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Postactivation Potentiation: Practical Implications in The Collegiate Setting

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POSTACTIVATION POTENTIATION
PRACTICAL IMPLICATION IN THE COLLEGIATE SETTING

By

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POSTACTIVATION POTENTIATION PRACTICAL IMPLICATIONS IN THE COLLEGIATE SETTING

Chairperson: Matthew Bundle Ph.D.

Postactivation potentiation (PAP) induced by a voluntary conditioning activity (CA) has been shown to increase peak force and rate of force development during subsequent muscle contractions increasing performance. We examined existing PAP literature, the underlying physiological mechanisms responsible for PAP, and the various factors that affect protocols used to elicit the PAP response. Furthermore, we aimed to determine what combination of factors are optimal for eliciting a PAP response in training and competition. The proposed mechanism underlying PAP are associated with a phosphorylation of regulatory light chains and an increase in neuromuscular activation through enhanced recruitment of faster motor units. The full understanding of these factors has been hindered by the confounding effects of muscle fatigue during brief intense muscular contractions. In addition to the physiological mechanisms responsible for the PAP phenomenon it is also critical to understand the effect subject characteristics have on PAP. An individual’s training status, strength level and muscle fiber type composition play a role in the magnitude of PAP response. These protocols use various approaches to stimulate and condition the muscle to elicit PAP. These protocols include traditional resistance training, maximum isometric voluntary contractions, whole body vibration and low-load ballistic exercises. Individuals with a higher training status (age), strength level and fast-twitch muscle fiber type distribution may be more likely to express PAP at a greater magnitude (if at all). These individual factors also must be considered when deciding which conditioning activity and rest interval to use when applying PAP in training or competition. From a practical standpoint, conditioning activities with short rest intervals are more advantageous for application. Further investigation is needed into the mechanisms of PAP under varying conditions, specifically how PAP could be applied to competitive sport and chronic adaptations from training.
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Chapter One: Introduction/Review of Literature

Strength and conditioning professionals use a variety of muscle focused training methods to optimize the performance of their athletes. The development of muscular power is of particular interest to these practitioners as it is vital to success in many sports. Athletes that can express the greatest amount of force in the shortest time excel in accelerating, jumping and throwing. In contrast to the extensive literature documenting muscular function and force production (Häkkinen et al. 1998, Young et al. 2001, Powers & Jackson, 2008) and applied endeavors to augment these outputs, virtually nothing is known about how these basic elements of muscle function are augmented by the nervous system itself. A strength training technique that has become the subject of recent investigation is postactivation potentiation (PAP) a phenomenon by which muscle function is increased as a direct result of its contractile history (Robbins, 2005). Within the strength and conditioning literature this is the premise upon which complex and contrast training is based (Robbins,2005). Practitioners use complex and contrast training methods to induce a state of preparedness or potentiation within their athletes. Understanding the various neuro muscular factors that affect PAP may make it possible to utilize an effective training or competitive mechanism.

Two primary physiological mechanisms are thought to play an important role in the PAP phenomenon. These mechanisms are: 1. an increase in the phosphorylation of myosin regulatory light chains (Hamada et al., 2003, Hodgson et al., 2005, Sale, 2002) and 2. An increase in muscle neural activation (Gullich and Schmidtbleicher, 1996, Hodgson et al. 2008), primarily through the enhanced recruitment of faster motor units (Gullich and Schmidtbleicher, 1996).The full understanding of these factors has been hindered by the confounding effects of muscle fatigue during brief intense muscular contractions.

As there are numerous methods used to increase muscular strength and power, so are there numerous protocols utilized to produce a potentiated state. These protocols use various approaches to stimulate and condition the muscle to elicit PAP. These protocols include traditional resistance training, maximum isometric voluntary contractions, whole body vibration and low-load ballistic exercises.
In addition to the neuromuscular basis of the PAP phenomenon it is also critical to understand the effect subject characteristics have on the PAP phenomenon. The most influential subject characteristics to the effectiveness of PAP are: training status, athlete versus non-athlete, strength level and muscle fiber type composition.

The aim of this review is to examine existing potentiation literature, the underlying physiological mechanisms responsible for PAP, and the various factors that affect protocols used to elicit the PAP response. Furthermore, this study aims to determine what combination of factors are optimal for eliciting a PAP response in both the practical training and competitive settings.

**Mechanisms of Potentiation**

**Phosphorylation of Regulatory Light Chains**

The most accepted physiological mechanism for PAP within the literature is the phosphorylation of myosin regulatory light chains (Hodgson, 2005, Sale, 2002, Hamada et al., 2000). This suggests that changes in muscle performance are attributed to a phosphorylation induced increase in calcium sensitivity, and increased cross bridge cycling between actin and myosin. The increase in calcium sensitivity is thought to stem from an elevated myosin light chain kinase activation (Sweeny et al., 1993). In addition to an increased calcium sensitivity, the enhanced rate of cross bridge cycling result from a greater transition from weak-binding to strong binding sites allowing for a greater number of force-generating cross-bridges during contraction, which is thought to significantly contribute to muscle force and speed (Rassier & Macintosh 2000, Hodgson, 2005). This mechanism is supported by the results of Ryder et al. 2007 who demonstrated that MLCK is the limiting factor for myosin regulatory light chain phosphorylation. These investigators generated transgenic mice which expressed an MLCK bio sensor in skeletal muscle to identify whether MLCK is the limiting factor to twitch potentiation. Regulator light chain phosphorylation lead to enhanced twitch-force potentiation consistent with a gain of MLCK activity. Similar results were witnessed in human skeletal muscle by Stuart et al. 1988 which recorded elevated phosphate content of the regulatory light chains in the vastus lateralis muscle and a significant potentiation of twitch tension of the knee extensors following a 10 second maximal voluntary isometric
contraction. There was also correlations between the extent of twitch potentiation, the amount of phosphorylation and the percentage of type II muscle fibers. Vandenboom et al. (1993) concluded that the state of muscle prior to and during activity may contribute to the amount of phosphorylation that occurs. The investigators found that calcium sensitivity exerted its greatest effect on muscle performance when myoplasmic calcium levels were low during low frequency contractions, but not during high frequency tetanic contractions where elevated calcium levels are typically witnessed. However, other studies have shown an inconsistent relationship between potentiation and regulatory light chain phosphorylation.

Smith & Fry, 2007 sampled muscle biopsies from the vastus lateralis and measured leg extension performance pre and seven minutes following a bout of 10 second maximum voluntary contractions of the leg extensors. The authors reported no significant change in myosin regulatory light chain phosphorylation or performance for the entire sample. As such, the extent of that role regulatory light chains phosphorylation plays in the PAP phenomenon still remains unclear but based off of the current literature it is likely that increased phosphorylation of myosin light chains following a conditioning activity contribute in some way to PAP.

