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The Acute Effects of Ballistic and Non-Ballistic Concentric-Only Half-Squats on Squat Jump  
Performance

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A dissertation

presented to

the faculty of the Department of Exercise and Sport Sciences

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Doctor of Philosophy in Sport Physiology and Performance

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by

Timothy John Suchomel

August 2015

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Keywords: Postactivation Potentiation, Half-Squat, Squat Jump

## ABSTRACT

### The Acute Effects of Ballistic and Non-Ballistic Concentric-Only Half-Squats on Squat Jump Performance

by

Timothy J. Suchomel

The purposes of this dissertation were to examine bilateral asymmetry as a factor of postactivation potentiation, examine and compare the acute effects of ballistic and non-ballistic concentric-only half-squats on squat jump performance, and compare the potentiation and temporal profiles of strong and weak subjects following potentiation protocols that included ballistic and non-ballistic concentric-only half-squats. The following are major findings of the dissertation. Squat jump performance may be acutely enhanced following ballistic concentric-only half-squats; however the changes in performance do not appear to be related to bilateral symmetry. Ballistic concentric-only half-squats acutely improve various squat jump performance variables at various time intervals; however the changes in performance are not related to the bilateral symmetry of the subject. Ballistic concentric-only half-squats produced superior acute potentiation effects with regard to jump height, peak power, and allometrically-scaled peak power as compared to non-ballistic concentric-only half-squats and a control protocol. Stronger subjects potentiated earlier and to a greater extent as compared to their weaker counterparts. This dissertation indicates that bilateral symmetry may not be considered as an underlying factor affecting postactivation potentiation. However, it is suggested that future research should continue to investigate the factors that are associated with postactivation potentiation. The findings of this dissertation also demonstrate the importance of how an

individual performs a concentric-only squatting motion. By training with ballistic movements, a greater training stimulus may be achieved as compared to training with non-ballistic movements. While this dissertation discussed the acute potentiation differences between ballistic and non-ballistic concentric-only half-squats, longitudinal research is needed to determine if different training effects result from each training method. This dissertation also supports that notion that stronger individuals may benefit more with regard to potentiation effects. In order to optimize performance and realize the greatest potentiation effects, it is recommended that greater levels of relative strength should be sought. It is suggested that further research is needed on the longitudinal differences in the potentiation effects an individual can realize based on their strength levels.

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## DEDICATION

I would like to dedicate this dissertation to my family and friends who have supported me in my professional and personal life in pursuit of this achievement. I would also like to dedicate this dissertation to my colleagues within the sport science field.

## ACKNOWLEDGEMENTS

I would like to thank the following people:

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My friends and colleagues at East Tennessee State University, from already graduated and those just starting, I admire your passion for the sport science field. All of you help fuel my drive and desire to continue the pursuit of excellence within this field. Your friendship and support is invaluable and I could not have completed this project without you. I wish you the best of luck in everything you pursue.

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## CHAPTER 1

### INTRODUCTION

Strength and conditioning professionals use a variety of strength training methods to optimize the performance of athletes in their respective sports. Of particular interest is the development and improvement of upper and lower body muscular power. A strength training technique that has become the subject of frequent investigations is postactivation potentiation. Postactivation potentiation (PAP) has been defined as an acute enhancement of muscle performance as a result of contractile history and is considered the basis of complex training (Robbins, 2005). Topics that have been investigated within the PAP literature include underlying physiological mechanisms, various potentiating stimuli, the rest interval following a stimulus, characteristics of the subjects, and the electromyography or muscle activation differences following a stimulus. Through the use of PAP, researchers have attempted to identify stimuli that will acutely improve the subjects' overall performance. By identifying stimuli that will improve performance, it may be possible to use PAP as a training or competition mechanism.

There are a number of physiological mechanisms that have been proposed to be components of the PAP phenomenon. Proposed mechanisms with the most support include: an increase in the phosphorylation of myosin regulatory light chains (Cochrane, Stannard, Firth, & Rittweger, 2010; Hodgson, Docherty, & Zehr, 2008; Palmer & Moore, 1989; Rassier & Herzog, 2001; Ryder, Lau, Kamm, & Stull, 2007; Tillin & Bishop, 2009; Vandenboom, Grange, & Houston, 1995) and an increase in the level of neuromuscular activation (Burkett, Phillips, & Ziuraitis, 2005; Hamada, Sale, MacDougall, & Tarnopolsky, 2000b; Suzuki, Kaiya, Watanabe, & Hutton, 1988; Tillin & Bishop, 2009; Trimble & Harp, 1998). Other proposed mechanisms



include a possible change in muscle pennation angle (Mahlfeld, Franke, & Awiszus, 2004; Tillin & Bishop, 2009), and an increase in muscle stiffness (Chu, 1996; Hutton & Atwater, 1992; Shorten, 1987).

Two other factors that should be considered when it comes to PAP are joint velocity characteristics and bilateral force production symmetry. To the author's knowledge, no previous studies have examined the joint kinematic or kinetic changes of a static jump as a result of potentiation. Because muscle stiffness has been identified as an underlying mechanism of potentiation, it is possible that joint kinematics may change based on the length of the muscles involved. Although previous research has not investigated bilateral strength symmetry during jumps and the effect on jump performance, a previous study by Bailey et al. (2013) reported statistically significant moderate to strong negative relationships between peak force symmetry and jump height and peak power. Their study indicated that higher jump values were observed from those who possess more symmetrical peak force values. Whether a potentiating stimulus causes acute changes in bilateral force production symmetry remains unknown. However, if bilateral force production symmetry is changed following a potentiating stimulus, jumping performance may be affected. In order to understand what causes acute changes in performance, it is necessary to review all potential factors that may contribute.

Most of the research that investigates PAP uses a resistance training method termed complex training. Complex training (CT) involves pairing repetitions of a resistance exercise with biomechanically similar exercises often with a plyometric component (Hodgson, Docherty, & Robbins, 2005; Robbins, 2005). Within the potentiation literature, protocols whose goal is to produce a potentiated state are known as strength-power potentiating complexes (SPPCs) (Robbins, 2005; Stone, Sands, Pierce, Ramsey, & Haff, 2008). Specifically, SPPCs involve the

performance of a high force or high power movement that is used to enhance, or potentiate, a high power or high velocity movement that follows. There is an abundance of lower body SPPCs that have been investigated with the intent to produce a potentiated state in which an individual can acutely improve a subsequent performance. Specific protocols have included maximal voluntary contractions, back squats, half-squats, quarter-squats, front squats, whole-body vibration, plyometrics, weightlifting exercises and their variations, running and/or cycling, throwing implements, weighted vests, intermittent exercise, and the leg press. As discussed above, previous research has used many different SPPCs in an attempt to harness the PAP stimulus for a subsequent explosive performance.

Despite the abundance of SPPCs that exist, a paucity of research has investigated the potentiation differences following ballistic and non-ballistic exercise. A recent study by Seitz et al. (2014c) compared the potentiation effects of a ballistic exercise (i.e. power clean) and non-ballistic exercise (i.e. back squat) using 90% of the 1RM for each exercise. Their results indicated that the power clean produced superior sprint potentiation effects as compared to the back squat. While the ballistic exercise produced superior potentiation effects, it should be noted that the movements and loads for each exercise are very different. In order to understand the potentiation differences that result from ballistic and non-ballistic exercise, a comparison should be made between a ballistic and non-ballistic movement that occurs using the same biomechanical motion with the same absolute loads.

A recent study examined the potentiation effects of concentric-only half-squats on sprinting performance (Dechechi, Lopes, Galatti, & Ribeiro, 2013). Their study indicated that three concentric-only half-squat repetitions at 90% 1RM concentric-only half-squat strength (90° of knee flexion) produced a statistical improvement 50m sprint displacement time whereas three

eccentric-only half-squat repetitions at 90% 1RM concentric-only half-squat strength displayed no change in performance. Because only one study (Dechechi et al., 2013) has examined the potentiation effects of concentric-only half-squats on performance, further research is needed. If concentric-only half-squats at 90% 1RM concentric-only half-squat strength performed from 90° of knee flexion have the potential to produce improvements in 50m sprint time (Dechechi et al., 2013), it is possible that static jump performance may be enhanced following the stimulus. As partial squats, such as concentric-only half-squats, are regularly incorporated into training programs (Clark, Bryant, & Humphries, 2008; Clark, Humphries, Hohmann, & Bryant, 2011; Harris, Stone, O'Bryant, Proulx, & Johnson, 2000; Stone et al., 2000), it appears that further research investigating the manner in which concentric-only half-squats are performed is warranted.

Following a PAP stimulus, a state of both fatigue and potentiation are present (Hodgson et al., 2005; Sale, 2002). This interaction between fatigue and potentiation may in fact be modeled acutely based on the fitness-fatigue paradigm (Zatsiorsky, 1995), where physical performance is the result of the interaction of fatigue and fitness after-effects that result following an exercise stimulus. In this case, the potentiating exercise raises the “preparedness”, or difference between fitness and fatigue, of the participant for the subsequent activity (Stone et al., 2008). However, in order to effectively use the benefits of potentiation for a specific stimulus, it is likely that each individual potentiating stimulus requires its own specific rest interval in order to bring about an enhanced subsequent performance. Thus, in order to overcome fatigue and improve performance, a number of studies have examined the rest interval following the potentiating stimulus and its effect on overall performance. Previous research has indicated that the PAP effect may last from 5-20 min following a heavy resistance stimulus

(Chiu et al., 2003; Gilbert, Lees, & Graham-Smith, 2001; Gullich & Schmidtbleicher, 1996). More recent research has indicated that a positive potentiation effect may occur as early as two min post-stimulus (Rixon, Lamont, & Bembem, 2007) and last as long as 6 hours (de Villarreal, Gonzalez-Badillo, & Izquierdo, 2007). As previously mentioned, it is vital to consider the necessary rest periods needed for peak performance to occur. Thus, when a new stimulus is introduced, identifying the optimal rest period for peak performance is of paramount importance.

While an SPPC is one of the primary factors in potentiation, the other primary factor involves the subjects and their characteristics. Previous research has indicated that several subject characteristics including training status, training age, chronological age, genetics (fiber type and composition), sex, relative strength, and absolute strength of subjects (Docherty & Hodgson, 2007; Hodgson et al., 2005; Sale, 2002; Stone et al., 2008; Tillin & Bishop, 2009) may alter the effect of PAP on subsequent performances. As a result, previous research has examined potentiation differences between strong and weak subjects, athletes and non-athletes, men and women, and individuals who are fast twitch fiber dominant or slow twitch fiber dominant. Although sport scientists and practitioners cannot manipulate a number of the previously listed characteristics, a subject's strength levels (relative and absolute) can be enhanced with regular strength training. Previous research supports the notion that stronger subjects potentiate earlier and to a greater extent than their weaker counterparts following heavy back squats (Jo, Judelson, Brown, Coburn, & Dabbs, 2010; Seitz, de Villarreal, & Haff, 2014a). While previous literature suggests that stronger subjects will potentiate earlier and to a greater extent following a non-ballistic exercise, no research has examined if this trend exists following ballistic exercise.

### Dissertation Purposes

1. To examine the effects of strength-power potentiating complexes on bilateral symmetry and how symmetry affects squat jump performance at various rest intervals.
2. To examine and compare the acute effects of ballistic and non-ballistic concentric-only half-squats on squat jump performance.
3. To compare squat jump performance between strong and weak subjects at various rest intervals following a strength-power potentiating complexes that include ballistic and non-ballistic concentric-only half-squats.

### Operational Definitions

1. Absolute strength: the maximum amount of weight an individual can lift for one repetition.
2. Allometric scaling: the mathematical process of scaling a performance variable to account for differences in the body shape and size of subjects, whereby the original performance variable value is divided by the body mass of the subjects raised to the exponent of 0.67.
3. Bilateral force production symmetry: the extent to which both lower extremities produce the same amount of force during a dynamic or isometric movement.
4. Complex training: pairing repetitions of a resistance exercise with biomechanically similar exercises often with a plyometric component.
5. Concentric-only half-squat: half-squat performed without an eccentric component where the participant's knee angle starts at 90° of knee flexion at the lowest position of the exercise.
6. Countermovement jump (CMJ): a type of vertical jump that requires an individual to descend from an initial standing position by flexing at the hips and knees before immediately extending their hips and knees and plantar flexing their ankles to jump

7. Force: a characteristic of movement with both a magnitude and direction that causes an acceleration of an object; a push, pull, or tendency to distort.
8. Force-time curve: a graph representing the measured vertical ground reaction forces with time plotted on the X axis and the vertical ground reaction forces plotted on the Y axis of a force-time trace.
9. Half-squat: squat performed with an eccentric and concentric component to where the participant's knee angle reaches 90° of knee flexion at the lowest position of the exercise.
10. Joint angle: static or dynamic angular position between two joint segments; typically expressed in degrees or degrees of flexion from an initial starting point.
11. Jump height: vertical displacement of the center of mass from the take-off to the apex of the flight.
12. One repetition maximum (1RM): the maximum load one can lift with proper technique for one repetition, but not two.
13. Peak force: greatest calculated value of force under defined conditions.
14. Peak force symmetry index score: calculated percentage of lower extremity force production symmetry where 0% indicates perfect symmetry; calculated by subtracting the smaller peak force value produced by one extremity from the larger peak force value produced by the other extremity, dividing the difference between extremities by the total peak force value produced by both extremities, and then multiplying by 100 to obtain a percentage under defined conditions.
15. Peak power: greatest calculated value of power under defined conditions.
16. Postactivation potentiation: an acute enhancement of muscle performance as a result of contractile history, considered the basis of complex training.

17. Power: the rate at which work can be completed under defined conditions.
18. Rate of force development: calculated as the change in force divided by the time duration over which the change in force occurred under defined conditions.
19. Relative strength: the maximum amount of weight an individual can lift for one repetition, but not two, relative to their body mass.
20. Static jump: a type of vertical jump that is performed without an eccentric component and is initiated from a knee angle of 90 degrees.
21. Strength-power potentiating complex: training protocols used to produce a state of potentiation that typically use a high force or high power movement followed by a high power or high velocity movement.
22. Take-off: the point during a countermovement jump at which the feet of the individual leave the ground.

## CHAPTER 2

### COMPREHENSIVE REVIEW OF LITERATURE

Strength and conditioning professionals use a variety of strength training methods to enhance the performance of athletes in their respective sports. Of particular interest is the development and improvement of lower and upper body muscular power. A strength training method that has become the subject of frequent investigations is the phenomenon known as postactivation potentiation. Postactivation potentiation (PAP) has been defined as an acute enhancement of muscle performance as a result of contractile history and is considered the basis of complex training (Robbins, 2005). Topics that have been investigated within the PAP literature include the underlying physiological mechanisms, various potentiating stimuli, the rest interval following a stimulus, the characteristics of the subjects, and the electromyography or muscle activation differences following a potentiating stimulus. Through the use of PAP, researchers have attempted to identify stimuli that will acutely improve the subjects' overall performance. By identifying stimuli that will improve performance, it may be possible use PAP as a training or competition mechanism.

