Acute Effects of Back Squats on Countermovement Jump Performance Across Multiple Sets of a Contrast Training Protocol in Resistance-Trained Men

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Abstract

Bauer, P, Sansone, P, Mitter, B, Makivic, B, Seitz, LB, and Tschan, H. Acute effects of back squats on countermovement jump performance across multiple sets of a contrast training protocol in resistance-trained men. *J Strength Cond Res* 33(4): 995–1000, 2019—This study was designed to evaluate the voluntary postactivation potentiation (PAP) effects of moderate-intensity (MI) or high-intensity (HI) back squat exercises on countermovement jump (CMJ) performance across multiple sets of a contrast training protocol. Sixty resistance-trained male subjects (age, 23.3 ± 3.3 years; body mass, 86.0 ± 13.9 kg; and parallel back squat 1-repetition maximum [1-RM], 155.2 ± 30.0 kg) participated in a randomized, crossover study. After familiarization, the subjects visited the laboratory on 3 separate occasions. They performed a contrast PAP protocol comprising 3 sets of either MI (6 × 60% of 1-RM) or HI back squats (4 × 90% of 1-RM) or 20 seconds of recovery (CTRL) alternated with 7 CMJs that were performed at 15 seconds, and 1, 3, 5, 7, 9 and 11 minutes after the back squats or recovery. Jump height and relative peak power output recorded with a force platform during MI and HI conditions were compared with those recorded during control condition to calculate the voluntary PAP effect. Countermovement jump performance was decreased immediately after the squats but increased across all 3 sets of MI and HI between 3 and 7 minutes after recovery. However, voluntary PAP effects were small or trivial, and no difference between the 3 sets could be found. These findings demonstrate that practitioners can use MI and HI back squats to potentiate CMJs across a contrast training protocol, but a minimum of 3 minutes of recovery after the squats is needed to benefit from voluntary PAP.

Key Words postactivation potentiation, complex training, peak power, jump height

Introduction

In the past few years, there has been a growing interest in the phenomenon of voluntary postactivation potentiation (PAP), which refers to the acute improvements in muscular performance during a voluntary contraction after the completion of a conditioning activity (30). A number of mechanisms have been proposed to explain the phenomenon, including phosphorylation of myosin-regulatory light chains (15) and the recruitment of higher order motor units (16). In addition to evoking a potentiation response, the performance of conditioning activities may also induce a fatigue response (27). The extent of both fatigue and potentiation is determined by the interaction of several factors, including the physical characteristics of the athlete, the force-time parameters of the conditioning activity, the movement pattern and velocity characteristics of the subsequent performance test, and the rest period between the conditioning activity and the performance test (31,35,37). Given the complexity of the factors influencing voluntary PAP response, it is not a simple process to predict general patterns of acute performance improvements. Nonetheless, considerable evidence supports the efficacy of conditioning activities to acutely improve various athletic tasks that depend on the production of muscle power, such as jumping, sprinting, and throwing (31). It is hypothesized that this acute increase in performance, which is the basis of complex or contrast training (9–12,17), can be used to amplify the long-term training adaptations (19,28).

One situation in which the time course of the voluntary PAP response must be known is the programming of contrast training sessions. Contrast, or complex, training

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sessions involve the performance of a high-load (and thus lower-velocity) exercise set followed with a short rest by a lower-load (and thus higher-velocity) exercise set (12,28). The aim of contrast training is to use the voluntary PAP phenomenon to improve subsequent high-speed movement performance and thus evoke a strong adaptive response. However, careful inspection of the scientific literature reveals that most voluntary PAP studies have used protocols where only a single conditioning activity sequence is followed by a single light exercise sequence; few studies have investigated the voluntary PAP effect in a more applied (i.e., contrast) training environment where high-load exercises are repeatedly alternated in a set-by-set basis with lighter or explosive exercises. However, conflicting results have been reported because some studies showed improvements in athletic performance (2,3,24,32) while others did not (1,10,36). In addition, these studies vary significantly in the type of subjects studied, conditioning activities used, rest periods allowed, and the characteristics of the subsequent performance test creating a level of heterogeneity that makes comparison difficult. Considering that volume and intensity of the conditioning activities are 2 of the main mediators of voluntary PAP (14,31), it is noteworthy that only one study has directly compared the effect of different conditioning activity intensities on subsequent performance across multiple sets of a contrast training protocol (34). Smilios et al. (34) examined the effects of loaded half squats and loaded jump squats with low and moderate loads (i.e., 30 and 60% of 1-RM squat) on squat jump and the CMJ performances for a total of 3 sets and reported an intensity-dependent behavior of the voluntary PAP response. After low-load jump squats, CMJ height increased significantly after the first and second sets (i.e., 3.9%), whereas moderate load jump squats potentiated CMJ height after the second and third sets (i.e., 3.3%). Compared with pre-exercise values, CMJ height increased only after the moderate load half squat protocol by 3.6% in the first and the second sets. Nevertheless, the use of low and moderate load conditioning activities is probably insufficient to alter the neuromuscular mechanisms underpinning voluntary PAP and improve subsequent CMJ performance (31).

