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Brief Review

Postactivation Potentiation and Its Practical Applicability: A Brief Review

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Abstract. Robbins D. W. Postactivation potentiation and its practical applicability: A brief review. *J. Strength Cond. Res. 19(2):453–458. 2005.*—It has been suggested that postactivation potentiation (PAP) may be manipulated to enhance both acute performance and chronic adaptation. PAP refers to the phenomenon by which acute muscle force output is enhanced as a result of contractile history. Evidence exists regarding the existence of PAP. However, the determination of methods to best manipulate and exploit PAP remains elusive. Studies to date would seem to indicate that the practical applicability of PAP in terms of enhancing athletic performance is limited.

Key Words. postactivation potentiation, complex training, performance, neuromuscular, contractile

Introduction

The contractile response of skeletal muscle is partially determined by its contractile history. Repetitive contractile stimulation results in an attenuation of performance due to fatigue. However, at the same time fatigue is realized, postactivation potentiation (PAP) is also elicited (21, 27). PAP refers to the phenomenon by which acute muscle force output is enhanced as a result of contractile history and is the premise upon which "complex training" is based. It has been postulated that explosive movements may be enhanced if preceded by heavy resistance exercise (3, 4, 10, 12, 13, 25, 29, 30). For example, the execution of a set of high-intensity squats prior to the performance of vertical or horizontal jumps enhances jumping performance. Loading of the neuromuscular system elicits an "excited" or "sensitive" state in which performance is enhanced (13).

Contractile activity produces both fatigue and PAP, and it is the balance between the two that determines whether the subsequent contractile response is enhanced, diminished, or unchanged (21). The poststimulus state depends on the timelines of PAP and fatigue. Both PAP and fatigue may increase immediately following contractile activity and then gradually return to prestimulus levels (27). The optimal recovery time or window is dependent on the decay rate of PAP and the dissipation of fatigue. That is, the coexistence of fatigue and PAP may result in a net potentiated state, a net attenuated state, or a constant state as compared to the prestimulus state. When discussing PAP in this review, the operational definition of PAP will be a net potentiated response. PAP and its mechanisms have been examined in a number of studies. Although there is consensus regarding the existence of PAP, the mechanisms underlying it are yet to be determined.

This review will briefly provide evidence for the existence of PAP (through an abridged review of the existing literature) and discuss the perceived paucity of information with respect to PAP and performance enhancement. The main purpose of this paper will be to critically discuss the practical applicability of PAP and, in particular, to raise interest in determining how best to exploit it. It is not the intent of this review to detract in any way from the importance of studies conducted on PAP at a physiological level. A clear understanding of PAP and its mechanisms will be necessary to take full advantage of this phenomenon. However, for exercise physiologists the ultimate goal is to improve athletic performance; assuming the existence of PAP, it would seem to be our obligation to determine if and how this phenomenon can be manipulated in order to achieve that goal.

Evidence of PAP

Evidence supporting the existence of PAP has been provided in a number of settings. Metzger et al. (22) conducted a study in which skinned mammalian skeletal muscle fibers were examined. They observed twitch potentiation in the skinned fibers and concluded that the potentiation was a result of increased myosin light chain phosphorylation. Studies have also examined the twitch contractile properties of muscle in vivo and have consistently described increased twitch tension, increased rate of tension development, and decreased poststimulus relaxation time (2, 14, 15, 23, 24). These studies measured PAP as the difference in electrically evoked twitch characteristics prestimulus and poststimulus.

Unlike the skinned-fiber experiments and in vivo studies outlined above in which contractile properties were examined, a number of studies have been successful in eliciting PAP in the form of enhancements in athletic performance. Güillich and Schmidtbleicher (13) loaded participants' neuromuscular systems by using 3–5 unilateral leg press maximal voluntary isometric contractions (MVICs). Following this loading of the neuromuscular system, subjects performed vertical countermovement jumps (CMJs) and depth jumps (DJs) on a Kistler dynamometric platform. The mean of 8 jumps was calculated for the sets of jumps pre- and postloading. The researchers found that the participants jumped on average 3.3% higher following 3 independent MVICs than they did in the set of jumps prior to the loading. These results represented a significant mean improvement in vertical jump height ($p < 0.001$). The investigators also elicited PAP in the upper body, using MVICs in the bench press position as the loading stimulus and bench press throws as the performance measurement. Unfortunately, the experimental design utilized in this study is somewhat unclear.