**Neural Mechanisms**

Another proposed mechanism of PAP is an increase in neuromuscular activation. The neural contribution to PAP is widely thought to be due to augmented descending neural drive to the motor units. This effect is studied with the Hoffman reflex test (H-reflex). The H-reflex is an electrically induced reflex similar to the mechanical patellar tendon spinal stretch reflex. Action potentials are stimulated to follow the afferent and efferent pathways to ultimately activate a muscle twitch (Chiu et al. 2003). Electromyogram (EMG) data is then recorded, an early response M wave (muscle) typically occurs 3-6ms followed by a later H wave (neural) response. The H-reflex is a potentially useful tool in measuring exercise induce neuromuscular adaptations in vivo (Zehr, 2002). The test anticipates that an increased H-reflex is directly proportional to the magnitude of muscle twitch, thus greater muscle twitch from a conditioning activity will lead to a greater H-reflex response. The first study to examine the PAP response using the H-Reflex pathway was Gullich and Schmidtblecher (1996). This study measured changes in
subjects H-wave amplitude at the gastrocnemius before and after preforming five repetitions of a 5 second isometric maximum voluntary contractions (MVIC) of the triceps surae with a 1 minute rest interval. The results showed a significant decrease in H-reflex amplitude in the lateral gastrocnemius during the first minute following the preconditioning activity. However, 4-11 minutes following the conditioning activity the lateral gastrocnemius showed a 32% increase in H-reflex amplitude above the baseline. More significantly for athletic performance the subject pool was divided by training status into untrained and athlete, the athlete group demonstrated a 42% increase in H-Reflex amplitude compared to an 11% increase from the untrained group (Gullich and Schmidtblecher, 1996). The increase in force output was attributed to increased neural muscular activation and motor unit recruitment. Subsequent, studies have demonstrated potentiation through increased H-reflex amplitude occurring 3-11 minutes following the conditioning activity using MVIC (Folland et al. 2008, Trimble & Harp, 1998).

However, the precise role neural mechanisms play in PAP remains unclear. Recently Iglesias-Soler et al (2011) examined H-reflex amplitude and PAP by measuring mechanical power during explosive plantar flexions of the ankle, after a maximum isometric voluntary contraction at 5 sec, 4min and 10 min. Subjects performed four different conditioning protocols that varied in duration of muscle activity (7-10sec) and contraction intensity (10-100% of max voluntary contraction). These authors found significant increase in mechanical power (calculated from explosive ankle plantar flexions ) at 4 min following conditioning activity, although there was no change in H-reflex after the conditioning stimulus. Suggesting the enhancements in muscular power were not related to spinal H-reflex excitability. Nonetheless, the general consensus across this area of research is an increase in neuromuscular activation is one of the primary mechanism of force augmentation achieved through PAP.

The Confounding Influence of muscle fatigue on PAP

The contractile response of muscle can depend on the recent history of activation. The most widely studied effect of contractile history on force production is fatigue, which is the inability of muscle to continue to generate an achievable level of force. However, Kraup (1981) suggested that both
potentiation and fatigue result from previous muscle activity: thus, it is best to expect both processes are initiated when muscle is activated and may be present following a preconditioning stimulus.

The coexistence of potentiation and fatigue, has been documented in several non-human muscle studies (Jami et al., 1983, Vegara et al., 1977, Nassar-Gentina V et al., 1981, Rankin et al., 1988). Potentiation and fatigue is primarily observed by differences in muscle force response as neural drive is altered. Using one example (Rankin et al., 1988) assessed the fatigability of motor units in vitro from the hind limb muscles of rats. Twitch and tetanic contractions of the isolated soleus and extensor digitorum longus were measured following 6 min of intermittent (1 Hz) tetanic contractions (40 Hz for 330 ms). Both of the muscles showed a linear relationship between rate of fatigue (force decline after 360-s fatigue test) and magnitude of twitch force following the fatigue test. However, twitch force was enhanced relative to pre-fatigue twitch while tetanic contraction was depressed, demonstrating the coexistence of potentiation and fatigue.

It has been suggested that potentiation and fatigue can also occur in voluntary human exercise (Garner et al., 1989, Grange, 1991, Skurvydas and Zachovajevs, 1998, Fowels and Green, 2003). Fowles and Green (2003) explored the role of muscle potentiation to overcome low-frequency fatigue. This type of fatigue is characterized by a proportionally greater loss of force due to low-frequency stimulation (Edwards et al., 1977, 1981) brought on by voluntary contraction and the impairment of the excitation-contraction coupling (Edwards et al. 1977). Eight males performed isometric leg extension at 30 percent of their maximal voluntary contraction for 60 min using a 0.5 duty cycle (1 s contraction, 1 sec rest). Maximum rate of force development and maximum twitch force within the activity, were measured at 5, 20, 40, 60 and 15 minutes following. Maximal force was not significantly compromised by the protocol, while twitch force was maintained. These results suggest that the low frequency fatigue developed over time were compensated for by muscle potentiation. More recently Chiu et al. (2004) assessed the acute neuromuscular responses to two (4-6 hours apart) high intensity (HIT) training sessions in 12 recreationally trained males. Neuromuscular performance was measured using unilateral isometric knee extensions and muscle biopsies were taken for myosin heavy chain analysis. Peak force was impaired
9.5% and 18.4% following both HIT sessions respectively. Initial rate of force development was depressed from the baseline following both session but this was dependent on muscle fiber type composition. Significant correlations were witnessed between the rate of force development and the myosin heavy chain expression. The authors determined that the impaired neuromuscular performance following the first HIT session occurred due to fatigue. Whereas individuals with predominantly type II muscle fiber type induced PAP during the second HIT session, resulting in the restoration of initial rate of force development. These studies and demonstrate the coexistence of potentiation and fatigue skeletal muscle from voluntary contractions in vivo.

**Temporal Relationship: Between the Conditioning Activity and Augmented Force Production**

In order to exploit the PAP phenomenon effectively there must be a balance between two factors: the temporary fatigue from a preconditioning stimulus and the potentiation (Tilin, 2009). In strength and conditioning literature, the interaction between fatigue and potentiation is paralleled by the fitness-fatigue paradigm. The paradigm states that physical performance is the result of the interaction of fatigue and fitness from a conditioning or exercise stimulus (Zatsiorsky, 1995). Thus, potentiating exercises that utilize heavy loads for brief durations eliciting minimal fatigue may enhance muscle performance by raising “preparedness” of an athlete (Stone et al., 2008). Regardless, to effectively reap the benefits of potentiation or preparedness, specific rest intervals must be used between the conditioning activity and the muscular performance enhancement.

Killduff et al. (2007) assessed the optimal recovery time between a conditioning activity and explosive performance (exerting maximal amount of force in the shortest possible time interval) in athletes. In this study 23 professional rugby players performed seven counter movement jump and ballistic bench press throws (An upper body power performance measure where an athlete accelerates and then releases a weighted implement) at 40% of one repetition maximum (1RM) at specific time points (15 sec, 4, 8, 12, 16, 20 and 24 min) following a bout of heavy resistance exercise. The heavy resistance exercise consisted of 2-3 sets of 3RM in the back squat and bench press exercises. Peak power outputs and rate of force development were determined from the counter movement jumps and ballistic bench
press throws heights. Performance (jump and throw height) was increased 3-5% at the 8 and 12 minute marks and peak power output also increased at the 8 and 12 minute marks in both upper and lower body measurements. These results demonstrate that muscle performance can be increased 8-12 min following a bout of heavy resistance exercise. Two recent meta-analyses done by Wilson et al. (2013) and Gouvea et al. (2013) sought to quantitatively identify the components of PAP and the most effective time periods between conditioning activity and performance assessment. In total 334 subjects were assessed using various modes of exercise as a preconditioning stimulus (static and dynamic upper and lower body). Ideal rest times were determined to be at 7-10 minutes and 8-12 minutes respectively for maximal power performance in explosive sport movements such as running, jumping and throwing implements (approx. <10 seconds).

