META-ANALYSIS OF POSTACTIVATION POTENTIATION AND POWER: EFFECTS OF CONDITIONING ACTIVITY, VOLUME, GENDER, REST PERIODS, AND TRAINING STATUS

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ABSTRACT

Wilson, JM, Duncan, NM, Marin, PJ, Brown, LE, Loenneke, JP, Wilson, SMC, Jo, E, Lowery, RP, and Ugrinowitsch, C. Meta-analysis of postactivation potentiation and power: Effects of conditioning activity, volume, gender, rest periods, and training status. *J Strength Cond Res* 27(3): 854–859, 2013—There is no clear agreement regarding the ideal combination of factors needed to optimize postactivation potentiation (PAP) after a conditioning activity. Therefore, a meta-analysis was conducted to evaluate the effects of training status, volume, rest period length, conditioning activity, and gender on power augmentation due to PAP. A total of 141 effect sizes (ESs) for muscular power were obtained from a total of 32 primary studies, which met our criteria of investigating the effects of a heavy preconditioning activity on power in randomized human trials. The mean overall ES for muscle power was 0.38 after a conditioning activity ($p < 0.05$). Significant differences were found between moderate intensity (60–84%) 1.06 and heavy intensity (>85%) 0.31 ($p < 0.05$). There were overall significant differences found between single sets 0.24 and multiple sets 0.66 ($p < 0.05$). Rest periods of 7–10 minutes (0.7) after a conditioning activity resulted in greater ES than 3–7 minutes (0.54), which was greater than rest periods of >10 minutes (0.02) ($p < 0.05$). Significant differences were found between untrained 0.14 and athletes 0.81 and between trained 0.29 and athletes. The primary findings of this study were that a conditioning activity augmented power output, and these effects increased with training experience, but did not differ significantly between genders. Moreover, potentiation was optimal after multiple (vs. single) sets, performed at moderate intensities, and using moderate rest periods lengths (7–10 minutes).

KEY WORDS warm up, training status, regulatory light chains, motor unit recruitment

INTRODUCTION

The capacity to maximize muscular power is critical to successful outcomes in a number of athletic events, such as the long jump and the high jump. Several authors have demonstrated that muscle postactivation potentiation (PAP) is a phenomenon that can acutely increase muscular power and, consequently, performance (6). Short-term gains in power after heavy muscle preloading are thought to result from phosphorylation of myosin regulatory light chains and increased recruitment of higher order motor units (52). Accordingly, a great deal of research has attempted to identify methods to elicit PAP through a variety of conditioning activities during warm-up routines (1,3,4,6,9,11–14,16,21–24,26–34,37–39,42,43,46,49,53–55).

The efficacy by which a conditioning activity can stimulate PAP mechanisms and acutely enhance muscular performance ultimately depends on the balance between fatigue and potentiation (52). This balance is affected by numerous factors including, but not limited to, training experience (27), rest period length (28), and the intensity of the conditioning activity performed (45). Chiu et al. (6) reported a 1–3% increase in vertical and drop jump heights

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5 minutes after 5 sets of 1 repetition back squat, performed at 90 % of their concentric 1 repetition maximum (1RM) in trained subjects. In contrast, recreationally trained individuals exhibited a 1–4% decline in performance postconditioning activity. In addition to training experience, absolute individual strength appears to influence PAP because there is a moderately positive correlation ($r = 0.63$) between 1RM values and countermovement jump potentiation, after a high-intensity activity (27). These findings can be explained by greater fatigue resistance in trained than in untrained subjects after a conditioning activity, which is typically performed at high intensities (e.g., 75–95% of 1RM). In general, although authors 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 (52).

A robust and quantitative approach to define the factors that contribute the most in eliciting PAP can be provided by a meta-analysis of the data presented in the current body of literature. This technique minimizes subjectivity by standardizing treatment effects of relevant studies into effect sizes (ESs), pooling the data, and then analyzing it to draw conclusions. Thus, the primary objective of this investigation was to quantitatively identify which components of conditioning activities optimize power output.

