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Short-Term Performance Effects of High Power, High Force, or Combined Weight-Training Methods

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ABSTRACT

Some controversy exists concerning the ''transfer of training effect'' from different methods of resistance-training programs to various athletic performance variables. The purpose of this study was to examine the effects of 3 different resistance-training methods on a variety of performance variables representing different portions of the force velocity curve, ranging from high force to high speed movements. Forty-two previously trained men (1 repetition maximum [RM] squat kg per kg body mass $\geq$ 1.4) served as subjects. After a 4-week high-volume training period and the pretests, the subjects were randomly assigned to 1 of 3 groups. The groups were high force (HF; n = 13), high power (HP; n = 16), and a combination training group (COM; n = 13); each group trained 4 d·wk^{-1} for 9 weeks. Group HF trained using 80–85% of their 1RM values. Group HP trained at relative intensities approximating 30% of peak isometric force. Group COM used a combination training protocol. Variables measured pre- and posttraining were the 1RM parallel squat, 1RM 1/4 squat, 1RM midthigh pull, vertical jump (VJ), vertical jump power, Margaria-Kalamen power test (MK), 30-m sprint, 10-yd shuttle run (10-yd), and standing long jump (SLJ). Data were analyzed within groups with t-tests, and the between-group analysis used a group X trials analysis of variance test. The HF group improved significantly in 4 variables ($p \leq 0.05$ for squat, 1/4 squat, midthigh pull, MK), the HP group in 5 variables ($p \leq 0.05$ for 1/4 squat, midthigh pull, VJ, MK, SLJ), and the COM group in 7 variables ($p \leq 0.05$ for squat, 1/4 squat, midthigh pull, VJ, VJP, 10-yd). These results indicate that when considering the improvement of a wide variety of athletic performance variables requiring strength, power, and speed, combination training produces superior results.

Key Words: weight training, resistance training, strength, power, speed

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Introduction

It can be argued that success in many, and likely in most, sports depends upon attainment of some threshold level for maximum strength, power, and speed (25, 36). Success in many sports, such as American football, rugby, and basketball, requires that the athlete be able to master a variety of performance skills (e.g., sprinting, jumping, cutting) that are related to strength, power, and speed parameters. The design of resistance-training programs that can result in beneficial adaptations across a variety of performance skills is a challenging undertaking, especially when dealing with well-trained athletes. In order for resistance training to enhance performance, the isometric and dynamic force–related characteristics (i.e., peak force, rate of force development, etc.) and the power developed must transfer to the skill (33). Considerable information suggests that adherence to the concept of specificity can enhance the transfer of training effect (10, 28, 33). In this context, specificity is concerned with performance- and training-associated kinetic and kinematic factors. Besides movement pattern, one of the more important aspects of specificity of training concerns the speed of movement.

The speed of muscular contraction and movement can be influenced by the design of the training program. The design of the training regimen can be chosen from 1 of 3 commonly used methods of weight training: typical heavy weight training (low speed/high force), high speed/high power weight training, or a combination. Each of these methods is based on theoretical reasons as to their efficacy in producing alterations in performance.

Low speed/high force weight training, in which the relative intensity of training is typically 80% or higher, can result in marked maximum strength gains (4, 10) and has resulted in equal or superior power and speed gains when compared to training with light weights (30, 41). Theoretically, the use of heavy weight

Table 1. Physical characteristics of the subject (mean ± *SEM*).

Group*	Age (y)	Height (cm)	Body mass (kg)	% Body fat
HF (n = 13)	19.4 ± 0.4	179.3 ± 2.2	88.1 ± 2.2	14.2 ± 0.8
HP (n = 16)	18.5 ± 0.2	180.5 ± 1.4	88.5 ± 3.8	13.8 ± 1.7
COM (n = 13)	19.8 ± 1.0	179.6 ± 1.8	86.3 ± 1.5	11.6 ± 1.5

* HF = high force group; HP = high power group; COM = combination group.

training could increase maximum speed and power of movement by 2 mechanisms. First, type II fibers play a primary role in the high force and power outputs associated with dynamic strength/power activities such as sprinting, jumping, and weightlifting movements. The size principle of motor unit recruitment (28) indicates that maximum or near-maximum forces may be necessary to fully recruit and therefore to fully train type II motor units. Second, speed of movement can be enhanced, provided that the training mode results in high rates of muscular force development and provided that there is an intention to make fast movements (3).

