Post-activation potentiation: Enhancing Speed and Explosive Power after Warm-up with Heavy Load

Dr / Mohamed Fekry Elmoghany [1]

(1) Assistant Professor, The Department of Sports Training, Faculty of Physical Education, Kafr-Elsheikh University, Egypt

Abstract

Resistance exercises incorporated in the warm-up may improve subsequent performance involving explosive movements by eliciting the acute effects of post-activation potentiation (PAP). The aim of this study was to investigate the influence of heavy load back squat exercises included in the warm-up routine on explosive power and speed.

Ten long jump and triple jump male players, who were able to lift twice their body massing the back squat exercise, participated in the study.On separate days, participants performed countermovement jump (CMJ), standing long jump (SLJ) tests in the laboratory and a 30m sprint test on the track, 4 minutes before and after exercises involving heavy load warm-up. The heavy-load exercises consisted of 1 set of 5 repetitions at 50% of 1 repetition maximum(1RM), followed by the second set of 3repetitions at 75% of 1RM, followed by 3 sets of ~93% of 1RM. The rest periods were 30 seconds between the first 2 sets, 1 minute between the second and the third set, and 2 minutes rest between the last 3 sets.

A paired-samples T test found significant pre-to post-intervention improvements for all the variables ($p < 0.05$) including 30 m sprint, standing long jump, and countermovement jump. We concluded that explosive power and speed can be significantly enhanced following a bout of heavy exercise (preload stimulus) involving high-intensity resistance training with multiple sets and adequate recovery.

Keywords : (Post-activation potentiation, resistance training, conditioning activity, exercise intensity, performance enhancement, warm-up.)

Introduction:

Post-activation potentiation (PAP) refers to the phenomena by which muscular performance is acutely enhanced because of the preceding muscle contractile history (25: 453). It is the net effect between the performance-enhancing physiological adjustments and the deleterious effects of fatigue)1: 2496).PAP has emerged as a means to maximize muscular power in athletes (18: 234) as muscular power is critical for successful outcomes in a number of athletic events, such as long jump, triple jump, and high jump(33: 854).PAP has significant implications for strength and conditioning practitioners as it may produce additional benefits compared with traditional warm-ups (16: 2418).For example, including resistance exercise in the warm-up may improve performance by eliciting the acute effects of PAP (19: 151).

Although the mechanism of PAP has not been fully elucidated (24: 483), it has been attributed to increased phosphorylation of the regulatory myosin light-chains and increased recruitment rates of motor units (23: 499). From these effects, significant increases in muscle tension and, consequently, in muscular strength and power production have been observed (23: 499), (32: 147).The overall potentiated effect may be due to a number of factors, including training intensity of the conditioning activity (CA), duration of rest intervals between CA and performance activity, type of contraction and categorical variables (muscle strength level, training status, and fiber-type composition) (26: 898). Although relevant studies have identified several factors that may affect the occurrence of PAP, there is no clear agreement regarding the ideal combination of these factors to optimize performance after a conditioning activity. (32: 147)

The inconsistencies in the PAP research may arise from a few sources. In previous research, the loads used during the CAs have varied considerably (34: 294). To optimize PAP, an ideal time interval between the CA and subsequent performance is not known (33: 854) since the intensity and type of stimulus will dictate the duration of the interval (McCann & Flanagan, 2010). The time interval must be long enough to promote recovery from fatigue, but short enough to affect muscles in a potentiated state (20: 1285)

It is worth noting that following the CA, both fatigue and PAP can coexist in skeletal muscle. (14: 2). Close examination of the literature reveals that increases in muscle performance after a CA (e.g., a preload stimulus) depend on the net balance between fatigue and potentiation, which co-exist at varying degrees after the completion of the CA (23: 499). Muscle performance may be increased if potentiation dominates or remain unchanged if fatigue and potentiation are at similar levels or decrease if fatigue dominates. (30: 231). Consequently, it is worth investigating the effectiveness of loading strategies that concurrently enhance potentiation and limit fatigue for optimal performance in athletes (3: 2059). In particular, the effectiveness of a heavy load warm-up may extend to a wide variety of high-power activities (5: 671).

