THE TEMPORAL PROFILE OF POSTACTIVATION PONTENTIATION IS RELATED TO STRENGTH LEVEL

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ABSTRACT

Seitz, LB, de Villarreal, ES, and Haff, GG. The temporal profile of postactivation potentiation is related to strength level. J Strength Cond Res 28(3): 706–715, 2014—The purpose of this investigation was to determine whether stronger individuals are able to express postactivation potentiation (PAP) earlier than weaker individuals during a vertical squat jump test. Eighteen junior elite rugby league players were divided into strong (relative 1 repetition maximum [1RM] back squat ≥2 × body mass) and weak (relative 1RM back squat <2.0 × body mass) groups. Each subject performed squat jumps before, 15 seconds, 3, 6, 9, and 12 minutes after a conditioning activity (CA) that contained 1 set of 3 back squats performed at 90% of 1RM. A force plate, which sampled at 1000 Hz, was used to determine the power output and height for each squat jump. Stronger individuals expressed PAP between 3 and 12 minutes post-CA, whereas their weaker counterparts displayed potentiation between 6 and 12 minutes post-CA. Moreover, the stronger group exhibited a significantly (p ≤ 0.05) higher PAP response than the weaker group at all post-CA squat jump tests. The stronger group displayed the greatest potentiation at 6 minutes post-CA, whereas the weaker group displayed the greatest potentiation response at 9 minutes following the CA. Based on these results, stronger individuals appear to be able to express PAP earlier after a CA than weaker individuals. Additionally, stronger individuals express significantly greater postactivation responses than weaker individuals. From a practical standpoint, strength and conditioning coaches should consider the athletes’ strength levels when constructing postactivation complexes (CA + performance activity) as strength will dictate the time frame required between the conditioning and the performance activity.

KEY WORDS potentiating stimulus, recovery interval, back squat, peak power, rugby league

Introduction

The enhancement of muscle force and power by use of a voluntary conditioning activity (CA) has been referred to as postactivation potentiation or PAP (9,16,17). Previous studies have reported that vertical jump performance is increased 5–18.5 minutes after the execution of submaximal back squats or an isometric maximal voluntary contraction in the leg press exercise (19,26,31). Recently, Wilson et al. (23) in a meta-analysis on potentiation responses to a CA reported that the greatest PAP responses occur somewhere between 7 and 10 minutes (effect size [ES] = 0.7) after the completion of a CA. Conversely, several other studies have failed to demonstrate any increase in vertical jump performance 15 seconds–5 minutes after the use of near-maximal back squats (2,10,17). Similarly, Wilson et al. (23) report that when the rest period is <2 minutes there is a minimal effect (ES = 0.17) on the expression of PAP, whereas longer rest periods of 3–7 minutes result in potentiation (ES = 0.54) responses. Interpretation of the optimal rest period reported in the scientific literature on potentiation is often difficult because the magnitude of the PAP response and the time course of its occurrence post-CA is influenced by several parameters, such as the training status of the athlete (31), the athlete’s level of strength (18,26), and the time course of recovery between the CA and the subsequent performance activity (2,18,19).

Overall, it is generally believed that stronger individuals express a higher degree of potentiation (2,18,26,30). Typically, stronger individuals have higher type 2 fiber content which has been linked to a greater expression of PAP (30) and possibly a more rapid recovery after a CA. Recently, Ruben et al. (26) suggested that individuals who can squat ≥2 × body mass express a greater degree of PAP when compared with their weaker counterparts. Additionally, the individual’s strength level may also impact the time course before PAP is expressed (18). When looking at the literature, many of the published studies have used a 4- to 5-minute recovery time period between the CA and the performance activity. It is possible that studies which have failed to find a PAP response while using shorter rest intervals between the CA and performance activity with weaker individuals may have not allotted enough recovery time for the optimization of performance. A suboptimal recovery...
time may create a scenario where the accumulated fatigue results in a muting of the potentiation response, which is indicated by a reduction in performance capacity.

