Power and Power Potentiation Among Strength–Power Athletes: Preliminary Study

Michael H. Stone, William A. Sands, Kyle C. Pierce, Michael W. Ramsey, and G. Gregory Haff

Purpose: To assess the effects of manipulating the loading of successive sets of midthigh clean pulls on the potentiation capabilities of 7 international-level US weightlifters (4 men, 3 women). Methods: Isometric and dynamic peak-force characteristics were measured with a force plate at 500 Hz. Velocity during dynamic pulls was measured using 2 potentiometers that were suspended from the top of the right and left sides of the testing system and attached to both ends of the bar. Five dynamic-performance trials were used (in the following order) as the potentiation protocol: women at 60, 80, 100, 120, and 80 kg and men at 60, 140, 180, 220, and 140 kg. Trials 2 vs 5 were specifically analyzed to assess potentiation capabilities. Isometric midthigh pulls were assessed for peak force and rate of force development. Dynamic lifts were assessed for peak force (PF), peak velocity (PV), peak power (PP), and rate of force development (RFD). Results: Although all values (PF, PV, PP, and RFD) were higher postpotentiation, the only statistically higher value was found for PV (ICC $\alpha = .95$, $P = .011$, $\eta^2 = .69$). Conclusions: Results suggest that manipulating set-loading configuration can result in a potentiation effect when heavily loaded sets are followed by a lighter set. This potentiation effect was primarily characterized by an increase in the PV in elite weightlifters.

Keywords: weightlifting, force–time curve, isometric force, rate of force development

Although the idea of postcontraction potentiation is not new, the use of strength–power-potentiating complexes (SPPC) or complex pairs has been the focus of a great deal of recent discussion and study. The use of these SPPCs has, in some cases but not all, been shown to acutely increase performance. Briefly,
an SPPC involves the performance of a high-force\textsuperscript{4} or high-power\textsuperscript{9} movement to potentiate a subsequent high-power or high-velocity movement. For example, heavy squats might potentiate subsequent vertical jumps\textsuperscript{10} or sprinting performance.\textsuperscript{11} The use of these SPPCs could be useful as a training method or as an acute performance-enhancing factor immediately precompetition.

A theoretical foundation for SPPCs can be found in the fitness-fatigue concept (Figure 1). Briefly, this theory suggests that as a result of training, both fitness and fatigue characteristics are accumulated.\textsuperscript{12} This “accumulation” is related to the volume and intensity of training. Fatigue masks the ability to manifest the effects of fitness, so as long as fatigue remains high, the potential to perform (ie, preparedness) is suppressed. If volume is decreased, fitness and fatigue become aftereffects of training that begin to diminish in magnitude. Fatigue decreases at a faster rate than does fitness, however, so at some point preparedness reaches a peak relative to fatigue. If fitness falls off too much (eg, tapers for too long), preparedness (and performance) also declines. In terms of performance, this theoretical concept can be viewed as a long-term factor or an acute factor.

![Figure 1](image)

**Figure 1** — Fitness-fatigue theory of preparedness and performance. Preparedness is determined by the summation of positive (fitness) and negative (fatigue) responses to a stimulus. As training load decreases fitness falls off—however, fatigue falls off at a faster rate, allowing preparedness to manifest itself. An athlete’s performance is (to an extent) a reflection of how well he or she is prepared. This model proposes that immediate training effects are characterized by their opposing action. In addition, this concept can be used to describe the acute aftereffects of a potentiation exercise. A potentiation exercise can be used to “create” aftereffects such that preparedness is acutely enhanced as fatigue dissipates.
From an acute standpoint, conceptually the potentiating exercise raises the “fitness” level of the athlete, as well as fatigue. Increased fitness arises from the stimulation or alteration of specific underlying mechanisms in the neuromuscular system. At the termination of the potentiating exercise, fitness and fatigue again can be viewed as aftereffects; the rate of decay of these aftereffects again determines the level of “preparedness” and potential performance—in this case, in the short term.