Methods

Experimental Approach to the Problem

A meta-analytic statistical analysis was conducted to evaluate the effects of training status, volume, rest period length, conditioning activity, and gender on power augmentation because of PAP. Relevant studies were combined and analyzed statistically to provide an overview of the body of research on this topic. Conclusions were based on the results of the statistical analysis with suggestions for applications and future research for strength and conditioning professionals.

Subjects

Subject characteristics can be found in table 1.0. Of the studies included there were 141 male and female subjects with an average age of 20 +/− 5 years of age.

Literature Search

Searches were performed for published studies with 4 specific criteria.

First, the primary focus of the study was to investigate the effects of a conditioning activity on a specific criterion power task (force × velocity). Second, the conditioning activity had to be performed at a greater load than the criterion task (e.g., a free weight squat performed before a vertical jump). Third, the study could not use any outside electrically elicited stimuli during the conditioning activity. Fourth, all studies were limited to human controlled randomized trials. Scientific articles were retrieved based on an extensive search of the following data bases completed in February 2011: MEDLINE (1966–2011), EMBASE (1974–2011), Cochrane Database of Systematic Reviews (1993–2011), Lilacs (1982–2011), Scielo (1997-–2011), and Google Scholar (1980–2011). Computer search engines used the following key words combinations: 'postactivation potentiation,' 'power,' 'countermovement jump,' 'warm-up,' and 'Wingate.' Exclusion of studies with irrelevant content and doublets were

TABLE 1. Effect size for muscle power.

	Mean (95% CI)	*N*		
Overall	0.38 (0.21, 0.55)	141		
Moderators				
Gender				
Male	0.42 (0.23, 0.61)	113	$p > 0.05$	
Female	0.20 (−0.31, 0.71)	16		
Male and female	0.21 (−0.38, 0.79)	12		
Age				
<25 y	0.38 (0.21, 0.55)	141		
Training status				
Untrained	0.14 (−0.27, 0.57)	25		$p < 0.05$
Trained	0.29 (0.03, 0.55)	68	$p < 0.05$	
Athletes	0.81 (0.44, 1.19)	32		
Conditioning activity				
Dynamic low body	0.42 (0.22, 0.61)	107	$p > 0.05$	
Static lower body	0.35 (−0.19, 0.89)	14		
Dynamic upper body	0.17 (−0.28, 0.63)	20		
Intensity (%1RM)				
Moderate (60–84%)	1.06 (0.54, 1.57)	15	$p < 0.05$	
Heavy (85–100%)	0.31 (0.13, 0.49)	121		
Volume				
Single	0.24 (0.37 0.44)	95	$p < 0.05$	
Multiple	0.66 (0.36, 0.95)	46		
Rest periods (min)				
<2:00	0.17 (−0.23, 0.58)	24		
3–7	0.54 (0.31, 0.77)	75	$p < 0.05$	
7–10	0.70 (0.10, 1.30)	11		
>10	0.02 (−0.33, 0.38)	31		

carried out in 3 steps. First, the titles of the articles were read. Second, the abstracts were read. Third, the entire article was read. The reference lists of relevant articles were, in turn, scanned for additional articles (published or unpublished) that met the inclusion criteria. Attempts were made to contact authors requesting any unpublished work. Conference abstracts and proceedings were excluded. Relevant studies were selected and searched for data necessary to compute ES and descriptive information regarding the PAP protocol. As a result, 44 articles (1,3,4,6,8,9,11–24,26–35,37–40,42–44,46,49,51–55) related to postactivation potentiation and power in response to exercise were considered, all of which were full-text articles and published in the English language. After using selection criteria previously described, a total of 32 studies were selected to be used for this study (1,3,4,6,9,11–14,16,19,21–24,26–34,37–40,42–44, 46,49,53–55).