There are several factors that need to be addressed when investigating PAP. These factors include:

- The choice of exercise(s) that is/are used as a potentiating stimulus
- The volume and intensity of the warm-up protocol
- The muscle groups involved
- The characteristics of the movement
- The type of muscle action used during the stimulus and subsequent activity
- The period of time between the conclusion of the warm-up and the subsequent performance



- The performance level of the athletes, and the applicability to different events (Docherty & Hodgson, 2007; Koziris, 2012; W. B. Young, 1992).

The following comprehensive review of literature will discuss:

- The underlying mechanisms associated with potentiation
- The complex training principle
- Various lower body potentiation protocols
- The rest intervals examined within the potentiation literature
- Subject characteristics and how they relate to potentiation
- Electromyography research as it relates to potentiation.

Because the primary research questions within this dissertation are concerned with the lower body, the following comprehensive review of literature only discussed lower body potentiation research as upper body potentiation research was considered tangential.

### Underlying Physiological Mechanisms

There are a number of physiological mechanisms that have been proposed to be components of the PAP phenomenon. The underlying mechanisms with the most support include: an increase in the phosphorylation of myosin regulatory light chains (Cochrane et al., 2010; Hodgson et al., 2008; Palmer & Moore, 1989; Rassier & Herzog, 2001; Ryder et al., 2007; Tillin & Bishop, 2009; Vandenboom et al., 1995) and an increase in the level of neuromuscular activation (Burkett et al., 2005; Hamada et al., 2000b; Suzuki et al., 1988; Tillin & Bishop, 2009; Trimble & Harp, 1998). Other proposed mechanisms include a possible change in muscle pennation angle (Mahlfeld et al., 2004; Tillin & Bishop, 2009), and an increase in muscle stiffness (Chu, 1996; Hutton & Atwater, 1992; Shorten, 1987).

Two other factors that should be considered when it comes to potentiated subsequent exercise are joint characteristics and bilateral force production symmetry. Currently, no literature exists on either factor or how they are affected in a potentiated state. If a movement is potentiated, sport scientists should understand what changes occurred allowing for an acute improvement in subsequent exercise performance. Do changes in joint kinematics in a potentiated state allow for greater force production during a countermovement jump? Are greater joint velocities displayed following a strength-power potentiation complex? Does potentiation alter one's bilateral force production symmetry to allow for greater bilateral force production? These are just a few questions that remain unanswered within the scientific literature.

How each of the above mechanisms and factors are affected may determine whether or not subsequent exercise is acutely potentiated. A proposed deterministic model of a potentiated jump is displayed in Figure 2.1.

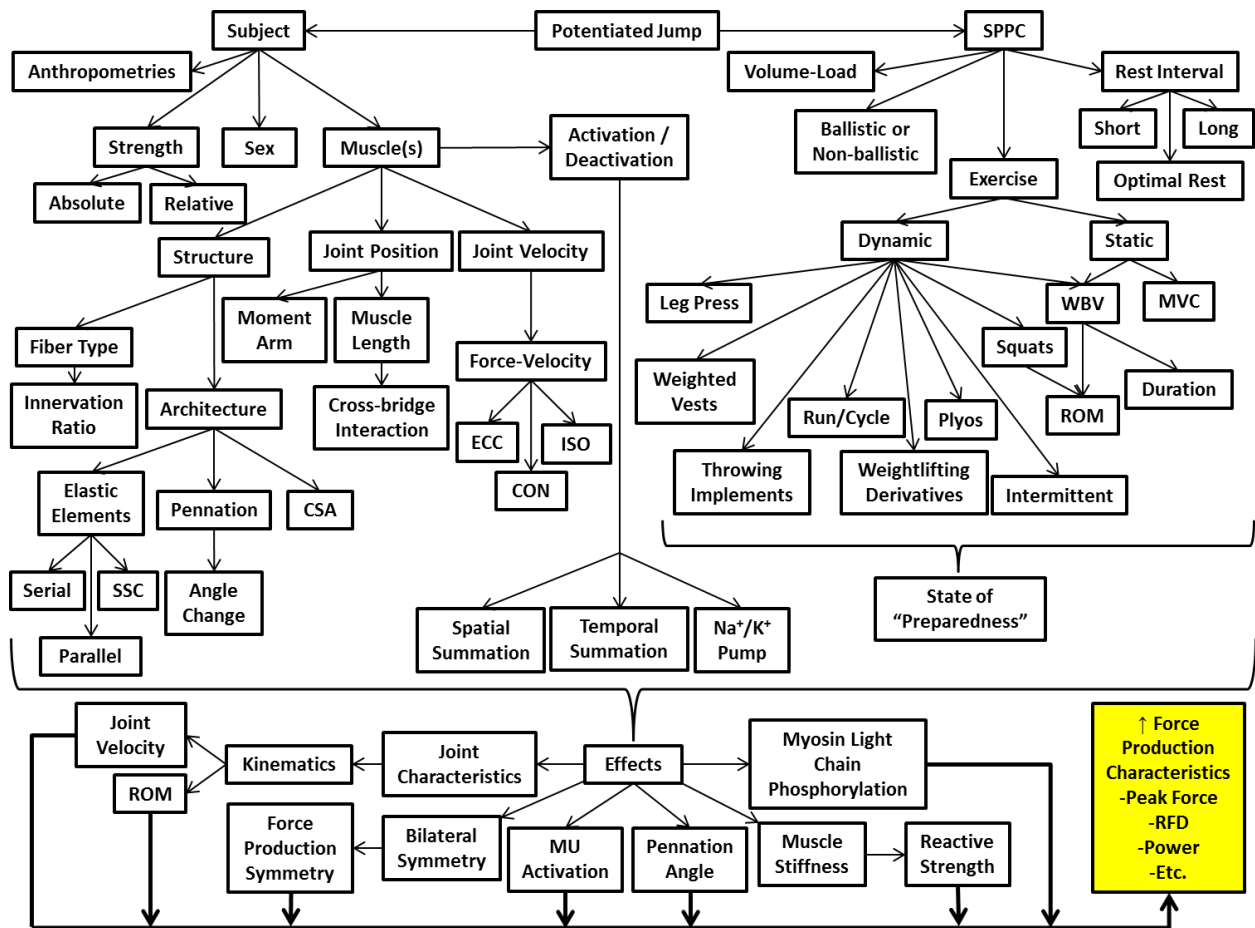


Figure 2.1 Deterministic model of vertical jump potentiation

### Increased Myosin Light Chain Phosphorylation

Much of the potentiation literature has attributed changes in muscular performance to enhanced phosphorylation of the myosin light chains within skeletal muscle. For example, Palmer et al. (1989) concluded that isometric tension potentiation in intact skeletal muscle in mice was due to myosin light chain phosphorylation-induced sensitization of the contractile elements to activation by calcium. From a physiological perspective, an increase in the phosphorylation of myosin light chains is thought to lead to increased calcium sensitivity and cross-bridge formation between thick and thin filaments (Tillin & Bishop, 2009). While the

sensitivity to calcium in thick and thin interactions is increased, the structure of the myosin heads is altered, resulting in a higher force generation state of the cross-bridges that are formed. (Rassier & Macintosh, 2000). In order for phosphorylation of the myosin light chains to occur, skeletal muscle must overcome some limiting factors. A previous study by Ryder et al. (2007) indicated that skeletal muscle myosin light chain kinase is typically the limiting factor for myosin regulatory light chain phosphorylation. However, an earlier study by Houston and Grange (1990) indicated that there is an inconsistent relationship between twitch potentiation and myosin light chain phosphorylation in the in vivo human model. Others have concluded that the state of the muscles prior to and during activity may contribute to how much phosphorylation occurs. Vandenoorn and colleagues (1993) indicated that increased calcium sensitivity exerted its greatest effect on muscle contraction when myoplasmic calcium levels were low during both twitch and low-frequency contractions, but not high frequency tetanic contractions where calcium saturation will typically occur. It is clear that a large body of research supports the notion that the phosphorylation of myosin light chains is the primary contributing factor to improved performance following a potentiating stimulus. While not all research may agree, it is likely that the increased phosphorylation of myosin light chains following a potentiating stimulus contributes in some way to subsequent muscle performance.

### Increased Neuromuscular Activation

As previously noted, there is an abundance of research that supports the viewpoint that increased neuromuscular activation is the primary contributing factor in determining a subsequent muscular performance following a potentiating stimulus. Neural mechanisms may include an increase in motor-unit synchronization, desensitization of alpha motor-neuron input,

and a decreased reciprocal inhibition to antagonist muscles (Chiu et al., 2003; Gullich & Schmidtbleicher, 1996). Gullich and Schmidtbleicher (1996) indicated that previous muscle contractions may increase the excitation potential resulting in an increase in motor unit recruitment. Furthermore, the excitation state can last for several min, leading to increased postsynaptic potentials that lead to enhanced force generation. The increased state of neuromuscular excitation is often viewed by measuring the Hoffmann Reflex (H-reflex). For clarification, the H-reflex has been identified as an excitation potential generated as a segmental spinal reflex that follows maximal impulses to activate the contractile elements of muscle (Chiu et al., 2003). An increased H-reflex is directly proportional to the magnitude of muscle activation and thus, greater muscle activation will result in greater potentiation via the H-reflex. Physiologically, a greater H-reflex is associated with an increase in reflex transmission between Ia afferents and alpha motor neurons, which may then enhance force production by optimizing the reflex contribution of neural drive (Hodgson et al., 2005). From a practical standpoint, the result of enhanced motor neuron excitability can be seen in a large improvement of rate of force development and therefore in power production (Sale, 2002; Vandenboom et al., 1993). Collectively, it appears that a greater neural drive via an increased H-reflex contributes to an enhanced subsequent muscular performance. Furthermore, it appears that potentiation stimuli should focus on increasing neuromuscular activation so that subsequent activities can be enhanced. It should be noted that a recent study has indicated that the PAP following a 10-second maximal voluntary contraction (MVC) cannot be attributed to an increase in neuromuscular activation through the reflex pathway as assessed by the H-reflex (Xenofondos et al., 2014). However, the abundance of previous research that supports an increase in neuromuscular activation as a mechanism of PAP vastly overshadows this one study.

### Change in Pennation Angle

As compared to an increase in the phosphorylation of myosin light chains and an increased neuromuscular activation, only a handful of studies support the view that an enhanced subsequent performance following a potentiation stimulus is attributed to a change in the muscles' pennation angles. Based on the orientation of muscle fibers in relation to connective tissue, the pennation angle will directly affect the transfer of force from muscle tissue to the tendons and bones (Folland & Williams, 2007; Fukunaga, Ichinose, Ito, Kawakami, & Fukashiro, 1997). Furthermore, a decreased pennation angle can create a mechanical advantage likely allowing for improved transfer of force (Folland & Williams, 2007; Fukunaga et al., 1997). From a practical standpoint, if a potentiating stimulus can decrease the pennation angle(s) of the relevant musculature, it may be possible to enhance subsequent performance. Mahlfeld et al. (2004) examined the pennation angle of the vastus lateralis following three 3s isometric maximal voluntary contractions (MVCs). Immediately following the MVCs, the pennation angle ( $15.7^{\circ}$ ) was not statistically different from the pre-MVC values ( $16.2^{\circ}$ ). However, 3-6 min following the MVCs, the pennation angle of the vastus lateralis displayed a statistically significant decrease ( $14.4^{\circ}$ ). Tillin et al. (2009) indicated that the change in pennation angle would only result in a 0.9% increase in the transfer of forces to the tendons, but that this change may contribute to PAP. How potentiating stimuli affect changes in pennation angle and as a result, force transmission to the tendons, remains unclear.

### Increased Muscle Stiffness

An increase in muscle stiffness may allow an individual to become more explosive by altering the muscle's properties, namely its elastic elements (Tillin, Pain, & Folland, 2012).

Specifically, the intrafusal muscle fibers may reset at an increased gain following a contraction (Hutton & Atwater, 1992). Furthermore, tendon organ pathways may undergo a brief period of desensitization, resulting in a greater amount of force generation by the previously contracted muscles during a subsequent activity. Because much of the extant literature has examined heavy resistance training as a method of inducing PAP, previous literature has indicated that an increase in muscle stiffness may be the determining factor in an improved subsequent performance (Chu, 1996; Shorten, 1987). Comyns et al. (2007) indicated that heavy lifting may cause a subsequent fast stretch-shortening cycle activity (drop jump) to be performed with a greater stiffness in leg spring action, ultimately resulting in improved performance. Their study also demonstrated that the heaviest load examined (93% 1RM) during the back squat may increase vertical leg spring stiffness to a greater extent than a lighter load. While the previous literature supports the notion that an increase in muscle stiffness may be an underlying mechanism of potentiation, more scientific evidence may need to be gathered before this mechanism is considered a primary factor in potentiation.

Two other factors that should be considered when it comes to PAP are joint velocity characteristics and bilateral force production symmetry. To the author's knowledge, no previous studies have examined the joint kinematic changes of a bilateral static jump as a result of potentiation. Because muscle stiffness has been identified as an underlying mechanism of potentiation, it would make sense that joint kinematics may change based on the physiological state of the muscles involved. For example, it is possible that while potentiated, an individual may have recruited more motor units allowing for greater force and rate of force production. The ability to produce greater values of force and rate of force production may change the concentric angular velocity of the lower body, possibly allowing for greater jump height.

Although previous research has not investigated bilateral strength symmetry during jumps and the effect on jump performance, a previous study by Bailey et al. (2013) reported a statistically significant moderate to strong negative relationships between peak force symmetry and jump height and peak power, indicating that higher jump values were observed with those who possess more symmetrical peak force values. Whether a potentiating stimulus causes acute changes in bilateral force production symmetry remains unknown. However, if bilateral force production symmetry is changed following a potentiating stimulus, jumping performance may be affected. In order to understand what causes acute changes in performance, it is necessary to investigate all potential mechanisms that may contribute.

### Complex Training

The PAP phenomenon is based on a specific training method termed complex training. Complex training (CT) has been described as a method of training that involves completing a resistance exercise prior to performing a ballistic exercise that is biomechanically similar (Comyns et al., 2007; Hodgson et al., 2005; Robbins, 2005). Complex training was developed in an attempt to allow participants to perform high force or power exercises at a higher intensity (Chu, 1996; Docherty, Robbins, & Hodgson, 2004; Ebben, Jensen, & Blackard, 2000; Verkoshansky, 1986), thus creating a superior training stimulus. It has been suggested that the enhanced training stimulus that results from CT during each training session may result in superior performance gains longitudinally in comparison to the implementation of normal training methods (Chu, 1996; Docherty et al., 2004; Ebben & Blackard, 1997; Ebben & Watts, 1998). Therefore, it may be possible to produce chronic adaptive responses that are beneficial to the athlete with the use of complex training (Ebben, 2002).



Although PAP is based on CT principles, protocols designed to produce a potentiated state are termed strength-power potentiating complexes (SPPCs) (Robbins, 2005; Stone et al., 2008). Specifically, SPPCs involve the performance of a high force or high power movement that is used to enhance, or potentiate, a high power or high velocity movement that follows. Although a few CT training studies have been conducted (Ingle, Sleaf, & Tolfrey, 2006; Santos & Janeira, 2008; Verkhoshansky & Tatyana, 1973), no training study has examined the effectiveness of applying PAP principles to resistance training programs or concluded that PAP produced a superior training stimulus as compared to other training protocols (Docherty & Hodgson, 2007). It is thought that CT will provide a broader range of stimuli that will ultimately stimulate greater adaptations in both speed and strength (Jones & Lees, 2003).

