Potentiation of Vertical Jump Performance During a Snatch Pull Exercise Session

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Potentiation has been reported in power tasks immediately following a strength stimulus; however, only whole-body performance has been assessed. To determine the acute effects of weightlifting on vertical jump joint kinetics, performance was assessed before, during, and after snatch pull exercise in male athletes. Jumping was assessed using 3D motion analysis and inverse dynamics. Jump height was enhanced at the midpoint (5.77%; p = .001) and end (5.90%; p < .001) of the exercise session, indicating a greater power-generating ability. At the midpoint, knee extensor net joint work was increased (p = .05) and associated with increased jump height (r = .57; p = .02). Following exercise, ankle plantar flexor net joint work was increased (p = .02) and associated with increased jump height (r = .67; p = .006). Snatch pull exercise elicited acute enhancements in vertical jump performance. At the midpoint of the exercise session, greater work at the knee joint contributed to enhanced performance. At the end of the exercise session, greater work at the ankle contributed to enhanced performance. Consequently, potentiation is not elicited uniformly across joints during multijoint exercise.

Keywords: postactivation potentiation, mechanical work, power, multijoint coordination

Previous research has demonstrated the physiologic phenomenon of postactivation potentiation (PAP) during isometric (Hamada et al., 2000a, 2000b; Hicks et al., 1989) and dynamic actions (Chiu et al., 2003; Duthie et al., 2002; French et al., 2003; Gullich & Schmidtbleicher, 1996; Young et al., 1998). PAP manifests as an improvement in performance following a maximal or near-maximal conditioning stimulus. The conditioning stimulus typically involves single or multiple sets of resistance exercise, such as the squat (Chiu et al., 2003; Young et al., 1998) or leg press (Gullich & Schmidtbleicher, 1996); whereas the performance task usually involves a high-power activity, such as jumping (Chiu et al., 2003; Gullich & Schmidtbleicher, 1996; Young et al., 1998). Investigations utilizing jumping as a performance task have consistently demonstrated 2.5–5.0% increases in jump height resulting from PAP (Chiu et al., 2003; Gullich & Schmidtbleicher, 1996; Young et al., 1998). The majority of PAP investigations have used a similar study design. Typically, one to five sets of heavy resistance exercise are performed and the high-power activity is then tested. This study design has been likened to sport competition, and it is speculated that PAP may be used in competition to improve performance (Gullich & Schmidtbleicher, 1996).

To a lesser extent, PAP has been investigated during a training session. Linnamo et al. (2000) reported an increase in dynamic rate of force development following explosive strength training on a leg press apparatus. Similarly, Chiu et al. (2004) reported an increase in isometric rate of force development following the second of two resistance training sessions in a single day. While it is well known that excessive exercise results in fatigue, these investigations suggest performance may be enhanced when a low volume of high-intensity exercise is performed. Anecdotally, elite athletes, such as Bulgarian weightlifters, use training programs that may capitalize on the PAP phenomenon (Garhammer & Takano, 1992; Stone et al., 2008). These training programs use a concept known as wave loading. In wave loading, each wave consists of multiple sets of exercise where the resistance is increased for each set. At the completion of a wave, the resistance is decreased and a successive wave is performed. In theory, heavier loads can be lifted on successive waves due to PAP, resulting in a greater training stimulus and subsequently greater adaptation. Whether wave loading elicits acute physiologic responses such as PAP has not been investigated.

In athletic populations, where wave loading may be used, resistance training typically involves multijoint
exercises. Mechanical loading varies across muscles and joints in multijoint tasks (Chiu and Salem, 2006; Enoka, 1988). For example, weightlifting exercises such as the snatch have higher hip extensor than knee extensor and ankle plantar flexor net joint moment (NJM) (Enoka, 1988; Garhammer, 1979). The magnitude of potentiation has been associated with the force generated by a muscle in single-joint tasks. Therefore, it may be hypothesized that PAP would not influence each muscle or joint uniformly. However, research of PAP using multijoint tasks have only investigated gross motor performance (Chiu et al., 2003; Young et al., 1998). For example, jump height and power generated during jumping are common parameters assessed. As PAP increases a muscles force generating ability, a nonuniform response may influence the kinetics at each joint differently. Therefore, this study had two purposes: (1) to investigate the effects of a wave-loading protocol during and after multiple sets of the snatch pull exercise and (2) to investigate whether PAP responses occurs uniformly or nonuniformly at the hip, knee, and ankle.

