Postactivation Potentiation Following Different Modes of Exercise

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Abstract

Esformes, JI, Cameron, N, and Bampouras, TM. Postactivation potentiation following different modes of exercise. *J Strength Cond Res* 24(7): 1911–1916, 2010—The performance characteristics of skeletal muscle are transient in nature and have been shown to be significantly affected by its contractile history, where the phenomenon of acute enhancement is termed postactivation potentiation (PAP). Acute enhancement of dynamic activity has been observed when preceded by resistance exercises; however little information exists for plyometric activity as a conditioning stimulus. In addition, no study has examined PAP effects on more than one subsequent performance trial. The purpose of the present study was to determine whether countermovement jump (CMJ) performance could be enhanced if preceded by heavy-resistance exercise or by dynamic plyometric activity over 3 trials. Thirteen anaerobically trained male subjects (mean ± *SD*: age, 22 ± 3 years; height, 182.4 ± 4.3 cm; body mass, 82.7 ± 9.2 kg) performed in a counterbalanced order 3 half squats using a 3 repetition maximum loading (SQUAT), a set of 24 contacts of lower body plyometric exercises (PLYO), or a control of no activity (REST) 5 minutes before each CMJ. Three sets of each treatment and CMJ were performed in total and maximal displacement (d_{max}), peak power (P_{peak}), and peak vertical force (F_{peak}) were recorded, whereas rate of force development and relative force (*F*/body mass) were calculated for every trial. No significant differences were revealed for any of the other variables, but greater displacement was found for SQUAT compared to REST or PLYO, whereas no differences were revealed for any of the conditions for the repeated trials. Although heavy resistance–induced PAP seems to enhance jump height compared to REST or PLYO in repeated CMJ performance, it has no additional benefit on repeated trials.

Key Words plyometrics, complex training, reactive index, power performance

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Introduction

Performance of skeletal muscle is significantly affected by its contractile history, because acute responses are affected by the muscle contractions preceding the activity (22). Increased muscular activity results in decreased neuromuscular force generation and fatigue (20), having a negative impact on subsequent strength and power performance. In contrast, optimal previous muscular activity can increase force generation and improve subsequent strength and power performance, a phenomenon termed postactivation potentiation (PAP [22]).

This enhancement has been primarily attributed to 2 mechanisms: regulatory light chain phosphorylation and increased recruitment of motor units. Regulatory light chain phosphorylation has been shown to increase the sensitivity of the actin–myosin interaction to the Ca^{2+} released from the sarcoplasmic reticulum and alter the structure of the myosin head, resulting in a higher force–producing state for the myosin crossbridges (20). For the second mechanism, it is postulated that previous contractions increase the excitation potential across the spinal cord, which lasts for several minutes after the initial contractions, resulting in increased postsynaptic potentials and, subsequently, increased force generation capacity (8).

One of the factors affecting PAP is the intensity of the conditioning activity, with higher intensity activities appearing to be more effective (6,22,27). Indeed, the majority of studies examining the effect of PAP on athletic performance have reported positive effects when using heavy weights before explosive movements such as short sprints, vertical jumps, or explosive strength jumps (2,16,29). Chiu et al. (2) used 5 sets of 1 back squat repetition at 90% of the subject's 1 repetition maximum (1RM) and reported a significant improvement in jump squat power using 30, 50, and 70% of 1RM. Their results agree with findings by Weber et al. (29), who reported an increase in vertical ground reaction force and jump height after 5 repetitions at 85% of 1RM. McBride et al. (16) used 3 repetitions at 90% of 1RM and reported a significant improvement in 40-m sprinting times of football players. Finally, Kilduff et al. (13) using a 3RM back squat set reported a 6.8% increase in countermovement jump (CMJ) performance. Conversely, Jones and Lees (12) reported no improvement in CMJ after 5 squat repetitions at 85% of 1RM. Nevertheless, there was no reduction in performance, suggesting that execution of heavy-resistance exercise before CMJ was not detrimental. It is possible, therefore, that Jones and Lees did not observe fatigue because of an induced PAP, as fatigue and PAP are initiated together after muscular contractions (20).

