Postactivation Potentiation Improves Acute Resistance Exercise Performance and Muscular Force in Trained Men

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Abstract

Conrado de Freitas, M, Rossi, FE, Colognesi, LA, de Oliveira, JVNS, Zanchi, NE, Lira, FS, Cholewa, JM, and Gobbo, LA. Postactivation potentiation improves acute resistance exercise performance and muscular force in trained men. *J Strength Cond Res* 35(5): 1357–1363, 2021—The purpose of this study was to investigate the effects of heavy back squat (90% one repetition maximum [1RM]) postactivation potentiation (PAP) on acute resistance exercise performance and force production in recreationally trained men, and to verify the relationship between maximal strength and the PAP response. Ten resistance-trained men randomly completed 4 experimental trials: (a) back squats without PAP (No-PAP), (b) back squats with PAP, (c) maximum voluntary isometric contraction (MVIC) of the quadriceps without PAP, and (d) MVIC with PAP. Back squats were performed with 4 sets at 70% of 1 RM with 2 minutes of rest interval. The number of squats repetitions performed was recorded for each set, and a total number of repetitions were calculated to analyze performance. Maximum voluntary isometric contraction was measured using electronic dynamometer, and the peak force and mean force were recorded. Blood lactate concentration was analyzed presquat and postsquat exercise. Repetitions performed in the first set was significantly ($p < 0.001$) greater in the PAP condition (22.00 ± 5.14) compared with No-PAP (15.50 ± 5.10), which resulted in significantly ($p = 0.001$) more total repetitions performed in the PAP (56.20 ± 17.3) condition compared with No-PAP (48.80 ± 14.5). Maximum voluntary isometric contraction peak was higher in PAP than in No-PAP (PAP = 765.7 ± 147.8 vs. No-PAP = 696.8 ± 131.5 N, $p = 0.006$). No significant correlations were observed between back squat 1RM relative to body mass and the PAP response in squat and MVIC. There were no significant differences in lactate concentration between conditions. In conclusion, PAP resulting from a heavy load prior back squat exercise improved total volume during resistance exercise. In addition, PAP was effective to increase force production during MVIC, but there was no relationship between relative 1RM values and the PAP response in trained men.

Key Words resistance training, strength exercise, muscle hypertrophy

Introduction

Postactivation potentiation (PAP) is a practical strategy to improve acute force or power production and, with chronic training, performance (1,11,25). Postactivation potentiation consists of performing 2 consecutive exercises, an exercise of maximal or near-maximal contraction, called the conditioning activity (CA), followed by a similar movement pattern that requires a rapid expression of force or power (19). Increases in muscular performance observed after the CA depends on the balance between fatigue and the magnitude of potentiation being influenced by the volume and intensity of CA, as well as the recovery period between CA and the subsequent exercise (25,27).

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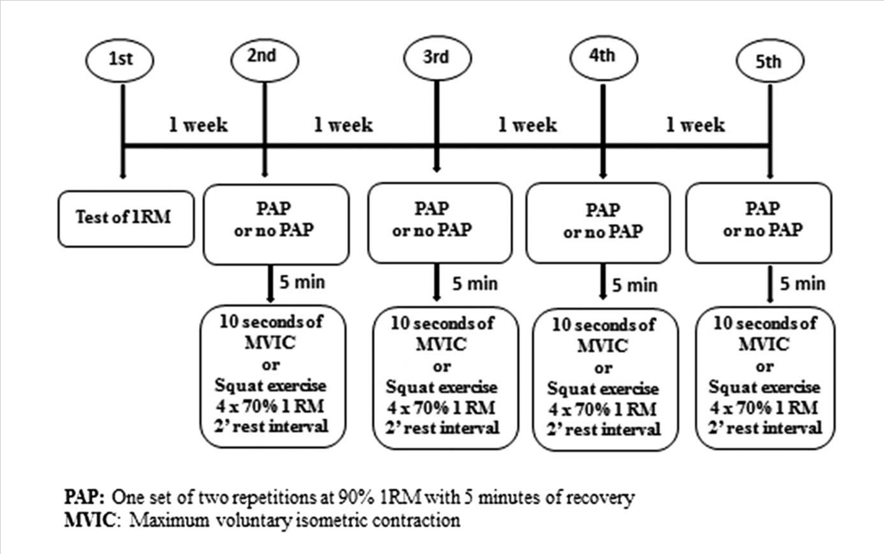