**Methods**

**Experimental Approach**

This investigation used a longitudinal approach where performance was assessed before, during, and after a weightlifting training session. The primary performance criterion was vertical jump height. Net joint kinetics were determined as secondary criteria to investigate whether PAP responses were uniform or nonuniform at the hip, knee, and ankle. Correlations were used to determine the relations between changes in net joint kinetics and vertical jump height.

**Subjects**

Thirteen men volunteered to participate and were informed of all risks, hazards, and benefits. Subjects provided written informed consent as approved by the Institutional Review Board at the authors’ university. Subjects were actively training and competing in power sports (weightlifting, track & field—sprints, volleyball). From self-reported training histories, subjects had a minimum of 3 years of experience performing weightlifting exercise, including variations of the snatch, clean, and jerk. Descriptive statistics of the subjects are presented in Table 1. Well-trained individuals were recruited for two reasons: first, the exercise performed (snatch pull) requires sufficient practice to develop proficient technique and to lift maximal weights. To elicit PAP, muscles must be maximally activated during exercise (Gullich & Schmidtbleicher, 1996; Vandenboom et al., 1993). Second, previous investigations have indicated that PAP responses are greater in athletic and strength-trained individuals (Chiu et al., 2003; Young et al., 1998).

**Table 1 Subject characteristics (mean ± SD)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>27.31 ± 4.21</td>
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<tr>
<td>Height (m)</td>
<td>1.79 ± 0.11</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>96.09 ± 17.61</td>
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<tr>
<td>Weightlifting Experience (years)</td>
<td>6.46 ± 2.63</td>
</tr>
<tr>
<td>1 RM Snatch (kg)</td>
<td>123.46 ± 19.99</td>
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<tr>
<td>1 RM Clean &amp; Jerk (kg)</td>
<td>151.73 ± 24.14</td>
</tr>
<tr>
<td>Weightlifting Total (kg)</td>
<td>275.19 ± 43.86</td>
</tr>
<tr>
<td>Weightlifting Total—Sinclair Points</td>
<td>313.03 ± 39.50</td>
</tr>
<tr>
<td>Front Squat (kg)</td>
<td>171.23 ± 28.60</td>
</tr>
<tr>
<td>Vertical Jump Peak Power (W)</td>
<td>5121 ± 2746</td>
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**Protocol**

Subjects performed a weightlifting training session, involving the snatch pull exercise. This exercise involves three phases—the first pull, second knee bend, and second pull (Enoka, 1988; Garhammer, 1979). In the first pull, the barbell is raised from the floor to midthigh height by extending the knees (Figure 1A to 1B). The second knee bend requires ankle dorsiflexion and knee flexion to reposition the trunk to an upright posture (Figure 1B to 1C). In the second pull, the knees are forcefully and rapidly extend to impart vertical momentum to the barbell (Figure 1C to 1D). A brief warm-up was performed, consisting of callisthenic exercise, followed by the snatch pull with progressively increasing barbell loads (3–4 sets). For the training session, two waves were performed, with four sets in each wave (Figure 2). Two repetitions were performed for each set and 3 min of rest was allowed between sets. Subject’s self-reported their one repetition snatch, which was verified from training logs or competition results. As the snatch pull does not involve raising the bar overhead as in the snatch, it is possible to perform multiple repetitions at 100% of the one repetition maximum snatch.

**Biomechanical Testing**

Vertical jumps were performed after the warm-up (PRE), after the first wave (MID), and following the second wave (POST; see Figure 2). MID and POST jumps were performed 3 min following the preceding set of exercise. Three vertical jumps were performed at each occasion and data were averaged across all three repetitions. For the vertical jumps, subjects were instrumented with passive reflective markers on their lower extremity (pelvis, left and right thigh, left and right shank, and left and right feet). The six degree-of-freedom ($df$) marker set has been described in previous investigations (Chiu & Salem, 2006).
Vertical Jump During a Snatch Pull Exercise

Hz using the Vicon 612 motion capture system. Reliability of sagittal plane net joint kinematics and kinetics of vertical jumps performed in this manner has been established in our laboratory (ICC > 0.85).