There is some evidence that long recovery periods may not be needed to benefit from PAP. In opposition to this understanding some investigators have found significant increases in drop jump height and knee extension power (5% increase, 6% increase, p<.05) in track and field athletes, performed immediately after three sets of 3 second maximum isometric voluntary contractions (MVIC) of the knee extensors (French et al., 2003). Additionally, Cochrane et al. (2010) and found a 12.4 % increase in peak muscle twitch force following whole body vibration (WBV) a conditioning activity consisting of holding static squat on vibration plate. Terzis et al. (2009) found a 8% increase in underhand shot put throw performance immediately following a bout of ballistic exercise (BE). These studies demonstrate the ideal rest interval may be influenced by the type of conditioning activity used to elicit PAP. In the most recent meta-analysis by Seitz & Haff (2015) found that greatest PAP effect seemed to be elicited .3- 4 min following a conditioning activity consisting of BE and at least 5 min following HRE. While the majority of literature supports the presence of an optimal recovery time in order to fully utilize PAP. Inconsistency remains in respect to the intensity and duration of potentiating stimulus, the type of conditioning activity and the individual subject characteristics.

Identifying PAP window
Within the literature rest intervals range from 0-30 min. Meta-analysis data (Wilson et al. 2012, Gouvêa et al. 2013, Seitz & Haff 2015) reported the greatest levels of potentiation after .3-12 min of recovery following a conditioning activity. However, for the reasons discussed later in the manuscript the temporal profile of PAP appears to be dictated by individual strength level and the type of conditioning activity used. Chapter 2 outlines two types of protocols that can be used to identify an individual’s optimal PAP window, long duration (4-15 min) and short duration (0-5min). The short duration protocol is designed for conditioning activities that place less overall stress on the athletes and may require less recovery time (WBV, MVIC, BE). The long duration protocols are designed primarily for traditional heavy resistance training as it causes more stress to athlete thus, greater recovery times may be needed.

**Complex Training**

The primary method used by coaches to exploit the PAP phenomenon is complex or contrast training. Complex training was developed as a method for athletes to train at higher forces and intensities (Chu, 1996; Docherty, Robbins, & Hodgson, 2004; Verkhoshansky, 1986). Complex training is a method of training that involves completing a resistance exercise followed by an explosive ballistic or sport specific maneuver that shares similar movement pattern (Comyns et al., 2007; Hodgson et al., 2005; Robbins, 2005). The higher forces and intensities allowed by complex training may provide a superior training stimulus and resulting enhanced performance when compared to normal training methods (Chu, 1996; Docherty et al., 2004). Thus, through the utilization of complex training it may be possible to produce chronic beneficial adaptations (Ebben, 2002). These high power and velocity training methods are used to enhance or potentiate subsequent high velocity movements, are known as strength-power potentiating complexes (SPPCs) (Robbins, 2005, Stone et al., 2008). Through the use of a broad range of stimuli utilizing SPPCs protocols, greater gains in strength and power may be achieved (Jones & Lees, 2003).

*see Chapter 2*
Types of Conditioning Activity

As there are numerous methods used to increase muscular strength and power, so are there numerous SPCCs used to produce PAP. Tillin & Bishop (2009) surmised that different types of muscle actions during SPCCs protocols may elicit different effects on subsequent explosive performance. The following sections will examine current literature on SPCCs protocols including traditional heavy resistance training (HRE), maximal voluntary isometric contractions (MVIC), whole body vibration (WBV) and low-load ballistic exercise (BE). Wilson et al. (2013) conducted a meta-analysis which found significant statistical differences between loading intensities (percentage of 1RM) and the volume of work used to elicit the PAP response. The bulk of current potentiation literature has been focused on how varying SPCCs protocols will affect subsequent performance.

Heavy Resistance Exercise

The most widely investigated method used to elicit the PAP response is traditional heavy resistance exercise (HRE). HRE involves the use of multi-joint free weight exercises exceeding typically 80-85% of 1 repetition maximum (1RM). Killduff L et al. (2007) and Linder (2010), highlight the effectiveness of HRE. The study by Kilduff (2007) showed increases in explosive power (vertical jump/throw height and peak power) performed after a conditioning activity consisting of HRE of 3RM in squat and bench press exercises. Linder (2010) assessed the effects of PAP on sprint performance in collegiate track and field athletes. Twelve female sprinters performed a condition activity of 4RM in the back squat exercise (approx. 85% of 1RM) followed by 100m after a 9 min rest interval. The investigators found a 0.19 second improvements in sprint times. This study demonstrates that HRE may be a potent PAP stimulus for dynamic sport movements.

There is conflicting evidence on what the ideal load is for eliciting PAP using traditional heavy resistance exercise. A meta-analysis done by Wilson et al. 2013 reported that moderate-intensities (60-84% of 1RM) were ideal for eliciting PAP when compared with higher intensity load (>85% of 1RM). This contrasts with a more recent meta-analysis done by Seitz and Haff (2015). Which found that high-intensity loads (>85% of 1RM) maybe more effective than moderate-intensity loads in inducing PAP.
There may be several reasons for these discrepancies such as methodological differences between the various studies analyzed or variance subject characteristics. These findings demonstrate the need for further investigation into the effectiveness of various HRE SPPCs and their influence on PAP.

*Table 1.1

**Maximum isometric contractions**

French et al. (2003) proposed that an MVIC may be more practical in training and performance than traditional dynamic exercises as less equipment it required. During MVIC’s subjects are asked to give maximal effort over designated ranges of time typically from five to 30 seconds (Smith & Fry, 2007, Gullich & Schmidtleicher, 1996 and Maisulis et al., 2007). Several studies have assessed the effect of MVIC on subsequent explosive performance with unclear results. The equivocal nature of the MVIC is largely due to methodological differences between studies utilizing various rest intervals, duration of stimulation and muscle groups (See Table 1.2) Regardless the majority of literature supports MVIC based protocols as an effective stimulus in eliciting PAP. Further inquiry into established MVIC protocols regarding their effectiveness may be warranted.

*Table 1.2

**Whole Body Vibration**

Whole body vibration is implemented through standing, squatting or performing dynamic movements on a platform vibrating typically between 30-50Hz. Physiologically whole body vibration is proposed to improve muscle performance, peak force and RFD through activation of α-motor neurons (Cardinale & Bosco, 2003). This improvement in muscle performance has been attributed to increased muscle activation, inhibition of antagonist muscle, stretch reflex potentiation and motor unit synchronization (Cardinale & Bosco, 2003).

Cochrane et al. (2009) investigated the effect whole body vibration in the static squat position on PAP, muscle twitch and patellar reflex properties. Twelve National level athletes performed either WBV of 5min static body weight (BW) squat at 36 HZ, a static BW squat without WBV and cycling at 70 watts. Twitch force and rate of force development were administered at 90 sec, 5 and 10 min following
the conditioning activity. No significant differences were found in the static squat or cycling protocols, while the WBV protocol reported potentiation with increases in muscle twitch peak force of 12.4% and rate of force development of 11.4%. Additional work provides further support for the technique Ronnestad et al. (2011) and Padul et al. (2013) reported 2-3% increases in 40m sprint and repeated sprint ability in soccer players utilizing similar WBV protocols. While, the initial evidence supporting the use of WBV is promising further investigation is needed to determine its practical use and effectiveness.

*See Table 1.3

**Ballistic Exercise**

Ballistic exercise is defined as the intention to perform a movement with maximal velocity (Desmedt & Godaux, 1977). Ballistic exercises involve either a jumping or throwing action where mass is accelerated (Newton et al. 1996). The ability to perform a conditioning activity without the need of equipment makes ballistic exercise an attractive choice for training or competition.

