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Post-Activation Potentiation of a Back Squat to Romanian Deadlift Superset on Vertical Jump and Sprint Time

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Abstract Post-activation potentiation (PAP) has been shown to contribute to acute enhancements in lower body power output. Power output is crucial to athletic performance and is often exhibited in multiple ways during competition (e.g., both jumping and sprinting). **PURPOSE:** To examine the effects of a PAP conditioning activity (i.e., a back squat (BS) to Romanian deadlift (RDL) superset), coupled with 8 minutes rest on vertical jump (VJ) height and 36.6-meter sprint time. **METHODS:** 20 male recreationally resistance trained participants completed three test sessions over the course of three weeks (age 27.9± 5.5 years; height 179.2± 12.3 cm; mass 83.3± 12.7 kg). Session one consisted of a dynamic warm-up (WU) coupled with an 8-minute rest period followed by three trials of both the VJ and 36.6-meter sprint; 2-3 minutes of rest was allowed between trials. Session two consisted of the identical dynamic WU followed by a PAP conditioning activity comprised of 3 independent supersets of a 5-RM BS to a 5-RM RDL, with each independent set immediately followed by an 8-minute rest period; then at 8 minutes post each superset, half of the participants were tested for VJ height and the other half were tested for the 36.6-meter sprint time. Therefore, the entire procedure looked as follows: Set 1: Lift – Rest 8 minutes – Test VJ or Sprint. Immediately move to Set 2: Lift – Rest 8 minutes – Test VJ or Sprint. Immediately move to Set 3: Lift – Rest 8 minutes – Test VJ or Sprint. Session three was identical to session two with the exception that participants crossed over with respect to the VJ and 36.6-meter sprint measures. Paired t-tests were used to compare the VJ height and 36.6-meter sprint times between the dynamic WU and dynamic WU plus PAP superset conditions (i.e., trial 1 vs trial 1; trial 2 vs trial 2; trial 3 vs trial 3). **RESULTS:** The dynamic WU (Session 1) VJ height (cms) and 36.6-meter times (secs) were: Trial 1: 60.1 ± 18.0, 6.03 ± 0.81; Trial 2: 63.1 ± 17.4, 5.99 ± 0.74; Trial 3: 65.0 ± 17.4, 6.02 ± 0.71. The dynamic WU plus PAP superset condition (Session 2 and 3) VJ height (cms) and 36.6-meter times (secs) were: Trial 1: 61.2 ± 17.0, 6.00 ± 0.75; Trial 2: 65.4 ± 16.7*, 5.96 ± 0.73; Trial 3: 68.1 ± 16.5*, 5.99 ± 0.69. The VJ trial scores that followed the dynamic WU plus PAP superset condition had significant improvement during trials two (3.6%) and three (4.8%) compared to the dynamic WU trial scores ($p < 0.05$)*. There was not a significant or practical difference in the 36.6-meters sprint trials between the dynamic WU and the dynamic warm-up plus PAP superset condition ($p>0.05$). **CONCLUSIONS:** The PAP conditioning activity of supersets of a 5-RM BS to a 5-RM RDL was successful at improving VJ performance beyond 24 minutes of the initial PAP conditioning activity. No effect was observed on sprint performance. **PRACTICAL APPLICATIONS:** Sport performance is often comprised of a combination of sprinting and jumping. A coach or practitioner may consider using this PAP protocol to improve VJ without compromising sprint performance.

Keywords 5-RM, 36.6-meter sprint, PAP, Vertec

1. Introduction

The use of heavy resistance exercises (e.g., 5-RM back squat) that specifically target a muscle group, followed by a defined rest period, has provided benefits to increase muscular power output by generating a post-activation potentiation (PAP) effect [6, 9, 11, 18, 25, 30, 31, 34, 37, 42, 43, 47, 51, 55, 58-60]. PAP is a phenomenon known to cause an acute increase in voluntary muscle activation through a conditioning activity performed at near maximal intensity [20, 57]. The PAP phenomenon may acutely enhance peak muscular rate of force development when there is sufficient rest between the conditioning activity and the targeted movement [26]. The Romanian deadlift (RDL) and/or back squat (BS), coupled with a dynamic warm-up, are crucial exercises for the purpose of increasing vertical jump height and horizontal speed in athletes [5, 30]. PAP induced through resistance training prior to competition might prove better than just a conventional warm-up period to enhance an athlete's performance during explosive sport activities that include jumping, throwing and sprinting [57].