Another important parameter to consider is the time course of changes in performance after the conditioning activity. There is evidence to suggest that performance is decreased immediately after the conditioning activity (29), and that recovery periods of 5–7 minutes are needed to benefit from voluntary PAP. However, to date, no attempt has been made to determine whether repeated exposure to conditioning stimuli affects this time course.

It has therefore been hypothesized that, across a contrast training protocol, higher load conditioning activities may improve jump performance to a greater extent than lower-load conditioning activities (34) and that rest periods of 5–7 minutes are needed to benefit from voluntary PAP.

Therefore, this study was designed to evaluate the voluntary PAP effects of moderate-intensity (MI) or high-intensity (HI) back squat exercises on CMJ performance across multiple sets of a contrast training protocol.

Methods

Experimental Approach to the Problem

The acute effects induced by different intensities of a squat-conditioning activity on CMJ performance were investigated in a randomized, crossover study design. Each subject attended the laboratory on 4 separate occasions, once for familiarization and 3 further times to perform one of 3 test protocols in a randomized order (Figure 1). The protocols involved 3 sets, each comprising either a conditioning activity of HI or MI, or no activity for control session (CTRL). After each conditioning set, 7 CMJs were performed over a 11-minute period. Vertical ground reaction forces were recorded for each jump on a portable piezoelectric force platform and used to calculate both jump height and peak power relative to body mass.

Subjects

Sixty resistance-trained male subjects (mean ± *SD*: age, 23.3 ± 3.27 years; body mass, 86.0 ± 13.9 kg; parallel back squat 1-RM, 155.2 ± 29.98 kg; and relative parallel squat 1-RM, 1.8 ± 0.19 kg·kg^{-1}) with different athletic background (American football, track and field, weightlifting, powerlifting, and martial arts) volunteered for this study. The sample size of 60 was chosen as sufficient to detect significant differences between the mean values, for each dependent variable, with alpha = 0.05 and statistical power = 0.80. The relevant effect sizes were derived

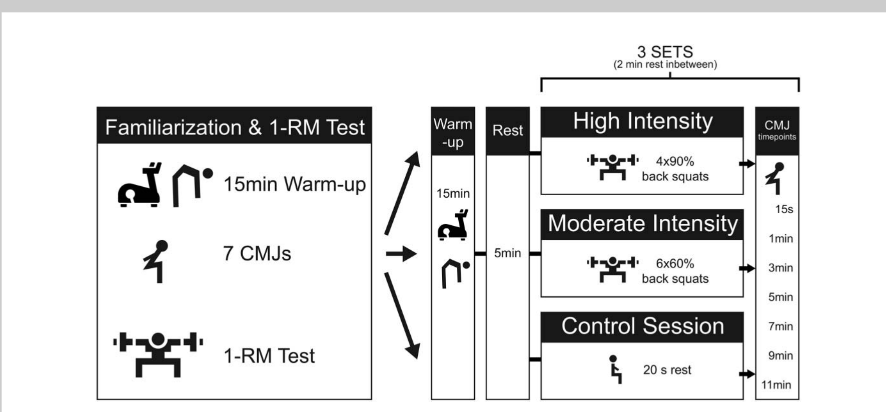

Figure 1. Test protocols.

from an unpublished pilot study on 7 subjects in our laboratory. Inclusion criteria for participation were the absence of injury and illness (which was ascertained using a modified PAR-Q), a minimum of 1-year resistance training experience as well as a relative 1-RM for the parallel back squat exercise of at least 1.5 kg per kg body mass (29). Information about the testing procedures, theoretical background of the investigation, and potential injury risks were provided before testing. Subjects were instructed to refrain from caffeine for at least 6 hours and from strenuous exercise for at least 48 hours before attending the laboratory on all occasions. All tests were performed at the same time of the day. Written informed consent was acquired from each participant before familiarization session. The ethics committee of the University of Vienna gave its approval to all planned procedures.