Although intense exercise results in a potentiation of power performance (35: 82) because of increased neuromuscular activity (13: 67), there is no uniform agreement and general recommendation about the optimal preload stimulus to gain optimal performance benefits for increasing subsequent explosive activity as no previous study has addressed this question.

Objectives:

The purpose of the present study was to investigate the influence of the heavy load back squat (BS) exercises as a

conditioning activity on the explosive power and speed in long jump and triple jump athletes.

Hypothesis:

The hypothesis is that heavy load back squat exercises would produce significant increases in the subsequent explosive power and speed.

Research Importance:

If the influence of heavy resistance exercises on the subsequent jump length, jump height, and sprint running are clarified, strength and conditioning professionals and coaches can apply conditioning activity by modulating exercise intensity based on the scientific evidence as a method for enhancing sport performance.

Methods:

Study Approach:

This study employed a 1-group experimental design before and after an acute exerciser bout.

Participants:

Ten highly trained men were randomly selected from long jump and triple jump athletes to participate in the study (with at least 2 years of systematic resistance-training experience and the barbell BS exercise with correct technique). Subjects were able to lift twice their body mass (BM) in the BS exercise (Table 1). All the participants were free from any musculoskeletal injuries. The participants were athletes in long jump and triple jump events where speed and explosive power are significant determinants of success. When testing took place, all participants were in the competitive phase of their training cycle. The participants regularly undertook resistance training at least 3 times a week, with training loads ranging from 30-95% of 1RM, along with training for their selected sports (long or triple jump). At the time of entry into the study, the participants had completed a power phase which incorporated squat, countermovement jump, long jump, and sprints. The sample size was selected based on previous studies, suggesting an adequate strength level necessary to induce PAP (5: 671).After thorough explanation of the procedures and risks of the study, subjects read and signed an informed consent form in accordance with the policies and procedures of the Kafrelsheikh University's Research Ethics Committee (Attachment 1)..

Table (1)
Descriptive characteristics of the participants. N=10

Variable	Mean ±SD	SEM	CV%
Age (y)	19.8 ± 1.3	0.41	6.6%
Height (cm)	180 ± 7	2.32	4.1%
Mass (kg)	76.4 ± 4.6	1.46	6.1%
Back Squat 1 RM (kg)	155± 5	1.58	3.2%
Back Squat 3 RM (kg)	145± 5	1.58	3.5%
Back squat 1 RM: body weight ratio	2.0 ± 0.2	0.06	9.9%

RM= Repetition Maximum

Statistical characterization which is presented in Table 2 shows that the variables are moderate and are characterized by the natural distribution, where skewness coefficients are ranging between -0.23 and 2.40 and approaching zero, confirming the normality for variables before the experiment.

Table (2)
Statistical characterization of baseline dependent variables (N=10)

Descriptive stats / variables	Unit	Mean	Median	SD	Skewness	Kurtosis	CV%
Countermovement Jump	cm	53.7	53.5	2.41	0.08	-0.99	0.04
Standing Long jump	m	2.66	2.66	0.03	-0.23	-0.64	0.01
30 m sprint	sec	3.92	3.90	0.09	2.40	6.68	0.02

Study Design:

The experimental procedure of this study is shown in Figure 1. At the start of each experimental session, the participants were required to complete general warm-up. A recovery period of 2-minutes separated the general warm-up and pre-tests in the laboratory or at the track.

Figure (1)
The experimental procedure of the study.
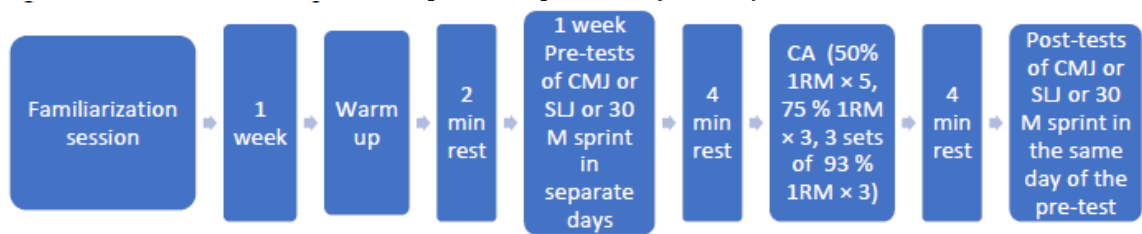
RM= Repetition Maximum, CMJ= Countermovement jump, SLJ= standing long jump

Maximal effort of CMJ, SLJ and 30 M Sprint were performed 4 minutes before and after each CA in separate days. A 48 hours recovery period was given between all the test sessions.