Two dilemmas must be resolved to enhance an athlete's vertical jump (VJ) and/or sprint performance utilizing

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the PAP phenomenon. First, the intensity of the conditioning/resistance activity must be great enough to create a measureable PAP response, but if too great could create fatigue. The second dilemma deals with the rest period between the conditioning/resistance activity and the beginning of the performance activity [57]. In the instance of PAP, a specific muscle's contraction history may influence the mechanical performance of proceeding muscle contractions within a short time frame. However, if a muscle's contraction history leads to excessive fatigue, it will impair performance. That being said, muscle contractions at high loads coupled with a specific duration of rest may enhance the muscle's potentiation response [26, 57]. The precise timeframe in which the effectiveness of PAP remains uncertain [31, 37, 42, 51, 59]. The longer the rest period, the greater the recovery from muscular fatigue, but this also creates a decline in the PAP mechanism [46, 57]. The goal is to find that point in the rest period where PAP is optimal for the performance activity.

The rest period between a heavy loaded resistance exercise and a movement such as a VJ or sprint has been an independent variable in certain studies. The rest periods for past studies ranged from 30 seconds to 16 minutes following heavy resistance exercises such as the BS leading into a performance measure to test the effects of PAP [1, 10, 31, 52, 60]. A topic of debate in the literature appears to be the rest period between the conditioning activity and the targeted movement. The results of many studies indicate that a rest period between 8-12 minutes between the conditioning activity and the targeted movement is effective [10, 11, 13, 18, 28, 31, 40, 43, 45, 49, 50, 57]. It appears that recovery periods shorter than 2–3 minutes are not sufficient because the effects of the conditioning activity fatigue outweigh the potentiation effect. Recovery periods lasting longer than 12 minutes will usually not be successful because, "the enzyme responsible for deactivating the enhanced muscle fibers may have completely eliminated the effects of the initial potentiation" [45].

The possible benefits of PAP related to explosive athletic movements seem to fluctuate from study to study based on the variables utilized for the conditioning activity in the study. Specifically, there appears to be complex interactions between the conditioning activity, intensity used to execute the conditioning activity, rest period and testing procedures used to assess the performance of the targeted movement [32, 43, 60]. Further, the level of training of an individual also plays a role in the probability that a positive and measureable PAP outcome can be achieved. The National Strength and Conditioning Association (NSCA) suggests that PAP should be reserved for resistance-trained power athletes with high relative strength [45].

In light of the aforementioned programmatic challenges, PAP has been shown to contribute to acute enhancements in lower body power output. Power output is crucial to athletic performance and is often exhibited in multiple ways during competition (e.g., both jumping and sprinting). In the current study we attempted to examine the effects of a PAP conditioning activity comprised of a BS to RDL superset coupled with 8 minutes rest on vertical jump (VJ) height and 36.6-meter sprint time. It was hypothesized that both VJ and sprint performance would be measurably potentiated by the PAP supersets and lead to enhanced performance measures.