Procedures

The first visit to the laboratory was designed to familiarize the subjects with the test protocol and to record anthropometric data. Body mass and height were measured using a Seca scale (Model 877, Hamburg, Germany) and Seca stadiometer (Model 217), respectively.

A standardized warm-up including 5 minutes of light cycling on an ergometer (Fitrocycle 5, Fitronic, Bratislava, Slovakia) at a constant power of 1W per kg body mass, and whole-body dynamic mobilization exercises were performed before the familiarization procedure. The familiarization tests started after a 5-minute rest period with each subject completing 7 CMJs to a self-selected depth at 15 seconds and 1, 3, 5, 7, 9 and 11 minutes, representing the exact jump series that were conducted during each of the subsequent test protocols. This time was chosen because previous research has indicated that significant voluntary PAP effects in power output may last to up to 10 minutes (38). The participants were required to keep their hands on their hips to minimize additional momentum of the upper extremities. A parallel back squat 1-RM test was then performed according to the recommendations of McGuigan (23). For each trial, subjects had to reach a back squat depth at which the hip joint was lower than the top of the knees to be counted as a valid repetition. Experienced sports scientists observed each movement and declared whether or not a repetition was valid.

The subjects attended the laboratory on 3 more occasions to execute one of 3 experimental protocols in a randomized order. Each protocol included the standardized general warm-up described earlier and 3 series of 7 CMJs, which were distributed over time in the same pattern that was used for familiarization (i.e., 15 seconds and 1, 3, 5, 7, 9, 11 minutes). Before the first set of back squats in both the MI and HI protocol, the subjects additionally performed an exercise-specific warm-up including 5 repetitions at 50%, 3 repetitions at 70%, and one repetition at 90% of the target load. Each series of CMJs was preceded by either one set of moderate-intensity back squats (MI protocol) involving 6 repetitions at 60% 1-RM, one set of high-intensity back squats (HI protocol) involving four repetitions at 90% 1-RM, or a control condition during which subjects were required to rest for approximately 20 seconds (CTRL protocol). Intensity and volume were chosen to match the volume load in both the HI and MI protocol, which was 360% 1-RM, respectively. A 2-minute rest period was given in between the last jump of a CMJ series and the subsequent protocol-specific conditioning activity.

On all four occasions, the CMJs were performed on a portable force platform (Model 9286B; Kistler, Winterthur, Switzerland), which was connected to an external control unit (Model 5233A2; Kistler). The signals were channeled into an amplifier (USB-6341; National Instruments, Austin, TX, USA) and processed by a computer using a custom-designed data acquisition software that was programmed in LabView (National Instruments). Vertical ground reaction force was recorded at a sampling rate of 1,000 Hz and exported to MS Excel to be further analyzed. Jump height was calculated according to the impulse-momentum theorem, as proposed by Linthorne (21). To determine peak power, momentary relative power was calculated for each time sample, and the highest value within the concentric phase of the CMJ was identified. The intrasession (baseline) and test-retest reliability (baseline vs. CTRL) of the vertical jump was determined by intraclass correlation coefficient (ICC) and coefficient of variation (%CV). Both jump height (JH) (ICC = 0.90–0.95 and %CV = 3.0–3.6%) and peak power (ICC = 0.91–0.97 and %CV = 1.6–3.1%) displayed good intrasession reliability. Test-retest reliability for JH and peak power was ICC = 0.81–0.89; %CV = 5.2–6.4% and 0.83–0.88; 3.5–4.2%, respectively.