Both the muscle and nervous system might be involved in producing potentiation, although the exact mechanisms that underlie the potentiating effect are unclear at present. One mechanism is likely related to postactivation potentiation (PAP). PAP involves one or more mechanisms by which muscle twitch force or low-frequency tetanic force can be potentiated in isolated muscle preparations by a series of evoked twitches (Treppe) or an evoked tetanic contraction. PAP is believed to occur in intact muscle and appears to partially explain the acute performance increase that can result from SPPCs. The primary mechanism whereby PAP occurs in isolated muscle appears to be a result of increased phosphorylation of myosin light chains, which in turn sensitizes the actin–myosin interaction with calcium ions. Phosphorylation is greater in type II muscle fibers than in type I; thus, animals or humans with a higher percentage of type II fibers display greater PAP. In addition, greater PAP has also been consistently observed in trained muscle and in trained versus untrained subjects. In general PAP has been suggested to have little effect on force output at the higher stimulation frequencies at which peak isometric force and high contraction velocities would be produced. Although PAP has been suggested to have little effect on peak isometric force or maximum (unloaded) shortening velocity, it has been shown to markedly increase the rate of force development during high-frequency stimulation. Increased rates of force development resulting from PAP could enhance the acceleration and therefore velocity attained at loads between zero \( V_{\text{max}} \) and peak isometric force. This possibility is partially supported by PAP-induced increases in velocity of shortening, amount of concentric work, and power output in isolated mouse muscle. Furthermore, PAP appears to occur as a phenomenon that is independent of the contraction type (ie, isometric, concentric, or eccentric). Thus, many sport activities such as jumping that rely on dynamic explosive strength might be enhanced by PAP, which results from SPPCs.

In intact muscle another potential mechanism that could help explain SPPCs involves the nervous system. The primary mechanism underlying force potentiation during high-velocity ballistic actions appears to be a neural effect. These neural mechanisms could include increased motor-unit synchronization, desensitization of alpha motor-neuron input, and decreased reciprocal inhibition to antagonists.

Three factors that might affect the degree of potentiation are initial strength levels, the current level of fatigue, and past training experience. Indeed, stronger athletes appear to produce potentiation effects to a greater degree (or more often) than weaker athletes. Fatigue appears to reduce the potentiation effects. The purpose of this study was hypothesis generating, in which measures of force, rate of force development, and power output were used to assess the potentiation effects of varying the load during successive sets of pulling movements in international-level weightlifters.
Methods

Subjects
The athletes were 3 female and 4 male resident weightlifters at the US Olympic Committee training center in Colorado Springs, CO. All athletes were USA national class, and all had made the 2003 world-championship team. The mean values for the athletes’ best snatch and clean-and-jerk performances are shown in Table 1. This study was conducted as part of a service project in conjunction with USA Weightlifting and the US Olympic Committee; all athletes attending the US Olympic training centers provide consent for testing as part of their participation there.

Design
The SPPCs were performed in the morning approximately 1.5 to 2 hours after breakfast. All athletes performed their normal warm-up (ie, calisthenics and various pulling movements including snatches and cleans up to approximately 75% to 80% of 1RM). The SPPC, using pulls from midthigh, was designed in accordance with typical training and exercise procedures: The loads began relatively light and increased to a target weight, and then an unload set (set 5), or “down” set, was performed. Thus, a unique aspect of this design was that the complex pair became part of the training session for that morning.

Physical Characteristics
Body mass was measured with a digital scale (Toledo International Inc, Columbus, OH). Height was measured to the nearest 0.1 cm using a stadiometer. Body composition (% fat) was assessed using skinfolds. Skinfolds were measured with Lange skinfold calipers (QuickMedical, Snoqualmie, WA). A 7-site skinfold protocol was used to determine approximate body-fat percentages. Experienced laboratory personnel measured all skinfolds on the right side. In our laboratory, test–retest reliability for skinfolds has been ICCα > .9. The physical characteristics of the athletes at the initiation of the study are shown in Table 1.

Table 1  Physical and Performance Characteristics (Mean ± SD)a

<table>
<thead>
<tr>
<th>Variable</th>
<th>Men</th>
<th>Women</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>174.0 ± 5.7</td>
<td>163.0 ± 7.1</td>
<td>169.3 ± 8.2</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>116.9 ± 27.5</td>
<td>72.4 ± 7.7</td>
<td>97.9 ± 31.1</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>19.6 ± 7.0</td>
<td>18.6 ± 4.8</td>
<td>19.1 ± 5.6</td>
</tr>
<tr>
<td>Snatch (kg)</td>
<td>173.1 ± 16.8</td>
<td>96.7 ± 8.0</td>
<td>140.4 ± 42.8</td>
</tr>
<tr>
<td>Clean and jerk (kg)</td>
<td>211.9 ± 18.3</td>
<td>117.5 ± 6.6</td>
<td>157.1 ± 78.2</td>
</tr>
</tbody>
</table>

a Statistical differences: Men > Women in height, body mass, snatch, and clean and jerk.
**Training**