Generally, the temporal profile of PAP demonstrates a decrease in performance in the early stages of recovery followed by a performance increase after a recovery period ranging from 3 (19) to 18.5 minutes (2). Recently, Wilson et al. (23) report that the time course of recovery after a CA impacts the ability to express PAP responses. Specifically, shorter recovery periods (<2 minutes) and very long rest interval (>10 minutes) result in smaller ESs for the PAP response when compared with rest periods of 3–5 minutes or 7–10 minutes. Additionally, Jo et al. (18) suggest that the time course of recovery between the CA and the subsequent performance activity is dictated by the individual’s strength level. Specifically, stronger individuals (1 repetition maximum (1RM) back squat >1.5 × body mass) appear to express PAP earlier after the cessation of a CA when compared with their weaker counterparts (1RM back squat <1.5 × body mass). Although the findings presented by Jo et al. (18) expand the scientific body of knowledge about PAP responses, they must be interpreted with caution as the performance test used to assess the PAP response was a 30-second Wingate test. This performance test measures anaerobic cycling power (13), which is very different from other performance tests because it assesses the ability to produce power in a cyclical fashion. Alternatively, the more commonly used squat jump test assesses the ability to produce vertical power, which may be more relevant to team-based sports such as rugby. Indeed, it has been previously shown that the ability to produce vertical power is strongly correlated with different types of activities such as sprinting (23,32), changing of direction (23), and weightlifting (12). The squat jump is, therefore, one of the most popular field tests to measure the vertical jumping performance and the power level of trained and untrained populations (12) and is commonly included in the training program of athletic and nonathletic populations.

To the best of our knowledge, however, no studies have determined whether stronger individuals are able to potentiate earlier than weaker individuals during a vertical jump task following heavy back squats. Therefore, the purpose of the present study was to determine whether following a set of near-maximal back squats, individuals with high strength level (relative 1RM back squat ≥2) are able to express PAP earlier than individuals with lower strength level (relative 1RM back squat <2) during sets of single squat jump.

**Methods**

**Experimental Approach to the Problem**

The present study required the participants to perform 1 familiarization and 1 experimental session to assess the impact of strength levels on the temporal performance responses to a CA and the relationship between relative strength and the time frame needed between a CA and vertical squat jump performance (Figure 1). During the familiarization session, anthropometric characteristics were measured, the 1RM in the back squat was determined, and the participants were familiarized with the experimental procedures. During the experimental session, the participants performed 3 maximal squat jumps before (baseline value) and single maximal squat jumps 15 seconds, 3, 6, 9, and 12 minutes (post-CA values) after 3 back squats at 90% of their 1RM. To assess the magnitude of PAP, absolute peak power output, relative peak power output, and jump height during a squat jump were compared between the baseline assessment and each of the post-CA time points.

**Subjects**

Eighteen elite junior rugby league players took part in this investigation (Table 1). All participants were recruited from the French Rugby League Academy and were divided into 2 groups based on their relative strength levels, strong (relative 1RM back squat ≥2 × body mass) and weak groups (relative 1RM back squat <2.0 × body mass). The 2 times body mass cutoff was selected based on previous studies (2,26), which have suggested that athletes who have achieved this squat to body mass ratio are able to express a greater degree of PAP. Participants were recruited on the basis that they were engaged in a regular training program that used combined maximal strength and power training for at least 1 year and were able to squat a minimum of 1.5 × their body mass. A back squat cutoff of 1.5 × body mass was selected to ensure that the subject group consisted of trained rugby players (4). Additionally, the 1.5 × body mass inclusion criteria were selected so that the present study would be consistent with other PAP studies that have defined training status as a minimum of 1.5 × body mass (2,26). An informed consent was signed by each player and by the parents of three players under the age of 18. This investigation was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University Pablo Olavide, Sevilla, Spain.

**Familiarization Session**

The familiarization session included anthropometric measurements, determination of the 1RM in the back squat exercise, and familiarization with the experimental procedure. Height and body mass were measured using a calibrated Tanita stadiometer (model HR-200; Tanita, Tokyo, Japan) and a Tanita scale (model BC-418MA; Tanita, Tokyo, Japan), respectively. The average of 2 measures was calculated for both height and body mass and selected for further analysis. The interclass correlation values for height and body mass assessments were 0.95 and 0.97, respectively.