Read et al. (2013) assessed the use of ballistic exercise on PAP and golf club head speed. Sixteen golfers underwent a SPCCs protocol consisting of three maximal counter jumps followed by a 1min rest interval. The subjects then performed golf swings were club head speed was measured. The investigators found a 2.2% increase in club head speed following the conditioning activity. Hilfker et al. (2007) found a 2.2% increases in average power for counter movement jumps, after performing five drop jumps from 60 centimeters in elite level skiers. Terzis et al. (2009) reported 4.6% increase in shotput throw distance from baseline, immediately following five maximal drop jumps from 40 cm in moderately trained subjects. The greatest improvement from the drop jump studies was observed by Lima et al. (2011), finding a 6% improvement in counter movement jump height and 2.7% increase in 50 meter sprint time, following two sets of five drop jumps from 75 cm with a 3 min rest interval. There are few studies that have assessed the effectiveness of ballistic exercises versus HRE the results are highly inconclusive. The most widely accepted reason for this is PAP protocols may need to be optimized in different ways with variations in intensity, load, and latency period. Future research into the various pap protocols needs be done when comparing conditioning activities. According to the current literature (Seitz et al., 2015, Wilson et al.
a one to five percent increase in performance activities (explosive/sport movements <10sec) can be expected to be seen from PAP protocols utilizing HRE, MVIC, ballistic exercise and WBV.

*Table 1.4

**Subject Characteristics**

Subject characteristics such as training status, strength level and muscle fiber type have shown to play a significant role in how strong of a PAP response is present in individuals (Seitz et al., 2014).

**Training Status: Athlete vs. Non Athlete**

An individual’s training status may influence both the PAP and the fatigue response that follows a conditioning activity. Chiu et al. (2003) assessed 24 subjects separated into athletes and recreational trained groups. The subjects completed a conditioning activity consisting of heavy resistance exercise, 5 x 1 back squats at 90% of 1RM. At 5 min and 18.5 min following the conditioning activity, subjects preformed jump squats and concentric only jump squats, peak power was then calculated from these performance measures. The groups were separated by training status the ATH group showed a 1-3% increase in power in contrast the recreationally trained group showed 1-4% decrease. The authors inferred that a higher training status provides fatigue resistance and permits a greater level of PAP. Consistent with this observation Koch et a. (2003) found that Division I track and field athletes performed better in broad jump when compared to college students following conditioning protocols. These studies indicate that potentiation mechanisms may favor athletes when compared to non-athletes, as athletes most likely incur less fatigue from conditioning activities.

**Strength level**

Many studies have shown that stronger subjects possess a greater ability to exploit the PAP response (Chiu et al, 2003, Wilson et al. 2013, Koch et al. 2003, Seitz et al 2014). A recent study by Seitz et al. (2014) tested the extent of the effect strength plays on PAP. Eighteen rugby players were split into two groups relative to 1RM back squat to body mass ratio. The stronger group consisted of those who could squat 2 x body mass while the weaker group contained those who squatted 1.5 x body mass. The
subjects performed a conditioning activity of 3 repetitions of 90% of 1 RM back squat followed by squat jumps at 15 sec, 3, 6, 9 and 12 min. The stronger group displayed a greater magnitude of PAP when compared to the weak group and were able to manifest PAP response earlier, 6 min vs 9 min. It has been suggested that strength and power athletes develop a fatigue resistance to higher loads as an adaptations to their training (Stone et al., 2008). Thus, practitioners should be aware that athletes possessing higher strength levels may benefit more from PAP protocols within their training program.

**Muscle Fiber Type**

An individual’s muscle fiber type composition may play a vital role in whether or not they achieve PAP following a preconditioning stimulus. Previous literature has shown that fast twitch fibers show a greater magnitude of potentiation when compared to slow twitch fiber (Gullich & Schmidtbleicher, 1996, Vandenboom et al 1993, Hamada et al. 2003). In support of these findings Hamada et al. (2003) investigated the relationship between muscle fiber type and PAP, by separating their subjects into two groups predominately fast-twitch (Type II) and predominately slow twitch (Type I). The Type II group reported a greater increases PAP during three second isometric MVIC when compare to Type I. Furthermore during a fatiguing protocol of 16 five second isometric MVIC of the knee extensors the Type II group showed greater twitch tension potentiation. These results demonstrate that subjects with greater density of Type II muscle display a greater PAP response. Most recently Seitz et al. (2016) investigated the relationship between PAP from voluntary contractions and maximal knee extensor torque, muscle cross sectional area and myosin heavy chain isoform percentage. The investigators found that PAP magnitude was strongly correlated with knee extensor torque, muscle cross sectional area and myosin heavy chain type II isoform percentage. However, the strongest correlation observed ($r=0.774$) was between PAP and type II isoform percentage which remained significant after accounting for all other variables. Within the existing PAP literature there is a general consensus that Type II muscle fibers are more effective in expressing the PAP response when compared to Type I fibers.
Summary

As strength and conditioning professional seek for new ways to increase the athletic potential of their athlete’s specifically muscular power PAP may prove useful tool. The most widely accepted physiological mechanisms responsible for potentiation are increased myosin light chain phosphorylation and increased neuromuscular activation. However, it is worth noting that lesser physiological mechanisms such as muscle tendon stiffness and muscle pennation angle may play a role in PAP but research is inconclusive. In order to fully understand PAP further investigations are necessary to understand the potential mechanisms of PAP.

The literature pertaining to the practical application of PAP phenomenon is based upon complex training principles. These principles involve the use of various modalities to induce a state of preparedness or potentiation. PAP Literature is focused on what combination of factor are most effective in eliciting PAP. These factors include modes of exercise used as a pre conditioning activity, the rest interval between activity and performance and the subject’s characteristics. While there is extensive literature on the factors involved in PAP there is no consensus on the ideal combination of these factors to optimize performance. Subsequently further investigation is needed into how various combinations of these factors may be most effective in real world practical settings.
Chapter Two: Practical Application of PAP Protocols

Introduction

Strength and conditioning professionals use a variety of muscle focused training methods to optimize the performance of their athletes. Development of muscular power and force production of particular interest as they are vital to success in many sports. A strength training technique that has gained wide spread popular support postactivation potentiation (PAP), a phenomenon which muscle function measured as either force or power is increased as a direct result of its contractile history (Robbins, 2005). Within the literature protocols whose goal is to elicit PAP are termed strength power potentiating complexes (Robbins, 2005). Strength and conditioning coaches currently use the complexes in form of complex and training to enhance neuromuscular performance.

This program integrates the contemporary understanding of PAP neurophysiology with an applied guide to effectively elicit the PAP response in the collegiate setting.
Overview of PAP

PAP

Subject

Muscle Fiber

Training Status (Experience)

Strength Level

Conditioning Activity

Rest Interval

Optimal

Short

Long

Dynamic

Static

Ballistic Exercise

Heavy Resistance Exercise

Whole Body Vibration

Isometric Contraction

Leads To

↑RFD

↑Peak Force

↑Force Production

↑Power

↑Performance
This method of training involves completing a conditioning exercise followed by an explosive ballistic exercise or maneuver that is biomechanically similar (Comyns et al., 2007; Hodgson et al., 2005; Robbins, 2005). This paring was created to allow athletes to train higher levels of force and greater intensities. This from of training may provide greater chronic adaptations in strength and power (Jones & Lees, 2003). Further, this type of training can be used to avoid the developmental plateaus and failure to augment muscular power through training.