There is little evidence in the literature to indicate that PAP can affect maximum force generation (26). However, PAP can improve rate of force development (RFD [6,22,26]), which is an important factor in explosive sport activities where high power outputs are required. Such high power output in explosive sports is usually achieved by substantial use of the stretch-shortening cycle (plyometrics). Despite the potential of plyometric exercises as a PAP stimulus, little is known about the acute effect plyometric exercises have on subsequent muscular performance. Masamoto et al. (15) examined the effect of 3 double-leg tuck jumps and 2 depth jumps on subsequent 1RM squat performance and reported a 3.5% improvement in the load lifted. McBride et al. (16) used a loaded CMJ for a single set of 3 repetitions at 30% of 1RM before a 40-m sprint but found no differences. The lack of any difference in performance was attributed to the single set being insufficient to induce PAP. The small number of studies and the contradicting results merit further investigation of the ability of plyometric exercises to induce PAP.

The potential impact of PAP on explosive sports raises another issue that merits further investigation. Many explosive sports, such as jumps and throws in athletics and Olympic weightlifting, involve repeated trials. Therefore, it is important to gain an understanding of PAP effects on repeated performances, for example, repeated CMJ trials. Smilios et al. (25) assessed the jump height of a CMJ at 6 time points. These time points were at baseline, after each set of conditioning jumps (3 sets) and at 5 and 10 minutes of recovery. The findings indicated that after an initial improvement in CMJ performance, the jump height subsequently remained similar or decreased after the first loaded jump squat. However, because heavy weights have been shown to elicit PAP more effectively (6,22,27), a higher load may have yielded different results. Lastly, no information exists on the ability of plyometric exercises to elicit PAP on repeated performances.

Therefore, the aim of the present study was to (a) examine PAP effects induced by heavy weight or plyometric exercises on repeated trials and (b) compare performances in repeated trials between the 2 modes of exercise. It was hypothesized that (a) both heavy weights and plyometric exercises would induce PAP and (b) plyometric exercises would have a greater impact on subsequent performance than heavy-weight exercise.

Methods

Experimental Approach to the Problem

The PAP effects induced by heavy-weight and plyometric exercises on repeated trials, and any potential differences between the 2 conditioning stimuli were examined using a randomized, counterbalanced, repeated-measures design. Subjects performed 3 CMJs on 3 separate occasions. On each occasion, each CMJ was preceded by a conditioning stimulus, with the sequence repeated 3 times (Figure 1). The conditioning stimuli were (a) resistance exercise (SQUAT), (b) plyometric exercise (PLYO), or (c) inactivity (REST). The plyometric exercise conditioning stimulus consisted of 4 different plyometric exercises totaling 24 foot contacts, whereas 1 set of 3 repetitions at 3RM was used as the resistance exercise conditioning stimulus. REST served as a control condition and was used to compare the effects of contractile history between subjects using inactive recovery and those using a preconditioning stimulus. Maximal displacement (d_{max}), peak power (P_{peak}), and peak vertical force (F_{peak}) were recorded from a force plate, whereas RFD and relative force (F/body mass) were calculated for every trial. The variables examined were selected as they are commonly used for assessing explosive performance and can provide an indication of any PAP effects.

Subjects

Thirteen male, competitive athletes (mean ± SD: age, 22 ± 3 years; height, 182.4 ± 4.3 cm; and body mass, 82.7 ± 9.2 kg) volunteered to participate in the current investigation and provided written, informed consent. The subjects participated in sports or events where explosive power was a significant aspect (100/200/400 m, $n = 7$; 400-m hurdles, $n = 1$; pole vault, $n = 1$; long jump, $n = 2$; and rugby, $n = 2$). When testing took place, all subjects were in the competitive phase of their training cycle, although at different points, because the athletics season finishes in the summer, whereas the rugby season starts in spring. All subjects included regular

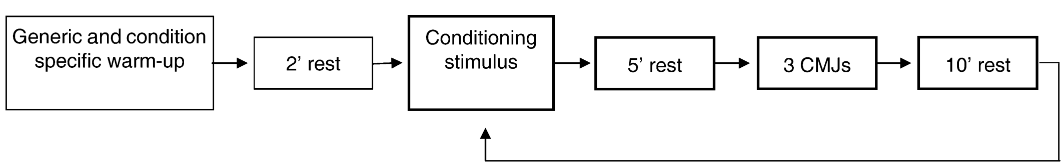

Figure 1. Schematic diagram of experimental procedures. The solid squares sequence was executed 3 times in total for each conditioning stimulus. Condition-specific warm-up or exercises refer to the inactivity (REST), plyometric exercises (PLYO), or heavy-weight squatting (SQUAT) modes of exercise.