All the athletes were training for the November 2003 World Championships. This assessment took place 6 weeks before the championships. The volume of training can be generally assessed using repetitions for major exercises (eg, squats, pulls, snatches, cleans, clean and jerks). During the 2 weeks before the observation the athletes were doing 300 to 400 lifts per week in training. Because chronic fatigue could be an inhibiting factor for potentiation effects, it is important to note that the athletes were accustomed to this level of training, which did not represent a high volume. Therefore, excessive fatigue that might have interfered with the possibility of potentiation\(^4,5\) should not have been a problem.

**Performance Tests**

All subjects had been familiarized with the tests and had several practice sessions before data collection began. All tests of force and power characteristics were measured in a specially designed custom lifting rack (Figure 2). Isometric and dynamic peak-force characteristics were measured using a force plate (Kistler, Amherst, NY) with a sampling rate of 500 Hz. Vertical velocity during dynamic movements was measured using 2 spring-loaded, multiturn potentiometers (Celesco, Inc, Chatsworth, CA), which were suspended from the top of the right and left sides of the testing rack. One potentiometer was attached to each end of the barbell, allowing

---

*Figure 2* — Example dynamic pull from midthigh (N = 7).
for velocity measurement of both sides of the barbell. Data from the potentiometers were averaged for further analysis. Isometric mid thigh pulls were measured from a position identical to that used in training (knee angle 120° to 135°, hip angle 170° to 175°). These positions corresponded to the bar at mid thigh positions previously measured with two-dimensional videography during a clean with 80%+ of 1RM (Vicon-Peak, Englewood, CO). In addition, each athlete was carefully questioned as to the “feel” of the barbell positioning to make sure the lifter–barbell interface was such that a maximum effort could be produced. All dynamic mid thigh pulls began at a position identical to the isometric position—dynamic pulls were finished with a simultaneous maximum-effort shoulder shrug and plantar flexion. This method (mid thigh pulls) of assessing force and power characteristics was chosen because it was movement and position specific to that used in training and competition, previous research had established its potential usefulness as a test, and the positions (hip and knee angle) achieved in the test and the explosive nature of the tests are similar to those of critical aspects and positions of weightlifting.

Measurements including peak force (PF) and peak rates of force development (PRFD) were made isometrically. Dynamic performance assessments of PF, peak power (PP), PRFD, and peak velocity (PV) were also measured. PRFDs were measured using a 5-millisecond window of the force–time curve. Dynamic performance was assessed in the following order: women at 60, 80, 100, 120, and 80 kg and men at 60, 140, 180, 220, and 140 kg. Rest between trials was approximately 2 minutes. These loads were chosen based on previous observation indicating that 80 kg for women and 140 kg for men produced similar values for PV, PF/kg, and PP/kg. Each type of pull was performed twice. No statistical differences were found between repeated tests. Test–retest reliability was assessed using an intraclass correlation (ICC): For all PFs values were $\alpha \geq .98$; isometric PRFD and PRFD, $\alpha = .81$ and .88; PP, $\alpha = .91$; and PV, $\alpha = .95$. These values were in agreement with previous measures (unpublished) using a large number of subjects.

Statistics

All lifting-trial data were analyzed with pair comparisons. To account for type I errors a Holm Bonferroni sequential adjustment of the alpha level was used. One postcomparison relationship between specific variables (IPF vs the percent change in postpotentiation 80/140 kg PV) was calculated using a Pearson product–moment correlation. A 1-way analysis of variance (ANOVA) was used to determine where sex differences existed for selected variables. All data are reported as mean ± SD. Statistical analyses were performed with SPSS 14.0 (SPSS Inc, Chicago, IL).

Results

Both male and female athletes were involved in the current investigation (Table 1). An analysis of the subjects’ body mass revealed a large difference between sexes ($P = .036$, $\eta^2 = .62$). Therefore, all force–time-curve data were scaled by body mass when comparing sexes. When scaled by body mass, there were no significant differences between sexes.
Data for isometric PF and PRFD are shown in Table 2. Table 3 and Figure 3 represent the force–time-curve data of the series of dynamic midthigh clean pulls for the combined data set.