**One Repetition Maximum Back Squat Testing**

The back squat 1RM protocol was developed based on the work of Jo et al. (18) and involved the players completing a standardized warm-up of 5-minute cycling (60 W, 1-kg resistance) on a cycle ergometer (Monark, Varberg, Sweden). Following a 2-minute recovery period, they performed 10 unloaded back squats, 8 repetitions at the 40% estimated 1RM, 6 repetitions at the 60% estimated 1RM, and 4 repetitions at the 70%
estimated 1RM with a 3-minute rest period between each load. After resting 3 minutes, they performed 1 repetition at the 90% estimated 1RM. If the attempt was successful, a 5-minute rest period was allowed, after which the load was increased based on the player’s perception of the previous attempt. The last successful attempt defined the player’s 1RM (18). Because the players regularly performed the back squat during their weight training sessions, only 2–3 attempts were required to determine their 1RM. Proper technique and squatting depth (i.e., top of the thighs parallels to the ground at the end of the eccentric phase of the movement) were visually assessed by the investigator. Following the 1RM measurement, there was a 10-minute recovery period before the players practiced the experimental procedures, which are outlined under the section Experimental Session.

**Experimental Session**

**Baseline Assessments.** The experimental session was conducted 7 days after the completion of the familiarization session with the players reporting to the laboratory having refrained from caffeine for at least 6 hours, from alcohol for at least 12 hours, and from any exercises for at least 48 hours. On arrival, they performed a standardized warm-up that was modified from previously published literature (5). This warm-up included 5-minute cycling (60 W, 1-kg resistance) on a cycle ergometer (Monark) followed by a standardized dynamic warm-up culminating with 6 submaximal unloaded squat jumps of increasing intensity being performed every 30 seconds. After observing a 2-minute rest period, assessment of vertical jump performance was conducted using the unloaded squat jump on a force plate (model BP-4051040; AMTI, Newton, MA, USA), which sampled at 1000 Hz. A squat jump was selected as a simple assessment of lower-body power of elite rugby players in the scientific literature (1). Briefly, the squat jump was undertaken from a stationary position with the knees flexed at an angle of approximately 90° and the top of the thigh parallel to the floor. The players were required to hold this position for 4 seconds and jump on the command “GO” (13,20). They were required to hold a 1.75-m wooden bar weighing 0.5 kg across their shoulders during the entire execution of the jump (i.e., take off, flight, and landing movements) and received verbal encouragements to jump as high and as fast as possible (14). The players performed 3 squat jumps interspersed with 1 minute of recovery (10), and the trial resulting in the greater absolute peak power output was used for further analysis. If any counter movements were noted in the force tracing, the trial was repeated.

**Conditioning Activity Protocol and Postconditioning Activity Assessments.** This protocol was adapted from previously published research on PAP responses in rugby players (19). Specifically, 10 minutes after the determination of the baseline squat jump data, the players performed 1 set of 3 back squats at 90% 1RM as...
a CA and completed single squat jumps 15 seconds and every 3 minutes until 12 minutes post-CA (Figure 1). One set of 3 performed with a 90% load was selected in accordance with previously described methods (19,22) and because it allows for minimal fatigue to be generated whilst allowing for PAP responses to occur (30). The post-CA squat jump assessment times were selected based on previously published research exploring the temporal pattern of the expression of PAP (5,17–19,21).

**Displacement and Power Output Calculations**

All data were filtered using a fourth-order Butterworth low-pass filter with a cut-off frequency of 9 Hz. The vertical ground reaction forces collected from the force plate were then used to determine the vertical displacement and the power output values achieved during each squat jump (3,6,14).

Maximal vertical jump displacement was determined from flight time using the following equation:

\[
\text{Vertical displacement} = \frac{g \times \text{flight time} \times \text{flight time}}{2},
\]

where \( g \) represents gravity, and the flight time was determined in seconds (3). The interclass correlation for the squat jump test was 0.87.