Figure 1. Experimental design.

with gains in muscular hypertrophy and strength (7,18,23), it is necessary to establish whether PAP response can increase total volume during resistance exercise. If PAP increases volume during an acute training session, future studies may then be conducted to investigate whether chronic PAP before higher volume resistance training sessions may enhance hypertrophic adaptations.

A number of studies suggest that stronger individuals, defined as a back squat of greater than 1.75 body mass (25), express greater potentiation levels in squat jumps (24), sprint velocity and acceleration (24), and plyometric jumps (22). Seitz and Haff (25) attribute the enhanced potentiation to a greater proportion of type II muscle fibers, greater fatigue resistance to heavy loading, and neurological adaptations associated with greater resistance training experience. All these studies have used short, powerful contractions (i.e., vertical jump) to assess PAP. It is currently unknown how differences in strength affect the potentiation of resistance exercise volume.

Thus, the purpose of this study was (a) to investigate the effects of PAP on resistance exercise performance and force in maximum voluntary isometric contraction (MVIC) in trained men and (b) to verify the relationship between 1RM values and PAP response. We hypothesized that PAP would increase acute total volume in resistance exercise and force during MVIC.

Previous studies demonstrated that PAP using back squat can increase lower-body explosive activity performance (3,4,10,15). Evetovich et al. (6) demonstrated that PAP protocol with back squat exercise at 85% of 1 repetition maximum (1RM) improved vertical and horizontal jump performance, and it was observed that PAP reduced the time to complete a sprint test in male and female athletes. Esformes and Bampouras (5) found that PAP protocol with the parallel and quarter squat (3RM load) enhanced countermovement jump height, peak power, impulse, and flight time in male rugby players. In accord with these results, others studies showed that PAP using heavy back squat can increase repeated-sprint ability in elite handball players (17) and 100-m sprint time in collegiate women (14).

Several studies have investigated the effects of PAP on subsequent muscular force production. French et al. (8) analyzed the influence of PAP using maximal isometric knee extensions (3 repetitions of 3–5 seconds) on drop and countermovement jumps in athletes. They observed that PAP increased jump height (5.03%), maximal force (4.94%), acceleration impulse (9.49%) in the drop jump, and improved knee extension maximal torque by 6.12%. Recently, Johnson et al. (12) demonstrated that PAP using drop jumps increased peak twitch torque, rate of strength development, and impulse significantly in athletes during 9 sets of 3 c electrically evoked maximal twitches interspersed, suggesting that PAP can enhance the force-generating capacity of the muscle (2,13,16). However, whether PAP could influence back squat performance using multiple sets is currently unknown. Given that greater resistance training volumes are highly associated

Table 1. General characteristics of the sample.*†

Age (y)	22.8 ± 2.4
Height (cm)	179.0 ± 7.7
Body mass (kg)	81.5 ± 14.3
Squat 1RM (kg)	104.6 ± 19.9
Relative squat 1RM ($kg \cdot kg^{-1}$)	1.30 ± 0.25
Experience (y)	6.2 ± 2.6
Weekly frequency training (d)	4.1 ± 0.7

*1RM = 1 repetition maximum.
†Data are mean ± *SD*.

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Table 2. Dietary intake and macronutrient distribution 24 hours prior each experimental trials.*

Dietary intake	Trial-1	Trial-2	Trial-3	Trial-4	*p*
Carbohydrate (g)	347 ± 134	335 ± 81	331 ± 93	302 ± 101	0.502
Protein (g)	158 ± 53	146 ± 46	164 ± 58	145 ± 44	0.539
Lipid (g)	91 ± 34	82 ± 17	85 ± 20	83 ± 15	0.762
Total intake (kcal)	2,907 ± 791	2,737 ± 568	2,815.7 ± 577	2,732 ± 670	0.799

*Data are mean ± *SD*.