**Methods to utilize PAP in training**

**Complex Training:** Consists of a heavy resistance exercise followed by an explosive or sport specific movement with similar movement pattern.

**Contrast Training:** Consists of a resistance exercise immediately followed by an explosive exercise of a similar movement pattern that is typically deloaded/assisted.
**French Contrast Training**: Combination of both complex and contrast training methods, considered the most effective yet most difficult to apply. Consists of a resistance exercise immediately followed by specific resisted and assisted similar movements. A bodyweight movement, a lightly resisted weighted movement (get creative) and an assisted or accelerated movement to emphasis development of RFD.

*there is more flexibility in regards to rest times when employing PAP in training, these recommendations can be adjusted depending on need.*

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**University of Montana Football average Vertical Jump (VJ) and Broad Jump (BJ) pre and post winter training.**

<table>
<thead>
<tr>
<th></th>
<th>Traditional Training 2015</th>
<th>Complex/Contrast Training 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VJ</td>
<td>BJ</td>
</tr>
<tr>
<td>Pre(in)</td>
<td>30.23</td>
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</tbody>
</table>

An underutilized aspect of the PAP phenomenon is its use in competition. The literature suggests that certain athletes could expect performance increases of 1-5% following an acute bout of exercise designed to elicit PAP. This performance increase is most readily observed in explosive movements lasting less than 10 seconds.

Any protocol designed to exploit PAP requires the assessment of individual athlete characteristics.

**How athlete characteristics affect PAP**

- **Training Status**
  - Trained athletes have a more favorable response to PAP
  - Better equipped to handle the stress of PAP protocols

- **Strength level**
  - Stronger athletes have an elevated response to PAP protocols when compared to weaker athletes
  - Stronger athletes are able to display the PAP effect quicker than weaker athletes

- **Muscle Fiber Type**
  - Type II muscle fiber dominate individuals are more effective in expressing PAP than Type I
  - Type II dominate athletes display a greater PAP magnitude than Type I

**Can be readily used in following disciplines**

- **Track and Field**
  - Short Sprints
  - Jumps
  - Throws

- **Gymnastics**
  - Vault
  - Bars
  - Floor Routine

- **Field and Court Sports**
  - Combines
  - Testing
  - Late game substitutions

- **Other**
  - Any explosive activity
  - Golf club head speed
  - Sprint Swims or rows
How to identify the PAP window in athletes?

When identifying an individual’s ideal PAP performance window there are two types of protocols which are dependent on the type of conditioning activity. The short rest interval protocol is ideal for conditioning activities that place less overall stress on the athlete (BE, WBV, MVIC). Long rest interval protocol is primarily used for conditioning activities using traditional heavy resistance training as it causes more stress to athlete thus, greater recovery times may be needed.

These protocols consist of performing a performance activity such as vertical jump (lower body) or medicine ball throw for distance (upper body) to establish a baseline (jump height, power output etc…). After a full rest interval > 5 min athletes will then perform the PAP conditioning activity (HRE, WBV, BE, MVIC) followed by the performance activity at specific time points. The time points with corresponding increase in performance will identify the athlete’s optimal PAP rest interval. This window will vary from athlete to athlete and year to year as training status and ability change.

**Short Duration protocol for utilizing- WBV, BE, MVIC**

Expected optimal PAP window 1-5 min*

Example of short duration PAP protocols

![Graph of vertical jump height over time](image)
Long Duration protocol - HRE

Expected optimal PAP window 4-12 min*

Example of long duration PAP protocol

![Graph showing vertical jump height over time]

Expected Optimal Rest Intervals by Type of CA

<table>
<thead>
<tr>
<th></th>
<th>0-15 sec</th>
<th>1 min</th>
<th>2 min</th>
<th>3 min</th>
<th>4 min</th>
<th>5 min</th>
<th>6 min</th>
<th>9 min</th>
<th>8 min</th>
<th>12 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>WBV, BE, MVIC</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>HRE</td>
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</tr>
</tbody>
</table>

Types of Conditioning Activity and Examples PAP Protocols

There is limited literature directly comparing the various modalities used to elicit PAP. While PAP protocols using traditional heavy resistance exercise (HRE) may lead to a stronger response, HRE is less applicable to competition for logistical reasons. Whereas ballistic exercises that employ body weight or light load plyometrics may be more effective for use in competition. Regardless of the type of conditioning activity used a 1-5% increase in performance can be expected. The choice on which conditioning activity to use will be largely dependent on type of sport, venue of competition, equipment availability and coaches preference.
HRE- Traditional heavy resistance exercise

Back Squat, Bench Press, Olympics and Variations

Loads of 60-95% 1RM

Lower Body Protocol

Strength Exercise
• Back Squat
  • 1 x 3 reps at 3 RM
  • Following warm up

Rest Interval
• Optimal window
  • 4-12 min

Explosive/Sport Maneuver
• Vertical Jump
  • Horizontal Jump
  • 40m Dash etc..

Upper Body Protocol

Strength Exercise
• Bench Press
  • 1 x 3 reps at 3 RM
  • Following warm up

Rest Interval
• Optimal window
  • 4-12 min

Explosive/Sport Maneuver
• Shot Put

BE- Ballistic Exercises

Jumps, throws, plyometric

Loads of 0-30% 1RM, BW or light resistance

Ballistic Exercise
• Dop Jumps
  • 2 x 5 1 min rest
  • Drop ht 30 in

Rest Interval
• Optimal window
  • Imm. -5 min

Explosive/Sport Maneuver
• 40m Sprint

WBV- Whole Body Vibration

Static/Dynamic

WBV Stimulus
• 30s WBV
  • Between 30-50Hz
  • 1-6 reps 20 sec rest

Rest Interval
• Optimal window
  • Imm. -5 min

Explosive/Sport Maneuver
• Vertical Jump
MVIC- Maximum Voluntary Isometric Contractions

Approx. 1-10 sec

Practical considerations when implementing PAP protocols for competition

- Athlete ability
- Time constraints, time leading up to event
- Type of CA

- Equipment availability
- Athlete/Coach buy in

Non Responders

PAP protocols for competition or training may not be suitable all athletes. If no PAP response is elicited it most likely to athletes characteristics insufficient training level or age, strength level or muscle fiber type distribution. Additionally, the protocols used to elicit PAP may be insufficient the inappropriate amount of stimulus the rest times can greatly affect PAP.

- Insufficient stimulus
- Inappropriate rest times
  - (to short, to long)

- Inappropriate for athlete
  - Undertrained
  - Insufficient strength
  - Fiber type
This program outlines the best methods to practically apply PAP based off of the current literature. However, there is no ideal protocol; coaches must decide how to best implement PAP for their athletes.
Chapter Three: Conclusion and Discussion

PAP in Training

The application of PAP in training has been largely popularized through the use of complex and contrast training methods. Complex and contrast training aims to allow athletes to train at higher forces and intensities exceeding their normal limits. Higher forces allowed by complex and contrast training may increase the potential training adaptations. Numerous studies (Docherty et al. 2004, Ebben 2002) have explored the effectiveness of the acute effects of complex and contrast training on subsequent performance. Oftentimes investigators imply that chronic neuromuscular adaptions may occur from these protocols when utilized within in a training regimen. Anecdotally many athletic performance professionals are convinced of the effectiveness of these training methods often employing them to break through stagnant periods in training. Empirically, there is little literature directly comparing the effectiveness of complex and contrast training methods against other training modalities. However, it would appear that a familiarization period is needed before potential benefits of complex and contrast training can be observed (Comyns et al. 2010, Tsimachidis et al. 2013). This should be taken into account when attempting to utilize complex and contrast training methods. In Chapter 2 examples of complex training protocols that are structured to exploit the PAP phenomenon are provided. These suggestions are guided by the existing literature on PAP in training but these protocols should also be determined on an individual basis. Practical factors such as equipment availability, athlete ability and time constraints must be taken into account to most effectively utilize these methods. Although the literature has reached the general consensus that complex and contrast training methods can induce PAP in explosive power based activities, the long term potential of this type of training and chronic neuromuscular adaptions are largely unexplored.