#### Lower Body Potentiation Protocols

There are a number of exercises and methods that can be used to improve lower body muscular strength and power. Similarly, there is also an abundance of lower body SPPCs and methodology that has been investigated with the intent to produce a potentiated state in which an athlete can acutely improve their subsequent performance during various explosive movements such as jumping and sprinting. However, it should be noted that different types of muscle actions during potentiation protocols may elicit different effects on the subsequent explosive performances (Tillin & Bishop, 2009). In fact, a recent meta-analysis by Wilson et al. (2013) indicated that statistical differences existed between different loading intensities and the number of sets used to bring about a state of potentiation with their results indicating that moderate loads (60-84%) produced a greater effect size ( $d = 1.06$ ) than heavier loads (>85%;  $d = 0.31$ ) and that multiple exercise sets produced a greater effect size ( $d = 0.66$ ) than single sets ( $d = 0.24$ ). Much

of the current PAP research was conducted in order to identify various protocols that improved subsequent performance. The following section will discuss the previous research that has examined various potentiation protocols that have included maximal voluntary contractions (MVCs), back squats, half-squats, quarter-squats, front squats, whole-body vibration, plyometrics, weightlifting exercises and their variations, running and cycling, heavy implements, weighted vests, intermittent exercise, and the leg press as the conditioning activities used to examine the PAP phenomenon.

### Maximal Voluntary Contractions

It has been suggested that MVCs may be more practical than isoinertial or dynamic exercises for both training and performance (French, Kraemer, & Cooke, 2003). As a result, a number of previous studies have implemented various protocols involving MVCs in order to investigate the effect on subsequent lower body performance. Maximal voluntary contractions typically involve a subject providing maximal muscular effort during a movement in which joint angles of the body segments in question do not move. In addition, subjects are asked to provide maximal effort for a given period of time. Length of MVC protocols have ranged from three (Babault, Maffiuletti, & Pousson, 2008) to 30s (Masiulis et al., 2007). Some studies have found a PAP-induced improvement in performance following the MVC while others have not. A summary of studies that have implemented an MVC protocol to bring about a potentiated state is displayed in Table 2.1.

Table 2.1 *Studies that Implemented MVC Protocols to Induce Potentiation*

Author	n (training status)	Intervention	Rest interval	Results
Arabatzi et al. (2014)	NS	3 x 3s MVC squats	20s, 4 min	↑ RFD as age increased in both males and males ↑ SJ performance only in men

Table 2.1 (continued)

Babault et al. (2008)	9 (NS)	3s MVC of knee extension	5s	No effect on SJ performance in teen-males, boys, and female groups ↑ RFD in both adult groups and teen-males No change in RFD in children ↑ Shortening angular velocity at 30°/s and 150°/s ↓ Lengthening angular velocity compared with isometric conditions
Batista et al. (2011)	23 (TR)	1 or 3 5s MVCs of leg press	4 min	No differences in CMJ height or take-off velocity existed between groups
Baudry & Duchateau (2007b)	10 (NS)	6s MVC of thumb adductors	5s, 1, 2, 3, 4, 5, 10 min	↑ RFD for twitch, tetanus, and ballistic contraction ↑ Twitch at 5s, ballistic at 1 min
Baudry & Duchateau (2007a)	10 (NS)	6s MVC of thumb adductors	5s, 1, 2, 3, 4, 5, 10 min	↑ Peak angular velocity for the different loads and twitch
Baudry et al. (2005)	10 (NS)	6s MVC of tibialis anterior	Imm, 0-20 min	↑ Twitch torque, maximal RFD, and relaxation in both young and elderly subjects
Behm et al. (2004)	9 (RT)	1, 2, or 3 10s MVCs of knee extension	1, 5, 10, 15 min	No change in MVC force following 1 or 2 MVCs at 10 and 15 min ↓ MVC force after 3 MVCs at 10 and 15 min ↑ Twitch potentiation after 3 MVCs as compared to 1 or 2 MVCs at 5 and 10 min
Bogdanis et al. (2014)	14 (TR)	3 x 3s MVC half-squat	15s, 2, 4, 6, 8, 10, 12, 15, 18, 21 min	↑ in CMJ performance as compared to baseline performance
de Lima et al. (2014)	23 (RT)	1 x 5s MVC of knee extensors	3min	↑ isometric peak torque, rate of torque development, and normalized root mean squared of vastus lateralis and ↓ time to peak torque of knee extensors during 5s MVC of knee extensors
Etnyre & Kinugasa (2002)	12 (NS)	3s MVC of knee extension	0.5, 1, 2, 3s	↑ Reaction, processing, muscle contraction time
Feros et al. (2012)	10 (TR)	5 x 5s MVCs at 110° knee angle	4 min	Faster 500m split time ↑ Mean power 0-500m ↑ Mean stroke rate 0-500m and 0-1000m No difference in time or mean power 0-1000m
Folland et al. (2008)	8 (RT)	10s MVC of quadriceps	0-18 min	No differences in RFD existed between 10s MVC and control ↑Hmax/Mmax Ratio after 10s MVC at 5, 7, 9, 11 min compared to control ↑ % change of Hmax/Mmax after 10s MVC at 5, 7, 9, 11, 13 min compared to control ↑ Twitch force at Hmax after 10s MVC at 5, 7, 9 min compared to control
French et al.	14 (TR)	3 x 3s or 5s	Imm	↑ DJ height, peak force, and acceleration

Table 2.1 (continued)

(2003)		MVC of knee extensors		impulse after 3s MVCs No change in DJ after 5s MVCs No changes in CMJ ↑ Peak torque during isokinetic knee extensions after 3s MVCs, but ↓ after 5s MVCs No changes in 5s cycle sprint No changes in EMG of vastus medialis No difference in peak torque between MVCs ↑ Rate of torque development and rate of relaxation No difference in contraction time or half relaxation time
Froyd et al. (2013)	5 (RT)	1 x 5s MVC of knee extensors repeated 4 times	Electric stimulation at 4s, 8s, 12s, 16s, 30s after each MVC	No difference in peak torque between MVCs ↑ Rate of torque development and rate of relaxation compared to pre-MVC values No difference in half relaxation time compared to pre-MVC values ↓ Contraction time compared to unpotentiated muscle No difference in electromechanical delay at any time point
Froyd et al. (2013)	6 (RT)	1x 5s MVC of knee extensors every minute for 10 min	Electric stimulation at 4s, 8s, 12s, 16s, 30s, and 45s after each MVC	↑ Maximal voluntary concentric torque after MVCs in fast condition (180°/s) compared to the slow condition (30°/s) No change in maximal voluntary concentric torque in slow condition ↑ M-wave amplitude of SOL Imm after Differences in Root mean squared EMG of lateral G existed between conditions ↓ SOL root mean squared EMG Imm after
Fukutani et al. (2013)	12 (UT)	3 x 6s MVC of plantar flexors	Imm, 1, 5 min	No differences in joint angle No change in velocity or peak power of knee extensions for any load
Gossen & Sale (2000)	10 (RT)	10s MVC of knee extension	Imm on 2 occasion	↑ VJ height at both 3 and 5 min, but greater at 5 min ↑ DJ flight heights ↑ H-reflex between 4 and 11 min ↑ Twitch peak torque ↑ M-wave up to 1 min
Gullich & Schmidtbleicher (1996)	36 (TR)	5s MVCs using leg press	3, 5 min	
Hamada et al. (2000b)	21 (RT)	10s MVC of knee extensors	30s, 5 min	
Hamada et al. (2000a)	40 (TR, RT, UT)	10s MVC of ankle plantar flexors	0-5 min	↑ Maximal twitch evoked contraction PAP in triathletes vs. sedentary
Higuchi et al. (2013)	24 (TR)	2 x 5s MVC pulls each with lead and trail batting hands	1 min	↑ Bat velocity acutely, chronically after 8 weeks of training
Hodgson et al.	13 (TR)	3 x 5s MVC	Imm, 30s, 1-	↑ Mean twitch torque at 30s and 1.5, 3.5,

Table 2.1 (continued)

(2008)		of plantar flexors	11 min	4.5, 6.5, 8.5, 9.5, 10.5 min compared to control
Iglesias-Soler et al. (2011)	14 (RT)	7s at 10% MVC 7s MVC 10s at 10% MVC 10s MVC	5s, 4, 10 min	↑ Mechanical power of explosive plantar flexion only with 10s MVC at 4 min
Lim & Kong (2013)	12 (TR)	3 reps of 3s MVC of knee extension 3 reps of 3s MVC back squat	4 min	No sprint time differences between protocols
Masiulis et al. (2007)	8 (UT)	30s MVC of knee extension 60s of 50% MVC using electrical stimulation	Imm, 1 min	↑ Potentiation during 30s MVC condition Imm and after 1 min recovery ↑ Half relaxation time after 50% MVC condition ↑ 10Hz force after 30s MVC condition
Miyamoto et al. (2010)	9 (RT)	10s MVC of plantar flexion	Imm, 1, 2, 3, 4, 5 min	↑ Twitch torque Imm after MVC compared to 5 min No effect of time or condition for M-wave amplitude ↑ Isokinetic peak torque at 1, 2, 3 min in MVC condition ↓ Medial G EMG activity Imm after MVC
Miyamoto et al. (2013)	21 (UT)	5s MVC of knee extension	1, 3, 5 min	↑ Isometric MVC torque following 12 weeks of resistance training compared to control ↑ Twitch potentiation in resistance trained group immediately after MVC No effect on M-wave amplitude
O'Leary et al. (1998)	20 (UT)	7s of tetanic stimulation of ankle dorsiflexors	0 – 5 min	No sex differences in twitch peak torque Sex differences in fatigueability and twitch/tetanus ratio existed
O'Leary et al. (1997)	20 (UT)	7s of tetanic stimulation of ankle dorsiflexors	0 – 5 min	↑ Twitch peak torque at 5s, 1 min, 2 min, and 5 min ↑ M-wave amplitude at 2 min
Paasuke et al. (1998)	23 (TR)	10s MVC of plantar flexors	NS	↑ Maximal twitch force, rate of twitch force rise, and relaxation in resting and potentiated in power athletes compared to endurance athletes No differences in twitch contraction or half-relaxation times
Paasuke et al. (2007)	36 (TR, UT)	10s MVC of knee	0 – 15 min	↑ Twitch peak torque, rate of torque development, and relaxation at 2s

Table 2.1 (continued)

		extensors		↑ Twitch peak torque for endurance athletes at 1 min and for untrained women and power trained subjects at 5 min No change in twitch contraction and half-relaxation times
Requena et al. (2008)	12 (RT)	7s MVC 7s 25% MVC voluntary contraction 7s 25% MVC tetanic contraction	0 – 10 min	↑ Peak torque Imm after 7s MVC ↑ Peak torque after MVC vs. 25% MVC tetanic contraction at 1 min No difference in peak torque in 25% MVC voluntary contraction condition ↑ Peak torque after 25% MVC tetanic contraction between 3-10 min
Requena et al. (2011)	14 (TR)	10s MVC of knee extensors	Imm,	↑ Twitch peak torque, maximum rate of torque development, and relaxation Negative correlations existed between 15m sprint time and CMJ, SJ heights. ↑ CMJ height and power
Rixon et al. (2007)	30 (TR, RT, UT)	3 x 3s MVC squat	3 min	No effect on CMJ performance
Robbins & Docherty (2005)	16 (RT)	3 x 7s MVC squat	4 min	No effect on explosive repetitions at 70% 1RM knee extension
Smith & Fry (2007)	11 (RT)	10s MVC knee extension	7 min	No effect on sprints or VJ height
Till & Cooke (2009)	12 (TR)	3 x 3s MVC knee extensions	Sprints at 4, 5, 6 min; VJ at 7, 8, 9 min	↑ CMJ power in men vs. no change in women ↓ Peak leg power at 8 and 12 min
Tsolakis & Bogdanis (2011)	23 (TR)	3 x 3s MVC knee extensions	Imm, 4, 8, 12 min	↑ Peak isometric force with 139° vs. 91° MVC squats ↑ CMJ performance after 139° MVC squats at 3, 6, 9, 12 min No change in CMJ performance after 91° MVC squats
Veligeakas et al. (2013)	13 (TR)	3 x 3s MVC squat at knee angle of either 91° or 139°	15s, 3, 6, 9, 12 min	No difference in SJ or DJ performance
Young & Elliott (2001)	14 (TR)	3 x 5s MVC of plantar flexors and knee extensors	4 min	

**Note:** CMJ, countermovement jump; DJ, drop jump; G, gastrocnemius; Imm = immediately following intervention; NS, training status not specified; RFD, rate of force development; RM, repetition maximum; RT, subjects reported as recreationally trained; SJ, squat jump; SOL, soleus; TR, subjects reported to be those who have trained at least twice per week for one year or athletes; UT, untrained subjects who have not participated in any resistance training over the previous year; VJ, vertical jump

Because an abundance of SPPCs that include MVCs have been investigated and shown mixed results, it is difficult to draw conclusions about SPPCs that involve MVCs. However, 31 out of 41 studies above (75.6%) displayed an improvement in some performance measure,

making a case that MVC-based SPPCs can be effective at producing a potentiated state.

Researchers should be aware however, that positive and negative changes in performance as a result of the SPPC may have resulted from the rest interval following the MVC. In order to determine if specific MVC-based SPPCs are effective, replication studies using previously established protocols are needed. Furthermore, a meta-analysis regarding the effectiveness of MVC-based SPPCs may be warranted.

### Back Squats

Back squats are a staple in many strength training programs. As such, it is not surprising that a large number of studies have examined the ability of various back squat protocols to produce potentiated subsequent exercise. An interesting aspect of the examined protocols is the wide range of loads examined among the studies. For example, back squat loads as low as 40% one repetition maximum (1RM) (Hanson, Leigh, & Mynark, 2007) and as high as 150% 1RM (Berning et al., 2010) have been examined within the back squat PAP literature. A summary of studies that have implemented a back squat protocol to bring about a potentiated state is displayed in Table 2.2.