High speed/high power weight training involves lifting relatively light weights as quickly as possible. This type of training can result in superior gains in power output (5, 10, 21, 24). High speed/high power training can be particularly important in ballistic exercises (such as jumping and throwing), where the movement is not limited by joint structure (26). Furthermore, training with jumping/squatting movements at optimal power outputs (approximately 30% of the maximum isometric value) has resulted in superior gains in a variety of dynamic athletic movements that depend on speed and power output (40). Theoretically, this type of training is superior in enhancing speed and power because specific high power movements produce very high rates of force development and may provide a superior stimulus for enhancing intra- and intermuscular coordination during high speed/high power movements (9, 10, 29, 33). Additionally, evidence suggests that short-term training with high power contractions (30% of maximum isometric strength) can affect increased contractile speed of the muscle compared to isometric training independent of neural innervation (7). Thus, high power training may influence both neural and contractile mechanisms.

Combination training would use both methods of training. Several authors have suggested that combination training may provide a more complete stimulus for adaptation of muscle and nervous systems, with the end result being a greater transfer of training effect to a wide variety of performance skills, especially those skills relying on power and speed (1, 25, 33, 34, 38). Thus, athletes training with a combination program, such as weightlifters, may produce superior strength/power performance measurements. Support for this concept can be derived from the observations that weightlifters produce power outputs, weighted and unweighted vertical jumps (1, 15, 32), and isometric rates of force development (15) higher than a variety of other strength/power athletes. Additionally, the manner in which the combination program is developed may be important. Evidence suggests that a periodized/varied program, in which the initial concentration is on strength development, with later emphasis on power and speed development, may produce superior results (1, 23, 33, 38, 39).

The purpose of this study was to investigate the effects of high force (≥ 80% 1 repetition maximum [RM]), high power (approximately 30% of peak isometric force), and combination weight training on measures of athletic performance. The measures of athletic performance were the 1RM squat, 1RM 1/4 squat, 1RM midthigh pull, vertical jump, vertical jump power index, Margaria-Kalamen power test, 30-m sprint, 10-yd (9.14-m) shuttle run, and the standing long jump.

Methods

Fifty-one men (1RM parallel squat kg per kg body mass ≥ 1.4) volunteered for the study. The subjects were recruited from the Appalachian State University football team, and all of them had at least 1 year of previous supervised strength training experience. Additionally, all subjects performed the same high-volume (sets of 10 repetitions) weight-training program for 4 weeks prior to the initiation of the study. After the 4-week high-volume training period and the pretests, the subjects were randomly assigned to 1 of 3 groups: high force (HF; n = 17), high power (HP; n = 17), or a combination training group (COM; n = 17). Subjects had to complete ≥90% of the training sessions to be included in the study. Nine subjects dropped out of the study for reasons unrelated to the training or testing. The initial physical characteristics of the 42 subjects who completed the study are shown in Table 1.

1RM testing took place 3 times (Figure 1) during the study (PRE, MID, POST). The subjects performed three 1RM tests: parallel squat (SQ), 1/4 squat (1/4 SQ) and midthigh pull (MTP). All subjects were ac-

PRE ------------- **5 WEEKS** ----------- **MID** ------------- **4 WEEKS** --------- **POST**

ALL MEASURES	1 RM'S	ALL MEASURES

Figure 1. Testing protocol.