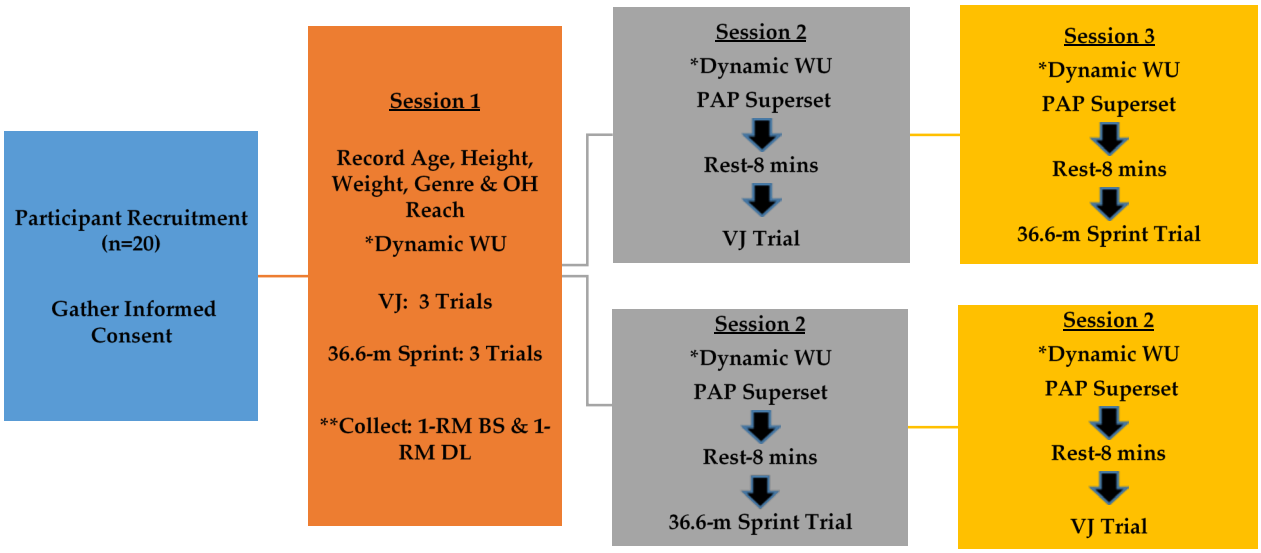

Figure 1. Chronology summary of study events. PAP-post activation potentiation; OH-Overhead Reach; WU-warm-up; PAP Superset- consisting of 5-RM BS and 5-RM RDL used as the PAP conditioning activity following dynamic warmup. *Dynamic warmup was performed prior to every session. **Collection of participant's 1-RMs were performed if necessary

2. Methods

2.1. Participants

Twenty male participants who were a mix of recreational weightlifters, CrossFit and amateur athletes volunteered for the study. Permission from 24 Hour Fitness and CrossFit Las Vegas was granted prior to the study being conducted. Likewise, permission from an Institutional Review Board to engage human subjects in research was obtained before conducting the study interventions or assessments. Participants were presented a written consent form to read and sign before any action in the study was taken. All participants were 18 years of age or older and were free of any injury that would inhibit their performance.

2.2. Instruments and Apparatus

The study took place in two separate locations; 24 Hour Fitness Tropicana and CrossFit Las Vegas. Equipment used to conduct the study included: deadlift platforms, squat racks, 20.45 kg Olympic style barbell, weighted plates (1.14 – 20.45 kgs), a Tandem Sports Vertical Challenger Vertec, Tandem Sports Vertical Challenger reset stick, two Sportline 240 Econosport stopwatches, cones, athletic tape and a measuring tape.

2.3. Procedures

2.3.1. Assessment

Session 1 consisted of recording the participant's age, height, weight, genre, and overhead reach. The investigator then reviewed the proper form and technique to perform the BS, DL, RDL, VJ and staggered start for the 36.6-meters sprint. After the introduction of the study and gathering of information the athlete then performed the dynamic warm-up consisting of thirteen specific exercises (see Section 2.3.2). The participant was then given 8 minutes of rest. The participants then completed three VJ attempts with 60 seconds' rest between each attempt. Participants then rested three minutes before performing three hand-timed 36.6-meters sprints with three minutes' rest between each attempt. If necessary, the participant had to rest 10 minutes before performing 1-repetition maximum (1-RM) testing of both the BS and deadlift (DL). The 1-RM is considered the heaviest load that is lifted once while retaining correct form and technique throughout the entire exercise movement [4]. If a participant's 1-RM had been established within a month of the study, that value of 1-RM was used for the purpose of the current study. The reliability of the 1-RM BS has been reported as ICC=0.91-0.99 [15, 40]. The National Strength and Conditioning Association (NSCA) recognize 1-RM measures (e.g. BS & deadlift) as reliable assessment of muscular strength [45].

Following the first session, 5-RM BS and 5-RM RDL were calculated per the recommendations of Baechle and Earle – BS (2008) [4] and Rippetoe - RDL (2015), respectively. The 5-RM BS and 5-RM RDL would later serve as the superset conditioning activity to induce a PAP (modality and intensity) during Sessions 2 and 3 (Figure 1).