Collected trials were processed in Vicon Workstation (version 4.5) where markers were labeled and saved in .c3d file format. The .c3d files were imported into Visual 3D (version 3.13; C-Motion, Rockville, MD), which modeled segment characteristics from static trials and generated body segment kinematics from dynamic trials. Intersegmental joint angles were determined for the hip, knee, and ankle. Joint angular velocities were calculated from joint angle-time data by taking the first derivative of linear regressions fitted at 5 ms intervals. Inverse dynamics, using published anthropometric data (Dempster, 1955), were applied for three planes of motion to determine net joint kinetics at the ankle, knee, and hip.

Vertical jump height was determined as the difference in the peak height and standing height of the center of mass of the pelvis. This method has previously been validated in our laboratory (Chiu and Salem, 2010). Sagittal plane kinematics and net joint kinetics at the ankle, knee, and hip were analyzed. Peak net joint moment (NJM) and NJM impulse (IMP; integrated area under the NJM-time curve) were determined from the initiation of the vertical jump until takeoff. NJM and IMP are expressed as external moments using a right-hand-rule coordinate system in the proximal segment of the joint. Peak net joint power (NJP) and net joint work (WORK; area under the NJP-time curve) were determined for the concentric phases of the vertical jump. NJM, IMP, NJP, and WORK for the left and right joints were summed (Vanezis and Lees, 2005). Examples of the NJM-time and NJP-time curves are presented in Figure 3.

Subjects performed the vertical jumps standing on two force platforms (AMTI-OR6–6; Watertown, MA) with their hands placed behind their head (i.e., without arm swing). Video data were collected at 120 Hz using eight MCAM2 (Vicon; Lake Forest, CA) near-infrared video cameras simultaneously with force platform data at 1560 Hz using the Vicon 612 motion capture system. Reliability of sagittal plane net joint kinematics and kinetics of vertical jumps performed in this manner has been established in our laboratory (ICC > 0.85).

Collected trials were processed in Vicon Workstation (version 4.5) where markers were labeled and saved in .c3d file format. The .c3d files were imported into Visual 3D (version 3.13; C-Motion, Rockville, MD), which modeled segment characteristics from static trials and generated body segment kinematics from dynamic trials. Intersegmental joint angles were determined for the hip, knee, and ankle. Joint angular velocities were calculated from joint angle-time data by taking the first derivative of linear regressions fitted at 5 ms intervals. Inverse dynamics, using published anthropometric data (Dempster, 1955), were applied for three planes of motion to determine net joint kinetics at the ankle, knee, and hip.

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Statistics

For the first purpose, investigating changes in jump performance before, during and after snatch pull exercise, jump height was analyzed using repeated-measures ANOVA. For the second purpose, investigating the localization of PAP responses, joint kinematics and kinetics were analyzed with repeated-measures ANOVA. Where significant main effects existed, the Tukey post hoc method was applied to determine the location of differences.
and effect sizes (ES) were determined. Effect sizes were interpreted using the criteria of Peterson et al. (2004). Percent potentiation (Chiu et al., 2003) was calculated for significant variables. Relationships between percent potentiation of the primary and secondary variables were assessed using Pearson product–moment correlations. Descriptive statistics are reported as mean ± SD.

Results

The main purpose of this investigation was to determine if snatch pull exercise elicited PAP of vertical jump performance. A significant main effect \((p < .001)\) existed for vertical jump height. Post hoc analysis indicated large increases in vertical jump height at MID \((p = .001; \, \text{ES} = 1.62)\) and POST \((p < .001; \, \text{ES} = 1.75)\) compared with PRE (Figure 4). No differences existed between MID and POST \((p = .94; \, \text{ES} = 0.13)\).

The second purpose of this investigation was to determine whether PAP was uniform across the lower extremity joints. Significant main effects existed for WORK during the concentric phase at the ankle \((p = .02)\) and knee \((p = .05)\), but not the hip \((p = .95)\). A trend that approached significance existed for WORK during the concentric phase at the ankle between PRE and MID \((p = .052; \, \text{ES} = 0.97)\) and a large difference existed between PRE and POST \((p = .02; \, \text{ES} = 1.16; \, \text{Figure 5})\). A significant difference was found for WORK during the concentric phase at the knee between PRE and MID \((p = .05; \, \text{ES} = 0.99)\) but not between PRE and POST \((p = .19; \, \text{ES} = 0.71; \, \text{Figure 5})\).