customed to the lifts used for testing, as they had previously been used in training. The 1RM tests were measured after the methods of Stone and O'Bryant (39). Test–retest reliability for these 1RM tests was consistently $r \geq 0.92$ in our laboratory. The 1RM tests were performed in the same order each measurement period: (a) The 1RM parallel squat was performed with each subject using his normal foot position. The subjects squatted to a depth at which the top of the thigh was parallel (or lower) to the floor. (b) The 1/4 squat was performed inside a power rack, with the bar adjusted to a height at which the angle of the knee was 135°. The foot position was identical to that used in the squat. In the 1/4 squat, the bar was accelerated as fast as possible; if the weight was light enough, the subject rose onto the balls of his feet. (c) For the pulling movement, the bar was placed on boxes adjusted so that the movement began with the bar at midthigh position. The bar/body position was identical to the "scoop" position in the "double knee bend" of a clean pull. The knee angle was approximately 135°. The subject extended upward as fast as possible using a "jumping movement." If the weight was light, the subject rose onto the balls of his feet and shrugged his shoulders. Rounding of the back was not allowed. For the midthigh pull, testing a full erect posture was used as the completion criteria. Hand grip was slightly wider than shoulder width, with normal foot placement. Height of the bar and positioning of the subject for the 1/4 squat and midthigh pull were standardized for both training and testing.

Five commonly used field tests, with which both the subjects and investigators were familiar, were chosen to further assess athletic performance (31, 38). The field tests were measured (Figure 1) at the beginning and at the end of the 9-week training period ("PRE" and "POST" in the figure). Test–retest reliability has consistently been $r \geq 0.90$ for these tests in our laboratory. The tests were as follows: (a) The countermovement vertical jump (VJ) was measured using a Vertec jump testing device (Sports Imports, Columbus, OH). Jumping height was measured to the nearest half-inch (1.27 cm). Average (AVJP) and peak vertical jump power (PVJP) were estimated using the Harman equation: Average Power (W) = 21.2 × jump height (cm) + 23.0 × body mass (kg) − 1393; Peak Power (W) = 61.9 × jump height (cm) + 36.0 × body mass (kg) − 1822 (18). (b) The standing long jump (SLJ) was measured in meters using a standard tape measure. Each subject stood behind the zero line with the toe of his shoe on the zero mark. The subject jumped as far as possible horizontally, and the distance jumped was marked from the heel. (c) The Margaria-Kalamen stair-climbing test (MK) was performed on stairs with a step ratio of 0.185-m rise to 0.285-m run. From a 6-m running start, subjects were instructed to sprint up the stair steps as fast as possible, with foot placement only on the third, sixth, and ninth steps. Power in watts was determined for each run using estimates of vertical work accomplished from the third to the ninth steps divided by the corresponding time interval (20, 22, 38). The time interval between foot strikes was measured with an accuracy of 0.01 second via switch mats placed on the third and ninth steps that were interfaced with an 8-bit microcomputer-controlled timing device. Work was expressed as a function of vertical displacement (6 steps × 0.185 m rise height = 1.11 m) and gravitational force relative to body mass (9.81 × body mass = Newton's force). (d) A 10-yard (10-yd) shuttle run (9.14 m) was performed in an indoor facility and used to assess agility. Three cones were used for this test: one cone was placed at the goal line, another was placed at the 2.5-yd line (2.29 m), and a third cone at the 5-yd line (4.57 m). The subject began the test facing the sideline at the 2.5-yd line. The subject turned laterally and sprinted as quickly as possible to the cone (on the dominant side), changed direction and sprinted to the far end cone, and then changed direction and ended at the 2.5-yd cone. Time was recorded with a stopwatch to the nearest 0.01 second. (e) The 30-m sprint was timed on a gym floor, using a stopwatch to record time to the nearest 0.01 second. Each testing period required 2 days to complete; on day 1, 1RMs, vertical jump, and anthropometric and skinfold data were collected; on day 2, the field tests were measured. All tests were carried out in the same order at each data collection period. The best of 3 trials for each test was used in the data analysis.