Free weight BS (Figure 2) was selected as a heavy loaded exercise because a) the study of Schwanbeck et al. 2009reported that muscle activation was 43% greater during free weight squats compared with squats performed using a Smith machine, suggesting that free weight squats may allow for a greater PAP effect.(29:2588), b) another research reported that the free weight condition produced superior mean power values (ES=0.60-1.41) compared with squats performed using a Smith machine, andc) the parallel BS is the exercise most used for leg power conditioning and for obtaining potentiation responses (22: 1486).

Figure (2)
Free weight back squats

The load of the CA consisted of 1 set of 5 reps at 50% of 1RM, followed by second set of 3repetitions at 75% of 1RM, followed by 3 sets of 3RM (~93% of 1RM). The rest was 30 seconds between the first 2 sets, 1 minute between the second and the third set, and 2 minutes rest between the last 3 sets.

Submaximal sets of back squats were performed as resistance warm-up since submaximal contractions of less than 85% of 1RM do not induce potentiation of the nervous system (13: 67). A 3RM loading was used in this investigation because a load of 3RM may cause a potentiating response (7: 530).

Experimental Procedures:
The participants were asked to refrain from strenuous activities and caffeine consumption 24 hours before the evaluations. To examine the effects of heavy resistance exercises, the participants were submitted to one familiarization session, 2 separate occasions at the laboratory, and 1 separate occasions at the track for the experimental sessions. The objective of the first testing session was to determine height, body mass, back squat 3RM and Back squat 1RM on the high bar back squat. In addition, the participants were familiarized with the study procedures to follow. One week after the familiarization session, muscular power and sprint tests were conducted over the three different experimental sessions.

The testing sessions were designed to be part of the athletes' regular training program. All the experimental sessions were conducted at the same time of the day to eliminate a possible time-of-day effect. Room temperature was maintained between 20 and 24°C. Participants were asked to maintain similar diet consumption before each session. Consumption of water (500 ml) was permitted during each test. Verbal encouragement was given to maximize performance throughout the testing sessions.

Experimental sessions warm up:
The participants underwent a standardized warm-up consisting of 5 minutes of light-intensity running at 9.0 km·h-1 on treadmill, followed by 3 min of dynamic

stretches with an emphasis on stretching the musculature associated with the testing session.

Tests:

Countermovement jump (CMJ) and standing long jump (SLJ) were performed for the measurement of lower- body explosive power. 30 m sprint running was performed for the measurement of speed. (7: 530). These dependent variables were chosen to represent muscular performance (1: 2496). SLJ and CMJ tests were chosen because these exercises/tests represent explosive type of movements,

which correlate well with other types of explosive movement such as the sprinting (17: 710).

The pre and post CMJ was performed on JUMP-DF Digital Vertical Jump meter) Takei Scientific Instruments, Niigata, Japan) at the laboratory of the Faculty of Physical Education at Kafrelsheikh University. The participants were asked to stand on the rubber mat and push the START button. After a few seconds, when the buzzer buzzed, the participants were asked to jump up as high as they could (Figure 3). Two trials were conducted, and a better value was displayed as the result.

Figure (3)
CMJ test on JUMP-DF Digital Vertical Jump meter

The pre and post SLJ were performed in the laboratory to measure jump distance in meters. For the measurement of the sprint speed, 30 m sprint runs were performed on the track using stopwatches. (Sportline 410 Alpha Sport Stopwatch, RYP Sports). The participants were instructed to run as fast as possible (7: 530).

Statistical Analyses:

To compare the differences in tests results before and after the CA, statistical analyses were carried out using paired samples T test. The percentage of improvement, Cohen effect size, and Eta square were performed using the Statistical Package for the Social Sciences (SPSS 25 for Windows, SPSS Inc., Chicago, IL). For all statistical analysis, the level of significance was set at $p<0.05$. All data are presented as means ±SD, unless otherwise stated.