Coding of Studies

Each study was read and coded by the primary investigator for descriptive information including gender and training experience. The primary outcome variable was power, which was coded as power output and performance on a criterion power task. Conditioning activity protocol was coded for mean intensity (low ≤60 % 1RM, moderate = 60–84% 1RM, and heavy ≥85% 1RM), sets (single vs. multiple), mode (isometric vs. dynamic), and rest period between the end of the conditioning activity and performance of the criterion task. Rest periods were coded as immediate (<2 minutes), short (3–7 minutes), moderate (7–10 minutes), and long (>10 minutes). Training status was coded as recreationally trained (active but not currently resistance training), trained (at least 1 year of resistance training experience), and athlete (criteria included either >3 years resistance training experience, National Collegiate Athletic Association college or pro level athlete, or competitive power or weight lifter). Gender was coded as male, female, or a combination (both men and women). Despite attempts, age could not be statistically compared, given all individuals in the studies included were young adults (18–35 years of age).

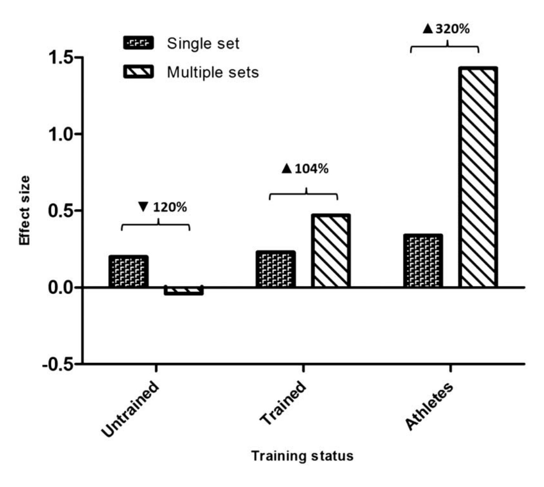

Figure 1. Effects of a single vs. multiple sets conditioning mode protocol on power in untrained, trained, and athletic populations.

Calculation and Analysis of Effect Size

Pre-ES and post-ES were calculated with the following formula: ([Posttest mean − pretest mean]/pretest *SD*). The ES were then adjusted for sample size bias. This adjustment consisted of applying a correction factor to adjust for a positive bias in smaller sample sizes. Descriptive statistics were calculated and univariate analysis of variance by groups was used to identify differences between training status, gender, conditioning activity, intensity, volume, and rest periods with level of significance set at $p < 0.05$. When a significant *F*-value was achieved, pairwise comparisons were performed using a Bonferroni corrected alpha. All calculations were made with SPSS statistical software package v.19.0 (SPSS Inc., Chicago, IL, USA). The scale proposed by Rhea et al. (41) was used for interpretation of ES magnitude. Coder drift was assessed by randomly selecting 10 studies for recoding by a second investigator. Per case agreement was determined by dividing the variables coded the same by the total number of variables. A mean agreement of 0.90 was required for acceptance. The mean agreement for this analysis was 0.97.

RESULTS

Overall ES and moderating variables are presented in Table 1. There were a total of 141 ESs for muscular power obtained from a total of 32 primary studies, which met our criteria (1,3,4,6,9,11–14,16,21–24,26–34,38,39,42,43,46,49,53–55). The mean overall ES for muscle power was 0.38 when a conditioning activity was performed before a criterion power task (95% confidence interval [CI]: 0.21, 0.55).

Moderating Variables

No significant differences were found between gender groups; the mean overall ES for male was 0.42 (95% CI:

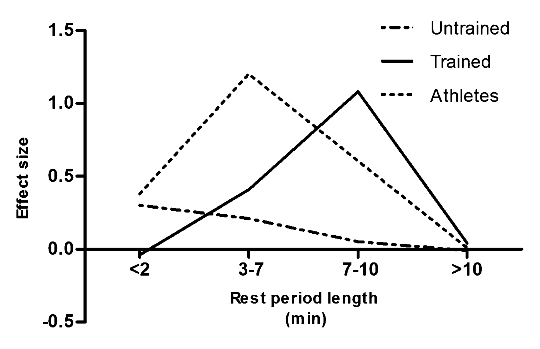

Figure 2. Power after immediate (<2 minutes), short (3–7 minutes), moderate (7–10 minutes), and long (>10 minutes) rest period lengths in untrained, trained, and athletic populations.