Session 2 and 3 were held exactly one week apart for each participant to ensure full recovery. Session 2 had all participants complete the same dynamic warm-up protocol as stated in Section 2.3.2, which was then followed by three minutes of rest. Then participants were randomly assigned to which dependent variable would be tested during the session, either VJ or the PAP 36.6-meters sprint. Subsequently, the participants performed 2-3 warm-up sets to build up to the respective 5-RM for both BS and RDL, simultaneously, in a superset fashion. After the 2-3 warm-up sets, participants then began their first PAP superset of 5-RM BS, 30 second rest, 5-RM RDL. Eight minutes following the PAP superset the participants completed their first assigned test attempt (1^{st} trial) (VJ or 36.6-meters sprint). This process would be completed two more times for a total of three trials. During session 3 participants crossed over in regards to the assigned test portion (dependent variable to be tested). The same dynamic warm-up protocol and PAP superset procedure was used in session 3 as in session 2.

The 8-minute rest period following the PAP superset consisted of walking and active movements instead of static positions (no sitting or standing). Sixty-seconds prior to their test trial, participants were notified to prepare. Participant's test trials were strictly regulated to the 8-minute rest period after each PAP superset. The 8 minute rest period selected for this study was based on the average of rest periods used in prior studies that improved both VJ height (power) and sprint speed [10, 11, 13, 18, 28, 31, 40, 43, 45, 49, 50, 57].

2.3.2. Dynamic Warm-up

The dynamic warm-up protocol used for every testing session, Sessions 1-3, was custom designed to fit the needs to fully prepare the participants for physical exertion. The dynamic warm-up consisted of (fixed order): 10-air squats, 5 each leg-prisoner split squat and twist, 5 each leg – lateral lunge, 5 each leg – hip openers, 5 each side – windmills, 5 each leg – track stretch, 10 each leg – hip circles forward & backward, 10-supermans, 5 each side-scorpions, 5 each side-iron cross, 10 each leg-single leg hip extension, and 10 countermovement jumps followed by 10 yard sprints performed twice.

2.3.3. PAP Warm-up Sets

Participants performed 2-3 warm-up sets of BSs to RDL supersets with 120-180 seconds rest between each superset (8-10 repetitions @ unloaded Olympic bar, 6-8 repetitions @ 30% 1-RM, and 5 repetitions @ 50% 1-RM). Once participants reached their respective 5-RM for both BS and RDL they were given another 2-3 minute rest period. Following the warm-up sets, participants were instructed to perform their first PAP superset of five BSs, then 30 second rest, and then five RDLs using their calculated 5-RM weight (considered the PAP conditioning activity).

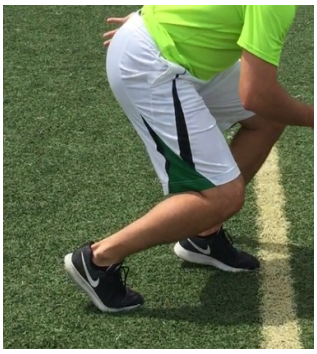

Figure 2. Staggered Athletic Stance

2.3.4. Vertical Jump

Before participants started their initial jumps, they stood next to the Tandem Sports Vertec apparatus with dominant arm fully extended vertical, the participant's overhead (OH) reach was then recorded via the apparatus. Participants started in a stationary athletic stance position directly under Tandem Sports Vertec apparatus. The participants then jumped-up, no step or run-up, and reached for the highest possible vane. The VJ height was then recorded (VJ height – standing OH reach) [4]. The apparatus height could be adjusted accordingly to the ability of each participant. To assure accuracy a Tandem Sport Reset Stick was used to reset/remove vanes prior to each. Each vane on the apparatus are separated by 2.54 cm increments. In the event of a fault, the participant was not given a re-jump and would move into the next PAP superset or end the session if it was their last jump.

The reliability coefficients of the VJ as measured by the Vertec have been reported as r>0.90. The Vertec also has also demonstrated a high intra-class correlation coefficient ICC=0.94) and low a coefficient of variation in intrasession (4.6%) and intersession (8%) studies [44].