The impulse-momentum approach was used to calculate the power output achieved during each jump based on the method of Dugan et al. (6) in which the sampling rate, subject mass, the vertical ground reaction force, and the initial velocity are used to determine power output. Based on this method, the instantaneous power is determined by multiplying force by velocity and then determining the peak of these values for the propulsive phase of the squat jump. The basic equation for each time point based on the sampling frequency

\[
v_{i+1} = v_i + \frac{F_i t}{m}
\]

\[
F_i = m \left( v_{i+1} - v_i \right)
\]

\[
\Delta v = \frac{F_i t}{m}
\]

Figure 2. A) Squat jump absolute peak power output before and after the CA for the strong and weak groups. B) Time course of postactivation potentiation for the strong and weak groups. *Significantly different from baseline (\( p \leq 0.05 \)). †Strong group significantly different from weak group (\( p \leq 0.05 \)). CA = conditioning activity.

Figure 3. A) Relationship between relative squat strength and maximum PAP effects on absolute peak power output following the conditioning activity (\( n = 18 \)). B) Relationship between relative squat strength and recovery duration eliciting maximum PAP effects on absolute peak power output following the conditioning activity (\( n = 18 \)). PAP = postactivation potentiation.
$P_i = F_i \times v_i$,

where $F$ = force, $t = 1$/sampling frequency, $m$ = mass of the body, $v = \text{velocity}$, and $P = \text{power}$. The velocity of the initiation of the movement was zero (6,14). The peak power was then divided by the subject’s body mass to present relative power output values. The interclass correlation value for the power values collected during the squat jump test was 0.96.

**Statistical Analyses**

Statistical analyses were conducted using Stata 9 for Windows (Stata Corp., College Station, TX, USA). Pre- and postchanges in absolute and relative peak power output and maximal jump height were compared between strong and weak groups using a $2 \times 2$ repeated-measures analysis of variance (group $\times$ time). If significant interactions were determined, the data were further analyzed using paired comparisons coupled with a Bonferroni correction to correct for type I errors. Pearson correlation analyses were used to assess the relationship between relative strength and maximum PAP response for each participant and between relative strength and the recovery duration necessary to elicit maximal PAP for each participant with regard to absolute peak power, relative peak power, and jump height. For all statistical analyses, the level of significance was set at $p \leq 0.05$.

**RESULTS**

**Absolute Squat Jump Peak Power**

When examining the temporal profile, the absolute squat jump peak power output was significantly decreased 15 seconds after the CA in both the strong ($p = 0.02; \text{ES} = -0.28$) and weak ($p = 0.02; \text{ES} = -0.28$) groups (Figure 2A). Additionally, the absolute peak power output of the strong group was significantly higher than baseline at 3 ($p = 0.008; \text{ES} = 0.87$), 6 ($p = 0.001; \text{ES} = 1.00$), 9 ($p = 0.002; \text{ES} = 0.95$), and 12 ($p = 0.01; \text{ES} = 0.52$) minutes post-CA. A similar pattern was noted for the weak group where absolute peak power output was significantly increased at 6 ($p = 0.05; \text{ES} = 0.31$), 9 ($p = 0.02; \text{ES} = 0.33$), and 12 ($p = 0.05; \text{ES} = 0.21$) minutes post-CA in comparison to baseline. In contrast to the strong group, the weak group did not display significantly increased peak power output 3 minutes after the CA ($p = 0.1$; ES = 0.05).

As shown in Figure 2B, the strong group exhibited less percent decrease in peak power output 15 seconds after the CA ($p = 0.05; d = 1.077$) and a greater percent increase at 3 ($p = 0.04; d = 1.082$), 6 ($p = 0.01; d = 1.339$), and 9 ($p = 0.03; d = 1.089$) minutes after the CA in comparison to the weak group. The difference between the groups 12 minutes following CA failed to reach statistical significance ($p = 0.19; \text{ES} = 0.635$).

Overall, the strong group exhibited significantly higher absolute peak power output values at baseline ($p = 0.001; d = 2.53$) and 15 seconds ($p = 0.001; d = 2.49$), 3 ($p = 0.001; d = 2.67$), 6 ($p = 0.001; d = 2.49$), 9 ($p = 0.001; d = 2.57$), and 12 minutes ($p = 0.001; d = 2.57$) following the CA in comparison to the weak group (Figure 2A).
Additionally, there was a large significant relationship ($r = 0.775; p = 0.002$) between relative 1RM back squat strength and maximum PAP effect on absolute peak power output following the CA (Figure 3A). Moreover, a large significant relationship ($r = -0.690; p = 0.002$) was found between relative 1RM back squat strength and the recovery duration necessary to elicit a maximal PAP effect on absolute peak power output (Figure 3B).