Results:

Significant increases in the explosive power and speed were observed after the preload stimuli. The pre and post explosive power and speed tests results of the participants are presented in Table 3, Figures 4, 5 and 6. The statistical significance of effect size (ES) in the tests is presented in Table 4. Effect sizes [ES] were interpreted depending on Eta square, where (<0.30), (30 0.49 –), and (0.50-1.00) are considered low, moderate, and high effects, respectively.

Table (3)
Explosive power and sprint before and after the exercise (N = 10)

Stats / Variables	Pre test		Post test		Paired Differences		t	P-value	%
	Mean	SD	Mean	SD	Mean	SD			
Counter Movement Jump	53.7	2.41	60.9	4.63	7.2	2.35	9.70*	0.00	13.4
Standing Long jump	2.66	0.03	2.81	0.06	0.15	0.03	16.02*	0.00	5.8
30 m sprint	3.92	0.09	3.84	0.07	0.08	0.03	8.49*	0.00	2.0

Figure (4)
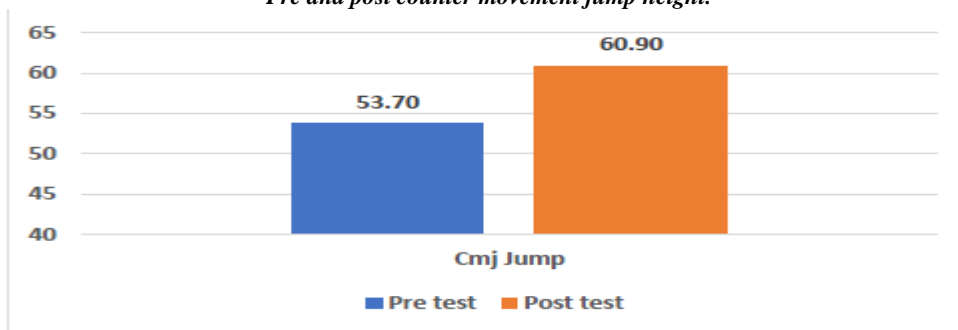*Pre and post counter movement jump height.*

Figure (5)
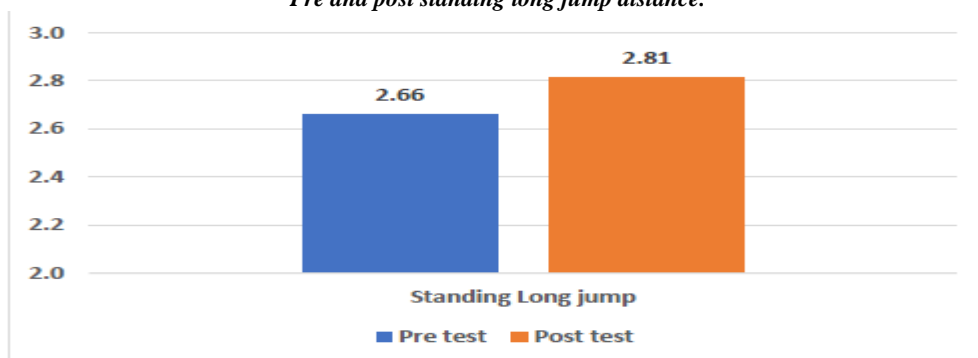*Pre and post standing long jump distance.*

Figure (6)
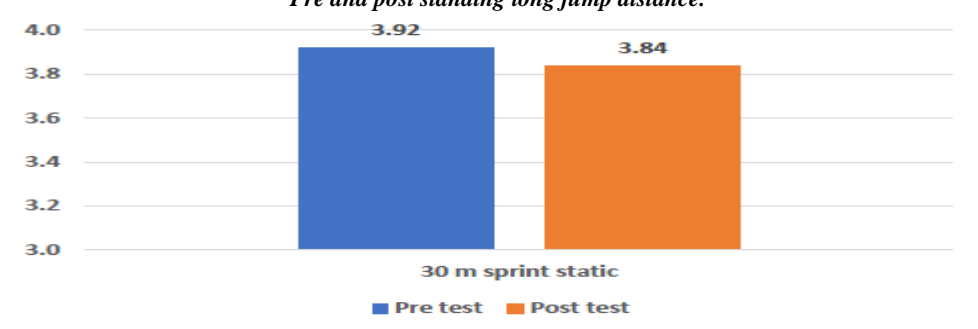*Pre and post standing long jump distance.*