Radcliffe and Radcliffe (25) conducted a study in which 5 warm-up protocols were performed: a standard warm-up, a warm-up plus 4 sets of back squats at 75–

85% 4 repetition maximum (4RM), a warm-up plus 4 sets of 4 power snatches at 75–85% 4RM, a warm-up plus 4 sets of 4 loaded jumps with 15–20% body weight added, and a warm-up plus 4 sets of 4 unloaded jumps. These warm-ups were performed 1 per day on nonconsecutive days in random order. Following the warm-up protocols, 3 maximal effort horizontal CMJs were performed. The results indicated that the jump distance was significantly greater for men after the warm-up plus snatch protocol than after the standard warm-up alone. The investigators concluded that using the power snatch in a warm-up protocol significantly improved horizontal countermovement jump performance. This study is available in abstract form only and lacks detail with regard to experimental design and methodology.

Young et al. (30) found a significant improvement (2.8%) in vertical jump height in a set of jumps postloading compared to preloading. The investigators preceded a 5RM half squat with a set of 5 loaded countermovement jumps (LCMJs). Another set of 5 LCMJs was performed 4 minutes postloading. Vertical-jump height attained in the set of jumps following the 5RM half squat was statistically greater than that attained in the set of jumps preceding the 5RM squat ($p < 0.05$). However, it should be noted that the experimental design consisted of 2 sets of LCMJs being performed prior to the loading. Therefore, possible cumulative effects on fatigue or PAP may have resulted from the ordering. That is, rather than attributing the increase in performance solely to the 5RM half squat, perhaps it can be attributed to the 5RM in combination with the sets of LCMJs.

More recently, PAP as reflected in performance enhancement has been observed in both the upper and lower body. A 2.39% improvement in vertical-jumping ability was found post- versus prestimulus (12). The investigators had the participants perform 5 sets of half squats of 2 repetitions each at 20, 40, 60, 80, and 90% of their 1RM. The researchers also found that participants with greater maximal strength experienced greater improvements in vertical-jump ability. Baker (3) investigated PAP in the upper body and found a 4.5% increase in power output following a 6RM bench press executed at 65% 1RM. Power output was measured while performing bench press throws with a resistance of 50 kg. The experimental design was similar to that used by Young et al. (30), and therefore potential ordering effects may have played a role in performance enhancement. Chiu et al. (4) compared explosive jumps prior to and following 5 sets of 1-repetition back squats at 90% 1RM. Although they initially found no significant enhancement in performance, when the subjects were divided into a trained power group and a recreationally active group and compared, significant differences were found. However, it was the potentiation percentage difference between the groups that was compared rather than the change in jump performance. French et al. (10) assessed a number of dynamic exercises following a sequence of leg extension MVICs of 3 repetitions at 3 seconds or 3 repetitions at 5 seconds. They found significant increases in jump height, maximal force, and acceleration impulse in the drop jump and significant increases in knee extension maximal torque following the 3×3 protocol.

Studies attempting to elicit PAP as measured by a poststimulus performance activity are much more equivocal than those examining twitch contractile properties. Gossen and Sale (11) conducted a study in which a 10-second MVIC was followed 15 seconds later by dynamic contractions. Performance, as measured by dynamic knee extension, was not enhanced poststimulus but rather was attenuated. The investigators concluded that the 15-second rest interval between resistive exercise and performance measurement was insufficient. That is, at 15 seconds poststimulus the effects of fatigue elicited via the 10-second MVIC were greater than the benefits of any elicited PAP. Ebben et al. (9) examined the effect of a set of high-intensity bench press on subsequent medicine ball power drop. They found no significant enhancements in mean ground reaction force, maximum ground reaction force, or integrated electromyographic values for the pectoralis major and triceps muscles. The investigators concluded that the coupling of biomechanically similar exercises in a "complex training" modality offered no training advantage or disadvantage. They suggested that the absence of attenuation in performance supported the postulate that complex training may be advantageous in terms of efficiency and organization, in that it allows for resistance and plyometric training to be performed in the same session.

Hrysomallis and Kidgell (16) performed a study in which PAP was assessed in the upper body. Performance, as measured by explosive push-ups, was not enhanced as a result of a 5RM bench press. The authors suggested that the absence of PAP could be due to a number of reasons, including the supposition that the requirements to elicit PAP in the upper body may differ from those required to elicit PAP in the lower body. Jensen and Ebben (17) investigated the effect of a 5RM back squat on CMJ performance executed at varying poststimulus rest intervals. They found there to be no ergogenic advantage associated with complex training and suggested that a decrease in performance is realized immediately poststimulus, with no significant differences in jumps performed 1–4 minutes poststimulus as compared to jumps performed prestimulus. Koch et al. (19) compared the effect of 3 warm-up routines on standing broad jump (SBJ) performance and found no significant differences among the routines. The routines compared were high-force, low-repetition squats; high-power, low-repetition speed squats; and stretching. These findings do not support the suggestion that the stimulus needs to be performed quickly at relatively low intensity in order to alleviate any potential neural output attunement due to slow lifting speeds. That is, this study does not support the suggestion that studies that failed to elicit enhancements in performance did so because they used a stimulus other than a high-speed contraction.