Table 2.2 *Studies that Implemented Back Squat Protocols to Induce Potentiation*

Author	n (training status)	Intervention	Rest interval	Results
Andrews et al. (2011)	19 (TR)	3 x 3 at 75% 1RM	3 min	↓ CMJ vertical displacement during third set
Berning et al. (2010)	21 (TR, UT)	Functional isometric squat with 150% 1RM	4, 5 min	↑ CMVJ height in trained subjects No difference in CMVJ height in untrained subjects
Bevan et al. (2010)	16 (TR)	1 x 3 at 91% 1RM	4, 8, 12, 16 min	No main effect of time on sprint performance ↑ Sprint performance with individuals
Buttifant & Hrysomallis (2015)	12 (TR)	3 x 3 at 3RM 3 x 3 with high resistance bands	5, 10 min	↑ Jump squat power with both squat protocols No difference between squat protocols
Chiu et al.	24 (TR, RT)	1 x 5 at 90%	5 and 18.5 min	No effect on jump squats, but athletes

Table 2.2 (continued)

(2003) Comyns et al. (2010)	11 (TR)	1RM 1 x 3 at 3RM	4 min	had greater % ↑ 30m sprint in Session 1 slower than baseline ↓ Max and average velocity after Session 1 ↑ Velocity at 20m and 30m from Session 1 to 4
Comyns et al. (2007)	12 (TR)	1 x 3 at 65% 1RM 1 x 3 at 80% 1RM 1 x 3 at 93% 1RM	4 min	↓ DJ contact time after 93% squats ↑ Vertical leg spring stiffness after 93% squats ↓ Flight time after 65%, 80%, and 93% squats ↓ Reactive strength index after 65% squats
Comyns et al. (2006)	18 (TR)	1 x 5 at 5RM	30s, 2, 4, 6 min	No change in peak force No change in peak force ↓ Flight time in entire group and women at 30s and 6 min
Crewther et al. (2011)	9 (TR)	1 x 3 at 3RM	15s, 4, 8, 12, 16 min	No sex differences ↓ CMJ height at 15s and 16 min ↑ CMJ height at 4, 8, 12 min No change in sled push performance, sprint splits ↑ Relative changes in CMJ height than 3m sled push and 5m, 10m sprint tests
de Villarreal et al. (2007)	12 (TR)	2 x 4 at 80% 1RM, 2 x 2 at 85% 1RM (A) 2 x 4 at 80% 1RM, 2 x 2 at 90% 1RM, and 2 x 1 at 95% 1RM (B) 3 x 5 at 30% 1RM (C)	5 min, 6 hrs	↑ CMJ height after A and B at 5 min ↑ DJ height after A and B at 5 min and 6 hrs ↑ Loaded CMJ height after A and B at 5 min No difference in CMJ, DJ, or loaded CMJ after C
El Hage et al. (2011)	17 (RT)	1 x 3 at 85% 1RM 1 x 1 at 100% 1RM	Imm, 2, 4 min	↓ DJ height
Esformes et al. (2013)	27 (TR)	1 x 3 at 3RM	5 min	↑ Jump height, impulse, peak power, and flight time
Evetovich et al. (2015)	20 (TR)	1 x 3 at 85% 1RM	8 min	↑ VJ and horizontal jump performance
Evetovich et al. (2015)	10 (TR)	1 x 3 at 3RM	8 min	No difference in shot put performance
Evetovich et al. (2015)	7 (TR)	1 x 3 at 3RM	8 min	↑ 36.6 meter sprint performance
Evetovich et al. (2015)	11 (TR)	1 x 3 at 3RM	8 min	No difference compared to control condition
Fukutani et al. (2014)	8 (TR)	Heavy: 1 x 3 at 90% 1RM Moderate: 1 x 3 at 75% 1RM	60s	↑ Twitch torque in both Heavy and Moderate conditions, but greater ↑ after Heavy ↑ CMJ height after both Heavy and Moderate conditions, but greater ↑ after



Table 2.2 (continued)

				Heavy No effect on M-wave amplitude or root mean squared for any muscle in either condition
Gilbert & Lees (2005)	15 (TR)	5 x 1 at 100% 1RM 5 x 1 at Max Power	1, 2, 3, 9, 10, 11, 19, 20, 21, 59, 60, 61 min	↓ RFD at 2, 10 min after 100% squats ↑ RFD at 15, 20 min after 100% squats ↑ RFD at 2 min after Max Power squats
Hanson et al. (2007)	30 (TR)	1 x 8 at 40% 1RM 1 x 4 at 80% 1RM	5 min	No difference in maximal force No effect on VJ performance
Hirayama (2014)	14 (TR)	1 x 1 at 20%, 40%, 60%, 80% 1RM and 6s MVC half-squat	1 min after each set	↑ VJ height after 60%, 80%, and MVC squats ↑ VJ height after MVC squat vs. 60% and 80% squats ↑ VJ height after 80% squat vs. 60% squat
Jensen & Ebben (2003)	21 (TR)	1 x 5 at 5RM	10s, 1, 2, 3, 4 min	↓ Jump at 10s No effect at 1-4 min
Jones & Lees (2003)	8 (TR)	1 x 5 at 85% 1RM	Imm, 3, 10, 20 min	No main effects for CMJ performance or EMG activity No main effects on DJ performance ↑ Biceps femoris activity during propulsive phase of DJ
Khamoui et al. (2009)	16 (TR)	1 x 2-5 at 85% 1RM	5 min	No effect on VJ height or take-off velocity ↓ Force and impulse
Kilduff et al. (2011)	9 (TR)	1 x 3 at 87% 1RM	Imm, 4, 8, 12, 16 min	↑ Peak power and jump height at 8 min than all other time intervals ↓ Peak power and jump height Imm after squats ↑ Peak vertical and horizontal force after squats compared to swim-specific warm-up
Kilduff et al. (2008)	20 (TR)	3 x 3 at 87%	15s, 4, 8, 12, 16, 20, 24 min	↓ Jump height 15s ↑ Power output, RFD, and jump height at 8 min than all other time intervals
Kilduff et al. (2007)	23 (TR)	1 x 3 at 3RM	15s, 4, 8, 12, 16, 20 min	↓ CMJ at 15s ↑ CMJ at 8-12 min
Koch et al. (2003)	32 (TR, RT)	1 x 3 speed squats at 20, 30, 40% 1RM; 1 x 3 at 50, 75, 89.5% 1RM	Imm, 15 min	No effect on broad jump
Lim & Kong (2013)	12 (TR)	1 x 3 at 90% 1RM	4 min	No difference in 30m performance
Low et al. (2014)	16 (TR)	1 x 3 at 91% 1RM	8 min	↑ Repeated anaerobic sprint test performance with heavy squats compared to control
Lowery et al. (2012)	13 (TR)	1 x 5 at 56% 1RM 1 x 4 at 70% 1RM	Imm, 0, 2, 4, 8, 12 min	No change in VJ power after 56% squats ↓ VJ power Imm after 70% and 93% squats

Table 2.2 (continued)

		1 x 3 at 93% 1RM		↑ VJ power 4 min after 70% squats ↑VJ power 4, 8 min after 93% squats No difference in VJ height and power between 70% and 93% squats ↑ 40m sprint speed
McBride et al. (2005)	15 (TR)	1 x 3 at 90% 1RM	4 min	
McCann & Flanagan (2010)	16 (TR)	1 x 5 at 5RM	4, 5 min	↑VJ height No time effect No sex differences in VJ height or peak force
Miarka et al. (2011)	8 (TR)	5 x 1 at 95% 1RM 3 x 2 at 90% 1RM with 5 horizontal jumps	3 min	No difference in number of throws, index of heart rate and throws, heart rate after, and heart rate 1 min after Special Judo Fitness Test
Mina et al. (2014)	16 (RT)	2 x 3 at 85% 1RM 2 x 3 at 85% 1RM with variable resistance elastic bands	5 min	No differences in peak or mean EMG between protocols during warm-ups No differences in peak or mean knee angular velocities between protocols during warm-ups ↑ knee flexion angle following variable resistance protocol during warm-ups ↑ 1RM by 81% of subjects following variable resistance protocol No difference in 1RM following regular protocol ↓ peak and mean knee angular velocities during eccentric and concentric phases following variable resistance compared to regular protocol ↑ CMJ height and peak twitch
Mitchell & Sale (2011)	11 (TR)	1 x 5 at 5RM	4 min	
Moir et al. (2011)	11 (TR)	1 x 3 at 90% 1RM 1 x 12 at 37% 1RM	2 min	No difference in CMJ height or vertical stiffness between protocols
Moir et al. (2009)	10 (TR)	1 x 10 at 40% 1RM 1 x 8 at 50% 1RM 1 x 6 at 60% 1RM 1 x 2 at 80% 1RM	2, 4, 6, 8, 10 min	No difference vertical stiffness or force between protocols
Mola et al. (2014)	22 (TR)	1 x 3 at 3RM	15s, 4, 8, 12, 16, 20 min	No difference in CMJ peak power or jump height between experimental and control No time effect existed for peak power and jump height
Nibali et al. (2011)	11 (TR)	1 x 5 at 5RM	30s, 2, 4, 6, 8, 10, 12 min	No difference in peak power at any time point despite small and moderate substantial differences
Radcliffe &	35 (TR)	4 x 4 at 75-85%	3 min	No change in performance compared to

Table 2.2 (continued)

Radcliffe (1996)		4RM		standard warm-up
Rahimi (2007)	12 (TR)	2 x 4 at 60% 1RM (A) 2 x 4 at 70% 1RM (B) 2 x 4 at 85% 1RM (C)	4 min	↓ 40m sprint time during each squat protocol ↓ 40m sprint time after C compared to A
Reardon et al. (2014)	11 (RT)	3 x 10 at 75% 1RM 3 x 3 at 90% 1RM 1 x 1 at 100% 1RM	8, 20 min	No change in VJ height, peak power, or average power for any protocol No change in rectus femoris or vastus lateralis cross-sectional area or pennation angle
Ruben et al. (2010)	12 (NS)	1 x 3 at 90% 1RM	5 min	↑ Average jump height, maximum jump height, average power, peak power, average force, and peak force
Scott & Docherty (2004)	19 (TR)	1 x 5 at 5RM	5 min	No acute or linear improvement in VJ or horizontal jump performance
Seitz et al. (2014a)	18 (TR)	1 x 3 at 90% 1RM	15s, 3, 6, 9, 12 min	↓ SJ power at 15s for both strong and weak groups ↑ SJ power at 3, 6, 9, 12 min in strong group ↑ SJ power at 6, 9, 12 min in weak group
Seitz et al. (2014c)	13 (TR)	1 x 3 at 90% 1RM	7 min	↑ 20m sprint performance, velocity, and average acceleration
Smith et al. (2001)	9 (TR)	10 x 1 at 90% 1RM	5, 20 min	↑ Average power and relative average power during 10s sprint cycle test at 5 min compared to control ↑ Relative average power during 10s sprint cycle test at 5 min compared to 20 min
Sole et al. (2013)	10 (TR)	1 x 3 at 90% 1RM	4, 8, 12 min	No difference in stride length, stride frequency, stance time, and flight time between squat protocol and control during agility test
Sygulla & Fontaine (2014)	29 (TR)	1 x 3 at 90% 1RM	5 min	No difference in SJ height or peak power
Weber et al. (2008)	12 (TR)	1 x 5 at 85% 1RM	3 min	↑ Peak and mean jump height and force of 7 consecutive SJs
West et al. (2013)	36 (TR)	3 x 3 at 87% 1RM	8 min	↑ CMJ peak power after both active and passive recovery ↑ Delta and % change in peak power after passive recovery as compared to active recovery
Witmer et al. (2010)	24 (TR, RT)	1 x 3 at 70% 1RM	3, 6, 9, 12, 15, 18, 21, 24, 27, 30 min	No difference in VJ height or stiffness compared to control for neither sex No difference in responses between men and women
Yetter & Moir (2008)	10 (TR)	1 x 3 at 70% 1RM	4 min	↑ Speed during 10-20m and 30-40m intervals compared to control

No difference in average speed during  
0-10m interval.

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**Note:** CMJ, countermovement jump; DJ, drop jump; EMG, electromyography; Imm, immediately following intervention; NS, training status not specified; RFD, rate of force development; RM, repetition maximum; RT, subjects reported as recreationally trained; SJ, squat jump; TR, subjects reported to be those who have trained at least twice per week for one year or athletes; UT, untrained subjects who have not participated in any resistance training over the previous year; VJ, vertical jump

Because an abundance of SPPCs that include back squats have been investigated and shown mixed results, it is difficult to draw conclusions about SPPCs that involve back squats. Only 31 out of 53 studies above (58.5%) displayed an improvement in some performance measure, indicating that SPPCs that include a back squat protocol are effective just over half the time at producing a potentiated performance. A number of factors can affect these results, including the back squat protocol itself, training status of the subjects, and the rest intervals used. In order to determine if specific SPPCs that include back squats are effective, replication studies using previously established protocols are needed. Furthermore, a meta-analysis regarding the effectiveness of back squat-based SPPCs may be warranted.

### Half-Squats

In addition to the abundance of back squat protocols displayed above, half-squat protocols have also been examined as PAP stimuli. Similar to the above back squat protocols, the loads examined within the various half-squat protocols also varied ranging from 30% 1RM (Smiliou, Piliandis, Sotiropoulos, Antonakis, & Tokmakidis, 2005) to 90% 1RM (Chaouachi et al., 2011; Dechechi et al., 2013; Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003). In addition, the depth of the half-squats performed has also been variable within the literature. Some research has specified that their half-squats were performed to a knee angle of 90° while in a Smith machine (Chatzopoulos et al., 2007). However, Mangus et al. (2006) failed

to specify the depth of their half-squats position, resulting in questions regarding their methodology. A summary of studies that have implemented a half-squat protocol to bring about a potentiated state is displayed in Table 2.3.

*Table 2.3 Studies that Implemented Half-Squat Protocols to Induce Potentiation*

Author	n (training status)	Intervention	Rest interval	Results
Bogdanis et al. (2014)	14 (TR)	Equal Impulse of: Concentric-only half-squats at 90% 1RM Eccentric half-squats at 70% 1RM	15s, 2, 4, 6, 8, 10, 12, 15, 18, 21 min	No change in CMJ performance after either protocol as compared to baseline values at any time point
Boulossa et al. (2013)	12 (RT)	1 x 5 at 5RM (Traditional) 1 x 5 at 5RM with 30s between reps (Cluster)	1, 3, 6, 9, 12 min	No main effects for CMJ parameters ↑ Peak power after Cluster set at 1 min ↑ Peak power after Traditional at 9 min
Boyd et al. (2014)	10 (TR)	1 x 1 at 150% 1RM functional isometric 1 x 3 at 150% 1RM	2, 5, 8, 11 min	No differences between protocols in peak force, power, displacement, velocity at any time point ↑ peak force following squat protocols for combined condition CMJ data ↓ peak power following squat protocols for combined condition CMJ data
Chaouachi et al. (2011)	12 (TR)	1 x 10 at 70% 1RM 1 x 5 at 70% 1RM 1 x 5 at 85% 1RM 1 x 3 at 85% 1RM 1 x 3 at 90% 1RM 1 x 1 at 90% 1RM	1, 2, 3, 5, 10, 15 min	No differences between protocols in jump height, peak power, force, velocity, or mean power at any time point
Chatzopoulos et al. (2007)	15 (TR)	10 x 1 at 90% 1RM	3, 5 min	↑ Speed 0-10m and 0-30m at 5 min No difference in 0-10 or 0-30m speed at 3 min
Dechechi et al. (2013)	10 (TR)	1 x 3 concentric at 90% 1RM 1 x 3 eccentric at 90% 1RM	4 min	↓ 50m sprint time after concentric squats No difference in 50m sprint time after eccentric squats
Duthie et al. (2002)	11 (TR)	Complex: 3 x 3 at 3RM half-squats before jump squats at 30% 1RM Contrast: Alternating 1 x 3 at 3RM half-squats and jump squats at 30% 1RM for 3 sets Traditional: All jump	5 min	No differences between protocols in mean jump height, peak power, or peak force ↑ Mean peak power after Traditional vs. Complex No differences in mean jump height between sets for any protocol