Table (4)
The effect size of the test results (N= 10)

Stats / Variables	Unit	t	P-value	Effect size Eta square	Effect size Cohen	direction
CMJ Jump	cm	9.70*	0.00	*0.91	0.69	High
Standing Long jump	m	16.02*	0.00	*0.97	0.35	High
30 m sprint	sec	8.49*	0.00	*0.89	0.89	High

Statistical analyses in Table 3, Table 4 and Figure 4 revealed significant differences between the mean jump height for the CMJ test after the CA of heavy load (preload stimulus) in comparison to the pre-test values. (53.7±2.4 vs.60.9±4.6 cm, T=

9.70,P<0.05, ŋ2; a measure of effect size was high= 0.91 ≥0.50). In addition, significant changes were observed in mean jump length of the post-standing long jump test after the CA of heavy load when compared with the pre-test values (2.66±0.03 vs. 2.81±0.06 m, T= 16.02,P<0.05, ŋ2; a measure of effect size was high = 0.97 ≥0.50). For the 30 m sprint test, significant decrease in the mean running time was noted after the CA of heavy load (preload stimulus) compared to the pre-test values (3.92±0.09 vs. 3.84±0.07 sec, T= 8.49, P<0.05, ŋ2; a measure of effect size was high = .089 ≥0.50).

Discussion:

The results of the present study indicate that warm-up and multiple sets of heavy load resistance exercise with moderate rest maximized the PAP effect on sprint speed and explosive power in athletes. These results support our hypothesis that the heavy load BS exercise produces increases in explosive power and speed. This finding also suggests that previous findings in which the positive effect of condition activities on jump performances was not found may be because the intensity of condition activities might have been too low.

The results of CMJ agree with the results of Chiu et al. (2003)who found 1–3% increases in CMJ after a heavy conditioning activity consisted of 5 sets of 1 repetition at 90% 1 RM back squatting resistance-trained individuals (5: 671).Moreover, Esformes & Bampouras (2013) reported improvements in jump performance of CMJ height following heavy squats performed at 93% 1RM with rest periods of 5 minutes were imposed between the heavy squats and the CMJ test for male rugby union players (8: 2997). In support of this, the study by Mitchell & Sale (2011) observed a 2.9% increase in CMJ height in 11 male athletes. A rest period of four minutes was used between the 5-RM squat and the CMJ test (21: 1957).In addition to that, Gourgoulis et al. (2003) found increase in the vertical jumping (4.0%) in subjects with greater maximal strength after applying a progressive heavy squat protocol. Twenty physically active men performed 5 sets of half- squats with 2 repetitions at each of the following intensities: 20, 40, 60, 80, and 90% of the 1RM load. A rest period of 5 minutes was imposed between the sets for recovery of the central nervous system (12: 342).These significant increases in

jump height after the squat exercises may be associated with the enhancement of the force-generating capability of muscle due to PAP. (10: 2236).Moreover, it seems that as the maximum strength increases, the aptitude to elicit PAP also increases (11: 3010).Since the participants were able to lift at least twice their BM in the BS exercise, this may be one of the reasons why the subjects demonstrated significant improvements in performance.

The finding of CMJ test contrasts with Esformes et al. (2010)who reported that a 3RM squat exercise had no effect on CMJ performance using a slightly shorter rest interval than the present study. The present study reports an increase in jump height, and the author used moderate rest reach to 4 minutes (9: 1911). Additionally, the results of CMJ test contrasts with the findings of Jones & Lees(2003) who reported no significant change in CMJ height following 3, 10, or 20 minutes of recovery, following a single set of 5-squats at 85% of 1RM in eight strength trained men(15: 694). One possible explanation is because the training protocol involved only 1 set. Regarding volume, a comprehensive meta-analysis indicated that multiple sets (e.g., 2 or 3) were more likely to optimize PAP than single set (33: 854).Another possible explanation maybe because the intensity of condition activities was too low. Thus, it seems reasonable to suggest that performing only 1 set may not have been sufficient to induce any physiological events related to PAP. Additionally, it is unlikely that more sets with appropriate rest induced enough fatigue to mask PAP effects (1: 2496).

