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Postactivation Potentiation Response in Athletic and Recreationally Trained Individuals

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ABSTRACT

To determine if training status directly impacted the response to postactivation potentiation, athletes in sports requiring explosive strength (ATH; n = 7) were compared to recreationally trained (RT; n = 17) individuals. Over the course of 4 sessions, subjects performed rebound and concentric-only jump squats with 30%, 50%, and 70% 1 RM loads. Jump squats were performed 5 minutes and 18.5 minutes following control or heavy load warm-ups. Heavy load warm-up consisted of 5 sets of 1 repetition at 90% 1 RM back squat. Jump squat performance was assessed with a force platform and position transducer. Heavy load warm-up did not have an effect on the subjects as a single sample. However, when percent potentiation was compared between ATH and RT groups, force and power parameters were significantly greater for ATH ($p < 0.05$). Postactivation potentiation may be a viable method of acutely enhancing explosive strength performance in athletic but not recreationally trained individuals.

Key Words: explosive strength, warm-up, resistance training

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Introduction

Various forms of warm-up exist for practice, training, and competition activities of athletes. The traditional warm-up paradigm involves a brief period of low intensity aerobic-type activity, followed by static stretching and activity-specific movements (19). Research to support these methods, in part and as a whole, is equivocal, suggesting both positive and negative effects (19). As the physiological requirements of activities differ, the type of warm-up should be specific to the task demands. The overall intention of the warm-up should be to acutely maximize performance and reduce risk of injury in the given sport (6, 19). Consequently, in sports requiring explosive strength, performance factors that should be addressed during the warm-up include optimal stiffness of the series elastic component (26, 27) and rapid activation of the contractile apparatus (18).

Heavy resistance training is a component in the long-term preparation of athletes for competition. The primary purpose of chronic heavy resistance training for athletes is typically to increase muscle force production, and subsequently velocity and power expression. Heavy resistance training, when performed in a maximally accelerative pattern, results in long-term improvement in measures of power and explosive force (13). Despite the research focusing on the long-term effects of heavy resistance training, the current understanding of the acute effects is less than comprehensive. On an acute level, it is clear that excessive volume and load may result in fatigue (7), however, scenarios exist in which heavy weight training may enhance performance immediately afterwards (6, 10, 14, 20, 28).

Research in animals using electrically induced tetanization has shown a twofold increase in posttetanus twitch tension (14). This has been termed the posttetanic potentiation effect. Two mechanisms have been proposed to explain this phenomenon. These mechanisms include phosphorylation of the regulatory myosin light chain at the molecular level and reflex electrical activity in the spinal cord (6, 10, 11, 14, 16). Recent evidence has demonstrated that potentiation can be induced through voluntary activation. Known as postactivation potentiation, this effect has been shown to occur under both isometric and dynamic test conditions, typically between 5 to 20 minutes following the stimulus (6, 11, 20). Postactivation potentiation following isometric and dynamic stimuli has been found to increase rate of force development, jumping height, and sprint cycle performance (6, 20, 28).

Table 1. Descriptive statistics of subjects (mean ± *SD*).

Age (y)	Height (cm)	Weight (kg)	% Fat	1 RM (kg)	1 RM : Weight
23.42 ± 2.89	170.15 ± 6.75	70.60 ± 16.06	16.80 ± 6.50	109.38 ± 48.91	1.50 ± 0.45

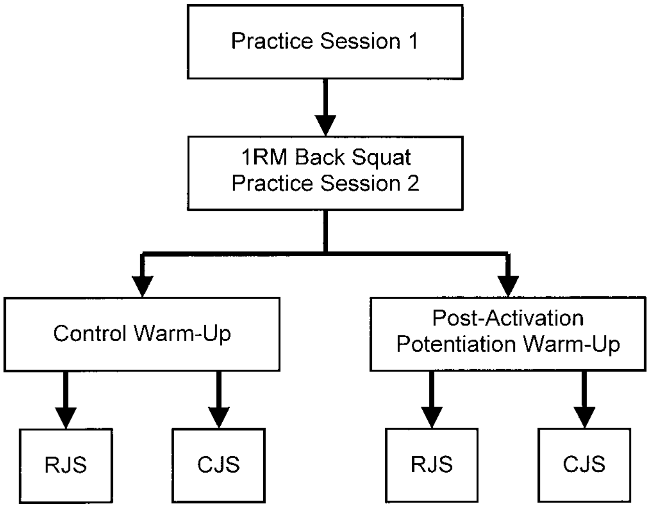

Figure 1.—Project design timeline. RJS = rebound jump squats, CJS = concentric-only jump squats.