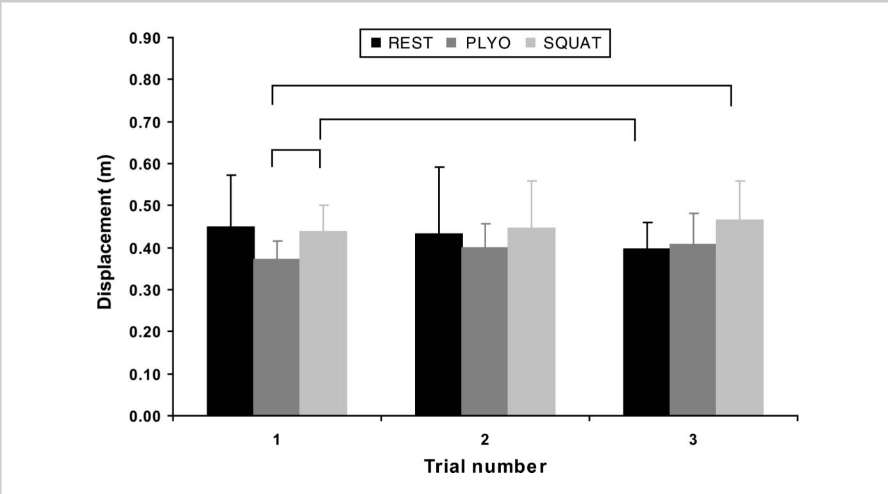

Figure 2. Maximal displacement for each trial for the inactivity (REST), plyometric exercises (PLYO), or heavy-weight squatting (SQUAT) conditioning stimuli. Square brackets indicate paired significant differences ($p < 0.05$). Values are mean ± *SD*.

and planned resistance training as part of their sport-training program for at least 2 years before the study. Their training included a minimum of 3 sessions per week, with training loads ranging from 30 to 90% of 1RM, depending on the phase of their training cycle. Finally, the subjects were free of any medical conditions or lower limb injuries in the 6 months before the investigation. The study was approved by the University of Wales Institute, Cardiff Ethics Committee.

Procedures

All subjects initially visited the laboratory to ensure familiarity with the half squat, the plyometric exercises, and the CMJ technique and to have their age, height, and weight recorded. Height was measured to the nearest 0.1 cm using a stadiometer (Harpenden, Burgess Hill, United Kingdom), and weight was measured using a calibrated balance beam scale (Seca, Birmingham, United Kingdom) and recorded to the nearest 0.1 kg.

Subjects were then required to complete a set of stabilization tests to determine whether they had sufficient stabilization strength to perform the plyometric exercises. These tests comprised a static stand (hip flexed), single-leg squat, hop for distance, hop down (from a 0.3-m platform), a repetitive jump test, and to be able to squat 1.5 times their body mass (23). Form and technique were observed and used to identify successful completion of the tests, with all subjects successfully completing all the stabilization strength tests. Each subject's 3RM half squat was then determined, with 3RM defined as a load that caused failure on the third repetition without loss of proper exercise technique. To establish the 3RM load, subjects attempted 3 repetitions of a load and, if successful, increased the loading. A 5-minute rest interval was allowed between trials, with 3–5 trials typically required for determining each subject's 3RM.