A study conducted by Duthie et al. (6) also failed to demonstrate enhancements in performance. This study attempted to examine power performance in loaded jump squats over 3 consecutive trials using 3 different protocols. The 3 protocols involved the combination of 3 sets of 3RM half squats with 3 sets of 4 jump squats performed at 30% of 1RM. One protocol attempted to take advantage of PAP over the 3 sets via a complex (referred to as "contrast" in the study) training method. However, performance enhancement was not observed in any of the 3 sets of 4 jump squats in any of the training protocols. Although enhancement of performance was not detected, a correlation between absolute strength and performance was determined with respect to the complex protocol. Specifically, absolute strength was correlated to peak power and maximal force at $r = 0.66$ and $r = 0.76$, respectively. Thus, 43.56% of the variability in peak power and 57.76% of the variability in maximal force are directly predictable from the variability in absolute power. This leaves approximately half of the variability in both peak power and maximal force unexplained. It is important to note that this correlation represents a relationship rather than cause and effect. Stronger subjects, although not achieving enhancement in performance, did realize a smaller decrement in the data measurements following the resistive exercise (as compared to the preresistive exercise values) than did the less strong subjects. This suggestion is supported by similar findings in Young et al. (30). The correlation indicated that subjects with greater absolute strength were better able to benefit from a training modality in which resistive exercises were followed by power exercises in an alternating fashion.

Three studies performed at the University of Victoria also failed to elicit any enhancements in performance following a resistive exercise. Scott and Docherty (28) saw no improvements in either mean or maximal vertical or horizontal jump height following a 5RM squat. However, some subjects did in fact enhance performance poststimulus, whereas others attenuated performance. This supports the postulate that PAP is an individual-specific phenomenon. King (18) found no enhancements in vertical jump performance following 2.5-, 5-, or 10-second MVICs performed in the squat position. It was postulated that the 10- and 5-second contractions may have elicited fatigue sufficient to outweigh any PAP. With respect to all contraction durations, individual-specific variables such as training status and fiber-type composition may have been responsible for the lack of enhancement in the performance measurement. A third study conducted at the University of Victoria investigated PAP over 3 consecutive sets and found no significant enhancements in performance (26). In an attempt to replicate a typical complex training session, a 7-second MVIC performed in the squat position was followed by a series of 5 CMJs. This complex pair was performed over 3 trials, and 6 dependent variables were measured for all 3 sets of CMJs.

Evidence for the existence of PAP with respect to twitch contractile properties is abundant. Evidence for PAP also exists in more practical performance-type measurements. However, the evidence for PAP in performance measurements has been somewhat confounded by studies which have failed to observe enhancements in poststimulus performance. Although scarce and perhaps confounded, evidence as to the existence of PAP with respect to both twitch contractile properties and performance measurements does exist.

EXPLOITATION OF PAP

Presuming that the phenomenon of PAP does exist, exercise physiologists must determine if, and how, it can be harnessed to enhance athletic performance. It has been hypothesized that PAP may be exploited in order to achieve short-term enhancement of power performance or to achieve chronic adaptation through training and thereby improve performance (6, 13, 30).

Short-term Enhancement of Power

It has been suggested that the execution of high-intensity contractions prior to the performance of an athletic activity can enhance the performance of that activity (3, 12, 13, 25, 30). That is, PAP may be exploited in a warm-up protocol to enhance subsequent performance. Güllich and Schmidtbliecher (13) reported that in 1995 a bobsledding team used maximal voluntary contractions (MVCs) prior to competition to elicit PAP and subsequently won the world championship. However, this was not a controlled study and any number of variables or combinations thereof may have been responsible for the bobsledding world championship. Perhaps PAP did contribute to their performance. However, it would seem problematic to conclude that the MVCs performed prior to competition contributed in a positive manner to the team's performance. This is not to say that the execution of high-intensity contractions prior to competition cannot work to enhance performance, but rather that further research is necessary before any conclusions can be drawn.