**Relative Squat Jump Peak Power**

The temporal profile of the relative squat jump peak power output displayed a similar profile to that reported for the absolute power data. There was a significant decrease in the relative peak power output 15 seconds after the CA in both the strong ($p = 0.03; ES = -0.1$) and weak ($p = 0.03; ES = -0.20$) groups (Figure 4A). The strong group displayed significant higher relative peak power output at 3 ($p = 0.01; ES = 0.30$), 6 ($p = 0.002; ES = 0.004$), 9 ($p = 0.02; ES = 0.32$), and 12 ($p = 0.01; ES = 0.17$) minutes post-CA in comparison to baseline value. A similar pattern was observed for the weak group where relative peak power output was significantly increased a 6 ($p = 0.05; ES = 0.19$), 9 ($p = 0.03; ES = 0.19$), and 12 ($p = 0.05; ES = 0.15$) minutes post-CA. Contrary to the strong group, the weak group did not display significant increase in relative peak power output 3 minutes after the CA ($p = 0.17; ES = 0.02$) (Figure 4A).

The strong group exhibited less percent decrease in relative peak power output 15 seconds after the CA ($p = 0.05; d = 1.077$) and a greater percent increase at 3 ($p = 0.04; d = 1.082$), 6 ($p = 0.01; d = 1.339$), and 9 ($p = 0.03; d = 1.089$) minutes after the CA in comparison to the weak group (Figure 4B). The difference between the groups failed to reach statistical significance 12 minutes following the CA ($p = 0.19; d = 0.635$).

The strong group exhibited significantly higher relative peak power output values during the squat jump at baseline ($p = 0.05; ES = 0.17$) and 15 seconds after the CA in both the strong ($p = 0.01; ES = 0.53$) and weak ($p = 0.04; ES = 1.01$), 3 ($p = 0.001; ES = 1.35$), 6 ($p = 0.01; ES = 1.21$), 9 ($p = 0.01; ES = 1.21$), and 12 minutes ($p = 0.05; d = 0.94$) following the CA in comparison to the weak group (Figure 4A).

There was also a moderate significant relationship ($r = 0.775, p = 0.002$) between relative 1RM back squat strength and maximum PAP effect on relative peak power output following the CA. Furthermore, a moderate significant relationship ($r = -0.690, p = 0.002$) existed between relative 1RM back squat and the recovery duration required to elicit a maximal PAP effect on relative peak power output.

**Squat Jump Height**

A similar temporal pattern to both the absolute and relative peak power data was observed when examining squat jump height. Specifically, there was a significant decrease in squat jump height at 15 seconds after the CA in both the strong ($p = 0.03; ES = -0.17$) and weak ($p = 0.02; ES = -0.49$) groups (Figure 5A). Additionally, squat jump height of the strong group was significantly higher than baseline at 3 ($p = 0.006; ES = 0.76$), 6 ($p = 0.002; ES = 0.90$), 9 ($p = 0.008; ES = 0.86$), and 12 ($p = 0.01; ES = 0.56$) minutes post-CA. The weak group also displayed significant increase in
squat jump height at 6 \( (p = 0.03; \ ES = 0.50) \), 9 \( (p = 0.01; \ ES = 0.56) \), and 12 \( (p = 0.03; \ ES = 0.37) \) minutes post-CA. In contrast to the strong group, the weak group did not display significantly increased squat jump height 3 minutes after the CA \( (p = 0.09; \ ES = 0.31) \).

As shown in Figure 5B, the strong group exhibited less percent decrease in squat jump height 15 seconds after the CA \( (p = 0.04; \ d = 1.34) \) and a greater percent increase at 3 \( (p = 0.04; \ d = 1.35) \), 6 \( (p = 0.009; \ d = 1.81) \), and 9 \( (p = 0.01; \ d = 1.56) \) minutes after the CA in comparison to the weak group. The difference between the groups 12 minutes following CA failed to reach statistical significance \( (p = 0.11; \ d = 0.79) \).