High-intensity BSs of 93% 1RM were adopted as the CA in Jenkins (2015(study, and CMJ performance was not significantly improved (14: 30).These results agree with the findings of Chiu et al. (2003) who did not find significant increase in jump performance using a 90% 1RM squat as their potentiating exercise.(5: 671).This may be due to the subjects who were recreationally- trained in these studies. The present study reports an increase in jump height in highly-trained athletes as subjects (squat/BM ratio: 2). As such, they might have been sensitive to the potentiation effect of conditioning activity. This could explain the conflicting results of these studies and the present study.

The results of SLJ test in the present study are supported by Bechtel et al. (2018) who indicate that horizontal jump (HJ) were significantly increased (+11.6 cm) following five repetitions of back squat (BSQ) at 87% 1RM with rest intervals set at five minutes between the BSQ and HJ(2: 26). These findings concur with Ruben et al. (2010) who observed that acute enhancements in horizontal jump was exhibited in the stronger individuals (squat ≥ 2.0 x BM), and both the maximum peak power (PP) output and peak force (PF) were higher, in the potentiation session, after executing an ascending squat protocol (i.e., 5 repetitions at 30% 1RM, 3 at 70% 1RM, and 3 at 90% 1RM) with rest intervals set at five minutes between the BSQ and HJ (27: 358).

One possible explanation for the increases in SLJ performance may be the high-intensity loading warm-up which bring about the greatest effects on subsequent neuromuscular explosive responses (6: 393).Although, the heavy potentiating protocol which consisted of 1 set of 3 repetitions in the squat at intensities of 50, 75, and 87.5% of 1RM which used in the study of Koch et al. (2003) failed to invoke any improvement in SLJ. The warm-up routine did not alter jumping ability as compared with the no activity condition. (17: 710). Based on previous research, it would be reasonable to speculate that the decrements in subsequent performance in the previous study could perhaps be due to the use of a single set and not multiple sets (33: 854). In support of this, Güllich &Schmidtbleicher (1996) observed that only

1 set may not have been sufficient to induce any physiological events related to PAP(13: 67).This could explain the conflicting results of Koch et al. (2003) study and the present study.

It is likely that the balance between fatigue and potentiation is more favorable with increased competitive levels and training experience of the participants. It should also be noted that trained individuals demonstrate elevated regulatory myosin light chain phosphorylation activity)28: 138), suggesting that increased power output may be bidirectionally mediated with increased training experience (greater PAP and lower fatigue).

Based on the results of 30m sprint test in the present study, this finding is in agreement with the findings of Chatzopoulos et al.)2007(who showed that running speed, after the resistance training increased for the (0– 30 m test), 5minutes after many sets of heavy resistance stimulus at 90% of 1 RM, and the time was significantly better compared to pre-5 min in basketball, volleyball, handball, and soccer players (4: 1278).   In support of this, 3 BS at 90% 1 RM induced a significant improvement in 20msprint time when included as part of a potentiation protocol in thirteen elite junior rugby league players, the improvements were in sprint time, velocity and average acceleration over 20 m (31: 643). Short-term gains in fitness after heavy muscle preloading are thought to include phosphorylation of myosin regulatory light chains and increased recruitment of higher order motor units (32: 147)

Conclusions:

In conclusion, the warm-up exercise, which included heavy resistance training with moderate rest and multiple sets, was effective in maximizing the PAP effect on subsequent speed and explosive power in long jump and triple jump players. In addition, the athlete's initial strength level may play an important role in the ability to utilize the PAP phenomenon. Thus, PAP has the possibility to be an effective strategy to enhance training efficiency. Future studies that adopt PAP are required in different sports.

Practical Application:

This study examined the effects of CA consisting of squat exercise with increasing loads (50% 1RM, 75% 1RM and 93% 1RM) with moderate rest and multiple sets. The results confirmed that this protocol enhances jump and sprint performance and that squat exercises should be performed from lower level to the maximal level of muscle action to gain greater benefit from PAP. The protocol presented here may be useful for the warm- up before competition or training, particularly for athletes who require high muscular power.

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