Table 2.3 (continued)

		squats at 30% 1RM completed before 3 x 3 half-squats at 3RM		No difference in mean peak force between sets with Traditional and Complex protocols ↑ CMJ height for single tests only No differences in VJ height between groups.
Esformes et al. (2010)	13 (TR)	1 x 3 at 3RM	5 min	
Gonzalez-Rave et al. (2009)	24 (UT)	3 x 4 at 85% 1RM 3 x 4 at 85% 1RM and 3 static stretches held for 15s	NS	
Gourgoulis et al. (2003)	20 (NS)	1 x 2 at 90% 1RM	Imm	No difference in power ↑ CMJ height
Linder et al. (2010)	12 (TR)	1 x 4 at 4RM	9 min	↑ Sprint speed
Mangus et al. (2006)	11 (TR)	1 x 1 at 90% 1RM	3 min	No difference in CMJ performance compared to control condition
Okuno et al. (2013)	12 (TR)	5 x 1 at 90% 1RM	5 min	↑ Repeated sprint ability-best ↑ Repeated sprint ability-mean No difference in repeated sprint ability-index
Rixon et al. (2007)	30 (TR, RT, UT)	1 x 3 at 3RM	3 min	↑ CMJ power compared to pretest
Smilios et al. (2005)	10 (TR)	3 x 5 at 30% 1RM 3 x 5 at 60% 1RM	1, 5, 10 min after 1 set and 5, 10 min after 3 sets	↑ CMJ with both low and moderate loads
Sortiropoulos & Smilios (2010)	26 (TR)	1 x 5 at 25% 1RM, 1 x 5 at 35% 1RM (A) 1 x 5 at 45% 1RM, 1 x 5 at 65% 1RM (B)	3 min	No difference between groups A and B in CMJ height or power
Talpey et al. (2013)	18 (RT)	Contrast: Alternated 1 x 4 half-squat at 5RM and 4 CMJs for 3 sets Complex: 3 x 4 at 5RM and then 3 sets of 4 CMJs	4 min	No difference in peak power between protocols.
Young et al. (1998)	10 (TR)	1 x 5 at 5RM	4 min	↑ Loaded CMJ

**Note:** CMJ, countermovement jump; DJ, drop jump; Imm, immediately following intervention; NS, training status not specified; RM, repetition maximum; RT, subjects reported as recreationally trained; TR, subjects reported to be those who have trained at least twice per week for one year or athletes; UT, untrained subjects who have not participated in any resistance training over the previous year; VJ, vertical jump

Because mixed results within the number of half-squat SPPCs have been shown, it is difficult to draw conclusions about SPPCs that involve half-squats. However, 12 out of 17 studies above (70.6%) displayed an improvement in some performance measure, indicating that SPPCs that include half-squats are frequently effective at producing a potentiated state. Again,

researchers need to be aware that the half-squat protocol, rest interval(s), and subject characteristics may interfere with whether or not potentiation occurs. It is recommended that further research, including replication studies, should be completed using previously established protocols. Furthermore, a meta-analysis examining half-squat protocols as a part of SPPCs may be warranted.

### Quarter-Squats

Despite the large amount of different back squat and half-squat protocols, several studies have examined quarter-squats (Crum, Kawamori, Stone, & Haff, 2012; Ebben, Wurm, Garceau, & Suchomel, 2013; Esformes & Bampouras, 2013; Mangus et al., 2006). As with the previously listed back squat and half-squat protocols, the loads examined within the quarter-squat PAP literature have also varied with loads ranging as low as 60% 1RM of a subject's quarter-squat (Crum et al., 2012) to as high as 120% of the subject's 1RM back squat (Ebben et al., 2013). Crum et al. (2012) investigated the effects of a moderately loaded (60% 1RM quarter-squat), concentric-only quarter-squat (knee angle starting at 135°) on CMJ performance at various time intervals. The authors found no statistical difference in CMJ performance following the concentric-only quarter-squats, regardless of the rest interval. It should be noted that the authors indicated that the lack of eccentric component in their quarter-squat may have led to their findings.

Those who tested quarter-squats with eccentric and concentric components have noted mixed results. Mangus et al. (2006) investigated the effect of one repetition of 90% of their subjects' 1RM quarter-squat on three subsequent CMJs after their subjects rested for three min. The authors reported no change in their subjects' performance between their quarter-squat and

control conditions. However, as with their half-squat protocol above, the authors failed to mention the number of sets performed and the depth of the quarter-squats, making their methodology difficult to interpret and repeat. In contrast, Ebben et al. (2013) showed that two back squat repetitions at 80% 1RM (90° of knee flexion) following one repetition of a supramaximally loaded quarter-squat (120% 1RM back squat) performed to 65° of knee flexion, produced a statistically greater concentric rate of force development and upward inertial force as compared to two back squat repetitions at 60% 1RM performed to 90° of knee flexion. The most recent study examining a quarter-squat potentiation protocol was completed by Esformes et al. (2013). Their study indicated that quarter-squats performed to a knee angle of 135° with a 3RM load statistically enhanced CMJ jump height ( $d = 0.99$ ), impulse ( $d = 0.53$ ), peak power ( $d = 0.54$ ), and flight time ( $d = 0.80$ ) after five min of rest. However, their study also indicated that parallel squats performed with at 3RM load produced greater effect sizes ( $d$ ) for each measure (1.23, 0.62, 0.67, and 1.05, respectively). There appears to be mixed results when it comes to using quarter-squats as a potentiating mechanism. While all of the other studies examined their potentiating stimulus on CMJ performance, the study by Ebben et al. (2013) examined the effects of a supramaximal load on squat performance. Therefore, it is unknown how their protocol would affect subsequent jumping performance. Because there is a paucity of literature examining quarter-squats and their PAP effects, this topic requires further investigation.

### Front Squats

Despite being a commonly prescribed strength training exercise, only two studies to date have examined the PAP effects of front squats. Yetter and Moir (2008) examined the effect of heavy front squats and back squats on three 40m sprint trials. Their results indicated that the



front squat protocol did not alter 10-20m or 30-40m sprint performance. However, heavy back squats produced statistically greater speeds during the 30-40m interval than the heavy front squats. Another study by Needham et al. (2009) compared the vertical jump height, 10m sprint times, and 20m sprint times immediately following three different warm-up protocols and again at three and six min later. The three warm-up protocols included performing either 10 min of static stretching, 10 min of dynamic stretching, or dynamic stretching followed by eight front squats with dumbbells accumulating to 20% of each subject's weight. Their results indicated that the warm-up that included front squats produced superior results than both the static stretching and dynamic stretching warm-ups in all measures. The authors concluded that elite youth soccer players can enhance their jumping and sprinting ability with the inclusion of dumbbell front squats in their warm-up. It appears that the potentiation research related to front squat protocols is equivocal within the current literature. However, in contrast to the previously discussed potentiation literature on various MVC, back squats, and half-squat protocols, there is a paucity of research that has investigated the effectiveness of using a front squat protocol as a potentiating stimulus. Thus, it is difficult to draw concrete conclusions on the potential of front squats as potentiating stimuli.

### Whole-Body Vibration

Recent research has investigated the effects of whole-body vibration (WBV) on PAP. Whole-body vibration involves standing, squatting, or performing exercise on a vibrating platform. The physiological mechanism behind WBV that results in an improved acute performance is thought to be the activation of  $\alpha$ -motor neurons which cause muscle contractions similar to a tonic vibration reflex (Cardinale & Bosco, 2003; Delecluse, Roelants, &

Verschueren, 2003). The tonic vibration reflex is characterized by the activation of muscle spindles as the result of recruitment of Ia afferents and the activation of extrafusal muscle fibers through  $\alpha$ -motor neurons (Turner, Sanderson, & Attwood, 2011). Performance enhancement after acute vibration has been attributed to neural factors such as increased motor unit synchronization, stretch reflex potentiation, increased synergist muscle activity, and increased inhibition of the antagonist muscle (Cardinale & Bosco, 2003). As with previously discussed research, there have also been a number of protocols that have been used to elicit a PAP response. For example, WBV platforms have the ability to oscillate at various frequencies (15-60 Hz) and amplitudes or displacements (<1-105 mm) (Cardinale & Bosco, 2003; Delecluse, Roelants, Diels, Koninckx, & Verschueren, 2005; Rittweger, Beller, & Felsenberg, 2000; Turner et al., 2011). In addition, other studies have investigated different standing positions, knee angles, static squats, and dynamic squats (Osawa, Oguma, & Ishii, 2013). A summary of studies that have implemented a WBV protocol to bring about a potentiated state is displayed in Table 2.4.

Table 2.4 *Studies that Implemented Whole-Body Vibration Protocols to Induce Potentiation*

Author	n (training status)	Intervention	Rest interval	Results
Abercromby et al. (2007)	16 (NS)	30Hz, 4mm at knee angles 10-15°, 16-20°, 21-25°, 26-30°, and 31-35° during static, dynamic, and isometric squats	NS	↑ EMG of VL and G during rotational vibration ↑ EMG
Adams et al. (2009)	20 (UT)	Various protocols including different frequencies (30, 35, 40, 50Hz), displacement (2-4 or 4-6mm), and duration (30, 45, 60s)	Imm, 1, 5, 10 min	No effect of duration on normalized peak power ↑ Normalized peak power with higher frequencies with high displacements than higher frequencies and low displacements. ↑ Normalized peak power with lower frequencies with low displacements than

Table 2.4 (continued)

Armstrong et al. (2010)	90 (NS)	Various protocols including different frequencies (30, 35, 40, 50Hz) and amplitude (2-4 or 4-6mm) for 1 min	1, 5, 10, 15, 20, 25, 30 min	lower frequencies with high displacements. No differences in CMJ height over time between groups, frequencies, and amplitudes ↑ CMJ height at 5 and 10 min for whole group
Bosco et al. (1999)	6 (TR)	10 x 60s WBV at 26Hz with 10mm amplitude	NS	↑ Average force, velocity, and power at all loads during the leg press
Burns et al. (2015)	19 (RT) 18 (TR)	1 x 2min static squat at 120° of knee flexion with or without WBV at 30 Hz with 13mm amplitude	NS	No difference in VJ, isokinetic peak torque, or wingate between conditions No condition x group interaction effects for any performance measure except for isokinetic peak torque at 6.28 radians per second.
Cochrane et al. (2014)	12 (RT)	10, 8, and 5 body weight squats with WBV at 26Hz with 6.4mm amplitude with 60s between sets	30s and 2.5 min	No difference in peak power, mean concentric power, and RFD during two consecutive deadlift repetitions at 75% 1RM between the WBV, deadlift warm-up, and Control conditions. No difference in EMG of VL, biceps femoris, or gluteus maximus between conditions.
Cochrane & Booker (2014)	14 (TR)	6 x 60s WBV at 26Hz with 6mm amplitude with 30s between trials in isometric squat at 120° knee angle	90s before first trial and 1 or 2 min between each trial	↑ Repetitive horizontal jump distance compared to control No difference between 1 min or 2 min rest for WBV or Control ↑ Repetitive horizontal jump velocity compared to control ↑ Repetitive horizontal jump velocity at 2 min post-WBV compared to 1 min-post WBV and 1 and 2 min post-Control
Cochrane (2013)	8 (TR)	5 x 1 min side-alternating WBV at 26 Hz with 6mm amplitude with 1 min rest between trials	Imm	↑ 1.5m sprint after vibration compared to control ↓ 3m and 5m sprint No difference in reactive agility test
Cochrane et al. (2010)	12 (TR)	Static squat with 5 min WBV at 26Hz	90s, 5, 10 min	↑ Peak force and RFD after WBV compared with no WBV
Cormie et al. (2006)	9 (RT)	30s WBV at 30Hz with 2.5mm amplitude	Imm, 5, 15, 30 min	↑ CMJ height Imm after WBV compared to sham treatment

Table 2.4 (continued)

de Ruiter et al. (2003)	12 (UT)	5 x 1 min WBV at 30Hz with 8mm amplitude	90s, 30, 60, 180 min	No differences in iEMG of VL, VM, and BF between protocols ↓ Knee extensor force at 90s No change in muscle activation during MVC knee extensor production and maximal rate of force rise
Guggenheimer et al. (2009)	14 (TR)	5s of high knee running on vibration platform at 0, 30, 40, or 50Hz	1, 4 min	No differences in sprint times between vibration frequencies or conditions.
Hazell et al. (2007)	10 (RT)	Static and dynamic squat with WBV at 25, 30, 35, 40, and 45Hz with 2 and 4mm amplitude	EMG activity recorded during squats	↑ VL and BF muscle activity with WBV during static squat ↑ VL and BF muscle activity with WBV during dynamic squat
Jacobs & Burns (2009)	20 (RT)	6 min of WBV at 26Hz	Imm	↑ Peak torque following WBV compared to cycling ↑ Leg extension average torque following WBV compared to cycling No difference in knee flexor peak torque between WBV and cycling ↑ Knee flexion average torque following WBV compared to cycling
Kavanaugh et al. (2014)	21 (TR)	1 x 30s static squat at 120-130° knee angle with or without WBV at 50 Hz and 3mm amplitude	1 min	No difference in sprint distance between WBV and control protocol
Kavanaugh et al. (2011)	14 (RT)	3 x 30s static squat at 120-130° knee angle with or without WBV at 30Hz and 3mm amplitude	5 min	No difference in squat jump height, peak force, peak power, or RFD during jumps with 0 or 20kg
Lamont et al. (2010)	21 (RT)	1 x 30s WBV at 30Hz 3 x 10s WBV at 30Hz 1 x 30s WBV at 50Hz 3 x 10s WBV at 50Hz	2, 7.5, 17 min	No difference in CMVJ height between protocols ↑ % change of CMVJ height after 3 x 10s at 50Hz compared to 30s at 30Hz No difference in power or relative power between protocols
McBride et al. (2010)	19 (RT)	6 x 30s WBV at 30Hz with 3.5mm amplitude (1 <sup>st</sup> 3 sets bilateral squat, 2 <sup>nd</sup> 3 sets for each leg: unilateral squats)	Imm, 8, 16 min	↑ Peak force after WBV Imm and at 8 min. No difference in average iEMG, max H-reflex/M-wave ratio, or RFD
Naclerio et al. (2014)	15 (TR)	1 x 3 back squat at	1, 4 min	No main effects for

Table 2.4 (continued)