The strong group exhibited significantly higher squat jump values at baseline \( (p = 0.02; \ d = 2.18) \) and 15 seconds \( (p = 0.008; \ d = 2.48) \), 3 \( (p = 0.008; \ d = 2.51) \), 6 \( (p = 0.007; \ d = 2.67) \), 9 \( (p = 0.01; \ d = 2.38) \), and 12 minutes \( (p = 0.02; \ d = 2.16) \) following the CA in comparison to the weak group (Figure 5A).

A large significant relationship \( (r = 0.740, p = 0.004) \) was found between the relative 1RM back squat and the maximum PAP effect on jump height (Figure 6A). A moderate significant relationship \( (r = -0.690; p = 0.002) \) was determined between the relative 1RM back squat and the recovery duration required to elicit a maximal PAP effect on jump height (Figure 6B).

**Discussion**

The aim of the present study was to determine whether stronger individuals are able to potentiate earlier than their weaker counterparts during a vertical jump test following a set of heavy back squats. The results of the present study, in agreement with our hypothesis, show that stronger individuals expressed a PAP effect on absolute peak power output (Figure 2), relative peak power output (Figure 4), and jump height (Figure 5) after 3 minutes post-CA, whereas weaker individuals displayed PAP effects at 6 minutes post-CA. In addition, the stronger group exhibited a greater PAP effect on absolute peak power output (Figure 2), relative peak power output (Figure 4), and jump height (Figure 5) than the weaker group at 3, 6, and 9 minutes post-CA. These results are in agreement with the findings of Kilduff et al. (19), who found a significant correlation between relative strength levels and PAP effect on absolute peak power output during vertical jumps following a set of near-maximal back squats \( (r = 0.631; \ p = 0.009) \). Similarly, the present study found a significant correlation \( (r = 0.629; \ p = 0.005) \) between relative back squat strength and the degree of potentiation of absolute peak power output \( (r = 0.629; \ p = 0.005) \).
relative peak power output ($r = 0.492$, $p = 0.057$), and jump height ($r = 0.648$, $p = 0.004$) achieved after the CA. Collectively, the data from the present study and the work of Kilduff et al. (19) suggest that as strength increases the ability to express potentiation after a CA also increases. Interestingly, the stronger group in the present study was able to squat $>2 \times$ body mass which supports the findings of Ruben et al. (26), who suggested that individuals who squat $>2.0 \times$ body mass produce significantly greater degrees of potentiation than weaker individuals ($<1.7 \times$ body mass).

When examining the temporal profile of the expression of potentiation effects after a CA, there is a significant decrease in peak power output for both strong and weak groups immediately after the CA. This finding is in agreement with 2 previous studies indicating vertical jump performance is significantly decreased 10 or 15 seconds after 1 set of near-maximal back squats (17,19). This finding is not completely unexpected because the fatigue generated during the CA most likely results in the masking of the PAP response (29). In support of this contention, Wasserman and Macintosh (25) suggested that fatigue and potentiation can coexist and performance of the subsequent activity increases if potentiation offsets the fatigue that results from the CA. It is generally accepted that the time course to display PAP after a CA can be influenced by the amount of fatigue generated during the CA with greater workloads increasing the delay before performance gain can occur (27). Therefore, as time extends from the CA fatigue is dissipated and the ability to express PAP responses increases. If, however, the time between the CA and the subsequent performance is extended for too long, the ability to express PAP will decrease. In the present study, there was an increase in peak power output, relative power output, and vertical jump height at 3, 6, 9, and 12 minutes after the CA in the strong group. This finding is consistent with previous studies showing an increase in performance from 4 to 18.5 minutes following near-maximal back squats (2,7,11) and a recent meta-analysis which suggests that PAP is maximized between 3 and 10 minutes post-CA (31).