**Peak Force**

The PF values achieved during trial 1 were significantly different than trial 2 \( (P = .002, \eta^2 = .81) \), trial 3 \( (P = .001, \eta^2 = .87) \), trial 4 \( (P < .001, \eta^2 = .89) \), and trial 5 \( (P = .005, \eta^2 = .75) \). In addition, trial 4 was found to be significantly different from trial 2 \( (P < .001, \eta^2 = .91) \) and trial 5 \( (P = .003, \eta^2 = .80) \). When specifically examining the effects of potentiation, trial 2 and trial 5 were not statistically different \( (P = .58, \eta^2 = .35) \).

All PF data were then analyzed relative to body mass, which resulted in trial 1 being significantly different than trial 2 \( (P = .002, \eta^2 = .83) \), trial 3 \( (P = .002, \eta^2 = .81) \), trial 4 \( (P < .001, \eta^2 = .91) \), and trial 5 \( (P = .005, \eta^2 = .76) \). Trial 4 was significantly different than trial 2 \( (P < .001, \eta^2 = .93) \) and trial 5 \( (P = .005, \eta^2 = .76) \) for the combined data set. When the effects of potentiation were examined, no significant differences were noted between trials 2 and 5 \( (P = .33, \eta^2 = .16) \).

**Peak Velocity**

There were significant differences between the velocities of all the trials tested. The PV achieved during the postpotentiation exercise set (trial 5) was significantly less than trial 1 \( (P = .011, \eta^2 = .69) \) and significantly greater than trial 2 \( (P = .023, \eta^2 = .61) \), trial 3 \( (P < .001, \eta^2 = .91) \), and trial 4 \( (P < .001, \eta^2 = .93) \). Significant differences were also noted when comparing trial 1 with trial 2 \( (P = .002, \eta^2 = .82) \), trial 3 \( (P = .001, \eta^2 = .85) \), and trial 4 \( (P < .001, \eta^2 = .89) \). Trial 2 was also significantly different from trial 3 \( (P = .001, \eta^2 = .84) \) and trial 4 \( (P < .001, \eta^2 = .91) \), and trial 3 was significantly different from trial 4 \( (P = .001, \eta^2 = .87) \). A graphic depiction of the velocity responses to the various trials is shown in Figure 3.

**Peak Power**

Analysis of the PP data revealed no significant differences between any of the trials when correcting for type I error. Specifically, when we examined the prepotentiation set (trial 2) and the postpotentiation set (trial 5), we noted no significant differences \( (P = .27, \eta^2 = .20) \).

### Table 2  Isometric Measures \( (N = 7) \)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isometric peak force (N)</td>
<td>5102.4 ± 1536.3</td>
</tr>
<tr>
<td>Relative isometric peak force (N/kg)</td>
<td>52.6 ± 8.4</td>
</tr>
<tr>
<td>Isometric rate of force development (N/s)</td>
<td>16,998.6 ± 5878.4</td>
</tr>
<tr>
<td>Variable</td>
<td>1</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Peak force (N)</td>
<td>2966.0 ± 827.0</td>
</tr>
<tr>
<td>Relative peak force (N/kg)</td>
<td>30.6 ± 2.7</td>
</tr>
<tr>
<td>Peak power (W)</td>
<td>3643.0 ± 1435.0</td>
</tr>
<tr>
<td>Relative peak power (W/kg)</td>
<td>35.1 ± 6.8</td>
</tr>
<tr>
<td>Peak rate of force development (N/s)</td>
<td>22325.0 ± 9437.0</td>
</tr>
</tbody>
</table>

<sup>a</sup> Significantly different from trial 1 (<i>P</i> < .005).

<sup>b</sup> Significantly different from trials 2 and 5 (<i>P</i> < .005).
Rate of Force Development

No significant differences were observed between any of the trials, specifically, trial 2 and trial 5, when we examined the PRFD ($P = .22, \eta^2 = .24$).

Discussion

The primary finding of this study was that among very well-trained strength/power athletes there was evidence that an SPPC protocol (using midthigh pulls) can enhance subsequent performance. This is particularly evident in the significant 5.3% ± 4.3% increase noted for PV. Although all other variables tested were not significantly enhanced with the use of an SPPC, it is important to note that all variables exhibited increases as a result of the SPPC protocol (Figure 4). It is possible that the SPPC protocol implemented in this investigation resulted in a shift in the load (force)–velocity relationship that facilitated the increase in PV.