A number of considerations would need to be taken into account if an attempt were to be made to manipulate contractile history in order to enhance acute athletic performance through PAP. The training variables requiring consideration include type of contraction (e.g., isometric, concentric-eccentric, etc.), intensity, volume (e.g., repetitions, sets, cadence, time under tension), rest interval(s) between possible multiple sets, rest interval within the complex pair, and possible varying responses of different muscle groups. Young et al. (30) and Duthie et al. (6) have suggested that there is a relationship between strength and PAP, specifically, that stronger, better-trained athletes may be better equipped to benefit from PAP. Güllich and Schmidtbliecher (13) concluded that the time course of PAP varied greatly between individuals. These postulates suggest high interindividual variability with respect to PAP and further confound any attempt to manipulate contractile history for the purpose of enhancing performance. Assuming interindividual variability does exist, a multitude of categorical variables would also need to be considered. These include training status, training age, chronological age, genetics (e.g., fiber-type composition), anthropometrics, gender, relative strength, and absolute strength. Before any conclusions can be made as to the efficacy of exploiting PAP in a warm-up protocol designed to enhance performance, further scientific research is required.

Chronic Adaptation

It has been suggested that PAP may be manipulated when training to produce high chronic adaptation (6, 13, 30). The manipulation of PAP within a training protocol is commonly referred to as complex training. Complex training combines traditional resistance training with plyometric training in an attempt to transfer strength gains into power (5). Complex training utilizes biomechanically comparable exercises in conjunction with each other (8). Commonly, a high-intensity/low-volume resistance training exercise is paired with a plyometric exercise targeting the same muscle group, and this coupling is commonly referred to as a complex pair (5). For example, back squats may be followed by depth jumps in an attempt to develop lower body power. Different combinations of resistance and plyometric training have been utilized and investigated. In a review by Ebben (7) it was concluded that complex training (following a high-intensity resistance exercise with a biomechanically comparable plyometric exercise) was as effective as, or possibly superior to, other combinations of resistance and plyometric training. Plyometric training is done at maximum speeds in order to train the athlete to compete at higher speeds (5). Power is important for performance in many sports, and it has been suggested that complex training can be significant in its development.

It is the phenomenon of PAP that is the basis of complex training, although other mechanisms may also be involved in the mediating of performance through complex training. Complex training attempts to capitalize on PAP resulting from high-intensity resistance training. The plyometric phase, which is performed after heavy loading, is executed while the system is in an "excited state." Power performance is thereby enhanced and the training can be performed at a higher level. Although not directly concerned with PAP, a number of studies have provided scientific evidence to support the superiority of complex training as a method to train and develop athletic power (1, 29), concluding that it is an advantageous means of developing power and enhancing athletic performance. Studies performed by Verkhoshansky and Tatyan (29) and Adams et al. (1) concluded that complex training was superior in developing power to either resistance training or plyometric training alone. A second Verkhoshansky and Tatyan (29) study concluded that complex training was superior to resistance training but less effective than depth jumps alone in developing vertical jump power. These 3 studies act to support the hypothesis that complex training is an advantageous means of developing power.

Lyttle et al. (20) also suggested the superiority of complex training over resistance training or plyometric training alone as a tool for enhancing power development. Lyttle et al. (20) compared the effects on performance of complex training and maximal power training under the assumption that both modalities are superior to resistance training or plyometric training alone with respect to power development. Although it was determined that no significant differences exist between the 2 programs, that in itself is not an unfavorable conclusion with respect to complex training. In fact, it suggests that complex training is as effective as dynamic training in developing power. It should be noted that the term "complex training" has been used to describe varying combinations of resistance and plyometric training and that PAP could only be considered to have enhanced performance if the activity was performed poststimulus in the same "complex set".

The literature indicates that complex training is as effective as, if not more effective than, other training protocols with respect to developing power. One possible explanation for this could be the successful manipulation of PAP, which would allow the athlete to train at a higher level and consequently realize improved gains. However, it is important to note that these studies concerning complex training did not directly examine PAP. Therefore, it is impossible to draw any conclusions regarding PAP in relation to these studies. Evidence for the existence of PAP as measured in a performance activity has been provided through a number of studies. Although there is consensus regarding the existence of PAP, questions remain regarding how best to elicit PAP and how best to capitalize on it. In particular, protocols for eliciting PAP and exploiting it in the enhancement of athletic performance remain elusive. PAP is central to complex training, and, therefore, special importance should be devoted to this phenomenon.