		80% 1RM with or without WBV at 40Hz with 1.963mm amplitude 3 x 3 back squat at 80% 1RM with or without WBV at 40Hz with 1.963mm amplitude		condition x volume x rest period interaction for CMJ and best drop jump variables ↑ CMJ and best drop jump height after 4 min compared to 1 min ↑ CMJ height for non-vibration at low volume, but not low volume ↑ Best drop jump height during WBV in both low and high volume conditions ↑ Power of 3 repetitions of back squat at 75% 1RM after WBV
Rhea & Kenn (2009)	16 (TR)	30s WBV at 35Hz with 4mm amplitude	3 min	
Rittweger et al. (2003)	19 (NS)	Exhaustive squat exercise with 40% of body mass with and without WBV at 26Hz with 6mm amplitude	0-30s	No differences in jump height, ground contact time, and isometric torque between protocols. ↑ VL mean frequency during isometric torque after WBV ↓ Jump height at 10 and 15s after WBV
Rittweger et al. (2000)	37 (NS)	Exhaustive squat exercise with 40% of body mass with and without WBV at 26Hz with 6mm amplitude	~10, 15, 20s, 15 min	
Roelants et al. (2006)	15 (NS)	High, low, and one-leg squats with or without WBV at 35Hz	EMG activity recorded during squats	↑ RF, VL, VM, and G EMG after WBV during high, low, and one-leg squat
Rønnestad et al. (2013)	15 (TR)	30s WBV at 50Hz with 3mm amplitude in half-squat	1 min	↑ 10m and 20m sprint speed compared to control condition
Rønnestad et al. (2012)	12 (TR)	1 x 3 half-squat with 65kg with 50Hz WBV 1 x 3 half-squat with 100kg with 50Hz WBV 1 x 1 half-squat with 92% 1RM with WBV 1 x 1 half-squat with 1RM with WBV	3, 10 min	↑ Power output during 3 reps half-squat at 65 and 100kg ↑ EMG VM, VL, and RF EMG starting and peak values No difference in 1RM parallel back squat
Rønnestad & Ellefsen (2011)	9 (TR)	15 bodyweight squats for 30s either without WBV or with WBV at 30 or 50Hz	1 min	↑ 40m sprint performance after WBV at 50Hz compared to no vibration No difference in 40m sprint performance between WBV at 30Hz compared to no vibration
Rønnestad (2009b)	16 (RT, UT)	10 reps at 20kg, 5 reps of 40kg, 5 reps of 60kg, 1 rep of 80% 1RM, and 1 rep of	Half-squats performed during vibration	↑ 1RM half-squat in both recreationally trained and untrained subjects ↑ 1RM half-squat in

Table 2.4 (continued)

		90% 1RM, and 1RM attempt(s) WBV at either 20, 35, or 50Hz with 3mm amplitude		untrained subjects to greater extent than recreationally trained subjects ↑ 1RM half-squat after 50Hz compared to all other conditions ↑ SJ peak average power after 50Hz in both recreationally trained and untrained subjects ↑ CMJ peak average power after 50Hz in untrained subjects, but not recreationally trained No differences in CMJ and SJ peak average power after WBV at 20 and 35Hz
Ronnestad (2009a)	17 (RT, UT)	WBV protocols at 20, 35, and 50Hz with 3mm amplitude or no WBV *Time NS	NS	No difference in peak power, average power, or rate of fatigue during Wingate tests
Surowiec et al. (2014)	12 (TR)	5 x 2min with or WBV at 30Hz or Individualized frequency with 2mm amplitude	Imm	No difference in CMJ height between any of the protocols ↑ CMJ height pre-post after WBV at 40Hz
Turner et al. (2011)	12 (RT)	30s WBV in half-squat at 0, 30, 35, 40Hz with 8mm amplitude	NS	

**Note:** CMJ, countermovement jump; DJ, drop jump; G, gastrocnemius; Imm, immediately following intervention; NS, training status not specified; RF, rectus femoris; RFD, rate of force development; RM, repetition maximum; RT, subjects reported as recreationally trained; TR, subjects reported to be those who have trained at least twice per week for one year or athletes; UT, untrained subjects who have not participated in any resistance training over the previous year; VJ, vertical jump; VL, vastus lateralis; VM, vastus medialis

Many different SPPCs that include WBV have been investigated. Thus, it is challenging to make conclusions about SPPCs that involve WBV. Of the above protocols, 21 of 29 (72.4%) displayed an improvement in some performance measure, indicating that SPPCs that include WBV are often effective. Although this review of literature did not complete a meta-analysis, a recent meta-analysis indicated that using WBV would lead to greater improvements in knee extension muscle strength and CMJ performance than not using WBV (Osawa et al., 2013). However, in order to provide practitioners with the most practical information, it is recommended that a meta-analysis focusing on WBV-based SPPCs should be completed.

## Plyometrics

Previous research indicated that lower body plyometrics may raise the motor unit efficiency during the execution of maximum repetition during exercises (Fatouros et al., 2000). Furthermore, this increase in motor unit efficiency may result in an increased neural stimulation of the muscle and improve subsequent power production (McBride et al., 2005). For this reason, plyometrics have been a frequent topic of investigation in regard to its ability to bring about a potentiated state that will improve performance. A summary of studies that have implemented a plyometric exercise protocol to bring about a potentiated state is displayed in Table 2.5.

Table 2.5 *Studies that Implemented Plyometrics to Induce Potentiation*

Author	n (training status)	Intervention	Rest interval	Results
Baker (2001)	6 (TR)	2 x 6 of 40kg JSs (A) 2 x 6 of 40kg JSs with 1 x 3 60kg JSs in between each set (B)	2-3 min	↑ JS power output after B compared with A
Bergmann et al. (2013)	12 (RT)	8 x 10 maximal bilateral hops with 30s between sets	Imm, 30s between sets	↑ DJ height after hops No change in V-waves or EMG of SOL, G, TA, VM, and BF after hops No difference in DJ contact time or ankle and knee angles between hops and control
Bomfim Lima et al. (2011)	10 (TR)	2 x 5 DJs from 0.75m	5, 10, 15 min	↓ Sprint time at 10 and 15 min compared to baseline and 5 min ↓ Sprint time at 15 min compared to 5 min ↑ CMJ height at 15 min compared to baseline and 5 min
Bullock & Comfort (2011)	14 (TR)	1 x 2 DJs from 33cm	4 min	↑ 1RM squat strength following each protocol
Burkett et al. (2005)	29 (TR)	1 x 4 DJs from 33cm 1 x 6 DJs from 33cm 1 x 5 CMJ at 75% 1RM CMJ height 1 x 5 Weighted CMJ (10% bodyweight) onto box	2 min	↑ CMJ height after Weighted CMJ
Byrne et al. (2013)	29 (TR)	Dynamic warm-up with 3 DJs from optimal height	1 min	↓ 20m sprint time compared to control and dynamic warm-up only

Table 2.5 (continued)

Chattong et al. (2010)	20 (TR)	Weighted jumps onto a box with 5%, 10%, 15%, and 20% bodyweight	2 min	↑ VJ height
Chen et al. (2013)	10 (TR)	1 x 5 DJs 2 x 5 DJs	2, 6, 12 min	↑ CMJ height at 2 min compared to pretest, 6 min, and 12 min ↑ CMJ height at 6 min compared to 12 min No difference in CMJ height between protocols
Clark et al. (2006)	9 (TR)	1 x 6 LCMJs with 20kg (A) 1 x 6 LCMJs with 40kg (B)	4 min	↑ 20kg LCMJ height after B compared to A ↑ 20kg LCMJ peak power after B compared to A in 2 <sup>nd</sup> and 3 <sup>rd</sup> sets
de Villarreal et al. (2007)	12 (TR)	3 x 5 CMJs with optimal load	5 min, 6 hrs	↑ DJ height at 5 min and 6 hrs ↑ CMJ power ↑ LCMJ height at 5 min and 6 hrs
Esformes et al. (2010)	13 (TR)	3 x 24 plyometric bounds and hops	5 min	↑ CMJ height for single tests only
Hilfiker et al. (2007)	13 (TR)	1 x 5 modified DJs from 60cm	1 min	↑ CMJ power as compared to control
Masamoto et al. (2003)	12 (TR)	3 tuck jumps and 2 DJs (43.2cm box)	30s	↑ Squat 1RM
McBride et al. (2005)	15 (TR)	1 x 3 LCMJs at 30% 1RM	4 min	No effect on 10-, 30-, or 40m sprint speed
Miarka et al. (2011)	8 (TR)	10 x 3 consecutive jumps stepping off and jumping from 20cm to 40cm to 60cm	3 min	↓ Heart rate and throws index during Special Judo Fitness Test
Radcliffe & Radcliffe (1996)	35 (TR)	4 x 4 LCMJs with 15-20% bodyweight 4 x 4 tuck jumps	3 min	No differences between protocols existed
Read et al. (2012)	16 (UT)	1 x 3 CMJs	1 min	↑ Club head speed compared to control
Sarramian et al. (2014)	18 (TR)	1 x 5 jumps to box with 10% of body weight weighted vest	NS	No difference in 50m freestyle swim time
Smilios et al. (2005)	10 (TR)	3 x 5 squat jumps at 30% 1RM 3 x 5 squat jumps at 60% 1RM	1, 5, 10 min after each set and 5, 10 min after 3 sets	↑ CMJ with both low and moderate loads
Sortiropoulos et al. (2014)	12 (TR)	1 x 6 JSs at 70%, 100%, or 130% of load that maximized mechanical power	1, 3, 5, 7, 10 min	No difference in repeated JS height across time within or between any protocol ↑ JS mechanical power with 130% protocol compared to 100% and control at 5min ↑ JS mechanical power with 70% protocol compared with control at 7min ↑ Quadriceps EMG after 130%



Table 2.5 (continued)

Stieg et al. (2011)	17 (TR)	1 x 0, 3, 6, 9, or 12 DJs from individualized height	10 min	protocol compared to control at all times, 100% protocol at 1 and 5min, and 70% protocol at 1 and 3min ↑ Quadriceps EMG after 70% and 100% protocols compared to control at 3, 5, 7, and 10min No main effect differences in condition, time, or relative ground reaction forces existed ↓ VJ height after 9 DJs compared to 0, 3, and 6 DJs
Terzis et al. (2012)	10 (TR)	1 x 3 consecutive CMJs	1 min	↑ Average and best attempt shot put performance
Terzis et al. (2009)	16 (NS)	1 x 5 consecutive DJs from 40cm	20s	↑ Squat underhand throw distance in the group and only in men
Till & Cooke (2009)	12 (TR)	1 x 5 tuck jumps	4, 5, 6, 7, 8, 9 min	No difference in 10- and 20m sprint times, VJ, and average 10m and 20m sprint times or average VJ
Tobin & Delahunt (2013)	20 (TR)	2 x 10 ankle hops, 3 x 5 70cm hurdle jumps, and 5 DJs from 50cm	1, 3, 5 min	No difference in in VJ height ↑ CMJ height and peak force at 1, 3, 5 min
Tsolakis & Bogdanis (2011)	23 (TR)	3 x 5 tuck jumps	Imm, 4, 8, 12 min	↓ CMJ power at 8 and 12 min
Turner et al. (2014)	23 (TR)	3 x 10 alternate leg bounds with (W) or without 10% body mass weighted vest (NW) Walking control	15s, 2, 4, 8, 12, 16 min	↑ 10m sprint velocity following NW at 4 min and W at 8 min ↑ 10m sprint velocity after NW and W compared to control condition at 4 min ↑ 10m sprint velocity during W compared to NW and control conditions at 8 min ↑ 20m sprint velocity following NW at 4 min and W at 4 and 8 min ↓ 20m sprint performance following W compared to control at 15s ↑ 20m sprint velocity following W compared NW and control conditions at 4 and 8 min

**Note:** BF, biceps femoris; CMJ, countermovement jump; DJ, drop jump; EMG, muscle activation; Imm, immediately following intervention; G, gastrocnemius; JS, jump squat; LCMJ, loaded countermovement jump; NS, not specified; RFD, rate of force development; RM, repetition maximum; RT, subjects reported as recreationally trained; SOL, soleus; TA, tibialis anterior; TR, subjects reported to be those who have trained at least twice per week for one year or athletes; UT, untrained subjects who have not participated in any resistance training over the previous year; VJ, vertical jump; VM, vastus medialis

A recent review on ballistic activities, including plyometrics, and their use in SPPCs has been completed by Maloney and colleagues (2014). Strength-power potentiating complexes that include plyometrics have been also been thoroughly investigated. Of the above studies, 19 of 25 (76%) have displayed an improvement in some performance measure, indicating that SPPCs that include plyometrics produce a potentiated state quite often. As mentioned above with other SPPCs, it is recommended that replication studies using previously established protocols should be completed to provide further insight on the PAP phenomenon. In addition, the practical significance of these changes brought about by plyometrics-based SPPCs should be addressed in a meta-analysis.

#### Weightlifting Exercises and Variations

Because weightlifting exercises and their variations typically require the participant to move a heavy load quickly using large musculature, it should come as no surprise that previous research has examined PAP using these exercises. However, only eight studies have investigated potentiating protocols that have included weightlifting exercises and their variations. Specifically, previous research has examined the potentiating effects of the hang clean (Andrews et al., 2011; Dinsdale & Bissas, 2010; McCann & Flanagan, 2010), power clean (Guggenheimer et al., 2009; Seitz et al., 2014c), power snatch (Radcliffe & Radcliffe, 1996), mid-thigh pulls (Stone et al., 2008), and snatch pulls (Chiu & Salem, 2012).

Andrews et al. (2011) compared the effect of three sets of three repetitions of the hang clean at 60% 1RM paired with three sets of four CMJs to three sets of three back squats at 75% 1RM paired with CMJs, and three sets of four CMJs only. Their study indicated that the complex pair using hang cleans was a superior method of maintaining CMJ height as compared

to a complex pair using back squats or CMJs only. It should be noted that this study incorporated a back squat load of 75% 1RM, which may not be considered a heavy enough load to recruit the higher threshold motor units needed for enhanced force, power, and rate of force development. A second study that investigated hang cleans as a potentiating stimulus examined the effect of three repetitions of the hang clean at 90% 1RM on vertical jump performance (Dinsdale & Bissas, 2010). The results of this study indicated that hang cleans did not enhance vertical jump performance at any of the rest periods examined. In fact, vertical jump height statistically decreased immediately and at two and three min following the hang clean repetitions. A third study examined various potentiating protocols involving both the back squat and hang clean and their effect on VJ performance (McCann & Flanagan, 2010). The results of this study indicated that the optimal condition for subjects was highly individualistic, but neither the hang clean nor back squat was advantageous for men or women. Another pair of studies examined the ability of the power clean to be used as a potentiating stimulus (Guggenheimer et al., 2009; Seitz et al., 2014c). The first study from Guggenheimer et al. (2009) examined the effect of three repetitions of the power clean at 90% 1RM on 40m sprint times and reaction times. Their study showed no statistical differences between the potentiation and control conditions on 5, 10, and 40m sprint times, or reaction times. Using a similar protocol, Seitz et al. (2014c) compared the effects of one set of three repetitions at 90% 1RM of the back squat or power clean on 20m sprints. Both protocols resulted in statistical potentiation effects for sprint time, velocity, and average acceleration over 20m. However, the power clean produced a greater improvement in sprint time ( $d = 0.83$ ), velocity ( $d = 1.17$ ), and average acceleration over 20m ( $d = 0.87$ ) as compared to the back squat. Using a clean variation, Stone and colleagues (2008) examined how mid-thigh pulls performed at higher absolute loads potentiate lighter loads in

international-level weightlifters. Peak velocity during the potentiation set was statistically enhanced compared to the three previous warm-up sets. In contrast, no statistical differences in peak force, relative peak force, peak power, or rate of force development existed between the potentiation set and the previous warm-up set performed at the same absolute load. Another study by Chiu and Salem (2012) indicated that vertical jump height increased by 5.77% at the midpoint of training and 5.90% at the end of the training session following progressive snatch pulls performed at 70%, 80%, 90%, and 100% of the subject's 1RM snatch. Contrary to previous studies, Radcliffe and Radcliffe (1996) examined the effect that four sets of four power snatches had on three horizontal countermovement jumps for distance. Their study indicated that men jumped statistically farther following the snatch protocol as compared to the control condition. However, no statistical difference in female subjects or the whole group existed.