Methods

Experimental Approach to the Problem

This study used a randomized, crossover design. Subjects completed 4 experimental trials at the laboratory, which were separated by 1 week. All trials were performed at the same time of day (in the morning) to ensure chronobiological control. Before first experimental visit, anthropometrics and back squat 1RM were measured. On the following 4 visits, each subject performed randomly: (a) squat exercise without PAP, (b) squat exercise with PAP, (c) MVIC without PAP, and (d) MVIC with PAP (Figure 1).

Subjects

Ten young men (mean ± *SD*: age, 22.8 ± 2.4 years, 20-29 years, height, 179 ± 7.7 cm, body mass, 81.5 ± 14.3 kg) with at least 1 year of resistance training experience at a frequency of 3 days per week were recruited for this study (Table 1). All subjects could not have used any ergogenic substance in the past 6 months or during the study, and were instructed to keep their diet during the intervention. Additional exclusion criteria included injuries and smoking or medical conditions that might interfere with the exercise protocol. This study was approved by the Ethics Research Group of the School of Technology and Sciences. All subjects signed a consent form and were informed about the possible risks and the purpose of the study.

Procedures

Anthropometric Measurements, Dietary Intake Assessment, and Blood Lactate Concentration. Height was measured on a fixed stadiometer of the Sanny brand, with an accuracy of 0.1 cm and a length of 2.20 m. Body mass was measured using an electronic scale (Filizola PL 50; Filizola Ltd., São Paulo, Brazil), with a precision of 0.1 kg. The volunteers were instructed not to consume coffee, tea, alcohol, or stimulant drinks for a period of 24 hours before the assessment. Food questionnaires were distributed to all subjects to record food and fluid intake for 24 hours before each trial. Subject were instructed to replicate the first trial's dietary intake for the subsequent trials. All food intakes were analyzed for total kilocalorie and macronutrient intakes (Software–Dietpro version 5.8) to ensure that dietary intake was similar between experimental trials. The software used the database of Brazilian food composition table (TACO) to calculate dietary intake.

Blood samples were collected from the ear lobe of each subject to analyze the lactate concentration. This measurement was obtained at rest and after exercise. The blood lactate analysis was performed using the Yellow Spring 1,500 Sport lactimeter (Yellow Springs, OH, United States).

One Repetition Maximum Test and Postactivation Potentiation Protocol. Subjects performed 2 familiarization sessions to become acquainted with the 1RM test procedures and back squat exercise. Before 1RM testing, subjects completed a warm-up protocol, which consisted 5 minutes of walking and a subsequent 1 set of 10 repetitions at approximately 50% of the 1RM. The load was increased gradually (10–15%) during the test until the subjects were no longer able to perform the entire movement, and 3–5 attempts were allowed to meet the corresponding 1RM load (21).

For the PAP protocol, the subjects performed 1 set of 2 repetitions with 90% of 1RM in the back squat exercise (20). All routines were performed with normal speed (1-s eccentric and 1-s concentric actions with 1-s rest between each repetition). Five minutes after the PAP protocol, the subjects performed the resistance exercise or the MVIC.

Resistance Exercise Protocol. Initially, the subjects performed 10 repetitions of squats with their body mass for a warm-up. After the PAP protocol, the subjects completed 4 sets of back squats until movement failure at 70% of 1RM with normal speed (1-s concentric and 1-s eccentric) and 2 minutes of rest interval between sets. In the condition without PAP, the subjects directly performed the protocol described above after the warm-up. For better control of the repetitions to failure tests, a wooden bench with adjustable heights was placed behind the subject to keep the bar displacement and knee angle constant on each repetition. Two fitness professionals supervised all testing sessions. The total number of repetitions performed was recorded for each set, and the total volume (total repetitions) was calculated to analyze performance.