Conclusion

An attempt has been made not only to provide evidence for the existence of PAP, but also to present some of the factors which must be considered when attempting to manipulate PAP with the intention of enhancing athletic performance. An abundance of literature exists with respect to twitch contractile properties poststimulus compared to prestimulus. An even larger number of studies have examined mechanisms by which PAP occurs. However, literature regarding the manipulation of training variables in an attempt to elicit and subsequently exploit PAP as expressed in the enhancement of athletic performance is scarce. The determination of parameters for the training variables is confounded by the postulate that high interindividual variability is associated with PAP. Thus, the problem that arises is the identification of specific parameters for each training variable for an individual athlete or group of homogenous athletes. In order to determine optimal values for the 6 training variables discussed above, athletes would first need to be grouped according to the 8 categorical variables also discussed above. Following this, a series of experiments would need to be performed to determine if PAP could be exploited to enhance performance. That is, once the athlete had been categorized, the type of contraction, intensity, volume, and rest interval(s) could be set at optimal values through a series of trial-and-error experiments. This process would need to be repeated for varying muscle groups and varying athletic activities. Thus, parameters could be set for each homogenous group of individuals, thereby allowing the enhancement of acute athletic performance. This is assuming that PAP may be elicited in all athletic profiles. It is possible that certain individuals or groups may not respond. It has been suggested that stronger individuals are better equipped to respond to this type of training (6, 12, 13, 30), and as such exercise prescriptions targeting strength may be recommended prior to the prescription of complex training-type exercises.

Assuming that contractile history may be manipulated to result in enhanced performance, the question of feasibility is raised. It would be a considerable task to determine training variable parameters for countless different athletic profiles. Assuming training variables were determined in conjunction with the categorical variables, a myriad of other implications could arise. For example, if it were determined that a single 5-second MVIC performed in the squat position was optimal as a stimulus for a certain athletic profile in order to enhance high-jump performance, possible practicality problems could include (a) the availability of MVIC equipment at the site of competition, (b) coordinating the PAP/fatigue timelines within the competition timeline, and (c) subsequent jumps and any cumulative effects. Issues of transferability could also arise. Whereas the aforementioned MVIC may act to enhance high-jump performance, it may not act to enhance performance of an activity such as a 100-m sprint or rugby game. Again, a series of trial-and-error experiments would be necessary to determine the possible applicability of PAP to various athletic activities.

The concept of manipulating PAP in a training modality, such as complex training, requires scientific research. Studies have compared complex training to other modalities but have not specifically examined PAP. Two studies have investigated PAP over multiple sets (6, 26). However, these were acute studies and therefore cannot be extrapolated to chronic adaptation resulting from PAP. If training variable parameters could be determined for a given athletic profile, these could perhaps be applied to multiple sets and performed over a training macrocycle. This training modality (complex training) could be compared to other modalities aimed at developing power and some conclusions as to the efficacy of PAP with respect to chronic adaptation could perhaps be drawn. However, it is possible that the optimal parameters determined in order to enhance acute performance (assuming their existence) could not be applied to multiple sets. It is also possible that a net potentiated state may not be elicited over consecutive sets. It would again be necessary to perform a series of experiments to determine if and how a complex training modality is superior to other training programs in terms of developing power.

Assuming PAP could be exploited in such a way as to allow a complex training type of modality to result in superior gains in power as compared with similar training modalities, other obstacles could arise. For example, efficiency could become an issue if it were determined that in order to optimally develop lower-body power in a certain athletic profile 4 sets of a given complex pair should be performed with rest intervals of 5 minutes between and within the complex pair. Athletes and coaches may not be willing to spend approximately 40 minutes performing 4 complex sets.

PRACTICAL APPLICATIONS

The purpose of this review has not been to provide evidence for the existence of PAP. Rather, given the assumption that PAP does exist, an attempt has been made to examine the practical applicability of PAP with respect to enhancing athletic performance. The hypothesis that high-intensity contractions performed prior to a single activity (e.g., a 100-m sprint) can improve performance in that activity has been discussed. The results discussed in the literature regarding the enhancement of acute performance are equivocal, and the task of determining possible parameters allowing for consistent enhancement of performance is a daunting one. The hypothesis that the execution of high-intensity contractions prior to a prolonged activity (e.g., a rugby game) improves performance has not been examined in the literature, and as such, any conclusions lack supportive scientific evidence. With respect to chronic adaptation, some evidence does exist to suggest that complex training is at least as beneficial as other comparable training methods designed to develop power. However, as discussed above, it is impossible to speculate as to the significance of PAP in these studies. At present, the existing body of literature would seem to suggest that the practical applicability of PAP with respect to enhancing athletic performance is limited.

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