The subjects then visited the laboratory on 3 separate sessions. A standardized dynamic warm-up protocol was used for all sessions, which consisted of 400-m jogging and 4 repetitions of dynamic drills over 15 m (heel flicks, high knee jogging, walking lunges, and walking hamstring sweeps). After the standardized warm-up, the subjects were randomly assigned to 1 of the experimental groups; inactivity (REST), plyometric exercise (PLYO), or heavy-weight exercise (SQUAT). REST executed no additional warm-up. PLYO performed 1 set of 6 contacts of alternate speed bounds, right leg speed hops, left leg speed hops, and vertical bounds (total foot contacts = 24), with a 15-second resting interval allowed between each exercise. SQUAT subjects performed 2 sets of 6–10 half squats (90° knee flexion) at 60 and 85% of 3RM, respectively, with a minimum of 2-minute rest between sets. After the condition-specific warm-up, a minimum rest of 2 minutes was allowed.

The subjects then performed the conditioning stimulus (described below) with 5-minute rest and, subsequently, 3 CMJs with 10 minute-rest. This sequence was performed 3 times to approximate a sporting situation, because a number of events in Athletics have repeated attempts. A schematic diagram of the experimental procedure can be seen in Figure 1.

The conditioning stimulus for the PLYO group was 1 set of 6 foot contacts per plyometric exercise (alternate speed bounds, right leg speed hops, left leg speed hops, and vertical bounds), totaling 24 foot contacts per subject per trial. A 15-second resting interval between each exercise was allowed. Subjects were specifically instructed to minimize ground contact time and maintain technique on each repetition. The total time required for each subject to complete the plyometric exercises was approximately 70 seconds.

The conditioning stimulus for the SQUAT group was 1 set of 3 half squats at 3RM, performed as quickly as possible using a standard 20-kg Olympic barbell and weight plates (Ivanko, Reno, NV, USA). All resistance exercises were performed within the confines of a weightlifting safety cage. Subjects were permitted to use weightlifting belts, if desired. The use of support knee wraps and weightlifting body suits was not permitted. According to the International Powerlifting Federation rules, a lift was deemed to be successful if the subject could descend until the inguinal fold was lower than the patella and rise without help. Approximately 15 seconds was required by each subject to complete the squat exercise.

After the conditioning stimulus, subjects remained inactive for a period of 5 minutes, before performing 3 CMJs, separated by approximately 8 seconds each. The CMJ is commonly used for assessing lower limb explosive power and has been shown to be highly reliable (intraclass correlation coefficient = 0.97 [14]). In studies using similar CMJ protocols to ours, intraclass correlation coefficients were also high (r = 0.95 [25]). Countermovement jumps were initiated from an upright standing position, and upon command, the subjects squatted (the degree of knee bend used by each subject was self-determined) and then immediately after jumped vertically. The subjects were specifically instructed to aim for maximum height. To isolate the contribution from the lower limbs, subjects were requested to place their hands on their hips throughout each jump. A 10-minute rest interval was provided between the CMJs and the following conditioning stimulus. This rest interval was used to replicate the approximate temporal demands during the events of Athletics competitions. After the third and final set repetition, subjects were asked to undertake a cool down consisting of light jogging and stretching.

Maximal displacement (d_{max}), peak power (P_{peak}), and peak vertical force (F_{peak}) were measured on a Kistler force platform with an internal charge amplifier (Model 9287ba, Kistler, Winterthur, Switzerland). The force data were sampled at 1,000 Hz for 3 seconds and analyzed using Bioware software (version 3.2.6, Kistler). Rate of force development was calculated as maximum force/time to maximum force (30). Finally, relative force (RelF) was calculated as absolute force/body mass. For all measurements, the highest CMJ was used from each trial for each condition to reduce variability (18).

Subjects refrained from any strenuous activities or resistance training at least 24 hours before testing. All tests took place at the same time of the day and with a minimum of 24 hours intervening.

Statistical Analyses

Data were checked for normality using the Shapiro–Wilks test. Because data were found to deviate from normal distribution, Friedman's test was used to examine for differences within trials for all performance measures (d_{max}, P_{peak}, F_{peak}, RFD, and RelF). Where a difference was revealed, Wilcoxon's test was used to identify those differences. Significance level was set at $p \leq 0.05$. Because the measurements were directly or indirectly intercorrelated, no adjustments were made for multiple comparisons, but caution was exercised in the interpretation of the results (19,21). All statistical analyses were conducted using SPSS v14.0.