A growing body of research has found that an individual's training level may affect the response to postactivation potentiation (6, 9, 10, 28). Stronger individuals improved vertical jumping performance more than weaker individuals following a set of 5 RM back squats. Following 3 RM back squats, peak power and peak force were decreased during jump squat exercise in weaker individuals, whereas peak power and peak force increased in stronger individuals (4). Despite this preliminary evidence, only 1 investigation has directly compared the postactivation potentiation effect between individuals using training status as an independent variable (9).

Previous investigations have found improvements in performance during low load tasks following an acute bout of heavy resistance training (6, 17, 20). The effectiveness of these protocols, however, has not been studied in higher load tasks (>30% 1 RM). Furthermore, although high power sports may involve the stretch-shortening cycle and concentric-only actions, prior research has not distinguished the role of postactivation potentiation between these conditions. The purpose of this investigation was to determine if a heavy bout of resistance exercise is effective at acutely enhancing force, velocity, and power production in high power activity under both stretch-shortening cycle and concentric-only conditions. Additionally, the effect of training status and the time-course of adaptation are examined.

Methods

Experimental Approach to the Problem

Performance during stretch-shortening cycle and concentric-only movements across a load-spectrum were assessed following a typical and postactivation potentiation warm-up. The stretch-shortening cycle and concentric-only movements were rebound (RJS) and concentric-only (CJS) jump squats, which are commonly used tasks to evaluate explosive strength performance. In addition to evaluating the changes in performance for the entire sample, subjects were allocated, based on training history, to athletically and recreationally trained groups to determine if training status affected the response to postactivation potentiation. As the time course of adaptations following postactivation potentiation are not well studied, RJS and CJS were performed following the warm-ups with a short (5-minute) and long (18.5-minute) latency period.

Subjects

Men (n = 12) and women (n = 12) participated in this investigation subsequent to providing written informed consent as approved by the University of Memphis Institutional Review Board. Subjects were required to have a minimum of 6 months current experience performing the parallel back squat exercise and be able to squat a minimum load (men: 1.5 × body mass; women: 1 × body mass). Descriptive statistics of the subjects are provided in Table 1. During the investigation, subjects were instructed to minimize physical activity involving the lower body and avoid adrenergic-enhancing substances, such as caffeine.

Design

Subjects completed 2 practice sessions and 4 testing sessions over a 3-week period (Figure 1). Practice sessions consisted of performing RJS and CJS with loads of 30%, 50%, and 70% of the subject's self-reported 1 RM parallel back squat. RJS and CJS were performed by removing a loaded barbell from a power rack, squatting to a predetermined depth, and explosively jumping to the highest height possible. The depth was set at 10% of the subject's height and an elastic cord was placed underneath the subject such that the back of their thigh at the gluteal fold would touch the cord when the depth was achieved. The height of the elastic cord could be adjusted to the nearest inch (Figure 2). For the RJS, subjects changed direction immediately and performed the concentric portion of the move-

Figure 2.—Custom testing platform.

ment. For the CJS, subjects paused in the bottom position for an audible 4-second count before performing the concentric portion. Subjects were instructed to produce a maximum effort for each jump.

Following the second practice session, subjects were tested for their 1 repetition maximum (1 RM) in the high bar parallel back squat. A lift was successful if the subject could descend until the inguinal fold was lower than the patella and rise without help as per International Powerlifting Federation rules (24).