Body composition was assessed using a 7-site skinfold procedure (19). The skinfold sites were the chest, triceps, abdomen, suprailiac, subscapular, midaxillary, and thigh. The mean of 3 readings taken at each site was used in data analysis. Each of a particular site's readings had to be taken within 2 mm of the others, or else another set of measurements was taken. All

Table 2. HF protocol.*†

Exercise	Sets	Repetitions	% 1RM
Monday and Thursday			
Parallel squats	1 WU	5	50
	1 WU	5	65
	5	5	80
Quarter squats	5	5	80
Bench press	1 WU	5	50
	1 WU	5	65
	5	5	80
Push press	5	5	80
Crunches (5–10 kg)	5	5	—
Tuesday and Friday			
Quarter squats	1 WU	5	50
	1 WU	5	65
	5	5	80
Midthigh pulls	5	5	80
SLDL	5	5	80
Bent-over rows	5	5	80
Crunches (5–10 kg)	5	5	—

*HF = high force group; RM = repetition maximum; WU = warm-up sets; COM = combination group; SLDL = semi–straight-legged deadlift.

† The COM group followed the same program for weeks 1 to 5, with the incorporation of a heavy and light day routine (Monday was heavy: >80% 1RM; Thursday was light: 60% 1RM).

Table 3. HP protocol.*†

Exercise	Sets	Repetitions	% 1RM
Monday and Thursday			
Dumbbell squats	1 WU	5	20
	1 WU	5	25
	5	5	30
Quarter squats	5	5	35
Bench press	1 WU	5	20
	1 WU	5	25
	5	5	30
Push press	5	5	30
Crunches (5–10 kg)	5	5	—
Tuesday and Friday			
Quarter squats	1 WU	5	20
	1 WU	5	25
	5	5	35
Midthigh pulls	5	5	45
SLDL	5	5	30
Bent-over rows	5	5	30
Crunches (5–10 kg)	5	5	—

*HP = high power group; RM = repetition maximum; WU = warm-up sets; SLDL = semi–straight-legged deadlift.

skinfold measures at each measurement period were performed by the same experienced investigator.

Training was carried out 4 times per week for 9 weeks. The HF group (n = 13) performed heavy weight training for 9 weeks (Table 2). The HP group (n = 16) trained using a weight approximately equal to 30% of their maximum isometric strength for the squat, 1/4 squat, and midthigh pull (Table 3). The percentage of 1RM values corresponding to 30% of maximum isometric strength was previously established in a similar group of football players (n = 14) using a force plate measurement system. These percentages of 1RM were found to be approximately 30% for the squat, 34% for the 1/4 squat, and 45% for the midthigh pull. The COM group (n = 13) used a protocol that included aspects of both the HF and HP groups (Table 4). The training program was similar to the HF group for the first 5 weeks, with the additional incorporation of heavy and light days. The heavy and light day routine provided both slow and relatively fast movements within the same week. During the final 4 weeks, the COM group switched to a high force/high velocity protocol. The group's 1RMs were retested after 5 weeks to insure that the appropriate percentages were being used.

All groups also performed additional upper body

Table 4. COM Protocol for the last 4 weeks of training.*

Exercise	Sets	Repetitions	% 1RM	
Monday and Thursday			M	TH
Parallel squats	1 WU	5	50	50
	1 WU	5	65	55
	5	5	80	60
Quarter squats	5	5	80	60
Bench press	1 WU	5	50	50
	1 WU	5	65	55
	5	5	80	60
Push press	5	5	80	60
Crunches (5–10 kg)	5	5	—	
Tuesday and Friday			T	F
Dumbbell squats	1 WU	5	20	20
	1 WU	5	25	25
	5	5	30	30
Midthigh pulls	5	5	60	80
SLDL	5	5	60	80
Bent-over rows	5	5	60	80
Crunches (5–10 kg)	5	5	—	

* COM = combination group; RM = repetition maximum; WU = warm-up sets; M = Monday; Th = Thursday; T = Tuesday; F = Friday; SLDL = semi–straight-legged deadlift.