No significant main effects were found for peak concentric joint angular velocities \((p > .05)\), NJM \((p > .05)\) and NJP \((p > .05)\) at the ankle, knee and hip (Table 2). No significant main effects were found for concentric IMP \((p > .05)\) at the ankle, knee, and hip (Table 2).

Significant correlations were found between the percent potentiation in vertical jump height and WORK during the concentric phase at the ankle from PRE to MID \((r = .67; \, p = .006)\), and PRE to POST \((r = .67; \, p = .006)\). A significant correlation was found between the percent potentiation in vertical jump height and WORK during the concentric phase at the knee from PRE to MID \((r = .57; \, p = .02)\); whereas from PRE to POST, the correlation was not significant \((r = .17; \, p = .30)\). No significant correlations were found between percent potentiation in vertical jump height and eccentric NJP at the knee or hip.

**Figure 4** — Change in vertical jump height during the weight-lifting training session. *Denotes significant difference from PRE \((p < .05)\).

**Figure 5** — Concentric WORK at the hip, knee and ankle during vertical jumping. *Denotes significant difference from PRE \((p < .05)\).
Table 2  Concentric joint kinematics and kinetics (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Hip</th>
<th>Knee</th>
<th>Ankle</th>
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<tr>
<td></td>
<td>PRE</td>
<td>MID</td>
<td>POST</td>
</tr>
<tr>
<td>Peak Angular Velocity (rad·s⁻¹)</td>
<td>10.1 ± 1.8</td>
<td>10.5 ± 2.5</td>
<td>10.5 ± 2.5</td>
</tr>
<tr>
<td>Peak Net Joint Moment (N·m)</td>
<td>-401 ± 79</td>
<td>-415 ± 112</td>
<td>-415 ± 120</td>
</tr>
<tr>
<td>Impulse (N·m·s)</td>
<td>-145 ± 40</td>
<td>-139 ± 45</td>
<td>-139 ± 46</td>
</tr>
<tr>
<td>Peak Net Joint Power (W)</td>
<td>1643 ± 442</td>
<td>1648 ± 744</td>
<td>1726 ± 774</td>
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</table>

*Note.* Positive angular velocity indicates ankle plantar flexion, knee flexion, and hip extension. Positive net joint moment and impulse indicate ankle plantar flexor, knee flexor, and hip extensor.
Discussion

The first purpose of this study was to investigate whether vertical jump height would increase during and after multiple sets of snatch pull exercise. The average enhancement in vertical jump height (5.77% at MID and 5.90% at POST) is similar to that reported in other PAP investigations (2.5–5%) (Chiu et al., 2003; Gullich & Schmidtbleicher, 1996; Vandenboom et al., 1998). As vertical jump height is related to whole-body power production (Sayers et al., 1999), the enhancement of jump height is indicative of an enhanced capability to generate power. This is supported by the net joint kinetic results—the area under the concentric NJP-time curve (WORK) increased at the ankle and knee.

Typically, PAP is elicited using heavy loads or resistances (Chiu et al., 2003; Duthie et al., 2002; Fowles & Green, 2003), whereas in this investigation, submaximal loads were lifted. Relatively low loads (i.e., less than 85% 1 RM) have been reported to be ineffective for eliciting PAP (Gullich & Schmidtbleicher, 1996; Vandenboom et al., 1999), however, the current investigation as well as Chiu et al. (2004), Linnamo et al. (2000) and Stone et al. (2008) have reported PAP during high-power resistance training. To reconcile this difference, it is important to consider the nature of the exercise performed in this training session. The ability for high-power resistance exercise to elicit PAP, despite the low external resistances, can be explained by the nature of rapid muscular contractions. When muscular contractions are performed rapidly, the force threshold for recruitment of fast twitch motor units is lower (Desmedt & Godaux, 1977, 1979). Therefore, exercises performed explosively will result in activation of more motor units than if the exercise is performed at the same load but at a slower tempo. Movement speed in conjunction with load should be considered a factor in eliciting PAP.

Our data indicate that PAP increases work performed and therefore average power output over the course of a weightlifting training session. As such, this acute physiologic response should be considered in the design of resistance training programs (Stone et al., 2008). Specifically, average power output is related to the intensity of exercise, which is determined by the external resistance (mass) and the velocity of movement. An increase in power allows either the same mass to be lifted at a greater velocity, or a larger mass to be lifted at the same velocity. Because it is difficult to gauge the velocity of exercise (without instrumentation), the PAP effect is best accounted for by increasing the external resistance.