0.23, 0.61; *n*: 123), for female 0.20 (95% CI: −0.31, 0.71; *n*: 16), and for the combined group 0.21 (95% CI: −0.38, 0.79; *n*: 12) ($p > 0.05$). No significant differences existed between dynamic 0.42 (95% CI: 0.22, 0.61; *n*: 107) and static conditioning activities 0.35 (95% CI: −0.19, 0.89; *n*: 14). Significant differences were found between untrained 0.14 (95% CI: −0.27, 0.57; *n*: 25) and athletes 0.81 (95% CI: 0.44, 1.19; *n*: 32) ($p < 0.05$), and between trained 0.29 (95% CI: 0.03, 0.55; *n*: 68) and athletes 0.81 (95% CI: 0.44, 1.19; *n*: 32) ($p < 0.05$) (Table 1).

Significant differences were found between moderate intensity 1.06 (95% CI: 0.54, 1.57; *n*: 15) and heavy intensity 0.31 (95% CI: 0.13, 0.49; *n*: 121) ($p < 0.05$). There were overall significant differences found between single sets 0.24 (95% CI: 0.37, 0.44; *n*: 95) and multiple sets 0.66 (95% CI: 0.36, 0.95; *n*: 46) ($p < 0.05$). There were overall significant differences found between rest periods of 3–7 minutes 0.54 (95% CI: 0.31, 0.77; *n*: 75) and >10 minutes 0.02 (95% CI: −0.33, 0.38; *n*: 31) ($p < 0.05$), and between rest periods of 7–10 minutes 0.70 (95% CI: 0.10, 1.30; *n*: 11) and >10 minutes 0.02 (95% CI: −0.33, 0.38; *n*: 31) ($p < 0.05$).

DISCUSSION

After a conditioning activity protocol, mechanisms of muscular fatigue and potentiation coexist; however, subsequent power output and performance depend on the balance between these 2 factors. Although numerous studies have been conducted, to date, no precise consensus has been formed regarding the optimal acute conditioning mode protocol in recreationally trained, trained, and athletic populations. Therefore, we conducted a meta-analysis of 32 studies to quantitatively identify which components of the conditioning protocol (activity, intensity, rest period length) optimized power output and how these variables were affected by training status and gender. The primary findings of this study were that a conditioning activity augmented power output (ES = 0.38), and these effects increased with training experience but did not differ significantly between genders. Moreover, potentiation was optimal following multiple (vs. single) sets, performed at moderate intensities (60–84%), and using moderate rest periods lengths (7–10 minutes).

Our results indicated trivial (ES = 0.14), small (ES = 0.29), and moderate (ES = 0.89) augmentation of power after a conditioning activity in untrained, trained, and athletic populations, respectively (Table 1, Figure 1). Moreover, athletes with >3 years of resistance training experience appear to respond optimally to conditioning activities. These results agreed with the results of Chiu et al. (6) who found 1–3% increases in countermovement jump and drop jump heights after a heavy conditioning activity in resistance trained individuals, whereas those who were recreationally trained experienced a 1–4% decline in performance. Additionally, past research indicates a moderate correlation ($r = 0.63$) between 1RM strength values and countermovement jump potentiation, after a high-intensity activity (27). It is likely that the balance between fatigue and potentiation is more favorable with increased training experience. It should also be noted that trained individuals demonstrate elevated regulatory myosin light chain phosphorylation activity (45) relative to those untrained, suggesting that increased power output may be bidirectionally mediated with increased training experience (greater PAP and lower fatigue).