Table 5. Pre- and posttraining values for 1RMs, field tests, and percentage body fat (mean ± *SEM*).†

	HF (n = 13)		HP (n = 16)		COM (n = 13)	
	Pre	Post	Pre	Post	Pre	Post
SQ (kg)‡	132 ± 7	145 ± 8*	138 ± 11	143 ± 7	146 ± 14	163 ± 11*
1/4 SQ (kg)‡§	251 ± 12	336 ± 14*	258 ± 11	298 ± 13*	239 ± 14	329 ± 16*
MTP (kg)‡	184 ± 5	246 ± 9*	195 ± 7	239 ± 11*	188 ± 6	263 ± 9*
VJ (cm)	56.1 ± 0.03	57.4 ± 0.02	59.2 ± 0.01	61.5 ± 0.02*	62.2 ± 0.03	64.0 ± 0.03*
AVJP (W)	1833 ± 102	1889 ± 100	1890 ± 68	1929 ± 73	1911 ± 100	1964 ± 98*
PVJP (W)	4841 ± 235	4965 ± 187	5020 ± 139	5142 ± 151*	5135 ± 201	5270 ± 179*
SLJ (m)	2.32 ± 0.05	2.35 ± 0.05	2.32 ± 0.04	2.40 ± 0.04*	2.46 ± 0.07	2.50 ± 0.07
MK (W)	1808 ± 57	1924 ± 74*	1838 ± 69	1931 ± 84*	1895 ± 81	2080 ± 117*
10-yd (s)†	2.88 ± 0.04	2.91 ± 0.03	3.00 ± 0.04	3.05 ± 0.03	3.04 ± 0.05	2.97 ± 0.06*
30-m (s)	4.43 ± 0.06	4.43 ± 0.05	4.40 ± 0.04	4.43 ± 0.04	4.42 ± 0.08**	4.36 ± 0.08
Body mass	88.5 ± 3.8	89.7 ± 4.1	88.1 ± 2.3	87.7 ± 2.4	86.3 ± 4.5	86.9 ± 4.8
% Body fat	13.9 ± 1.7	13.8 ± 1.9	14.2 ± 0.8	14.9 ± 0.8	11.6 ± 1.6	11.3 ± 1.6

† RM = repetition maximum; HF = high force group; HP = high power group; COM = combination group; SQ = parallel squat; 1/4 SQ = quarter squat in a power rack; MTP = midthigh pull; VJ = vertical jump; AVJP = average vertical jump power; PVJP = peak vertical jump power; SLJ = standing long jump; MK = Margaria-Kalamen stair-climb power test; 10-yd = 10-yard (9.14 m) shuttle run; 30-m = 30-meter sprint.

‡ COM group significantly different from HP group.

§ HF group significant different from HP group.

* Asterisk indicates within-group significant difference ($p < 0.05$).

** Two asterisks indicate within-group significant difference at $p < 0.08$

exercises, providing a comprehensive training program. All groups were instructed and encouraged to perform all movements (except warm-ups) as explosively as possible, and thus the weight used limited the exercise speed. Two or more experimenters were present at each training session to assure adherence to the training protocol.

Within-group differences were analyzed using *t*-tests. Additionally, the data were analyzed using a group X trials analysis of variance test. A *t*-test was used to analyze significant differences between groups. The alpha level was set at $p \leq 0.05$.

Results

Body mass and body composition did not change significantly over the 9 weeks (Table 5). The 1/4 squat and midthigh pull improved significantly over time in all 3 groups. However, the 1RM squat improved only in the HF and COM groups. In the vertical jump, only the HP and COM groups improved significantly. Subjects' peak power, as estimated from the vertical jump, improved significantly in the HP and COM groups; average power showed a significant change only in the COM group. All groups improved significantly in the Margaria-Kalamen stair-climb test for power. For the 10-yd shuttle run, only the COM group improved significantly. Only the HP improved significantly in the standing long jump (Table 5). Between-group comparisons showed that the COM group increased significantly more than the HP group in the 1RM squat, 1RM 1/4 squat, 1RM midthigh pull, and 10-yd shuttle, and that the HF group improved significantly more in the 1RM 1/4 squat than the HP group did (Table 5).