2.3.5. Sprint 36.6-Meters

All participants started the 36.6-meter sprint test in a staggered athletic stance (see figure 2). The front foot's toe touched the starting line and the participant was to be stationary prior to starting. One of the two timers were instructed to call out, "ready, set, GO!" with a simultaneous sweep motion of the arm as the timer said "Go!". The testers started their stopwatch at the sound of "Go!" and simultaneous sweeping motion of the arm. This strategy was used to initiate a quick start for the participants [4]. When the participant's chest passed through the finish line the timers stopped the stopwatches. The two times were compared and the average of both times were recorded. All 36.6-meter sprint trials were organized to run from North to South. The 36.6-meters was measured by multiple testers using a tape measure to ensure consistency. Two timers were used at all test sessions using 240-Sportline stopwatches. The starting line and finish was marked with white athletic tape and bright orange cones. The hand timing aspect of the 36.6-meters dash has produced highly reliable data between trials by both experienced and inexperienced hand timers. The high rank order correlation of between hand times and electronic times (r=0.98) confirms that the athletes speed is categorized correctly regardless of timing method (hand timed vs. electronic time) [38].

2.3.6. Statistical Analysis

There were three trials of the DVs collected following the dynamic warm-up. Following each super set, a trial of the DVs was also collected. Paired t-tests were used to compare the dependent variables between the dynamic WU and dynamic WU plus PAP superset conditions (i.e., trial 1 vs trial 1; trial 2 vs trial 2; trial 3 vs trial 3). Significance for the study was set at $p<0.05$. Statistical calculations and data management were conducted with Microsoft Excel 2013.

3. Results

The 20 participants completed all test procedures without complications (VJs, 36.6 meter sprints, 1-RMs, supersets, and warm-up periods). The table depicted below (Table 1.) details the participant's descriptive information for age, height, mass, 1-RM assessments and 5-RM conversion that includes mean ± standard deviation.

The non-PAP VJ scores (cms) were 60.1±18.0, 63.1±17.4 and 65.0±17.4, for attempts 1-3, respectively. The VJs scores (cms) after performing the PAP SS were 61.2±17.0, 65.4±16.7, and 68.1±16.5, for attempts 1-3, respectively. The participants mean VJs after performing the PAP SS were significantly higher in the second and third attempt (see Table 2.) with an increase of 3.6% and 4.8%, respectively. The mean VJ after performing the PAP SS for the first attempt had a slight increase 1.8% (p=0.06) compared to Non-PAP VJ. The VJ trials (1-3) following the PAP SS progressively increased across trials.

The Non-PAP sprint trial times (secs) were 6.03±0.81, 5.99±0.74, and 6.02±0.71 for trials 1-3, respectively. The mean 36.6-meter sprint trial times (secs) following the PAP SS were 6.00±0.75, 5.96±0.73, and 5.99±0.69 for trials 1-3, respectively. The participant's PAP induced sprint times were not significantly lower for any of the trials (p>0.05).

Table 1. Study Participant Descriptive Information

N	Age (years)	Height (cms)	Mass (kgs)	5-RM BSQ	1-RM BSQ	5-RM RDL	1-RM RDL
20	27.9± 5.5	179.2± 12.3	83.3± 12.7	111.6± 27.3	139.5± 34.2	109.4± 30.0	156.4± 43.2

[1]Participant means and standard deviations for descriptive information. [2]1-RM-one repetition maximum, [2] BSQ-back squat, [3]RDL-Romanian deadlift, [4]DL-deadlift, [5]1-RM BSQ (kgs), [6]1-RM DL (kgs), [7] 5-RM- BSQ (kgs) [4], [8]5-RM RDL= 0.70 x 1-RM DL (kgs) [48].

Table 2. Vertical Jump (cms)

Trial	1st	2nd	3rd
Non-PAP SS (cm)	60.1 ± 18.0	63.1 ± 17.4	65.0 ± 17.4
PAP SS (cm)	61.2 ± 17.0	65.4 ± 16.7*	68.1 ± 16.5*
%Δ	1.8%	3.6%	4.8%
p-value	0.065	0.0017	0.000085

[1]Participant means and standard deviations (SD).
[2]PAP SS (superset) significantly greater than Non-PAP SS ($p<0.05$).
[3] *Paired t-test p-values.
[4] %Δ=(PAP SS VJ-Non-PAP SS VJ)/ Non-PAP SS VJ.