Banister et al. (2) provided a 2-factor mathematical theory on human performance. Their theory suggested that an athlete should be viewed as a system that receives input in the form of a training impulse and produces output in the form of performance. For a specific conditioning activity, the impulse is calculated by the intensity (percent of 1RM) multiplied by the volume performed. Banister et al. (2) suggested that the training impulse leads to the build-up of fitness and fatigue in the athlete and that performance is a result of the difference between those 2 variables. After a heavy conditioning exercise, fatigue may be elicited in the form of depletion of substrate (10), a build-up of hydrogen ions (50), or mechanical disruption of the myofibrillar architecture (7). 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 (52).

Our results indicate that moderate intensity (60–84% 1RM) (ES = 1.06) exercise is ideal for eliciting PAP when compared with very high intensities (>85% 1RM) (ES = 0.31), independent of training experience. Muscle damage appears to occur proportionally to previous contractile intensity (5). Thus, according to Banister et al.'s (2) model, it could be postulated that a moderately heavy conditioning activity elicits PAP (fitness) without as much mechanical trauma (fatigue) as a heavier activity.

When analyzing volume, we found overall that multiple sets resulted in a greater augmentation of power than single sets (Table 1). However, these findings were likely mediated by training status (Figure 1). Specifically, individuals with low training experience demonstrated approximately 120% declines in power when performing multiple as compared to single sets. In contrast trained individuals and experienced athletes augmented power approximately 104% and 320%, respectively, when comparing multiple with single sets. Chronic resistance training increases fatigue resistance via increased buffering capacity (25,47) and an overall greater resistance to skeletal muscle damage (36). These findings would suggest that the conditioning activity elicits far greater fatigue than can be overcome by PAP (fitness) when moving from single to multiple sets in less trained individuals. However, in trained individuals, it is likely that the increase in PAP from single to multiple sets outweighs the increase in fatigue.

Although the length of PAP manifestation remains unknown, research indicates that the ability to potentiate performance likely dissipates by 30 minutes after a conditioning activity (42). Within that framework, the last major component to optimizing PAP concerns the ideal interval of time after a given conditioning activity when examining power output. To date, the limited number of studies examining postconditioning activity rest periods has yielded varying and often conflicting results. These studies, collectively, suggest that brief (5 minutes) (48), moderate (8–12 minutes) (27), and extensive (18.5 minutes) (6) recovery durations, may elicit PAP. Such results highlight the need for our current statistical synthesis of the literature, which demonstrated that overall, moderate rest period lengths (7–10 minutes) appear to optimally augment power output after a conditioning activity (Table 1). However, as expected, these findings differed based on training status (Figure 2), possibly explaining past conflicts in the literature. Less experienced subjects demonstrated lower ES increases in power compared with those of a higher training status at all rest period lengths. Moreover, trained and experienced athletes peaked in power at moderate (7–10 minutes) and short (3–7 minutes) rest period lengths, respectively. Our results were recently supported by Jo et al. (23) who found that individuals with at least 1 year of weight training experience demonstrated a negative correlation ($r = -0.77$) between optimal recovery length and back squat 1RM.

Practical Applications

The impact of different variables will vary across subjects; therefore, it essential to always tailor programs specific to the individual. The benefit of a meta-analysis is that it can provide the optimal range for each variable and give the practitioner an idea of where to start and the absolute effect to expect from each training variable. Therefore, independent of gender, our analyses suggest that a preconditioning activity can augment power production capacity in several motor skills (i.e., sprinting, jumping, throwing). However, the optimal conditioning activity varies based on training experience. For the individual with little high-intensity weight training experience, it is important to emphasize that only a small augmentation of power can be expected. Therefore, a heavy conditioning activity may not be ideal until an individual has at least 1 year of resistance training experience. We suggest that the inexperienced individuals select a moderate intensity conditioning activity (60–85% 1RM loads) and only perform 1 set at this intensity before performing a criterion power task.

Individuals with at least 1 year of resistance training experience may realize a low to moderate augmentation of power after a conditioning activity. However, to optimize these effects, we suggest the use of multiple sets, moderate intensity (60–85% 1RM Loads), and rest periods lasting 7–10 minutes in length.

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