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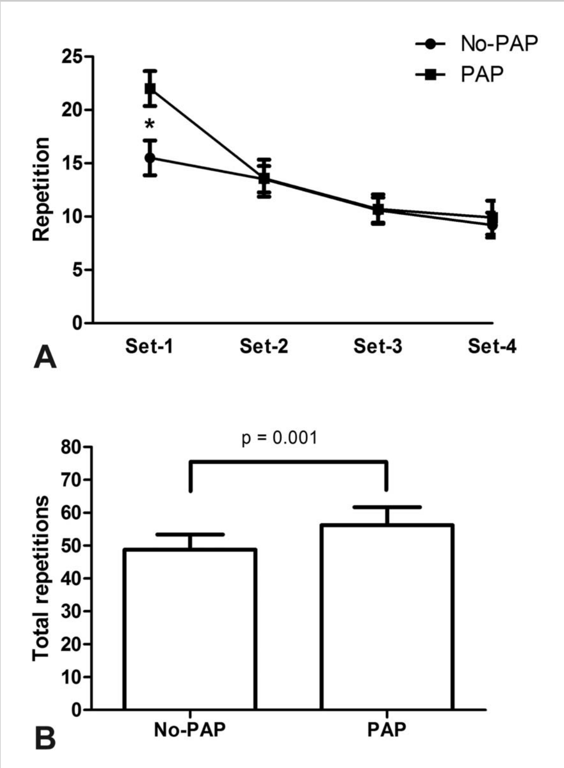

Figure 2. Comparison between conditions on the back squat exercise performance. A) Maximum number of repetitions in each set; *statistically significantly differences between conditions. B) Total repetitions (kg). Back squats without PAP (No-PAP); back squats with PAP (PAP). PAP = postactivation potentiation.

Maximum Voluntary Isometric Contraction. Initially, the subjects performed 10 repetitions of squats with their body mass for warm-up. The peripheral muscle force was estimated by electronic dynamometer (Power Din Standard; CEFISE, São Paulo, Brazil) for knee extension. After PAP protocol, the MVIC was performed during 10 seconds. In the condition without PAP, the subjects directly performed MVIC. The subjects remained seated with the knee flexed to 90°, and peak force and mean force (N) were recorded during MVIC.

Statistical Analyses

A 2 × 4 repeated-measures analysis of variance (RMANOVA) with the Bonferroni adjustment for multiple comparisons was used to compare the maximum number of repetitions performed in each set across conditions and time, respectively. A 2 × 2 RMANOVA with the Bonferroni adjustment for multiple comparisons was used to compare lactate concentration. For all measured variables, the estimated sphericity was verified according to Mauchly's W test, and the Greenhouse-Geisser correction was used when necessary. The comparison of total repetitions and force was performed using the Student *t* test for dependent samples. The difference between PAP and No-PAP for total repetitions (delta = PAP total repetition minus No-PAP total repetition) and isometric peak force (delta = PAP peak isometric force minus No-PAP peak isometric force) was calculated as percent differences and the Pearson's correlation between back squat 1RM relative to body mass was performed. Effect sizes for ANOVA were calculated using partial eta-squared (η^2) for time. Also, the effect size for total repetition and force was calculated through Cohen's *d*, and it was defined as small (0.20), medium (0.50), and large (0.80) (Morris, 2008), and 95% confidence intervals (CI 95%) were reported. Statistical significance was set at $p \leq 0.05$. The data were analyzed using the Statistical Package for Social Sciences 17.0 (SPSS Inc., Chicago, IL).