Results

A significant difference was revealed for displacement ($p = 0.009$; Figure 2). The pairwise comparisons indicated differences between SQUAT trial 1 with PLYO trial 1 ($p = 0.044$) and REST trial 3 ($p = 0.010$), and SQUAT trial 3 with PLYO trial 1 ($p = 0.018$) (Figure 2).

Table 1. Countermovement jump performance variables after the 3 different conditioning stimuli over 3 trials for each stimulus.*†

Conditioning stimulus	REST			PLYO		
Trial no.	1	2	3	1	2	3
Power (W)	2,254 ± 549	2,079 ± 419	2,041 ± 372	2,164 ± 220	2,174 ± 365	2,051 ± 233
Force (N)	1,332 ± 327	1,240 ± 265	1,352 ± 382	1,128 ± 294	1,258 ± 328	1,294 ± 288
RFD ($N \cdot s^{-1}$)	401,750 ± 210,841	462,553 ± 231,241	453,722 ± 98,521	372,034 ± 153,098	461,563 ± 90,461	360,124 ± 69,572
Relative force (N/BW)	1.66 ± 0.39	1.55 ± 0.30	1.67 ± 0.42	1.52 ± 0.31	1.55 ± 0.34	1.60 ± 0.28

Conditioning stimulus	SQUAT		
Trial no.	1	2	3
Power (W)	2,254 ± 391	2,267 ± 368	2,236 ± 492
Force (N)	1,332 ± 374	1,292 ± 347	1,323 ± 390
RFD ($N \cdot s^{-1}$)	343,965 ± 140,920	346,011 ± 120,404	310,779 ± 161,626
Relative force (N/BW)	1.67 ± 0.48	1.59 ± 0.36	1.63 ± 0.45

*REST = inactivity; PLYO = plyometric exercises; SQUAT = heavy-weight squatting; RFD = rate of force development.
†Values are mean ± *SD*.

No differences were revealed for any of the other variables. Descriptives (mean ± *SD*) for P_{peak}, F_{peak}, RFD, and RelF can be seen in Table 1.

Discussion

The aim of the present study was to investigate PAP by examining the effect of heavy-weight or plyometric exercises on repeated CMJ performance, and to compare CMJ performances between the 2 modes of exercise. Our findings show that heavy weight–induced PAP improved to some extent jump height compared to plyometric exercises or inactivity, as statistically significant differences were revealed in some comparisons only, whereas plyometric exercises presented no additional benefit to inactivity. Finally, neither heavy-weight nor plyometric exercises showed any significant improvements over the course of the 3 trials. To the authors' knowledge, this was the first study to directly compare heavy-weight resistance and plyometric exercises in relation to PAP over repeated trials preceded by the conditioning activity.

Heavy weights have been shown to improve vertical jump performance, in both intervention (1,17) and acute studies (7,29). In contrast, previous studies have reported no difference in acute CMJ performance after heavy-resistance exercise (12,16). Indeed, in the current study, no difference was revealed in CMJ jump height over the course of 3 trials. These results agree with the findings of Jones and Lees (12), who reported no effect of heavy-resistance exercise on repeated CMJ performance using similar rest intervals (12). It is worth noting that both the current study and that of Jones and Lees (12) employed a similar sample, with all subjects involved in sports requiring the development of explosive strength, particularly in the hip, knee extensors, and ankle plantar flexors and had experience performing resistance exercises. Although such athletes may have benefited from improved motor unit synchronization (2,15), this was not evident in the present study. Notwithstanding the lack of improvement in jump height, it is worth noting, from a practical perspective, that no impairment in performance was evident. As PAP and fatigue are simultaneously initiated after muscle contractions (20), we posit that the effect of PAP was sufficient to counteract the effect of fatigue in the SQUAT group but inadequate for enhancing performance.