Table 3. 36.6-meter Sprint (seconds)

Trial	1st	2nd	3rd
Non-PAP SS	6.03 ± 0.81	5.99 ± 0.74	6.02 ± 0.71
PAP SS	6.00 ± 0.75	5.96 ± 0.73	5.99 ± 0.69
%Δ	-0.5%	-0.5%	-0.5%
p-value	0.37	0.24	0.27

[1]Participant means and standard deviations (SD).
[2]Paired t-test p-values.
[3]%Δ = (PAP SS Sprint-Non-PAP SS Sprint)/ Non-PAP SS Sprint.

4. Discussion

The purpose of this study was to determine if a 5-RM superset conditioning activity coupled with a designated 8-minute rest period was superior at inducing a PAP effect to increase VJ height and reduce sprint time in the 36.6-meters dash compared to a non-PAP dynamic warm-up. To our knowledge this is the first study of its kind to use a superset conditioning activity with a designated 8-minutes of rest to elicit a PAP stimulus in the VJ test and 36.6-meters sprint. The hypothesis was that the dynamic warm-up, plus PAP superset conditioning activity would have a significant positive effect on both the participant's VJ and 36.6-meters sprint compared to a non-PAP dynamic warm-up.

The VJs that followed the PAP conditioning superset were significantly greater during trial two (3.6%: p=0.0017) and three (4.8%: p=0.000085) when compared to the VJs performed following the dynamic warm-up alone. It should also be noted that slight increases (1.8%) were also seen in the first PAP VJ trial, but not as significant (p=0.06) as seen in attempts two and three. There was not a meaningful or statistical improvement in the 36.6-meters sprint performances following PAP conditioning activity. With that said, it is also noteworthy that the 36.6-meters sprint performances did not degrade across the three trials following the PAP conditioning activity. This data suggests that a superset conditioning activity of 5-RM BS to 5-RM RDL induced PAP and increased VJ height after a designated 8-minute rest period following the superset exercises and did not lead to degraded 36-6 meter sprint performance.

The increase in VJ height due to a preluding PAP conditioning activity used in this study is consistent with previous studies that have shown significant increases in lower body power output due to a PAP conditioning activity with adequate 6-12-minute rest [6, 9, 11, 18, 25, 30, 31, 34, 37, 42, 43, 47, 51, 55, 58, 59, 60]. However, the PAP stimulus did not prove effective for decreasing 36.6-meters sprint times following the superset conditioning activity coupled with an 8-minutes of subsequent rest period. The lack of a potentiating effect on the 36-6 meter sprint times is not consistent with previous studies which have demonstrated that a preluding PAP conditioning activity can significantly increase both upper and lower body power output [1, 7, 12, 21-24, 36, 56].

The average of the three 36.6-meters sprint trial times recorded in the current study was 5.90±0.70 (secs) were higher than $10^{th\ \%ile}$ NCAA Division III North American football players (5.47 secs) [27]. The average VJ height of the third trial following the PAP SS in the current study was 68.1 ± 16.5 cm which was similar to NCAA Division I North American college football offensive guards [4]. The average of all three VJ trials (64.9 cm) following the PAP SS is reflective of the $20^{th\ \%ile}$ of NCAA Division I athletes (64.8 cm) [27]. The 1-RM BS for participants in the current study (139.5±34.2 kgs) was reflective of the $80^{th\ \%ile}$ BS scores of NCAA Division I male basketball players [27]. The 1-RM deadlift for participant's mass in kg (83.3±12.7) in the current study was 156.4±43.2 kg which is reflective of intermediate ability [53].

The 5-RM BSs recorded during the study were calculated based on 1-RM BS scores. The equation used to convert the participant's BS 1-RM to 5-RM was (1-RM x 0.80) (e.g. 139.5 kgs x 0.80 = 111.6 kgs). The 5-RM RDLs established during the current study were equated using the Mark Rippetoe Formula [48] (e.g. 1-RM deadlift x 0.75-0.65). The

study used each individual participant's 1-RM DL x 0.70 to calculate 5-RM RDL. There have been multiple studies that have used heavy-loaded BSs as a conditioning activity to increase lower body power via PAP [9, 11, 18, 25, 30, 31, 37, 42, 43, 47, 55, 58-60]. However, we are unaware of any study employing a RDL as a PAP conditioning activity. Likewise, we believe this is the first study to employ a superset as a PAP conditioning activity.