Results

We performed a power analysis of this study based on the observations from a previous study that verified whether PAP would influence isometric force measurement. The authors showed a difference of 1.77 $N \cdot kg^{-1}$ in isometric

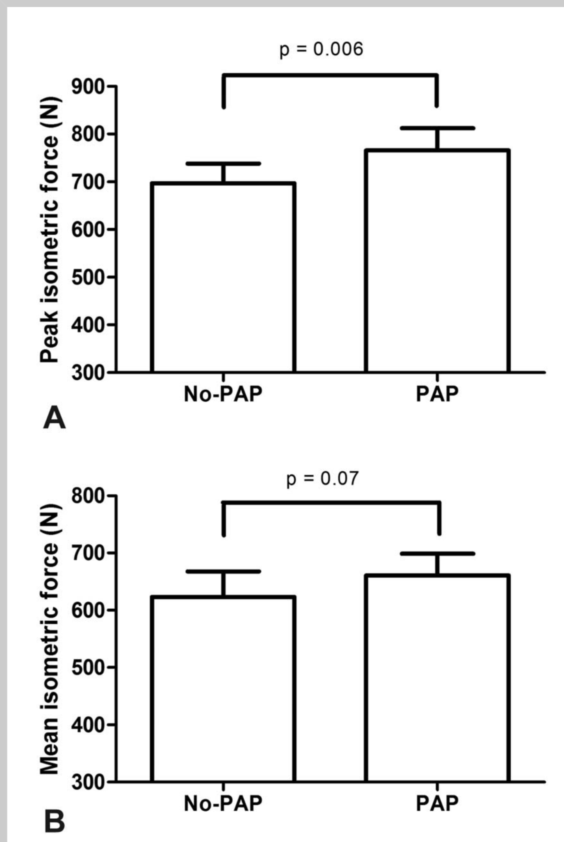

Figure 3. Comparison between conditions on the maximum voluntary isometric contraction of the quadriceps. A) Peak isometric force (N); (B), mean isometric force (N). Maximum voluntary isometric contraction without PAP (No-PAP); maximum voluntary isometric contraction with PAP (PAP). PAP = postactivation potentiation.

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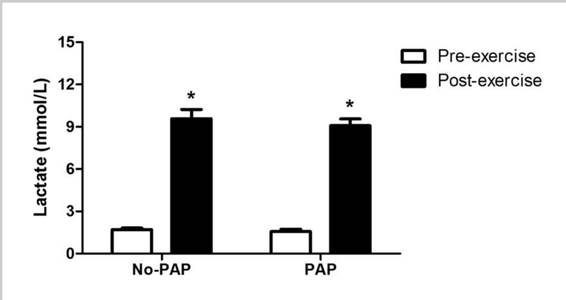

Figure 4. Comparison between conditions on the lactate concentration in back squat exercise. *Statistically significantly differences between pre-exercise. Back squats without PAP (No-PAP); back squats with PAP (PAP). PAP = postactivation potentiation.

peak force and a *SD* difference of 1.87 $N \cdot kg^{-1}$, with statistically significant increases for the responders group after set 4 compared with rest ($p = 0.001$) (9). When we used a type I error of 5% and 10 subjects, according to this study, using PS software (version 3.1.2, Dupont and Plummer, http://biostat.mc.vanderbilt.edu/wiki/Main/PowerSampleSize), we were able to reject the null hypothesis that this response difference is zero with a power (1-type II error) of 76%.

Table 2 presents values of mean and *SD* for dietary intake 24 hours before each experimental trial. There was no significant difference between trials.

Figure 2 shows the differences in maximum number of repetitions performed in each set and total repetitions. There was a main effect of time ($F = 40.955$, $p < 0.001$, $\eta^2 = 0.82$), statistically significant differences between conditions ($F = 21.962$, $p = 0.001$), and a significant interaction ($F = 8.168$, $p < 0.001$). Post hoc analysis showed a significantly greater number of repetitions for PAP at set-1 compared with No-PAP ($p < 0.001$). Total repetitions were greater in the PAP condition (56.2 ± 17.3 repetitions [CI 95% = 43.8–68.6 repetitions]) compared with the No-PAP condition (48.8 ± 14.5 repetitions [CI 95% = 38.4–59.2 repetitions]), and effect sizes ranged from small to medium ($d = 0.46$).