The present data also suggest that the temporal profile of PAP is related to the individual’s relative strength levels. Indeed, stronger individuals who were able to squat at least twice their body mass expressed PAP from 3 to 12 minutes post-CA, whereas their weaker counterparts who squatted less than double body mass expressed PAP between 6 and 12 minutes post-CA. Additionally, in the present study, there are significant correlations between relative back squat strength and the time to peak PAP of peak power output ($r = -0.689$, $p = 0.001$), relative power output ($r = -0.528$, $p = 0.024$), and jump height ($r = -0.547$, $p = 0.019$), which suggest that stronger individuals are able to display greater potentiation effects closer to the completion of a CA. Specifically, the stronger group achieved maximal PAP responses by 6 minutes, whereas the weaker group did not achieve a maximal PAP response till 9 minutes post-CA. These findings are consistent with the results of Jo et al. (18), who used a 30-second Wingate test to assess the PAP response after a set of heavy back squats. Stronger individuals (relative 1RM back squat $\geq 1.5 \times$ body mass) were able to express PAP 5 and 10 minutes after the CA, whereas weaker individuals (relative 1RM back squat $<1.5 \times$ body mass) did not display potentiation effects until 15 and 20 minutes after the CA. In the present study, the PAP response was measured with the squat jump, one of the most popular field test to assess the vertical jumping performance and the power level of trained and untrained populations (12). The different temporal profiles of PAP between stronger and weaker players might be explained by the fact that highly trained individuals develop fatigue resistance to heavier loads after a near-maximal effort (2,24). Support for this contention can be found in the scientific literature where trained individuals have been reported to express fatigue resistance to heavier loads (2,18,24). Given the relationship between strength, PAP, and fatigue, the stronger individuals in the present study might have dissipated their CA-induced fatigue quicker and therefore were able to express PAP earlier than the individuals in the weaker group. The results of the present study support this hypothesis in that the stronger group demonstrated less decrease in performance 15 seconds and a greater degree of potentiation all other time points following the CA.

Another possible explanation for the difference in the temporal profile between the stronger and weaker groups in the present study may be partially explained by skeletal muscle fiber characteristics. It is well documented that stronger individuals display elevated myosin light chain phosphorylation and also tend to have larger and stronger type II muscle fibers (15,24,28,30). Additionally, type II muscle fibers exhibit a greater neural excitation in response to high intensity resistance training exercises, such as those typically used as CA in potentiation complexes. Although fiber type and neural activation were not assessed in the present study, the body of scientific knowledge suggests that these factors may partially explain the differences found. To validate this hypothesis, further research which directly looks at the neuromuscular characteristics such as fiber type and neural excitation patterns is warranted to gain an understanding about the physiological factors related to strength that may impact the ability to express PAP responses.

Although the present study and most of those seen in the scientific literature have examined the acute performance effects of using a heavy-load squat CA, the ability to alter performance with the use of complex training may produce chronic adaptive responses which are beneficial to the athlete (8). However, the results of the present study and the work by Jo et al. (18) suggest that when constructing potentiation complexes (CA + performance activity), it is important to consider the temporal effects of the CA and how the athlete strength levels may play a role in determining the rest interval length need to optimize PAP.

In conclusion, the results of the present study suggest that the temporal profile of PAP is related to the individual's strength level, as stronger individuals express PAP earlier in
comparison to their weaker counterparts. Although the results of the present study are in line with other PAP studies (2,7,11), it is important to note that the effect of the CA on the PAP response cannot be completely isolated in the present study because of the lack of a control group and the methodology used. Specifically, it is possible that the post-CA activity vertical jump performance could have been influenced by the CA and each of the jump(s) that occurred before the time point of interest. For example, the PAP response at 12 minutes post-CA could have been influenced by the CA and each of the squat jumps performed at 1, 3, 6, and 9 minutes post-CA. To completely isolate the effects of the CA and determine if there is a potential cumulative effect of protocols similar to the present study, future studies should use a control group in their design or test only 1 poststimulus period per session. Additionally, further research is required to determine the neuromuscular mechanisms allowing stronger individuals to express PAP earlier than weaker individuals.

**Practical Applications**

Based on the results of this study and other potentiation studies (2,11,18,19,26), strength and conditioning coaches should consider the athlete’s strength level when designing PAP protocols to improve lower-body power performance. First, it appears that stronger individuals who are able to squat at least twice their body mass express a greater PAP response following a set of near-maximal back squats. Second, it appears that stronger individuals benefit from PAP earlier than their weaker counterparts. Therefore, when constructing PAP complexes, strength and conditioning coaches should consider the time frame between the CA and performance activity in relation to the individual athletes strength level to maximize the performance effects of a potentiation complex.

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