PAP in Competition

An underutilized aspect of PAP is its use in competition. Literature shows that an 1-5% increase in explosive performance can be achieved from an acute bout of exercise designed to licit PAP. While these increases in performance may seem minimal, when applied to activities of short duration tenths of a
second can frequently be the difference in competitive success. Thus, PAP may impact short duration explosive activity sports such as track and field and may be able to positively benefit field and court sports as well. Acute increases in neuromuscular performance, power output, neural drive and rate of force development may prove beneficial to almost any sport. Although the length of these athletic competitions posed a challenge for maintaining a potentiated state. It may be worthwhile to induce PAP for an athlete under certain circumstances including combine testing or during in game strategy. When implementing PAP protocols for competition several factors must be taken into account such as an individual’s athletic ability, equipment availability, time constraints, modality and coach/athlete buy in.

**Conclusion**

While there is extensive literature pertaining to the acute enhancements in performance that may be achieved from PAP, there is little literature pertaining to its practical application. It is possible to effectively apply the PAP phenomenon for competition or as a training stimulus for explosive sport maneuvers. To our knowledge, this is the first manuscript outlining how PAP may be designed specifically for training or acute enhancement in sport.

The inconsistencies within the literature pertaining to PAP appear to be due to the interactions of several factors. Individuals with a higher training status (age), strength level and fast-twitch muscle fiber type distribution may be more likely to express PAP at a greater magnitude (if at all). These individual factors also must be considered when deciding which conditioning activity and rest interval to use when applying PAP in training or competition. From a practical standpoint, conditioning activities with short rest intervals are more advantageous for application. Further investigation is needed into the mechanisms of PAP under varying conditions, specifically how PAP could be applied to competitive sport and chronic adaptations from training.
References


Bergmann, J., Kramer, A., & Gruber, M. (2013). Repetitive hops induce postactivation potentiation in triceps surae as well as an increase in the jump height of subsequent maximal drop jumps. *PLoS ONE*, 8(10)


Table 1.1  *Studies that utilized heavy resistance training to induce potentiation*

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Training Status(Sport)/n</th>
<th>CA</th>
<th>Rest Interval</th>
<th>Performance activity</th>
<th>Magnitude of improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berning et al. (2010)</td>
<td>RT, UT n=21</td>
<td>3 sec isometric back squat at 150% of 1RM</td>
<td>4.5min</td>
<td>CMJ performance</td>
<td>↑ in CMJ in the RT group (approx. 5.1- .5% ), no difference in UT group</td>
</tr>
<tr>
<td>Bevan et al. (2010)</td>
<td>Rugby, n=16</td>
<td>1x3 at 91% of 1RM</td>
<td>4, 8, 12, 16 min</td>
<td>Sprint performance 5m, 10m</td>
<td>No main effect for sprint performance, ↑ sprint performance in individuals</td>
</tr>
<tr>
<td>Buttifant &amp; Hrysomallis (2015)</td>
<td>Aussie Football, n=12</td>
<td>Squats, 3 x 3 at 3RM, 3 x 3 with resistance bands 1 x 5 at 90RM</td>
<td>5, 10 min</td>
<td>Jump Squat power at 20% of 1RM</td>
<td>↑ in jump squat power with both protocols</td>
</tr>
<tr>
<td>Chiu et al. (2003)</td>
<td>Ath/RT, n=24</td>
<td>5 sets of 1 rep at 90% 1RM, Back Squat.</td>
<td>5- 18.5 min</td>
<td>Percent potentiation and peak power at 30, 50, 70% 1RM</td>
<td>Initially no sig. effect. When divided into ATH and RT. ↑ in PAP 1-3% for ATH.</td>
</tr>
<tr>
<td>Crewther et al. (2011)</td>
<td>Rugby, n=9</td>
<td>1 x3 at 3 RM back squat</td>
<td>15 sec, 4, 8, 12, 16 min</td>
<td>CMJ performance</td>
<td>↓ CMJ height at 15s and 16 min, ↑ CMJ ht approx. 6%</td>
</tr>
<tr>
<td>Evetovich et al. (2015)</td>
<td>T &amp; F, n=20</td>
<td>1 x3 at 3 RM back squat</td>
<td>8 min</td>
<td>CMJ, HJ, Shot put, 36.6m Sprint performance</td>
<td>↑ in CMJ an HJ (approx. 2.7, 2.3 %), 36.6m sprint (approx. 1.2%), No difference in shot put or control</td>
</tr>
<tr>
<td>Hirayama (2014)</td>
<td>Collegiate Weight lifters, n=14</td>
<td>1 x 1 at 20, 40, 60, 80% of 1RM and 6s MVC half squats</td>
<td>1 min after each set</td>
<td>CMJ performance</td>
<td>↑ in CMJ after 60, 80% and MVIC Squats(approx. 4.3%, 6.7%, 10%)</td>
</tr>
<tr>
<td>Killduff et al. (2011)</td>
<td>Swimmers (elite), n=9</td>
<td>1x3 at 87% of 1 RM back squat</td>
<td>Imm., 4, 8, 12, 16 min</td>
<td>Peak Power CMJ performance, Swim specific horizontal and vertical force</td>
<td>↑ in Peak Power and CMJ ( approx..34% and 4.6%). ↑ Peak vertical and horizontal force swim specific.</td>
</tr>
<tr>
<td>Low et al. (2014)</td>
<td>Youth Soccer, n=16</td>
<td>1x3 at 91% of 1 RM</td>
<td>8 min</td>
<td>Repeated anaerobic sprint test</td>
<td>↑ Repeated anaerobic sprint test (p &gt; 0.05)</td>
</tr>
<tr>
<td>Duthie GM et al. (2003)</td>
<td>Hockey, Softball ,n=11</td>
<td>1 x 3 RM Half Squats</td>
<td>5 min</td>
<td>Mean Peak power CMJ height and maximal force</td>
<td>High Strength group showed 2.1% increase in max force.</td>
</tr>
<tr>
<td>Gourgoulis et al. (2003)</td>
<td>WBB , n=14</td>
<td>1 x 2 at 20, 40, 60 80 and 90% of 1RM. Ascending protocol 5min rest</td>
<td>Imm.</td>
<td>Mean CMJ performance</td>
<td>2.9% Inc. in mean CMJ (Divided into groups &lt;160 kg 1rm squats, &gt;160kg 1rm squat). Stronger group 4% inc .compared with .42% in weak group</td>
</tr>
<tr>
<td>Study</td>
<td>Participant Group</td>
<td>Exercise Specifications</td>
<td>Duration</td>
<td>Secondary Outcomes</td>
<td></td>
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<tr>
<td>Yetter &amp; Moir (2008)</td>
<td>RT, n=10</td>
<td>1 x 3 70% of 1 RM</td>
<td>4 min</td>
<td>10-40m Sprint Performance ↑ Mean increase of approx. 1.8% in sprint performance 3 min post No difference. 5 min post ↑ 1-3%</td>
<td></td>
</tr>
<tr>
<td>Chatzopoulos et al. (2007)</td>
<td>MBB,VB,Soccer, HB, n=15</td>
<td>10 x 1 at 90% 1RM back squat</td>
<td>3 min, 5 min</td>
<td>100m Sprint performance ↑ Mean increase of approx. 1.8% in sprint performance 3 min post No difference. 5 min post ↑ 1-3%</td>
<td></td>
</tr>
<tr>
<td>Linder et al. (2010)</td>
<td>T&amp;F Sprint, n=12</td>
<td>1 x 4 RM half squats</td>
<td>9 min</td>
<td>Maximal sprint times pre and post 10 week intervention,1RM back squat. ↑ 1RM 30.3+/-.15% and a significant ↑ in 30m sprint time</td>
<td></td>
</tr>
<tr>
<td>Tsimachidis et al. (2013)</td>
<td>Ath, RT, n=26</td>
<td>5 sets of 8 RM half squats (first five weeks), 5 sets of 5RM half squat (second 5 Weeks),</td>
<td>3 min</td>
<td>Peak Power from bench press throw performance ↑ .05sec improvement, .87% sprint performance 5.7% in CMJ. No sig difference in CMJ between protocol.</td>
<td></td>
</tr>
<tr>
<td>McBride et al. (2005)</td>
<td>Football, n=15</td>
<td>1 x 3 90% 1RM Squat, 30% of 1RM loaded CMJ</td>
<td>4 min</td>
<td>CMJ performance ↑ 4.5% peak power</td>
<td></td>
</tr>
<tr>
<td>McCann et al. (2010)</td>
<td>VB, n=16</td>
<td>5 x 5 RM of back squat or hang clean</td>
<td>4-5 min</td>
<td>No Difference Between groups</td>
<td></td>
</tr>
<tr>
<td>Baker et al. (2003)</td>
<td>Rugby, n=16</td>
<td>1 x6 at 65% 1RM bench press</td>
<td>4 min</td>
<td>No Difference Between groups</td>
<td></td>
</tr>
<tr>
<td>Brandenburg et al. (2005)</td>
<td>RT, n=8</td>
<td>1 x 5 at 100,75 and 50% of 5RM bench press</td>
<td>N/A</td>
<td>No Difference Between groups</td>
<td></td>
</tr>
</tbody>
</table>

