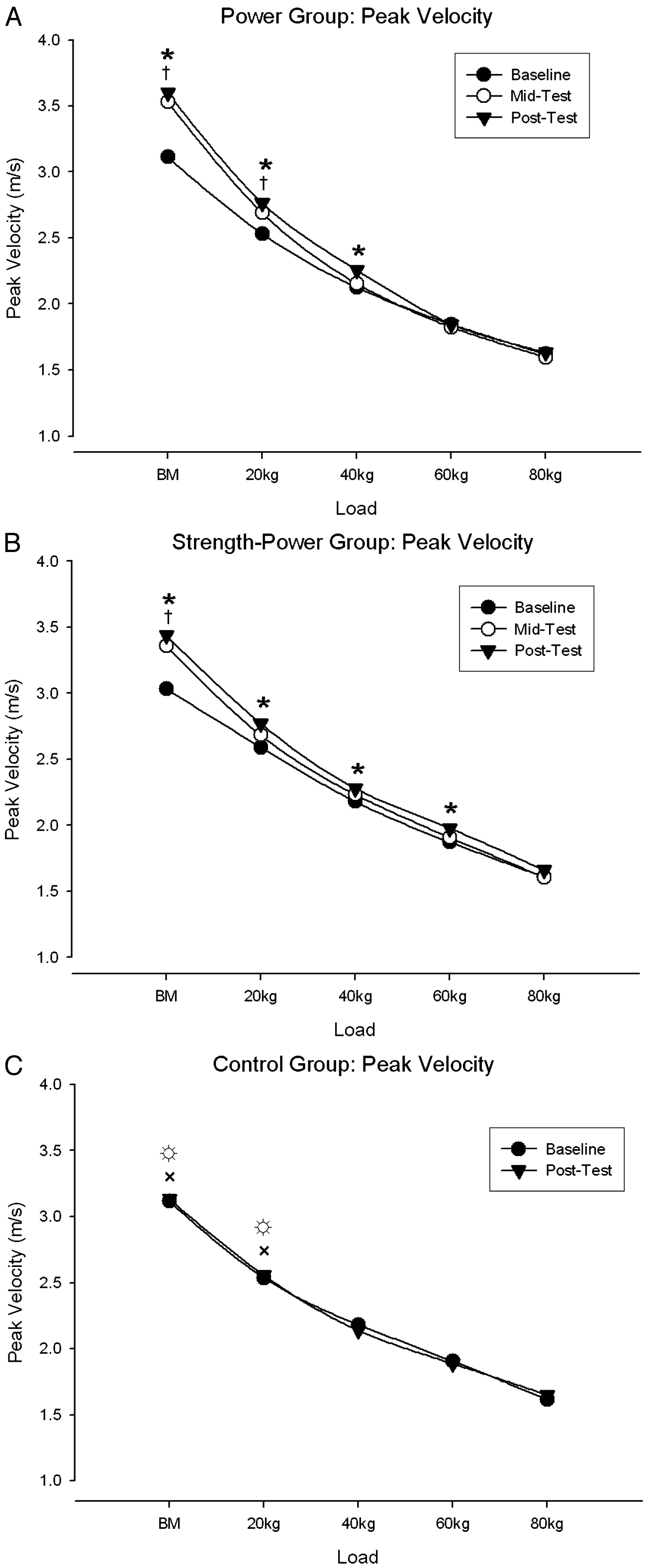

FIGURE 4—Peak velocity achieved by the power (*A*), strength–power (*B*), and control (*C*) groups across the loading spectrum at baseline, mid-, and posttests. * Significant difference between baseline and posttesting; † significant difference between baseline and midtesting; × significant difference between power and control groups at posttest; ☼ significant difference between strength–power and control groups at posttest.

transferred to increased power production and jump height at low intensities (i.e., velocity-specific adaptations). Although a lower volume of power training was conducted by the SP group, the stimulus was sufficient at eliciting similar changes to velocity, maximal power production, and maximal jump height. Therefore, both power-only and combined strength–power training are efficient training modalities for increasing maximal power output and maximal jump height in the jump squat.

Examination of power output throughout the loading spectrum (i.e., BM to 80 kg) revealed varied training adaptations between the P and SP groups. After power training, improvements in maximal power output occurred in the absence of change to F_{max} or maximal dynamic strength (squat 1RM: baseline = 108 ± 22 kg, posttest = 109 ± 16 kg; isometric squat peak force: baseline = 2202 ± 280 N, posttest = 2152 ± 322 N). In contrast, adaptations resulting from strength–power training, in addition to improved maximal power output, included improvements in F_{max} and maximal dynamic strength (squat 1RM: baseline = 119 ± 25 kg, posttest = 136 ± 25 kg ($P < 0.00$); isometric squat peak force: baseline = 2256 ± 585 N, posttest = 2521 ± 525 N ($P < 0.00$)). Consequently, the SP group displayed increased power output across all loading conditions examined, whereas the P group increased power output only at the low intensities (BM and 20 kg). The load–power relationship of both groups changed accordingly, with the shift of the SP group paralleling the pretraining curve, whereas power training resulted in an increased gradient of the posttest load–power curve. As a result of increasing F_{max}, the SP group increased power production across all loads examined. Whereas previous investigations have examined the impact of increasing F_{max} on maximum power output (8,11,24,25), the current study was one of the first to identify the effects of such changes to power output across a variety of loads. These findings suggest that combined strength–power training was more effective than power training at improving power output across a variety of loading conditions and, thus, may be more beneficial for athletes competing in strength–power sports (8,17,22).

The ability of this investigation to elucidate the more effective of the two examined training programs at improving maximal jump height and maximal power output was restricted by the short duration (12 wk) and training status (squat 1RM:body mass ratio = 1.4–1.5) of the subjects used; both of these factors may have affected the nature of the adaptations to the training stimulus. Because of the relatively low training status of the subjects in the current investigation, the observed improvements in maximal power output may have stemmed from neuromuscular adaptations commonly elicited by a new training stimulus (20). However, if the training were extended to a considerably longer period of time (3–6 months), or trained jumpers were used as subjects, it is possible that a theoretical ceiling of adaptation could be reached if power training were continued in the absence of improvements in strength (i.e., a point would be reached at which neuromuscular adaptations would taper) (20). Conversely, it is well established that increasing the mass and cross-sectional area of a muscle results in a more forceful contraction, and that strength training leads to such improvements (12). Thus, maximal power output may be continually improved by strength–power training because of the persistent increases in F_{max} and maximal dynamic strength and the subsequent alterations to the load–power relationship (25). Furthermore, the type and magnitude of adaptations to either power or strength–power training may be influenced by the inherent motor unit characteristics of the individual. Future research involving periodized training programs for a longer (3–6 months) training period and using elite athletes is required to elucidate the specific changes to the load–power relationship after power and strength–power training, as well as the mechanisms driving such changes.

In support of previous hypotheses, combined strength and power training resulted in increased power output for a greater portion of the load–power relationship than power training alone (8,17,22,24). While both types of training allowed for marked improvements in maximal jump height and maximal power output in the jump squat, the overall impact of strength–power training on the load–power, load–force, and load–velocity relationships indicate its superior transference to a wide variety of on-field demands associated with strength–power sports. Additional investigation is required to elucidate the exact mechanisms involved with the different adaptations observed between power and combined strength–power training.

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