Statistical Analyses

Statistical analysis was performed using the SPSS 22.0 for Windows (SPSS, Inc., Chicago, IL, USA). Descriptive statistics were calculated and reported as mean values and *SD*s. The Shapiro-Wilk test was performed to determine whether the data were normally distributed for each group. A 3-way repeated-measures analysis of variance (ANOVA) was used to assess the effects of condition (CTRL, MI, and HI), set (first, second and third), and time (15 seconds, 1, 3, 5, 7, 9 and 11 minutes) and their interaction with CMJ height and peak power. Levene's test was used to examine the homogeneity of variances before further statistical analyses were performed. If the assumption of sphericity was violated, Greenhouse-Geisser adjusted values were used. A series of repeated-measures ANOVAs were used to compare the conditions for each time point. Statistical significance was accepted at $p \leq 0.05$ (2-tailed) and adjusted using the Bonferroni method for all ANOVA pairwise comparisons. Cohen's d was calculated to determine the magnitude of differences for pairwise comparisons. These differences were considered trivial <0.20; small, 0.20–0.50; medium, 0.5–0.8; large, 0.8–1.30; or very large, >1.30 (18). The 95%

confidence intervals (95% CIs) were also calculated for the relative differences reported.

Results

The Shapiro-Wilk test indicated that both the CMJ height and peak power data were normally distributed within all conditions and time points for both dependent variables. The time course of changes in CMJ performance during the main trials is shown in Figure 2.

Countermovement Jump Height

For the CMJ height, the 3-way ANOVA revealed no significant interaction for condition × set × time ($F = 1.12$ and $p = 0.33$) and no condition × set interaction ($F = 2.50$ and $p = 0.053$), but a significant interaction for condition × time ($F = 16.10$ and $p = 0.001$) as well as a set × time interaction ($F = 5.90$ and $p = 0.001$). Further analysis for each time point indicated a decrease in CMJ height at 15 seconds after the back squats (MI and HI) across all 3 sets compared with CTRL (all $p \leq 0.05$ and $d = 0.24–0.42$). Both back squat protocols produced higher CMJ height at 3 minutes (MI: 4.37%, 95% CI [2.04–6.70], $p = 0.003$, $d = 0.28$ and HI: +3.65, 95% CI [1.44–5.86], $p = 0.019$, $d = 0.23$) and 5 minutes (MI: +3.18%, 95% CI [1.41–4.95], $p = 0.003$, $d = 0.22$ and HI: +2.99%, 95% CI [0.97–5.02], $p = 0.032$, $d = 0.20$) after the first set of back squats. Improvements in the second and third sets were not as prominent as in the first set compared with control condition ($p > 0.05$ and $d < 0.2$).

Relative Peak Power Output

For the relative peak power output, no significant interaction for condition × set × time ($F = 1.41$ and $p = 0.13$), but a significant interaction for condition × set ($F = 2.60$ and $p = 0.049$) as well as a condition × time interaction ($F = 25.90$ and $p = 0.001$) was found. Similar to jump height, the peak power was decreased after 15 seconds of rest after conditioning activity (MI and HI) across all 3 sets compared with CTRL ($p \leq 0.05$ and $d = 0.24–0.38$). Increase in peak power was found in both protocols at 3 (MI: +3.27%, 95% CI [2.11–4.42], $p = 0.001$, $d = 0.32$ and HI: +3.36%, 95% CI [1.98–4.40], $p = 0.001$, $d = 0.31$), 5 (MI: +3.06% 95% CI [1.84–4.28], $p = 0.001$, $d = 0.29$ and HI: +2.90%, 95% CI [1.69–3.91], $p = 0.001$, $d = 0.27$), and 7 (MI: +1.90%, 95% CI [0.63–3.17], $p = 0.046$, $d = 0.15$ and HI: +2.25%, 95% CI [0.88–3.54], $p = 0.013$, $d = 0.18$) minutes compared with control. In contrast to jump height, increase in peak power was also larger in the second set at 3 (MI: +1.31%, 95% CI [0.25–2.36], $p = 0.046$, $d = 0.13$ and HI: +1.79%, 95% CI [0.51–2.95], $p = 0.032$, $d = 0.16$), 5 (MI: +2.20%, 95% CI [0.90–3.49], $p = 0.016$, $d = 0.19$ and HI: +1.67%, 95% CI [0.40–2.77], $p = 0.048$, $d = 0.14$), and 7 minutes (MI: +2.30%, 95% CI [1.04–3.52], $p = 0.004$, $d = 0.20$ and HI: +2.12%, 95% CI [0.55–3.55], $p = 0.043$, $d = 0.18$), as well as in the seventh minute of the third set (MI: +2.13%, 95% CI [1.01–3.24], $p = 0.001$, $d = 0.21$ and HI: +1.70%, 95% CI [0.42–2.87], $p = 0.037$, $d = 0.15$).