Discussion

The results of this study indicate that increases in a variety of performance variables concerned with maximum strength and power are best accomplished using a training program that combines heavy strength training and high power exercises. Previous studies and reviews (10, 15, 33, 38) indicated that heavy weight training generally resulted in greater improvements at the high force end of the force–velocity curve and that high velocity/ high power training results in greater improvements toward the high velocity end. Conceptually, this would suggest that the transfer of training effect across a wide spectrum of performance measures would reflect the primary adaptation in the force–velocity curve. The results of the present study lend support to this concept. The HF group improved to a greater extent in high force output measures (1RM values), whereas the HP group showed the greatest improvement in power/speed–related movements (i.e., PVJP, MK, SLJ). Several authors (1, 25, 33, 34, 38) hypothesize that training using a combination of high force and high power exercises can result in adaptations encompassing a greater part of the force–velocity curve and therefore a wider variety of performance measures. The results of the present study support this hypothesis in that the COM group improved in a greater number and a wider range of performance tests than the other 2 groups did.

Although weight training can significantly alter body mass and body composition (35), in the present study, no significant differences were noted in any group. The lack of significant change in measures of body composition could be attributed to the initial trained state of the subjects. Baker et al. (2) suggest that an increase in lean body mass (LBM) is the most important mechanism accounting for strength gains in weight-trained individuals. However, the results of this study indicate that substantial increases in maximum strength (1RM values) can be made with little or no increases in LBM. The increase in 1RM values observed may be primarily due to alterations in neural factors or to subtle changes in myosin–myosin ATPase and may be related to the intensity of training (16).

High power training similar to that used in the present study has been shown to have primarily neural effects, with little effect on hypertrophic factors (10, 12, 13). The gains in velocity-related measures, such as the improvement in VJ scores noted in the HP group, likely occurred primarily as a result of neural/elastic component adaptation. From a biomechanical standpoint, the observed increased VJ displacement (with no significant body mass change) resulted from improvements in work accomplished and changes in impulse and are related to increases in takeoff velocity and the resulting improved power output (18). The COM group showed excellent adaptation for both high force (1RM) and high power/high velocity activities (i.e., VJ, PVJP, AVJP, MK, 30-m, 10-yd) with no demonstrable changes in LBM. The adaptations of the COM group to training suggests that neural/elastic component adaptations were responsible for both high force and high velocity effects. However, it is possible that the high power training may have altered muscle contractile properties, resulting in greater contraction speed and power (7) and thus contributing to the observed training adaptations.

In summary, the results of this study suggest that improvement in a wide variety of performance measures encompassing strength, power, and speed parameters is best accomplished using a combination of heavy weight training and high power movements.

Practical Applications

The method of programming the combination of high force and high power training is an important consideration. There is little doubt that in relatively untrained subjects, heavy strength training can improve both maximum strength and power measures resulting from both hypertrophic and neural adaptations (1, 33). The simultaneous improvement in measures associated with both maximum strength and power is not often observed among well-trained subjects as a result of heavy strength training (1, 33). Thus, the positive association between gains in maximum strength and gains in power are largely restricted to the early phases of training. Additionally, heavy strength training with little or no variation that is carried out for long periods (several months) has been shown to result in a diminished rate of isometric force production, power output, and neuromuscular activation as measured by electromyography (10, 12, 13, 14); such training may contribute to an overtrained state (8, 10, 37). These findings suggest that in order to optimize gains in strength and power, the training period should be divided into phases with different goals (1, 10, 11, 33, 38). Studies and observations of weightlifting methods (23, 39), the training of other strength/power athletes (27), and theoretical considerations (1, 10, 27, 33, 38, 39) suggest that in order to maximize high power/velocity movements, a specific order of periodized training should be used. These studies, observations, and theoretical considerations suggest that in sports that require high power/velocity outputs, the early emphasis in training should be more generalized, concentrating on maximum strength development, with the emphasis shifting to more specific exercises that develop power and speed later in the training cycle. This type of general to specific approach was successfully used in the COM group in the present short-term study.

Although there is little objective evidence (17, 36), some authors (6) have criticized weight training, and particularly ballistic training, as being excessively injurious. It should be noted that, among the group of college football players in the present study, no injuries of any type were reported as a result of the training programs used.

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