Collectively, weightlifting exercises, and their variations, appear to have the potential of enhancing acute explosive performance following specific warm-up protocols. However, some conflicting research exists, suggesting that replication studies are needed to determine if specific protocols are effective with certain subject samples and rest periods.

### Running and Cycling Protocols

Much of the potentiation research discussed above has involved using serial tasks in order to improve a subsequent explosive performance. In contrast, a several studies have investigated tasks that are more continuous in nature, such as running (Boullosa & Tuimil, 2009; Garcia-Pinillos, Soto-Hermoso, & Latorre-Roman, 2015; Latorre-Román, García-Pinillos, Martínez-López, & Soto-Hermoso, 2014; Terzis et al., 2012; Vuorimaa, Virlander, Kurkilahti, Vasankari, & Häkkinen, 2006) and cycling (Lawrence, Sevene-Adams, Berning, Curtin, &

Adams, 2010), in an attempt to improve similar performances. Similar to the previously discussed exercises used to induce a potentiation response, different running and cycling protocols were investigated, making their findings difficult to compare across studies. Boullosa et al. (2009) examined CMJ performance following two different running protocols, including the *Universite de Montreal Track Test* (UMTT) and a protocol that had a time limit at maximal aerobic speed (TLim). Both protocols produced a statistically significant increase in CMJ height two min following each protocol. However, the UMTT produced a statistically greater increase in CMJ height as compared to the TLim protocol. Furthermore, a performance enhancement of CMJ height following the UMTT was also present at seven min following the completion of the protocol. Another study compared the acute effect of three different running protocols, which included treadmill running until exhaustion, a 40 min tempo run, and intermittent running (two min running, two min rest), on CMJ height, half-squat power, and muscle activation of the vastus medialis, vastus lateralis, lateral gastrocnemius, and biceps femoris during a set of 10 half-squats (Vuorimaa et al., 2006). The results indicated that each protocol resulted in statistically significant improvements in CMJ height. In contrast, statistically significant decreases in the sum of EMG of the four muscles existed for every protocol. Individually, there was no change in muscle activation for any of the muscles examined. Finally, no change in half-squat power was found for any of the running protocols. Garcia-Pinillos and colleagues (2015) examined the effect of four sets of three 400 meter runs on CMJ performance, handgrip strength, and 400 meter time in 30 sub-elite male long distance runners. Their results indicated that statistically greater CMJ height, peak force, and peak power values were present for the entire group following various sets of the testing protocol. Furthermore, the responders (n = 17) produced statistically greater changes in countermovement jump performance and handgrip strength, but

no statistical difference in 400 meter time when compared to the non-responders ( $n = 13$ ). Another study from the same research group investigated the same four sets of three 400 meter runs on CMJ performance and handgrip strength in 16 sub-elite male long-distance runners (Latorre-Román et al., 2014). The results of their study displayed a statistical increase in countermovement jump performance, but no statistical differences in handgrip strength. As opposed to the four previous studies, Terzis et al. (2012) examined the effect of a single 20m sprint on shot performance in experienced male throwers. The authors indicated that the average and best shot put distances were statistically increased following the single bout of sprinting.

While the previous five studies examined various running protocols and their potentiating effects on subsequent performances, only one study has examined the potentiating effects of a cycling protocol on a subsequent explosive performance. Lawrence and colleagues (2010) investigated the potentiating effects of an overloaded cycling warm-up (pedaling against 10kg as fast as possible for 10s) on a 10s cycling performance with 7.5kg performed four min later. Their results indicated that there were statistically significant increases in both relative and absolute power as compared to a standard cycling warm-up (pedaling against 1kg for four min).

It appears that potentiating effects can be seen using both running and cycling protocols. However, because only six studies to date have examined running and cycling potentiating protocols, practitioners should interpret the results of these studies with caution. Replication studies should be conducted so that more scientific evidence exists to determine the effectiveness of specific running and cycling protocols.

## Throwing Implements

Recent research has investigated the effects of heavy implement (weight or shot put) throws on the subsequent performance of male and female high school (Judge, Bellar, & Judge, 2010) and NCAA Division I (Bellar, Judge, Turk, & Judge, 2012; Judge et al., 2013a; Judge, Bellar, Gilreath, Popp, & Craig, 2013b) track and field throwers. Judge et al. (2010) compared the peak weight throwing distance following either five one-heel turn throws with a standard weight or weights 1.37 kg or 2.27 kg heavier than the standard weight. Their results indicated that a greater throwing distance was achieved after the overweight implements were used in the warm-up as compared to the standard implement. However, no difference was found between the overweight implements. Using similar methodology with NCAA Division I athletes, Bellar et al. (2012) showed that overweight implements also potentiate subsequent throwing performance. Unique to this study, the lighter of the two overweight implements displayed a statistical increase on the first two throwing attempts (out of five) as compared to only the first throwing attempt when using the heavier overweight implement. A more recent study by Judge et al. (2013b) used a backward shot put throw as a potentiating stimulus. Their study indicated that a heavier shot put produced a statistically greater throwing distance of a standard weight shot put as compared to an underweight, light shot put and a standard weight shot put. Another recent study by Judge et al. (2013a) compared the effect of overhead shot throws with a competition weight shot, a shot weighing one kilogram heavier, and a shot weighing one kilogram less than the competition shot weight on maximal shot put performance. The heavier shot produced statistically greater shot put performance than the competition shot ( $d = 0.472$ ) and light shot ( $d = 0.513$ ). Collectively, the above studies indicated that overweight throwing implements such as a weight or shot put can be used to acutely enhance a subsequent throwing

performance in high school and NCAA Division I male and female track and field throwing athletes. Thus, it appears that track and field throwing coaches should consider using overweight throwing implements prior to throwing a standard weight implement in training and competitive settings in order to produce a superior performance.

### Weighted Vests

By exercising with a weighted vest, one puts an additional load on the body that will, in theory, provide a training stimulus that is superior to regular exercise without a weighted vest. Based on this theory, some researchers believe that exercise with a weighted vest can produce a potentiated subsequent performance. Three studies currently exist within the potentiation literature that have examined the potentiating effects of exercise with a weighted vest (Faigenbaum et al., 2006; Reiman et al., 2010; Thompsen, Kackley, Palumbo, & Faigenbaum, 2007). One study examined the effect of performing a dynamic warm-up with a weighted vest that had additional weight of 2% or 6% bodyweight on vertical jump, long jump, seated medicine ball toss, and 10 yard sprints in high school girls (Faigenbaum et al., 2006). Their study indicated that statistically significant increases in vertical jump and long jump existed following the dynamic warm-up with a weighted vest that had an additional 2% of the subjects' bodyweight. However, no statistical differences in seated medicine ball throw or 10 yard sprints were found. In addition, no statistical differences resulted from the dynamic warm-up with a 6% bodyweight weighted vest. Similar to previous findings, Thompsen et al. (2007) indicated that Division III female athletes that performed a dynamic warm-up with a weighted vest with 10% of their bodyweight, displayed statistically significant improvements in both vertical jump height



and long jump distance as compared to static stretching and a dynamic warm-up without a weighted vest.

While the previous studies displayed statistically significant improvements in performance measures, a more recent study found contrasting results. Reiman et al. (2010) investigated the effects of a dynamic warm-up with or without a weighted vest with 5% of each athlete's body weight had on the Margaria-Kalamen Power Test (Fox & Mathews, 1974) in male high school football players. Their study indicated that no difference in power output existed between protocols, suggesting that a resisted dynamic warm-up does not enhance a subsequent performance.

Inconclusive findings exist when it comes to the potentiating effects of weighted vests. Interestingly, it appears that there may be sex differences given the findings of the current literature that indicate high school girls and Division III female athletes potentiate after a dynamic warm-up with a weighted vest, while male high school football players did not. However, it should be noted that only three studies have examined the ability of weighted vests to produce a potentiated subsequent performance. Therefore, before any conclusions can be made on the potentiating abilities of weighted vests, further research should be conducted with a variety of subjects so that practitioners can be provided with information that he/she can base their training methods on.

### Intermittent Exercise

Three studies have investigated the potentiating effects of intermittent exercise. Batista et al. (2007) examined the effect that 10 maximal knee extensions performed at  $60^\circ \cdot s^{-1}$  with one performed every 30s had on peak torque production of three consecutive knee extensions. The

authors showed that peak torque was statistically enhanced at every rest interval (4, 6, 8, 10, and 12 min). Another study by Morana and Perrey (2009) examined the potentiation time course during 10 min of intermittent knee extension exercise (5s contraction, 5s rest) at 50% MVIC in endurance and power athletes following electrical stimulation of the femoral nerve. A statistically significant increase in peak torque of 52% was displayed in both groups during the first min of exercise. Subsequently, peak torque displayed a statistically significant decrease in power athletes whereas it remained about baseline values in endurance athletes until the end of exercise. A recent study by Seitz et al. (2014b) examined the potentiation effects of five different intermittent knee extension protocols including four repetitions at  $60^\circ \cdot s^{-1}$  (60/4), 12 repetitions at  $180^\circ \cdot s^{-1}$  (180/12), 20 repetitions at  $300^\circ \cdot s^{-1}$  (300/20), four repetitions at  $180^\circ \cdot s^{-1}$  (180/4), and four repetitions at  $300^\circ \cdot s^{-1}$  (300/4). Their results indicated that statistically greater voluntary torque following the 60/4, 180/12, and 300/20 protocols at four and seven minutes post-stimulus; however no difference in voluntary torque existed at 10 and 13 minutes post-stimulus. Similarly, twitch torque was statistically increased following the 60/4, 180/12, and 300/20 protocols at one and four minutes post-stimulus, while no difference in twitch torque existed at 7, 10, or 13 minutes post-stimulus. No statistically significant differences in voluntary or twitch torque existed following the 180/4 and 300/4 protocols.

Because only three studies have examined the effect of intermittent exercise on performance, it is difficult to make conclusive statements. However, based on the information available, it appears that intermittent exercise may increase one's ability to enhance peak torque, voluntary torque, and twitch torque of the knee extensors. Furthermore, the ability of an athlete to use potentiation over an extended period of time may be dependent on his or her previous training history, with endurance athletes possessing the ability to harness potentiation effects for

a longer period of time. As previously mentioned, only early hypotheses can be formed based on the scientific evidence available. Thus, it is necessary for further research to be conducted using intermittent exercise as a potentiating stimulus before concrete conclusions can be made.

### Leg Press

The leg press is another strength-based exercise that has been used to produce an acute enhancement in performance within potentiation literature. However, only three studies have used a leg press SPPC in order to elicit a PAP response. One study compared a leg press protocol that involved three sets of three repetitions at 90% 1RM with a lower body stretching protocol and their effects on an isometric squat held at 90 degrees (Bazett-Jones, Winchester, & McBride, 2005). The results of this study indicated that the potentiation leg press protocol resulted in no difference in peak force as compared to the stretching or control protocols. In addition, the potentiation protocol resulted in statistically lower rates of force development as compared to the control protocol. The authors indicated that the SPPC was too fatiguing as compared to the other protocols. A more recent study investigated the effects of three ballistic leg press throws each with a load of 150% bodyweight using both a stretch-shortening cycle or a concentric-only muscle action (McCarthy, Wood, Roy, & Hunter, 2011). The results of this study indicated that large amplitude stretch-shortening cycle leg press ballistic throws resulted in a statistically significant improvement in mean force, acceleration, velocity, and power early in the concentric range of motion. The third study that examined the potentiating effects of the leg press on 20-km cycling time trial performance in male cyclists (Silva et al., 2014). This study indicated that four sets of leg press with a 5RM load potentiated 20-km cycling time trial performance by producing a 6.1% decrease in time to completion and a greater cycling economy,

while power output during the first 10% of the time trial trended toward statistical significance. Because only three studies have used the leg press exercise as a means of potentiating a subsequent performance, it remains difficult to conclude whether or not this type of exercise can be used as an effective potentiating stimulus. This is confirmed by the inconclusive evidence that currently exists within the potentiation literature.

### Miscellaneous Protocols

Several studies within the potentiation literature have used unique protocols to elicit a potentiation response in their subjects. These protocols have included resisted sprints (Whelan, O'Regan, & Harrison, 2013), lunges and YoYo squats (Cuenca-Fernández, López-Contreras, & Arellano, 2015), a resisted dynamic warm-up with a cable crossover machine (Cilli, Gelen, Yildiz, Saglam, & Camur, 2014), and swimming with a resistive Power Rack (Hancock, Sparks, & Kullman, 2014). Whelan et al. (2013) examined the effect of 10 meter resisted sprints (25-30% body mass) on 10 meter sprint performance at various rest intervals. Their results indicated that step rate, step length, ground contact time, and running speed were not acutely enhanced following resisted sprints. Cuenca-Fernández and colleagues (2015) compared the potentiation effects of a lunge protocol (three repetitions at 85% 1RM) and four repetitions of YoYo squats with a flywheel device on swim start performance. Their results indicated that the YoYo squat warm-up resulted in the greatest improvement in covering the first five and 15 meters, angular velocity of knee extension, and reduction of time on the starting block, as compared to the lunge protocol. Another study by Cilli and colleagues (2014) examined the effect of dynamic warm-up performed with a cable cross machine with resistances of 2%, 4%, 6%, 8%, and 10% of the subjects' body mass on CMJ and SJ performance. Their results indicated that there were

statistically significant increase in CMJ and SJ in jump height following all of the loads examined. However, there was no difference between each of the loads. Hancock et al. (2014) compared the effect of a standard swimming warm-up with a swimming warm-up that was performed while the swimmers were attached to a resistive Power Rack (4 x 10 meter swims with one minute rest intervals) on a 100 meter freestyle swim performance. There were no statistical differences between conditions over the course of the first or second 50 meters of the swim. However, the potentiation warm-up produced a statistically faster swim time as compared to the standard warm-up. The authors also indicated that there was no difference between males and females in how they potentiated. All of the previously mentioned studies used unique potentiation protocols that have not been examined in any other study. The findings of these studies should be interpreted with caution as their results have not been replicated.

As discussed above, previous research has used many different SPPCs in an attempt to harness the PAP stimulus for a subsequent explosive performance. Despite the abundance of SPPCs, limited research exists that has investigated the effects of concentric-only half-squats as a performance stimulus. A recent study examined the potentiation effects of concentric-only half-squats on sprinting performance (Dechechi et al., 2013). Their study indicated that three concentric-only half-squat repetitions at 90% 1RM concentric-only half-squat strength (90° of knee flexion) produced a statistical improvement in 50m sprint displacement time whereas three eccentric-only half-squat repetitions at 90% 1RM concentric-only half-squat strength displayed no change in performance. Because only one study has examined the potentiation effects of concentric-only half-squats on performance, further research is needed. If concentric-only half-squats at 90% 1RM concentric-only half-squat strength performed from 90° of knee flexion have the potential to produce improvements in 50m sprint displacement time, it is possible that static

jump performance may be enhanced following the stimulus. To provide practitioners with a more in-depth understanding of the potential PAP benefits, there is a need to perform research using concentric-only half-squats as a stimulus within an SPPC.