One interesting finding of the study was the consistency of performance over those trials, despite no immediate effect of the SQUAT stimulus on the repeated CMJs. When the coefficient of variation (CV) was calculated (*SD*/average × 100 [20]), the SQUAT group demonstrated a much lower CV (1.3%) compared with PLYO (5.1%) and REST (4.3%). A similar displacement performance consistency was calculated from the study of Jones and Lees (12), where the CV was 1.2%. Although all the above percentages appear small, the CV needs to be considered in comparison to the performance gains expected. Significant differences in vertical jump height performance are in the region of 4% and above (14). A CV value above 4% (such as in the PLYO and REST groups), would make the interpretation of results very difficult, because any performance gain could be attributed to the variability of the measure. In addition, CV values for force (1.6%) and power (0.7%) indicate high consistency. It is suggested that in sports involving repeated performances and in which force and power are crucial, such as long jump (24), heavy-resistance exercises will assist in maintaining the required muscle output to allow the athlete to focus on the technical execution of the skill.

Plyometric exercises have been used widely as a training method to improve the efficiency of the stretch-shortening cycle as well as the muscle–tendon unit's ability to tolerate stretch loads (3). The positive effects obtained by this form of training on vertical jump performance have been established (9,23). However, less is known about the acute effects of plyometric or power exercises as a conditioning stimulus on subsequent vertical jump performance (26). To the authors' knowledge, this is the first study to examine the effect of plyometric exercises on subsequent plyometric activity. Our study indicated that previous plyometric exercises have no impact on force and power production and that they present no additional benefit to resting between trials.

Although no previous studies have examined the effect of plyometric exercises on subsequent CMJ performance, it was hypothesized that PLYO would improve power performance, because of PAP increasing RFD in explosive activities (22). Jensen and Ebben (11) and Ebben et al. (4) proposed that the concepts of plyometric intensity should be re-examined, as they reported that "high" intensity plyometric exercises, such as depth jumps, are recruiting muscle fibers as any other "less intense" plyometric exercise, such as single-leg hops. Interestingly, the vertical jump was shown to have higher muscle fiber recruitment compared to the other plyometric exercises used in their study (4). It is possible that the PLYO conditioning exercises used in the present study did not result in sufficiently high recruitment of muscle fibers to elevate the postsynaptic potentials (26). This assumption is supported by Masamoto et al. (15), who used tuck jumps (high muscle fiber recruitment [4]), resulting in increased 1RM performance. However, the opposite could also hold true. The plyometric conditioning exercises could have resulted in high recruitment of muscle fibers at maximum rate, in which case PAP would offer little benefit (22). Unfortunately, in the present study as in Masamoto et al. (15), electromyography (EMG) was unavailable, making it impossible to accept or refute any of these contentions. Therefore, future studies should use EMG to assist in offering an explanation on the mechanisms by which plyometric exercises enhance subsequent strength and power performance, especially in activities that involve the stretch-shortening cycle.

Finally, it is also possible that the duration of the plyometric exercises (~70 seconds) in the current study was too long. Vandervoort et al. (28) found that potentiation was partially suppressed by fatigue in muscle contractions over 10-seconds in duration, which may explain why shorter duration plyometric exercises have previously improved performance (15). The rest duration used in our study has previously been shown to be sufficient for allowing fatigue to subside (10,25,29). However, the duration of the conditioning exercises in these studies was lower compared to the exercise duration used in the present study, indicating that the complex relationship between duration of contractions and rest interval warrants further investigation.

Practical Applications

Although the majority of research into PAP has recommended its use for performance enhancement, few studies have specifically investigated how such acute augmentation may be achieved in repeated performances, as those encountered in athletics competition. The results of the present study indicated that lower body power performance, as measured by CMJ height, is enhanced when preceded by 3 half squats at 3RM followed by 5 minutes of rest, compared to plyometric exercises and rest. Therefore, the inclusion of sets of squats into a warm-up routine before and during the early stages of intermittent performance may provide a beneficial alternative to traditional warm-up practices. In addition, the inclusion of the above protocol in an athlete's preparation for their next performance (e.g., next jump or throw) will ensure consistent force generation across trials. The findings of the present study may be of particular importance to athletes involved in disciplines where maximal, brief efforts are required, such as the jumping events in Track and Field, where success is a product of force and take-off velocity (24). Although the extent of performance augmentation noted from the PAP mechanism is relatively small, the potential benefits that such acute improvements in performance hold to highly conditioned elite athletes should not be underestimated (5).

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