*Note: RT, recreational trained; UT, untrained; Ath, athlete not specified; MBB, men’s basketball, VB, volleyball; T & F, track and field; CMJ, countermovement jump; HJ, horizontal jump; RM, repetition max; Imm., immediately.
### Table 1.2 Studies that utilized maximal isometric voluntary contractions to induce potentiation

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Training Status(Sport)/n</th>
<th>CA</th>
<th>Rest Interval</th>
<th>Performance activity</th>
<th>Magnitude of improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arabatzi et al. (2014)</td>
<td>Athlete(youth, teen and adult), n=58</td>
<td>3x3 sec MVIC Squats</td>
<td>20 sec, 4 min</td>
<td>Squat Jump, peak RFD</td>
<td>↑ in SJ and RFD in adult and teenage groups</td>
</tr>
<tr>
<td>Baudry et al. (2005)</td>
<td>RT(adult and elderly), n=20</td>
<td>6s MVC of tibialis anterior</td>
<td>Imm, 0-20min</td>
<td>Muscle twitch torque, RFD</td>
<td>↑ in twitch torque and RFD, PAP magnitude increased by 36.5% in young and 11% in elderly</td>
</tr>
<tr>
<td>Bogdanis et al. (2014)</td>
<td>T &amp; F, n=14</td>
<td>3x3sec MVIC from the half squat position</td>
<td>15sec, 2,4,6,8,10, 12, 15, 18, 21 min</td>
<td>CMJ Performance</td>
<td>↑ 3% increase in CMJ</td>
</tr>
<tr>
<td>de Lima et al. (2014)</td>
<td>UT, n=23</td>
<td>1x5 sec MVIC</td>
<td>3 min</td>
<td>Peak torque, rate of torque development</td>
<td>↑ 5.2% in 500m split time, ↑ mean power by 6.6%, and mean stroke rate by 1.9%</td>
</tr>
<tr>
<td>Feros et al. (2012)</td>
<td>Rowers (elite), n=10</td>
<td>5 x 5 sec MVIC (rowing specific)</td>
<td>4 min</td>
<td>1,000 M rowing ergometer performance CMJ and DJ performance, Maximal force Knee ext. torque.</td>
<td>3x3 sec produced ↑ 5.03% CMJ ht; ↑ 4.94% max force and 9.40% acceleration impulse; ↑ 6.12% knee extension torque.</td>
</tr>
<tr>
<td>French et al. (2003)</td>
<td>T &amp; F, n=14</td>
<td>3x3 sec or 3x5 sec MVIC of knee extension</td>
<td>Imm.</td>
<td>Velocity and peak of power of knee extensions</td>
<td>No sig. difference found in any values. (Authors speculated to lack of recovery time)</td>
</tr>
<tr>
<td>Gossen et al. (2000)</td>
<td>RT, n=10</td>
<td>10 sec MVIC’s of single knee extension</td>
<td>Imm. On 2 occasions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamada et al. (2000)</td>
<td>Triathlete, RT, UT, n=40</td>
<td>10 sec MVIC (elbow extensors, ankle plantar flexor).</td>
<td>0-5min</td>
<td>Maximal twitch torque, peak torque.</td>
<td>Both triathletes and runners had significant increases in peak torque and time to peak torque compared to control and sed. 10-20%.</td>
</tr>
<tr>
<td>Folland et al. (2008)</td>
<td>RT, n=8</td>
<td>10sec MVIC knee extensors</td>
<td>0-18 min</td>
<td>Maximal twitch and RFD</td>
<td>No sig. difference found.</td>
</tr>
<tr>
<td>Lim &amp; Kong (2013)</td>
<td>T &amp; F, n=12</td>
<td>3x3 sec MVIC , MVIC squat, 3 Squat at 90% of 1RM</td>
<td>4min</td>
<td>Sprint performance</td>
<td>No sig. differences in sprint times between protocols</td>
</tr>
<tr>
<td>Robbins &amp; Docherty (2005)</td>
<td>RT, n=11</td>
<td>3x7 MVIC</td>
<td>4 min</td>
<td>CMJ Performance</td>
<td>No sig. difference in CMJ performance</td>
</tr>
</tbody>
</table>