Testing sessions were designed similar to those used by Smith et al (20). For each testing session, subjects performed jump squats following control and heavy resistance training warm-ups. The control warm-up consisted of 2 sets of 5 repetitions of unloaded parallel squats and 2 sets of 3 repetitions of vertical jumps. The heavy resistance exercise warm-up included the control warm-up, followed by 5 sets of 1 repetition at 90% 1RM in the parallel back squat with 2 minutes rest between sets. Two series of maximal effort RJS or CJS were performed with 30%, 50%, and 70% 1RM at 1-minute intervals. The first series was performed 5 minutes (5 minutes postactivation) following the warm-up and the second 10 minutes following the first or 18.5 minutes following the warm-up (18.5-minutes postactivation).

Measurement

Biomechanical measurement of the jump squats was performed using a system previously described (2). A single-component force platform was mounted in a wooden weightlifting platform. A linear position transducer was attached to the right side of the barbell to measure displacement. Signals from both devices were channeled through an analog-to-digital conversion board and sampled at 500Hz using the Analog module of the Ariel Performance Analysis System (Ariel Dynamics, Trabuco Canyon, CA).

Data analysis was performed using the BioProc2 software (D.G.E. Robertson, Ottawa, ON). The force and displacement signals were filtered using a low-pass, fourth-order, recursive Butterworth digital filter at a 5 Hz cutoff frequency. The first-order time derivative of both signals was calculated to yield RFD and velocity, respectively. The force and velocity channels were multiplied to obtain power.

Individual trials were broken into eccentric, isometric (lowest position plus 5 cm), and propulsion phases. As the velocity of the eccentric portion of the motion was not controlled, only the data from the propulsion phase was analyzed. For the RJS, the propulsion phase began at the midpoint of the quasi-isometric phase and ended after the concentric phase, defined as the point of take-off, where force was equal to zero. For the CJS, the propulsion phase began at the point of noticeable increase in force and ended after the concentric phase. The only variable analyzed that did not occur within the propulsion phase was peak displacement. Each variable was also assessed in terms of the percent potentiation, a commonly used measure to assess the relative change in performance following postactivation potentiation (Equation 1; 11).

$$\%\ \text{Potentiation} = \text{Potentiated Variable} \div \text{Unpotentiated Variable} \times 100 \qquad (1)$$

Percent potentiation equal to 100% indicates no potentiation, greater than 100% indicates PAP, and less than 100% indicates postactivation depression.

Statistical Analyses

All statistical procedures were conducted using Statistical Package for the Social Sciences (SPSS 11.0 for Windows, SPSS Inc., Chicago, IL). Reliability of variables was assessed using two-way average measure intraclass correlations (ICC), based on a subset of participants ($n = 6$) who performed additional sessions. Repeated measures univariate ANOVAs were used to determine differences between warm-up conditions during S1 and S2 (2×2 ANOVA; warm-up × time). RJS and CJS conditions were separately analyzed.

In addition to analyzing the subjects as a whole, subjects were divided into athletic (ATH; $n = 7$) and

Table 2. Post hoc analyses for significant warm-up by time interactions (mean ± *SD*).

		Series 1			Series 2		
Condition	Measure	Control	PAP	ES	Control	PAP	ES
30% RJS	Peak power (W)	3974.36* ± 1401.20	3855.60 ± 1618.20	0.485	3927.67 ± 1465.86	4053.91 ± 1465.86	0.516
30% RJS	Average power (W)	1757.80 ± 1465.86*	1651.35 ± 1558.02	0.616	1717.39 ± 619.95	1764.53 ± 716.47	0.273
30% RJS	Average force (N)	1581.23 ± 497.92	1540.53 ± 505.91	0.667	1560.11 ± 505.93	1578.23 ± 507.73	0.298
70% RJS	Average force (N)	1923.10 ± 630.07	1940.21 ± 631.84	0.406	1929.07 ± 633.26	1907.27 ± 640.48	0.517

* Denotes significant warm-up effect ($p < 0.05$).
RJS = rebound jump squat; PAP = postactivation potentiation; ES = effect sizes.

recreationally trained (RT; n = 17) groups as the efficacy of postactivation potentiation may be related to training status (4, 9, 28). ATH were defined as those subjects currently training and competing in a sport. This included a Division I NCAA soccer player, a triathlete who had qualified for the 2002 Hawaii Ironman, and 5 weightlifters, all of whom had met or exceeded the 2002 qualifying standard for USA Weightlifting's Collegiate National Championships. The percent potentiation was compared between RT and ATH using 2 × 2 repeated measures multivariate ANOVA (group × time).