The 8-minute rest period used in the current study was designated based on evidence from previous studies demonstrating that performance variables could be enhanced with such a rest period duration [1, 10, 18, 20, 31]. Crewther et al. (2011) [10] for example assessed the PAP effects of BSs on the countermovement jump (CMJ) height, sprint performance, and sled push after using a 3-RM load with various rest periods. Each session consisted of performance testing before a single set of 3-RM BSs, followed by testing at 15 seconds, 4, 8, 12 and 16 minutes. The researchers found that CMJ height following the 3-RM BS protocol improved at the 4, 8 and 12-minute mark compared to baseline testing values. Kilduff et al. [31] examined the effects of PAP on a CMJ and ballistic bench throws in a sample of professional rugby players (n=23) and reported that 8-12 minutes of recovery time was required between the PAP conditioning activity and the subsequent explosive activity in order to enhance muscle power output [4]. Gouvêa's et al. [18] meta-analytic review examined the extent and quality of research on the PAP acute effect of rest interval manipulation on jumping performance. Fourteen studies selected by two independent raters were included in the analysis. The rest intervals involved ranges including 0–3, 4–7, 8–12 and ≥16 min. Data from a pool of 193 participants were used in this analysis. While a rest interval of 0–3 min induced a detrimental effect on jump performance, the range including 8–12 min had a beneficial impact on jump height. Ah Sue, Adams & DeBeliso (2016) study used nine female collegiate volleyball players and demonstrated that PAP (5-RM BS) can increase muscular power output up to 10 mins as assessed by the standing long jump (SLJ). The study examined the optimal rest time frames relative to the PAP conditioning activity, in which the SLJ was performed at 2, 6, 10, 14 and 18-minute mark following the 5-RM BS [1]. The aforementioned research studies suggests that the rest interval of 8-12 mins is rather robust with regards to yielding a meaningful positive post-activation potentiation effect (independent of the conditioning activity). The aggregate results of these studies became the foundation for the designated 8-minute rest period used in the current PAP SS study [1, 10, 18, 20, 31].

A successful induced PAP procedure is found by creating an optimal stimulus that enables the coexistence of fatigue, while the muscle is in PAP state [46, 52]. Studies that have been unsuccessful at inducing a measureable potentiating effect may have not given participants sufficient recovery time following the conditioning activity [3]. Fatigue and muscle potentiation were likely not in co-existence with each other. Recovery periods subsequent to the PAP conditioning activity (e.g. VJ or 36.6-meters sprint) have proven to be a critical factor in order to achieve a measureable potentiating effect. An 8-12 minute rest period following the conditioning activity has proven adequate in optimally trained participants [1, 10, 18, 20, 31]. The current study used a designated rest period of 8 minutes and possibly was likely not a factor in the lack of measurable PAP effect on 36.6-meters sprint performance.

PAP is a body conditioning activity that utilizes high intensity exercises to induce greater muscular power production [26]. The notion that the PAP SS conditioning activity used in the current study could produce an acute improvement in a participant's sprinting and VJ performance has important implications to athletic competition and applications to a strength and conditioning program. The study's design could help consolidate training time through a major push/pull SS to maximize muscular rate of force development (power) through the PAP mechanism. This study was unique in that the PAP conditioning activity was comprised of a SS of a BS (axial load) coupled with a RDL (axial and anterior-posterior load) with the goal of simultaneously improving both VJ and sprint ability. While the PAP protocol employed in this study was unsuccessful at improving sprint performance, it is important to note that sprint performance was not degraded across the trials that lasted beyond 24 minutes of the first bout of the PAP conditioning activity.