*Note: RT, recreational trained; UT, untrained; Ath, athlete not specified; MBB, men’s basketball; VB, volleyball; T & F, track and field; CMJ, countermovement jump; HJ, horizontal jump; SJ, squat jump; DJ, drop jump; RM, repetition max; Imm., immediately, RFD, rate of force development.*
<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Training Status(Sport)/n</th>
<th>CA</th>
<th>Rest Interval</th>
<th>Performance activity</th>
<th>Magnitude of improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guggenheimer JD, et al.  (2009)</td>
<td>T&amp;F, n=22</td>
<td>4 x 5 sec high knee running on vibrating platform at 0, 30, 40, 50 Hz, 1 x3 reps at 90% 1RM power clean</td>
<td>1, 4 min</td>
<td>40m Sprint performance</td>
<td>No significant difference witnessed in sprint times.</td>
</tr>
<tr>
<td>Cochrane et al. (2010)</td>
<td>ATH , n= 12</td>
<td>Static Squat with Whole body vibration (WBV), Static squat without and cycling. 5 min</td>
<td>90 sec, 5, 10 min</td>
<td>Muscle Twitch Peak Force, RFD</td>
<td>↑PF 12.4%, RFD 11.4% with WBV</td>
</tr>
<tr>
<td>Ronnestad et al. (2011)</td>
<td>Soccer, n=7</td>
<td>30sec of half squats with WBV at 30 and 50 Hz, or half squats without vibration</td>
<td>1 min</td>
<td>Sprint Performance in 40m sprint</td>
<td>↑ with WBV at 50 he vs control (5.48+/-.19 vs. 5.52 +/- .21) no difference with WBV at 30 Hz</td>
</tr>
<tr>
<td>Padul et al.(2013)</td>
<td>Soccer, n=15</td>
<td>15sec WBV at 45 Hz between sprints</td>
<td>20 sec between sprints</td>
<td>Repeated Sprint Ability (RSA)</td>
<td>1.9-2.9% faster than control</td>
</tr>
<tr>
<td>Pojskic et al. (2015)</td>
<td>Football , n=21</td>
<td>5 x 60sec at half squat at 30% of BW or Static squat with WBV at 50 Hz</td>
<td>N/A</td>
<td>CMJ sprint performance</td>
<td>WBV showed significant differences</td>
</tr>
<tr>
<td>Cochrane &amp; Booker (2014)</td>
<td>T&amp;F, n=14</td>
<td>6 x 60s static squats with WBV at 26Hz with 6mm amplitude, 30s rest between sets</td>
<td>90s before first trial, 1-2 min between trials</td>
<td>Repeated horizontal jump performance</td>
<td>↑ in jump distance and velocity at 2 min post CA ( approx. 1.7%, 5.2%)</td>
</tr>
<tr>
<td>Cormie et al. (2006)</td>
<td>RT, n=9</td>
<td>30s WBV at 30Hz with 2.5mm amplitude</td>
<td>Imm, 5, 15, 30 min</td>
<td>CMJ performance</td>
<td>↑ in CMJ ht Imm after WBV vs control</td>
</tr>
<tr>
<td>Rhea &amp; kenn (2009)</td>
<td>Collegiate athlete , n=16</td>
<td>30s WBV at 35Hz with 4mm amplitude</td>
<td>3 min</td>
<td>Lower body power output during back squat</td>
<td>↑ Power of 1 x 3 75% of 1RM after WBV (5.20)</td>
</tr>
<tr>
<td>Ronnestad et al. (2013)</td>
<td>Ice Hockey, n=15</td>
<td>30s WBV at 50HZ with 3mm amplitude in half squat</td>
<td>1 min</td>
<td>Ice sprint performance</td>
<td>↑ in ice sprint performance 10 , 20m when compared to control (1.8%, 1%)</td>
</tr>
<tr>
<td>Turner et al. (2011)</td>
<td>RT, n=12</td>
<td>30s WBV in half-squat at 0, 30, 35, 40 Hz with 8mm amplitude</td>
<td>N/A</td>
<td>CMJ performance</td>
<td>No difference in any other protocols, ↑ in CMJ ht after WBV at 40 Hz (6.9%)</td>
</tr>
</tbody>
</table>

*Note: RT, recreational trained; UT, untrained; Ath, athlete not specified; MBB, men’s basketball, VB, volleyball; T & F, track and field; CMJ, countermovement jump; HJ, horizontal jump; SJ, squat jump; DJ, drop jump; RM, repetition max; Imm., immediately, RFD, rate of force development.
Table 1.4 *Studies that utilized ballistic exercise to induce potentiation*

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Training Status(Sport)/n</th>
<th>CA</th>
<th>Rest Interval</th>
<th>Performance activity</th>
<th>Magnitude of improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bergmann et al. (2013)</td>
<td>RT ,n=12</td>
<td>8 x 10 maximal bilateral hops with 30s between sets</td>
<td>Imm, 30s between sets</td>
<td>DJ performance</td>
<td>↑ in DJ ht after hops ( approx. 12%)</td>
</tr>
<tr>
<td>Bomfim Lima (2011)</td>
<td>T &amp; F, n=10</td>
<td>2 x 5 DJ from .75m</td>
<td>5, 10, 15 min</td>
<td>Sprint performance, CMJ performance</td>
<td>↑ sprint time at 10 and 15 min (approx. 2.4%, 2.7%), ↑ CMJ ht at 15 min (approx. 6%)</td>
</tr>
<tr>
<td>Bulluck &amp; Comfort (2011)</td>
<td>Collegiate Ath, n=14</td>
<td>1 x 2, 1 x 4, 1 x 6 DJ from 33cm</td>
<td>4 min</td>
<td>1RM back squat strength</td>
<td>↑ 1 RM squat strength following each protocol</td>
</tr>
<tr>
<td>Burkett et al. (2011)</td>
<td>Football, n=29</td>
<td>1 x 5 CMJ at 75% of 1 RM, 1 x 5 weighted CMJ at 10% of BW on to box</td>
<td>2 min</td>
<td>CMJ performance</td>
<td>↑ CMJ height after weighted CMJ to box</td>
</tr>
<tr>
<td>Byrne et al. (2013)</td>
<td>Collegiate Ath, n=29</td>
<td>Dynamic warm up, 3 DJ from optimal height</td>
<td>1 min</td>
<td>20 m sprint performance</td>
<td>↓20m sprint time compared to control and dynamic warm up protocol</td>
</tr>
<tr>
<td>Chattong et al. (2010)</td>
<td>RT,n=20</td>
<td>Weighted Jumps on to a box with 5, 10 15 and 20 % of BW</td>
<td>2 min</td>
<td>CMJ performance</td>
<td>↑ in CMJ mean increase of 1.3%</td>
</tr>
<tr>
<td>Esformes et al. (2010)</td>
<td>T &amp; F, Rugby, n= 13</td>
<td>3 x 24 plyometric bounds and hops</td>
<td>5 min</td>
<td>CMJ performance</td>
<td>No significant differences found</td>
</tr>
<tr>
<td>Sarramian et al. (2014)</td>
<td>Swimmers, n=18</td>
<td>1 x 5 weighted jumps to box with 10% of BW</td>
<td>N/A</td>
<td>50m freestyle swim</td>
<td>No difference in 50m freestyle swim time</td>
</tr>
<tr>
<td>Smilios et al (2005)</td>
<td>RT, n=10</td>
<td>3 x 5 squat jumps at 30 and 60% of 1RM</td>
<td>1, 5, 10 min</td>
<td>CMJ performance</td>
<td>↑ with both low and moderate loads (approx. 4.94%)</td>
</tr>
<tr>
<td>Terzis et al. (2012)</td>
<td>Shot putters, n=10</td>
<td>1 x 3 consecutive CMJ</td>
<td>1 min</td>
<td>Shot put performance</td>
<td>↑ shot put throw distance (approx. 3.65%)</td>
</tr>
<tr>
<td>Terzis et al. (2009)</td>
<td>RT, n=16</td>
<td>1 x 5 consecutive DJ from 40cm</td>
<td>20s</td>
<td>Underhand throw performance</td>
<td>↑ underhand throw distance ( approx. 8%)</td>
</tr>
</tbody>
</table>

*Note: RT, recreational trained; UT, untrained; Ath, athlete not specified; MBB, men’s basketball, VB, volleyball; T & F, track and field; CMJ, countermovement jump; HJ, horizontal jump; SJ, squat jump; DJ, drop jump; RM, repetition max; Imm., immediately, RFD, rate of force development*