Significance was set at the $p \leq 0.05$ level. Significant interactions were analyzed using a Tukey post hoc. Since previous research has shown no gender effect (15), men and women were pooled for all analyses. In addition to testing for significance, eta² (η^2; a measure of effect size) was calculated for the ANOVA and effect sizes (ES) for the post hoc analyses.

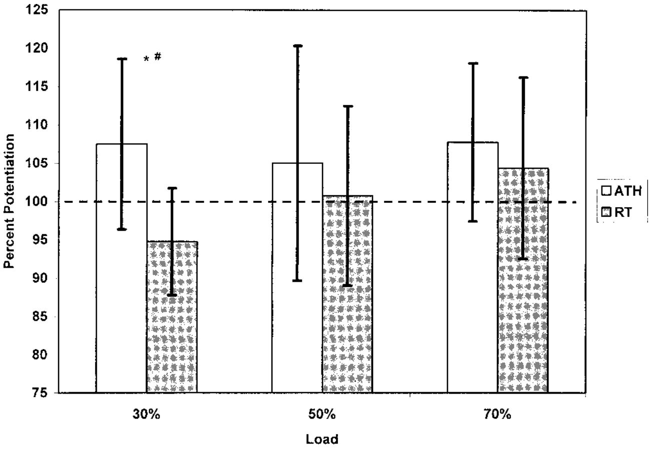

Figure 3.—Concentric-only jump squats average power percent potentiation. ATH = athletic, RT = recreationally trained. * Denotes athletic significantly different from recreationally trained $p < 0.05$. # Denotes large η^2.

Results

Most variables were found to be reliable; however, some parameters had an ICC < 0.70, the minimum standard (1). Only variables that demonstrated reliability across all loads for both CJS and RJS were used for further analysis. These parameters include peak force (ICC = 0.99–1.00), average force (ICC = 0.99–1.00), peak power (ICC = 0.95–1.00), average power (ICC = 0.92–0.99), peak RFD (ICC = 0.82–0.92), and average RFD (ICC = 0.72–0.91).

When all subjects were analyzed together, no significant interactions were found for CJS at all loads. For RJS, significant interactions were seen for average force ($p = 0.02$; $\eta^2 = 0.10$), average power ($p = 0.04$; $\eta^2 = 0.094$), and peak power ($p = 0.02$; $\eta^2 = 0.116$) at 30% load. Average force (0.03; $\eta^2 = 0.100$) for RJS at 70% load was also significant. These η^2 represent a moderate effect size (3). Post-hoc analysis (Table 2) found a significant warm-up effect for RJS average power at 30% only ($p < 0.05$; ES = 0.616).

When the percent potentiation for ATH were compared to RT, multivariate ANOVA showed significant between subject effects for CJS at 30% ($p = 0.013$; $\eta^2 = 0.576$) and 50% ($p = 0.006$; $\eta^2 = 0.622$) loads, and RJS at 30% ($p = 0.005$; $\eta^2 = 0.630$) load. A significant group-by-time interaction was found for RJS at 70% ($p = 0.04$; $\eta^2 = 0.524$) load. The largest differences appeared to exist for CJS average power at 30% load (Figure 3) and CJS peak power at 30% and 50% loads (Figure 4).

Post hoc analysis of the warm-up by time interactions for all subjects were performed to determine if a time effect occurred. For RJS at 30% load, no time effect was seen under the control warm-up condition. However, during the experimental warm-up condition, average force ($p < 0.05$; ES = 0.621), average power ($p < 0.01$; ES = 0.810), and peak power ($p < 0.05$; ES = 0.655) were significantly greater at 18.5-minutes postactivation than at 5-minutes postactivation. Although analyzed separately, similar patterns were statistically evident for stretch-shortening cycle (RJS) and concentric-only (CJS) conditions.