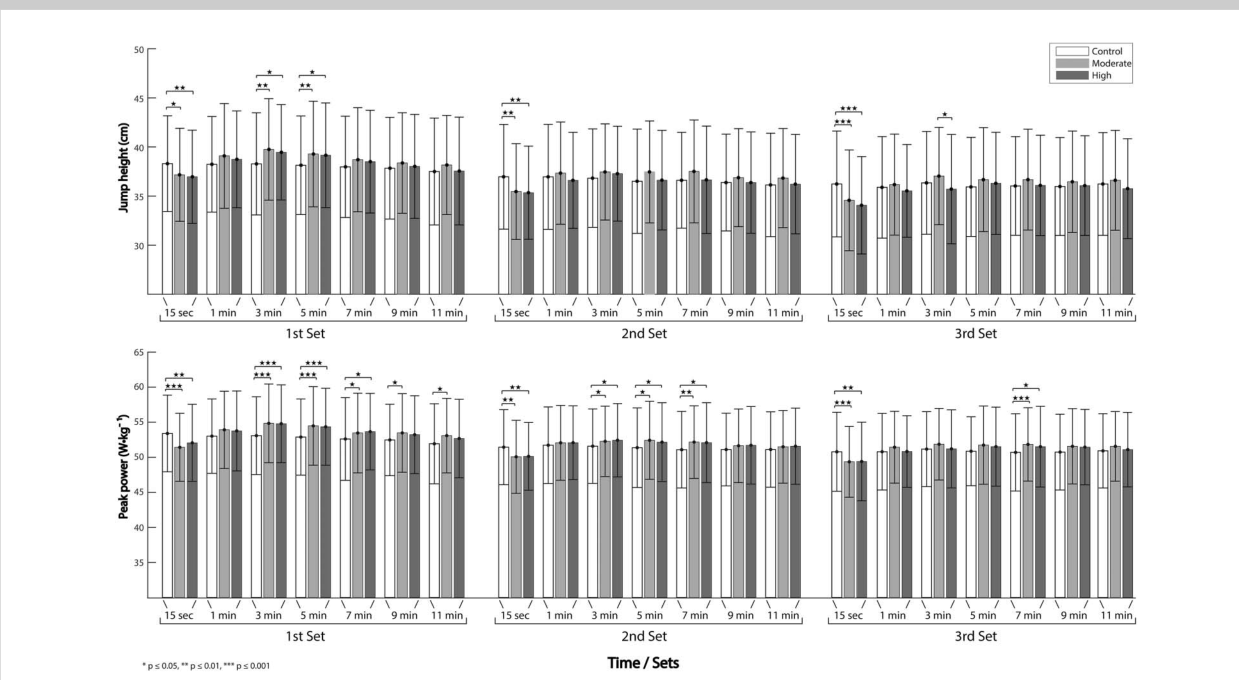

Figure 2. Time course of jump height & peak power for the control, moderate, and high conditions. Values are reported as mean ± *SD*. Square brackets indicate paired significant differences (*$p \leq 0.05$, **$p < 0.01$, and ***$p > 0.001$).

Discussion

The first objective of this study was to investigate whether a PAP effect could be elicited across 3 sets of a contrast PAP protocol involving back squats (MI or HI) and CMJs. The results indicated that both MI and HI protocols were effective in inducing improvements on CMJ performance in the first set compared with CTRL. This enhancement is in agreement with several studies analyzing the effects of back squats on CMJs in a single contrast pair (7,8,13,14,20,22,25). We observed that a voluntary PAP effect can also be elicited after the second and third set of MI and HI back squats. The differences in the second and third sets, however, were larger when measured by peak power but not by jump height. As proposed by Chaouachi et al. (5) fatigue-related impairments to coordination could be the reason for increase in power, force, or velocity, resulting in no net gain in jump height, although explicit testing of this hypothesis is required. Nevertheless, the results of this study once more support the assumption that there is a time-dependent behavior of voluntary PAP. Indeed, both protocols produced a decrease in CMJ performance immediately after the back squats (i.e., 15 seconds), which was followed by an increase peaking from 3 to 7 minutes after recovery. This trend could be observed in all 3 contrast pairs with the voluntary PAP effect progressively dissipating over time. The present findings are consistent with previous research demonstrating that PAP can be elicited across multiple sets during a contrast training protocol (2,3,24,32). However, these results are in contrast with studies of Talpey et al. (36), Andrews et al. (1) and Duthie et al. (10), who failed to elicit a voluntary PAP effect across repeated contrast pairs. It should be noted that only the study of Talpey et al. (36) showed a significant decrease of performance with additional conditioning activities compared with baseline values. The studies of Andrews et al. (1) and Duthie et al. (10) could not detect any treatment effect (increase or decrease in performance). This finding is particularly of importance for practitioners because the organizational benefits of combining high/moderate load resistance exercises and plyometric exercises in one training session could still remain, even without the presence of a significant increase in performance.