4.1. Detailed Results

The population genre of the participants in the current study was as follows: eight recreational weightlifters, five CrossFit athletes and seven amateur athletes. In the current study, 14 of the 20 participants experienced a measurable potentiation effect as measured by the Vertec as a result of the PAP superset conditioning activity as compared to non-PAP dynamic warm-up. The 14 participants that experienced measurable potentiation: seven amateur athletes, three CrossFit athletes and four recreational weightlifters. The six participants that did not experience a measurable effect were: one amateur athlete, two CrossFit (one having failed to reach baseline) and three recreational weightlifters. It should be noted that out of the six participants that did not experience a measurable potentiation effect, only one of the six participants experienced a lower VJ in the three PAP superset attempts compared to the Non-PAP attempts. This specific participant was categorized as a CrossFit athlete with considerable strength to body mass ratio (2.17 kg 1-RM BS/kg body mass and 2.28 kg 1-RM deadlift/kg body mass), yet failed to reach the baseline VJ test height in the PAP superset trials.

As for the 36.6-meters sprint test 10 of the 20 participants had a decrease in sprint time following the PAP superset stimulus compared to the non-PAP dynamic warm-up. The population of the 10 participants that decreased 36.6-meters sprint time due to the PAP superset stimulus: 4 of 8 amateur athletes, 3 of 5 CrossFit athletes and 3 of 7 recreational weightlifters. Of the 10 participants that decreased

36.6-meters sprint time, 8 of 10 ran faster than non-PAP trials on their first attempt, while one ran faster on second attempt and another on third attempt, respectively. It seems that for some of the participants that fatigue was a contributing factor in the sprint trials as participant's times increased or never reached non-PAP recorded time after completing the PAP superset. A recent study examined the impact of PAP using the BS versus the hang clean on sprint performance in eight NCAA Division I athletes [25]. These athletes were similar in nature to the current studies eight athletes. A significant effect for the PAP conditioning stimulus was found in the 30-meter sprint for both hang clean and BS compared to control conditions. The hang clean did produce significantly lower times in the 30-meter dash than the BS. The results of the aforementioned study suggests that PAP is a highly-individualized phenomenon due to biomechanical specificity even in a homogenous sample of athletes [25]. The concept of specificity has been further explored by Springall et al. (2016) where by a weighted lunge was used unsuccessfully as the PAP conditioning activity in order to enhance short sprint ability. Springall and colleagues suggested that the lack of a measurable potentiation effect in their study was likely due to the lower relative strength of the participants used in the study.

Results of prior studies indicates that PAP is measurable to a greater degree in highly trained individuals compared to recreationally trained individuals [4, 8, 14, 17]. The NSCA recommends that PAP should be used by those with "high relative strength" [45]. The current studies participants were 18 years of age or older and were at least minimally experienced in resistance training with some accustomed to physical conditioning protocols. The participant's strength to body mass ratios were on average 1.67 kg 1-RM BS/kg body mass and 1.87 kg 1-RM deadlift/kg body mass, these averages are considered low relative to what is stated by the NSCA's PAP recommendations for relative strength of a BS 1-RM/body mass equal to ≈2.0.

The NSCA states an athlete's training status is probably the largest factor when pursuing a meaningful level of post-activation potentiation. This is the fourth such study that has demonstrated PAP can be effective in individuals with lower relative body strength than is suggested by the NSCA [1, 21, 56]. However, we do acknowledge that the effects of the PAP stimulus used in this study may been amplified in participants with higher relative strength.

The current study, and in agreement with previous literature, proposes minimizing fatigue in the first 2-4 minutes with a recovery period of at least 8 minutes to capture the benefits of the induced PAP mechanism [1, 15, 29, 31, 37, 42, 51, 59]. It should also be noted that a dynamic warm-up was conducted prior to all sessions of data collection in the current study. Previous research suggests dynamic warm-ups enhance performance and should be considered before inducing a PAP stimulus [1, 41].

5. Conclusions

Within the parameters of this study it can be concluded: (1) There was significant improvements in the VJ following a 5-RM BS to 5-RM RDL superset, known as the PAP conditioning activity; (2) there was not a significant decrease in sprint time following the PAP conditioning activity for all three 36.6-meter sprint trials; (3) the designated 8-minute rest period following the PAP conditioning activity provided sufficient recovery from muscular fatigue with steady incline in the PAP mechanism, demonstrated in the VJ; (4) therefore, the results of this study suggest that, if the superset conditioning activity is performed within the specified context, that PAP conditioning activity may be used to improve power, specifically increasing VJ, in competitive environments. We suggest that future research should be focused towards implementation of supersets as a PAP conditioning activity in a competitive environment.

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