The rationale for considering the PAP effect is to maximize the training stimulus. Recent evidence indicates the importance of the magnitude of muscular tension during resistance exercise for eliciting adaptations. Magnitude of muscular tension is important for stimulating pathways affecting muscle hypertrophy (Fiatarone Singh et al., 1999; Hameed et al., 2003) and neural adaptations (Deschenes et al., 1993, 2000). It is clear from these physiologic investigations that greater muscle tensions are necessary to elicit specific adaptations. It can be hypothesized that greater tensions elicited via PAP will result in greater training adaptations; however, a causative link has not been established. Further research has found the nature of muscle tension, including the magnitude of tension, rate of tension development and tension-time integral elicit different signaling pathways (Frey et al., 2009). As PAP influences concentric WORK, the shape of the muscle force-time curve will also be affected. Future research should investigate the effects PAP has in eliciting physiologic adaptations.

The second purpose of this study was to investigate whether PAP was uniform across lower extremity joints during a multijoint activity. PAP was not uniform as WORK during the concentric phase performed at the knee and ankle increased, but not at the hip. The correlations between increased concentric WORK at the ankle and knee, and percent potentiation of vertical jump height suggest that PAP was responsible for the increased jump performance. WORK performed concentrically at the knee increased significantly at MID, and this increase was correlated to percent increase in jump height at MID. Ankle plantar flexor concentric WORK increased significantly at POST, and this increase correlated to increased jump height at this time point. These data indicate that during a multijoint exercise, PAP does not present equally or simultaneously in all muscles used. In addition, the localization of PAP appears to change with repeated sets of exercise. PAP effects at the knee suggest a preferential loading of the knee extensors during the first wave of exercise, whereas, fatigue of the knee extensors may have offset PAP at POST. Garhammer (1979) has reported an increase in knee extensor NJM to be an important factor in the ability to lift heavier weights in the snatch. Increasing use of the knee extensors over multiple sets of exercise, however, would ultimately result in fatigue. PAP at the ankle at POST may indicate a change in the strategy to decrease loading of the knee extensors while allowing performance to be maintained.

The NJM of the hip extensors is greater than the knee extensors and ankle plantar flexors during the snatch (Bauman et al., 1988; Garhammer, 1979). From these findings, it would be reasonable to hypothesize that PAP would be greatest in the hip extensors; however, concentric WORK was only increased following high-power exercise in the knee extensors and ankle plantar flexors. This may be explained by considering the role of each of these muscle groups in the snatch. The hip extensors are primarily used in the first pull (Figure 1A to 1B), which is relatively slower (Bauman et al., 1988; Enoka, 1988; Garhammer, 1979). The knee extensors and ankle plantar flexors are involved to a greater extent in the second pull (Figure 1C to 1D), where higher power outputs have been reported (Bauman et al., 1988; Enoka, 1988; Garhammer, 1979). The explosive nature of the second pull would require greater motor unit activation (Desmedt & Godaux, 1977; 1979) compared with the first pull, thus, leading to PAP manifesting in the knee extensors and ankle plantar-flexors, but not the hip extensors.
Nagano and Gerritsen (2001) and Cheng (2008) generated forward simulation models of vertical jumping to model the effects of increased strength on jump height. In both investigations, an increase in knee extensor strength had the greatest effect on jump height, followed by increasing ankle plantar flexor strength. Increasing hip extensor strength had the smallest effect on jump height. Therefore, even if PAP was present in the hip extensors, the physiologic response may not be beneficial for enhancing jump performance. A limitation of this investigation is that PAP was not directly assessed, for example using electrically elicitedwitches from the individual muscles. As our data indicate that PAP is not uniform during multijoint tasks, future research should directly measure the presence of PAP in individual muscles following a multijoint task, and the magnitude of the PAP response.

In summary, performance of vertical jumping is enhanced over the course of a weightlifting training session. Increased vertical jump performance and concentric WORK suggest that PAP increases the training intensity that can be used during the exercise session. In the design of resistance training programs, the PAP phenomenon should be considered by manipulating the external resistance to maximize the training stimulus. The PAP effect was observed at the knee and ankle, but not the hip, suggesting PAP is not elicited uniformly in active musculature during multijoint tasks. Furthermore, PAP at the knee occurred at MID and PAP of the ankle at POST, suggesting a change in the strategy used to perform exercise during the training session.

Acknowledgments

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References