Further analyses revealed that there is no difference in PAP magnitude between the MI and HI protocol across all 3 sets. This result is line with Lowery et al. (22), who found peak power and jump height peaking 3–4 minutes after a single set of back squats without a significant difference between MI (i.e., 4 × 70% 1-RM) and HI (i.e., 3 × 93% 1-RM) condition. On the contrary, Fukutani et al. (14) reported a significantly higher increase in jump height and twitch torque after high-intensity (i.e., 3 × 90% 1-RM) compared with moderate-intensity (i.e., 3 × 75% 1-RM) back squats. The conflicting results may be because of the different training status of the subjects studied. Fukutani et al. (14) used highly trained weightlifters (relative parallel squat 1-RM, 2.37 ± 0.24 $kg \cdot kg^{-1}$), which might have been more sensitive to the potentiation effect of the conditioning activity (6,29,33). It would be interesting to see whether strength level has an influence on PAP response across multiple sets of a contrast training protocol. Future studies could address this topic and directly compare moderately and highly trained subjects.

This study has several limitations that warrant further discussion. One factor that could have potentially influenced our results is that the repeated CMJs may inadvertently act as a further conditioning activity, thereby altering the voluntary PAP responses (26). Although Nibali et al. (26) only found insubstantial differences between continuous and discontinuous time course trials (i.e., 4, 8, and 12 minutes) for most CMJ variables after one set of 5-RM back squats, it cannot be excluded that repeated CMJs in combination with back squats impact the time course of voluntary PAP in the second or the third contrast pair. Second, it cannot be excluded that the exercise-specific warm-up before the first set of MI and HI (i.e., 5 × 50, 3 × 70 and 90% of the target load) could have been an effective voluntary PAP stimulus itself. Third, we acknowledge that interindividual differences within the group could have influenced the present findings. There is evidence showing that PAP response is highly individualized and indicative of a responder vs. nonresponder phenomenon (31). Last, it is important to note that potential mechanisms responsible for the performance improvement were not investigated in this study. Other mechanisms related to warm-up (e.g., increase in muscle temperature, psychological effects, etc.) may have contributed to our findings as well (4). Future studies should include more sophisticated measurement techniques (i.e., electrically evoked muscle twitches and intramuscular temperature) to identify the exact mechanisms causing PAP across a contrast training protocol.

In conclusion, this study suggests that CMJ performance can be potentiated after MI and HI parallel back squats after 3–7 minutes, and this voluntary PAP effect can be elicited across 3 sets, especially when measured by relative peak power output. Theoretically a greater training stimulus should occur over time, resulting in greater development of both strength and speed (19). However, there is a lack of well-designed, long-term training studies supporting the use of contrast or complex training, and therefore, it remains speculative whether this training method is superior to traditional training methods (9,31).

Practical Applications

There are several practical applications for coaches from this study, but any application requires careful implementation and individual experimentation. The most important finding in this research is that resistance-trained male athletes can benefit from both MI and HI back squats as a conditioning activity when alternated with CMJs in a contrast training protocol. Coaches can create greater variety in using voluntary PAP in their training plans and possibly save time by training high/moderate load resistance exercises and plyometric exercises in the same workout. It seems that there is an accumulation of fatigue over the course of a contrast training session, and therefore, coaches should be careful when implementing back squats, especially with less-trained athletes and HI protocols. In addition, coaches should be advised that the rest period between the conditioning activity and the explosive performance is of great importance. It seems that a minimum of 3 minutes after the conditioning activity is needed to benefit from PAP.

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