Discussion

Although some significant warm-up by time interactions and moderate effect sizes were found, the differ-

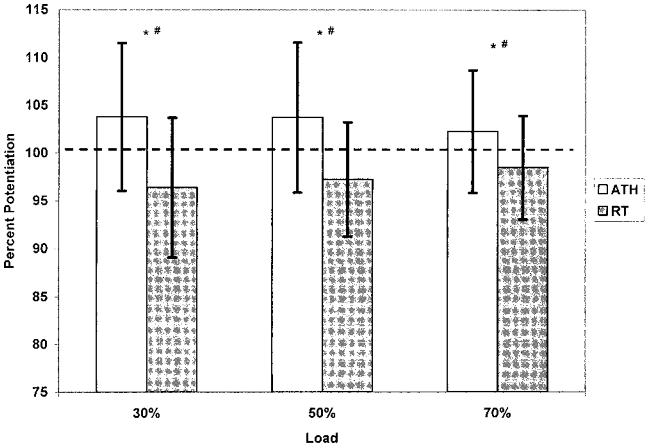

Figure 4.—Concentric-only jump squats peak power percent potentiation. ATH = athletic, RT = recreationally trained. * Denotes athletic significantly different from recreationally trained $p < 0.05$. # Denotes large η^2.

ences between warm-up conditions in the whole sample appeared to be minimal. However, when the sample was differentiated into ATH and RT groups, it appeared that the heavy resistance exercise warm-up improved performance. Performance for the ATH group following the experimental warm-up was greater than 100% at all loads for all parameters, whereas performance for the RT group was near or below 100%. Although moderate effect sizes were seen for CJS and RJS at all loads, the largest differences appeared to exist during CJS, particularly with lower loads.

Although Hrysomallis and Kidgell (12) found no effect of performing a high load exercise prior to a high power exercise, the majority of research investigating postactivation potentiation on performance has found a positive effect (6, 20, 28). This discrepancy may, however, be explained by differences in training level among the subjects in the present investigation. Duthie et al. (4) found that stronger subjects improved peak force and peak power during jump squats following 3 sets of 3 RM half squats. Conversely, weaker subjects showed a modest decline in peak force and peak power. Young et al. (28) found that stronger subjects had greater vertical jump increase following postactivation potentiation than weaker subjects.

Although training status is believed to be a factor in the postactivation potentiation response, only 1 prior study has directly compared subjects by training status. Hamada et al. (9) showed potentiation was greatest in muscles involved in the subject's sport. Triathletes and long distance runners both had potentiation greater than recreationally trained and sedentary individuals in the triceps surae; however, only triathletes had greater potentiation in the deltoid muscles. The results of the present investigation are in agreement with this prior research, indicating that athletic individuals respond more favorably to postactivation potentiation than recreationally trained individuals.

Subjects in the ATH group were all involved in sports requiring explosive strength, or the ability to produce relatively high force in minimal time, in the hip and knee extensors and ankle plantar flexors. Theoretically, explosive trained subjects would have greater activation of the musculature involved, which would affect the H-reflex and myosin regulatory light chain phosphorylation, 2 mechanisms involved in the postactivation potentiation phenomenon (11, 25). The H-reflex is an excitation potential generated as a segmental spinal reflex following maximal impulses to activate the muscle contractile apparatus (25). The H-reflex may superimpose on the motor signal, thereby increasing the signal to activate the muscle. The magnitude of the H-reflex is proportional to the magnitude of the activation of muscle, therefore, a greater activation of the muscle by those in the ATH group would result in greater potentiation via the H-reflex. Myosin regulatory light chains are phosphorylated following calcium release into the sarcomere (11). Greater activation of the muscle results in increased and prolonged calcium transients, resulting in greater phosphorylation. Phosphorylation of the myosin regulatory light chain results in faster contraction rates and rate of tension development (11, 16, 18). Further research is required to determine the individual contributions of these mechanisms to postactivation potentiation.

In addition to greater potentiation, ATHs may also have had decreased fatigue following the heavy resistance exercise warm-up. Rassier et al. (18) demonstrated that fatigue and potentiation could coexist simultaneously in skeletal muscle. This interaction between fatigue and potentiation can be modeled as an acute manifestation of the fitness-fatigue theory (29). In this model, performance is the result of the interaction of fatigue and fitness after-effects following an exercise stimulus. The fatigue after-effect is sharp in amplitude and short in duration, manifesting as an immediate decrease in performance. The fitness after-effect is dull in amplitude and long in duration, thus, as fatigue subsides, performance is enhanced.