Previous research has reported that PAP can increase the PRFD even at high stimulation frequencies.$^{19,28}$ Sale$^5$ suggests that this increase with loads from $V_{\text{max}}$ to peak isometric force could result in increased velocities of movement across the loading spectrum as a result of a shift in the load (force)–velocity relationship.
The current investigation partially supports this contention. The SPPC resulted in a significant increase in PV of movement that was strongly correlated \((r = .92, r^2 = .85, P = .003)\) with the increase in the PRFD. Although the increase in the PRFD associated with the SPPC failed to reach statistical significance, it is likely that the small sample size and the large standard deviations are at least partially responsible; however, small increments in this measure might be practically relevant in elite weightlifters seeking to improve performance during training and competition.

Increases in the PRFD, isometric force, and maximum velocity of shortening are stimulated by elevations in the phosphorylation of the subunit of myosin known as the regulatory or phosphorylatable light chain (R-LC). Grange et al. reported that increasing the phosphorylation of the R-LC 5-fold resulted in a potentiation of the rate of force development, maximal force production, and PV. Increases in R-LC phosphorylation appear to have a significant effect on Ca\(^{2+}\) sensitivity of the actin–myosin interactions that result in an increased rate of myosin cross-bridge interactions, which causes an alteration in the load (force)–velocity relationship. It appears that the potentiation effects of this increased phosphorylation of the R-LC dissipate in a linear fashion, which suggests that the recovery period between the potentiation activity and the performance is an important consideration when employing SPPC protocols.

The amount of time between the potentiation activity and the performance appears to be a critical point to consider when implementing an SPPC. If the

![Graph showing percent change from trial 2 to trial 5](image)
potentiation activity is too close to the performance, the effectiveness of the SPPC will be diminished as a result of the cumulative fatigue. If the time frame is extended the effectiveness of the SPPC is also significantly decreased. From a theoretical standpoint this process is similar to the fitness-fatigue concept presented in Figure 1, in which preparedness is a function of maintaining fitness while dissipating fatigue. Gossen and Sale report that when there is insufficient time between the potentiation activity and the actual performance the effectiveness of the PAP activity might actually be attenuated as a result of cumulative fatigue. The lack of statistical difference between the prepotentiation and postpotentiation trials in the current study is likely not a function of fatigue-induced impairments or decay of the PAP mechanism because all the trials exhibited increases, even though several variables failed to reach statistical significance. It appears that the 2-minute rest period between the potentiation activity and the performance measure was sufficient to induce an adequate decay of fatigue while maintaining the effects of the PAP specifically on PV.

The findings of the current investigation are important because velocity and PV play a crucial role in the success of weightlifting movements, as well as explosive ballistic movements in general. Enhancing velocity characteristics as a result of an SPPC could promote superior performance or a higher degree of success during subsequent explosive movements, thus suggesting that the SPPC might be an important tool for athletes and coaches to consider.

**Practical Application**

The differences between winning and losing are often quite small. For example, based on our analysis (unpublished data), the difference between first and fourth place in most sports in the last 3 Olympics is typically less than 1.5%. Thus, methods of enhancing performance with superior training or at the competition site should be investigated. One such method of possible enhancement is an SPPC. The results of this study give practical support to the concept of a potentiation complex in elite athletes. Performance of SPPCs such as the one used in the current study could enhance training adaptations such that PV and possibly other variables are enhanced beyond that of more typical training protocols, which could ultimately result in improved sport performance.

It might also be possible to use a similar protocol at a competition. For example, weightlifters are typically able to perform pulls with up to 120% of their maximum clean or snatch. In a competition the weightlifter might use a heavy pull from the floor (>100% maximum clean or snatch) to activate the PAP mechanism allowing force-generating capacities, which could result in better weightlifting performance.

**Conclusions**

The results of this study indicate that an SPPC, using a midhigh pull, can produce evidence of enhanced performance among international-class weightlifters. The enhanced performance was primarily evident as it pertains to PV.
Acknowledgments
Thanks to Paul Fleschler (USA Weightlifting/USOC men’s resident coach) and Bob Morris (USA Weightlifting/USOC women’s resident coach) for their aid in allowing the athletes to participate in this observation.

References