Figure 3 presents the differences between PAP and No-PAP on peak and mean isometric force. The peak isometric force was significantly greater in the PAP condition in relation to No-PAP (No-PAP = 696.8 ± 131.5 [CI 95% = 602.7–790.8 N] vs. PAP = 765.7 ± 147.8 N [CI 95% = 660.0–871.5 N], $p = 0.006$), but there were no significant differences in the mean isometric force between conditions (No-PAP = 623.0 ± 141.4 [CI 95% = 521.9–724.2 N] vs. PAP = 660.5 ± 122.1 N [CI 95% = 573.1–747.9 N], $p = 0.07$). The effect size was medium for peak force ($d = 0.50$) and small for mean force ($d = 0.28$).

Figure 4 shows the differences between PAP and No-PAP on lactate concentrations in the back squat exercise. Lactate significantly increased from rest to post-exercise (No-PAP: rest = 1.7 ± 0.3, post-exercise = 9.6 ± 2.0 vs. PAP: pre = 1.6 ± 0.5, post-exercise = 9.1 ± 1.4 $mmol \cdot L^{-1}$, $F = 265.12$, $p < 0.001$) but without differences between conditions ($p > 0.05$).

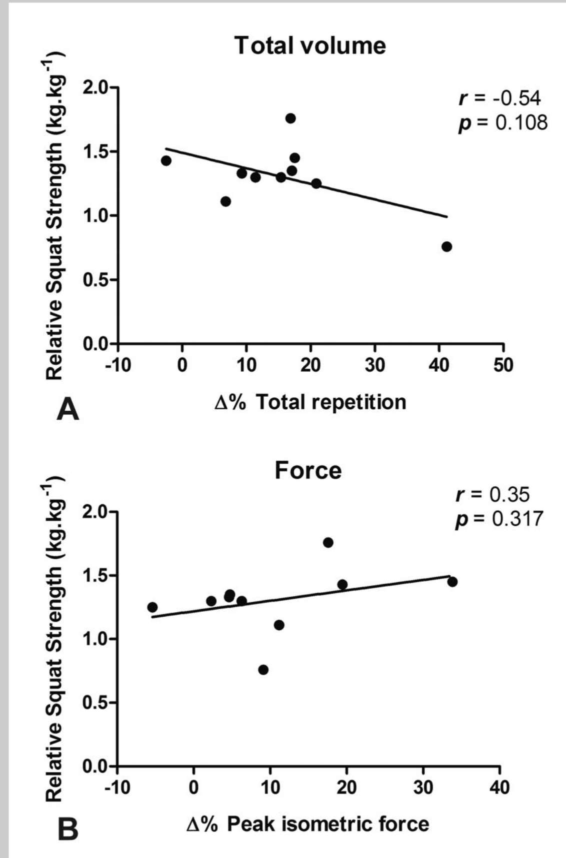

Figure 5. Correlation between relative 1RM and percent delta peak isometric force and total repetitions. A) Correlation between relative 1RM and percent delta total repetitions; (B), correlation between relative 1RM and percent delta peak isometric force. 1RM = 1 repetition maximum.

Figure 5 presents the correlation between relative 1RM and percent delta peak isometric force and total repetitions.

There were no significant correlations between relative 1RM and percent delta peak isometric force ($r = 0.35$, $p = 0.317$) or total repetitions ($r = -0.54$, $p = 0.108$).

Discussion

To our knowledge, this was the first study in the literature to investigate the effects of PAP on acute higher volume resistance exercise performance in trained men. The main findings of this study were that PAP improved total volume with a greater number of repetitions during the first set and over the 4 sets. Furthermore, PAP increased force production during MVIC, but there were no significant relationships between 1RM and the PAP response.

Investigations into the effects of PAP using back squat on lower-body explosive activity performance are widely explored at the literature, demonstrating improvements in

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vertical and horizontal jump, as well as sprint performance (3,5,6). Our results confirm these findings, as PAP using the heavy back squat increased peak force by approximately 9.8% during MVIC. These results are in agreement with French et al. (8) and Johnson et al. (12), suggesting that PAP can be a strategy to enhance the force-generating capacity of the muscle. In addition, the moderate effect size for MVIC was similar to effect sizes reported for vertical jump and sprint in a recent meta-analysis (25).