Hamada et al. (9) speculated that fatigue resistance may contribute to the postactivation potentiation effect. In discussion of why endurance athletes show enhanced isometric force following postactivation potentiation compared to recreationally trained and sedentary controls, it was suggested that less fatigue following the stimulus in endurance athletes would allow potentiation to predominate. Although recreationally trained individuals would have fatigue-resistance in comparison to sedentary individuals, it is likely that this quality would not be as extensively trained as in endurance-type athletes. Athletes in endurance and intermittent-activity sports (such as our triathlete and soccer player) would develop fatigue resistance as an adaptation to repeated prolonged activity (8). When compared to strength athletes and power athletes, endurance athletes were able to maintain isometric force production (60% of maximum) for a greater duration (8). Additionally, the decrease in peak force and peak RFD during the isometric task following the fatiguing trial was less in endurance than strength and power athletes, and recovery was faster. Thus, even at relatively high force production, endurance athletes are able to offset fatigue and recover quickly due to the nature of their training.

Power-type athletes (such as our weightlifters) would develop fatigue resistance to high loads as an adaptation to repeated high load training (22). In competition, a weightlifter may have to perform 2 maximal attempts with approximately 2 minutes rest. Elite junior weightlifters were found on 2 occasions to have minimal performance decrements following 1 week of high-volume, moderate-load training (22). Two to 3 daily training sessions were performed during the training phase, a considerable increase in training volume for the subjects. Weightlifters, therefore, are able to perform lifts with near-maximal loads repeatedly, a characteristic not typical of recreationally trained individuals.

The significant time effects for the whole sample are also indicative of the fitness-fatigue theory. Some parameters at 5-minutes postactivation were negatively affected, however, at 18.5 minutes postactivation, the parameters had returned to or exceeded control warm-up values. Thus, following this heavy resistance exercise stimulus, excess fatigue may exist at 5 minutes. During the subsequent 10-minute period, fatigue subsides. This time effect did not appear to exist for the ATH groups, thereby indicating that 5 minutes was sufficient for fatigue to subside in this population.

Only those variables that were found to be reliable were analyzed. These included peak and average force, power, and RFD. Variables excluded from analyses were peak and average velocity, and peak displacement. Gullich and Schmidtbleicher (6) found subtle changes to force and RFD parameters following postactivation potentiation, however, large differences were seen for displacement. Kinematic measures may be more sensitive indicators of the postactivation potentiation phenomenon than kinetic parameters.

Although analyzed separately, both stretch-shortening cycle and concentric-only activities exhibited similar statistical results. This suggests that the contribution of postactivation potentiation is the same for both types of activities. Thus, the effectiveness of a heavy load warm-up may extend to a wide variety of high power activities. Another interesting finding was that jump squat performance did not decrease greatly following the parallel back squats. It is commonly recommended to perform power-type exercises or tests prior high load exercises or tests (5). While a high volume of high load exercises leads to high frequency and metabolic fatigue (7, 8), a low volume of high load exercises may not result in the same fatigue. As the order of exercises or tests is important in strength and conditioning, this investigation provides an alternative for the commonly held notion that power-type exercises should always be performed first. The results of this investigation suggest that for moderately trained individuals, performing a low volume of high load squats does not negatively affect performance of a subsequent high power exercise.

Practical Applications

The response to a heavy resistance exercise stimulus designed to elicit postactivation potentiation appears to depend on training status. Recreationally trained individuals may exhibit fatigue in the 5 minutes following an acute heavy resistance exercise stimulus. In athletically trained individuals, however, this stimulus enhances power performance for 5 to 18.5 minutes. This method of postactivation potentiation appears to be a viable means of acutely enhancing explosive strength performance in athletes, but not recreationally trained individuals. The results of this study may be applicable to sports with brief, discrete, maximal efforts, such as weightlifting and sports involving short sprints, jumping, or throwing actions.

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