The literature shows that the magnitude of the PAP is dependent on the balance between fatigue and potentiation, whereby potentiation needs to overcome fatigue to induce performance gains (25). Previous studies show that intensity, volume of the CA, and recovery interval between CA and subsequent exercise can influence the magnitude of PAP (25,27). Our results demonstrated that the CA protocol used in this study (one set of 2 repetitions of back squat exercise with 90% of 1RM and 5 minutes of recovery) was effective to improve resistance exercise performance at the first set of resistance training, but no benefits were observed on the next 3 sets. Fatigue from the first set may have contributed to the impaired performance in subsequent sets, although total repetitions completed were greater in the PAP condition, suggesting that subtle increases in volume in latter sets may have occurred in more fatigue resistance subject. From a practical point of view, studies have shown the importance of volume to induce hypertrophy and strength gains (7,18,23). Volume can be modifiable in multiple ways within a session, by increasing the number of repetitions per set or increasing the number of sets per exercise (7). Thus, our findings demonstrate that total volume in back squats was higher with a PAP protocol by increasing the capacity to perform repetitions to exhaustion in the first set. Whether this phenomenon will occur when used over multiple sessions or lead to enhanced hypertrophic adaptations warrants further research.

It has been reported that PAP response is influenced by the level of strength and resistance training experience, suggesting that stronger individuals are able to exhibit higher performance gains with PAP (22,26). Seitz et al. (24) analyzed the influence of strength levels on PAP effects during a vertical squat jump test in elite rugby league players. The CA protocol used was 1 set of 2 repetitions in back squat at 90% of 1RM. They observed significant correlation between relative strength levels and PAP effect on jump height ($r = 0.74$) and peak power ($r = 0.75$), demonstrating that strong subjects express a greater PAP response than weak individuals. In this study, there were no significant relationships between 1RM relative to body mass and the PAP response in trained subjects. Although this seems to contradict previous research, it should be noted that relative back squat 1RM was 1.30 ± 0.25, and only one subject had a relative 1RM greater than 1.75, which is often used as the threshold to describe "strong" in the PAP literature (25). It is possible that had the subject pool in this study less been homogenous in regards to 1RM relative strength, differences in the PAP response may have been detected, at least, in the isometric force production like in previous studies. On the other hand, there was a weak-inverse correlation between relative 1RM strength and total volume. Whether this inverse relationship would become significant with a larger sample size and more heterogenous group (with respect to relative 1RM strength) requires further investigation.

Some limitations need to be considered when interpreting these results. First, we used only lower-body exercise in this study. Given that smaller effect sizes have been found for heavy exercise to potentiate upper-body ballistic movements (25), it is unclear whether similar results would occur in upper-body resistance exercise, such as the bench press. Second, training programs generally contain more than one exercise per session, and it is unclear whether the CA used herein, or PAP response, would potentiate or negatively affect subsequent movements in the session.

In summary, PAP using a heavy load improved total volume during lower-body resistance exercise and force production during maximal voluntary isometric contractions in trained men. However, there was no relationship between 1RM values and PAP response in these subjects.

Practical Applications

Our results can be implemented by coaches and trainers because the low number of repetitions applied during the PAP protocol (2 repetitions performed at 90% 1RM) resulted in a clear increase in first set repetitions and peak force in MVIC, 2 different expressions of muscle performance. In our opinion, this balance between fatigue and potentiation could possibly be used on a regular basis during a resistance training program aimed to increase muscle hypertrophy (following our experimental conditions of 70% 1RM) because it could lead to an increase in first-set repetitions and total repetitions, without resulting in enough fatigue to affect repetitions performed in subsequent sets. However, more research is needed to investigate the chronic effects of PAP on muscle hypertrophy.

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