### Rest Interval

A secondary topic within the PAP literature is the rest intervals of an SPPC. Specifically, research has attempted to identify the optimal rest interval required for peak performance to occur. Previous research has indicated that the PAP effect may last from 5-20 min following a heavy resistance stimulus (Chiu et al., 2003; Gilbert et al., 2001; Gullich & Schmidtbleicher, 1996). However, more recent research has indicated that a positive potentiation effect may be seen as early as two min post-stimulus (Rixon et al., 2007) and last as long as 6 hours (de Villarreal et al., 2007). Wilson et al. (2013) performed a meta-analysis within PAP literature and indicated that rest periods of 3-7 min ( $d = 0.54$ ) and 7-10 min ( $d = 0.7$ ) resulted in a greater effect as compared to greater than 10 min of rest ( $d = 0.02$ ). A second meta-analysis performed by Gouvêa and colleagues (2013) showed similar findings. Their study indicated that a medium negative effect size existed for rest ranging 0-3 min, while a positive medium effect existed for rest intervals ranging 8-12 min. In addition, a small positive effect size existed for rest intervals ranging 4-7 min while a negative small effect existed for rest intervals greater than 16 min. Based on these findings, it is clear that potentiation effects can arise at various rest intervals.

Following a potentiating stimulus, a state of both fatigue and potentiation are present (Fowles & Green, 2003; Hodgson et al., 2005; Rassier & Macintosh, 2000; Sale, 2002). This interaction between fatigue and potentiation may in fact be modeled acutely based on the fitness-fatigue paradigm (Zatsiorsky, 1995), where physical performance is the result of the interaction

of fatigue and the fitness after-effects that result following an exercise stimulus. In this case, the potentiating exercise raises the “fitness” level of the participant to prepare them for the subsequent activity (Stone et al., 2008). However, in order to effectively use the benefits of potentiation for a specific stimulus, it is possible that each individual potentiating stimulus requires its own specific rest interval in order to bring about an enhanced subsequent performance. For example, it has been suggested that the type, intensity, and duration of exercise and recovery will determine whether fatigue or potentiation is dominant over the other (Masiulis et al., 2007).

The length of the rest interval of an SPPC may be a determining factor for effectively bringing about an enhanced performance. Previous research has indicated that fatigue may dominate over potentiation in the early stages of recovery following the potentiating exercise (Tillin & Bishop, 2009). If the rest interval following the potentiating exercise is too short, fatigue may mask the benefits of potentiation (Gossen & Sale, 2000; Weber et al., 2008). Furthermore, if the rest interval is too long, the optimal potentiating effects may dissipate, leading to no change in performance. In this regard, several studies have suggested that fatigue dissipates faster than the potentiation effect (Houston & Grange, 1990; Requena et al., 2008; Vandervoort, Quinlan, & McComas, 1983).

In order to overcome fatigue and improve subsequent performance, a number of studies have examined the effect of various rest intervals following an exercise stimulus and their effect on overall performance. Table 2.6 summarizes the studies that investigated three or more rest intervals as part of an SPPC.

Table 2.6 *Studies that Investigated Rest Interval Effects on Potentiation*

Author	n (training status)	Intervention	Rest interval	Results
Armstrong et al. (2010)	90 (NS)	Various protocols including different frequencies (30, 35, 40, 50Hz) and amplitude (2-4 or 4-6mm) for 1 min	1, 5, 10, 15, 20, 25, 30 min	No differences in CMJ height over time between groups, frequencies, and amplitudes ↑ CMJ height at 5 and 10 min for whole group
Batista et al. (2007)	10 (UT)	10 maximal knee extensions at 60°/s, one every 30s	4, 6, 8, 10, 12 min	↑ Peak torque at every rest interval compared to baseline
Bevan et al. (2010)	16 (TR)	1 x 3 back squat at 91% 1RM	4, 8, 12, 16 min	No main effect of time on sprint performance ↑ Sprint performance with individuals
Bogdanis et al. (2014)	14 (TR)	Equal Impulse of: Concentric-only half-squats at 90% 1RM Eccentric half-squats at 70% 1RM	15s, 2, 4, 6, 8, 10, 12, 15, 18, 21 min	No change in CMJ performance after either protocol as compared to baseline values at any time point
Boullosa et al. (2013)	12 (RT)	1 x 5 half-squats at 5RM (Traditional) 1 x 5 half-squats at 5RM with 30s between reps (Cluster)	1, 3, 6, 9, 12 min	No main effects for CMJ parameters ↑ Peak power after Cluster set at 1 min ↑ Peak power after Traditional at 9 min
Boyd et al. (2014)	10 (TR)	1 x 1 at 150% 1RM functional isometric 1 x 3 at 150% 1RM	2, 5, 8, 11 min	No differences between protocols in peak force, power, displacement, velocity at any time point ↑ peak force following squat protocols for combined condition CMJ data ↓ peak power following squat protocols for combined condition CMJ data
Chaouachi et al. (2011)	12 (TR)	1 x 10 at 70% 1RM 1 x 5 at 70% 1RM 1 x 5 at 85% 1RM 1 x 3 at 85% 1RM 1 x 3 at 90% 1RM 1 x 1 at 90% 1RM *Half-squats	1, 2, 3, 5, 10, 15 min	No differences between protocols in jump height, peak power, force, velocity, or mean power at any time point
Chen et al. (2013)	10 (TR)	1 x 5 DJs 2 x 5 DJs	2, 6, 12 min	↑ CMJ height at 2 min compared to pretest, 6 min, and 12 min ↑ CMJ height at 6 min compared to 12 min No difference in CMJ height between protocols
Cochrane et al. (2010)	12 (TR)	Static squat with 5 min WBV at 26Hz	90s, 5, 10 min	↑ Peak force and RFD after WBV compared with no WBV
Cormie et al. (2006)	9 (RT)	30s WBV at 30Hz with 2.5mm amplitude in half-squat position	Imm, 5, 15, 30 min	↑ CMJ height Imm after WBV compared to sham treatment No differences in iEMG of VL, VM, and BF between protocols



Table 2.6 (continued)

Crewther et al. (2011)	9 (TR)	1 x 3 at 3RM	15s, 4, 8, 12, 16 min	<p>↓ CMJ height at 15s and 16 min</p> <p>↑ CMJ height at 4, 8, 12 min</p> <p>No change in sled push performance, sprint splits</p> <p>↑ Relative changes in CMJ height than 3m sled push and 5m, 10m sprint tests</p>
Dinsdale et al. (2010)	12 (TR)	1 x 3 hang clean at 90% 1RM	Imm, 1, 2, 3, 4, 5, 6 min	<p>↓ VJ height Imm, 2, and 3 min</p>
Fukutani et al. (2013)	12 (UT)	3 x 6s MVC of plantar flexors	Imm, 1, 5 min	<p>↑ Maximal voluntary concentric torque after MVCs in fast condition (180°/s) compared to the slow condition (30°/s)</p> <p>No change in maximal voluntary concentric torque in slow condition</p> <p>↑ M-wave amplitude of SOL Imm after</p> <p>Differences in Root mean squared EMG of lateral G existed between conditions</p> <p>↓ SOL root mean squared EMG Imm after</p> <p>No differences in joint angle</p>
Gilbert et al. (2005)	15 (TR)	5 x 1 back squat at 100% 1RM 5 x 1 back squat at Max Power load	1, 2, 3, 9, 10, 11, 19, 20, 21, 59, 60, 61 min	<p>↓ RFD at 2, 10 min after 100% squats</p> <p>↑ RFD at 15, 20 min after 100% squats</p> <p>↑ RFD at 2 min after Max Power squats</p> <p>No difference in maximal force</p>
Jensen et al. (2003)	21 (TR)	1 x 5 at 5RM back squat	10s, 1, 2, 3, 4 min	<p>↓ Jump at 10s</p> <p>No effect at 1-4 min</p>
Jones et al. (2003)	8 (TR)	1 x 5 at 85% 1RM back squat	Imm, 3, 10, 20 min	<p>No main effects for CMJ performance or EMG activity</p> <p>No main effects on DJ performance</p> <p>↑ Biceps femoris activity during propulsive phase of DJ</p>
Kilduff et al. (2011)	9 (TR)	1 x 3 back squat at 87% 1RM	Imm, 4, 8, 12, 16 min	<p>↑ Peak power and jump height at 8 min than all other time intervals</p> <p>↓ Peak power and jump height Imm after squats</p> <p>↑ Peak vertical and horizontal force after squats compared to swim-specific warm-up</p>
Kilduff et al. (2008)	20 (TR)	3 x 3 back squat at 87% 1RM	15s, 4, 8, 12, 16, 20, 24 min	<p>↓ Jump height 15s</p> <p>↑ Power output, RFD, and jump height at 8 min than all other rest intervals</p>
Kilduff et al. (2007)	23 (TR)	1 x 3 back squat at 3RM	15s, 4, 8, 12, 16, 20 min	<p>↓ CMJ at 15s</p> <p>↑ CMJ at 8-12 min</p>
Lamont et al. (2010)	21 (RT)	1 x 30s WBV at 30Hz 3 x 10s WBV at 30Hz 1 x 30s WBV at 50Hz 3 x 10s WBV at 50Hz	2, 7.5, 17 min	<p>No difference in CMVJ height between protocols</p> <p>↑ % change of CMVJ height after 3 x 10s at 50Hz compared to 30s at 30Hz</p> <p>No difference in power or relative power between protocols</p>
Lowery et al. (2012)	13 (TR)	1 x 5 back squat at 56% 1RM 1 x 4 back squat at 70% 1RM	Imm, 0, 2, 4, 8, 12 min	<p>No change in VJ power after 56% squats</p> <p>↓ VJ power Imm after 70% and 93% squats</p> <p>↑ VJ power 4 min after 70% squats</p> <p>↑ VJ power 4, 8 min after 93% squats</p>

Table 2.6 (continued)

Miyamoto et al. (2010)	9 (RT)	1 x 3 back squat at 93% 1RM 10s MVC of plantar flexion	Imm, 1, 2, 3, 4, 5 min	No difference in VJ height and power between 70% and 93% squats ↑ Twitch torque Imm after MVC compared to 5 min No effect of time or condition for M-wave amplitude ↑ Isokinetic peak torque at 1, 2, 3 min in MVC condition ↓ Medial G EMG activity Imm after MVC
Mola et al. (2014)	22 (TR)	1 x 3 at 3RM	15s, 4, 8, 12, 16, 20 min	No difference in CMJ peak power or jump height between experimental and control No time effect existed for peak power and jump height
Seitz et al. (2014a)	18 (TR)	1 x 3 back squat at 90% 1RM	15s, 3, 6, 9, 12 min	↓ SJ power at 15s for both strong and weak subjects ↑ SJ power at 3, 6, 9, 12 min in strong group ↑ SJ power at 6, 9, 12 min in weak group
Sole et al. (2013)	10 (TR)	1 x 3 at 90% 1RM	4, 8, 12 min	No difference in stride length, stride frequency, stance time, and flight time between squat protocol and control during agility test
Sotiropoulos et al. (2014)	12 (TR)	1 x 6 JSs at 70%, 100%, or 130% of load that maximized mechanical power	1, 3, 5, 7, 10 min	No difference in repeated JS height across time within or between any protocol ↑ JS mechanical power with 130% protocol compared to 100% and control at 5min ↑ JS mechanical power with 70% protocol compared with control at 7min ↑ Quadriceps EMG after 130% protocol compared to control at all times, 100% protocol at 1 and 5min, and 70% protocol at 1 and 3min ↑ Quadriceps EMG after 70% and 100% protocols compared to control at 3, 5, 7, and 10min
Till & Cooke (2009)	12 (TR)	1 x 5 deadlift at 5RM 1 x 5 tuck jumps 3 x 3s MVC of knee extensors	4, 5, 6, 7, 8, 9 min	No statistical differences in 10 and 20m sprints nor VJ existed for any protocol No differences in warm up protocols existed for average 20m sprint and VJ performance
Tobin et al. (2013)	20 (TR)	2 x 10 ankle hops, 3 x 5 70cm hurdle jumps, and 5 DJs from 50cm	1, 3, 5 min	↑ CMJ height and peak force at 1, 3, 5 min
Tsolakis et al. (2011)	23 (TR)	3 x 5 double-legged tuck jumps	Imm, 4, 8, 12 min	↓ CMJ power at 8 and 12 min
Turner et al. (2014)	23 (TR)	3 x 10 alternate leg bounds with (W) or without 10% body mass weighted vest (NW) Walking control	15s, 2, 4, 8, 12, 16 min	↑ 10m sprint velocity following NW at 4 min and W at 8 min ↑ 10m sprint velocity after NW and W compared to control condition at 4 min ↑ 10m sprint velocity during W compared to NW and control conditions at 8 min ↑ 20m sprint velocity following NW at 4 min and W at 4 and 8 min

				↓ 20m sprint performance following W compared to control at 15s ↑ 20m sprint velocity following W compared NW and control conditions at 4 and 8 min
Witmer et al. (2010)	24 (TR, RT)	1 x 3 back squat at 70% 1RM	3, 6, 9, 12, 15, 18, 21, 24, 27, 30 min	No difference in VJ height or stiffness compared to control for neither sex No difference in responses between men and women

**Note:** CMJ, countermovement jump; DJ, drop jump; Imm, immediately following intervention; NS, training status not specified; RFD, rate of force development; RM, repetition maximum; RT, subjects reported as recreationally trained; SJ, squat jump; TR, subjects reported to be those who have trained at least twice per week for one year or athletes; UT, untrained subjects who have not participated in any resistance training over the previous year; VJ, vertical jump

By identifying the rest interval specific to a potentiating stimulus, practitioners may be able to use this information to program various SPPCs into their athletes' resistance training regimens. Based on the above literature, it appears that certain SPPCs may require rest periods specific to that particular SPPC. It is likely that SPPCs that involve a higher volume-load may require a longer rest period before a positive potentiation effect can be observed. Furthermore, a number of studies suggest that it may be necessary to provide participants using SPPCs to invoke a potentiation response with individualized rest periods in order to provide the optimal training stimulus (Bevan et al., 2010; Comyns et al., 2006; Kilduff et al., 2007; Linder et al., 2010; McCann & Flanagan, 2010).

### Subject Characteristics

Another important facet of potentiation literature is the characteristics of the subjects being investigated. Previous research has indicated that several subject characteristics may alter the effect of PAP on subsequent performances. These factors include the training status, training age, chronological age, genetics (fiber type and composition), sex, relative strength, and absolute strength of subjects (Docherty & Hodgson, 2007; Hodgson et al., 2005; Sale, 2002; Stone et al.,

2008; Tillin & Bishop, 2009). Based on these concepts, researchers may be interested in questions regarding if the subjects were stronger versus weaker, athletes versus recreationally trained, or male versus female. Finally, researchers may be interested in investigating the differences in potentiation based on the fiber type and composition of subjects.

### Stronger vs. Weaker Subjects

Many researchers have investigated the magnitude of the PAP response based on the strength level of the subjects. Many studies have indicated that stronger subjects demonstrate a greater potential to harness the PAP response following a potentiating stimulus that will lead to acute enhancements in performance as compared to their weaker counterparts (Berning et al., 2010; Chiu et al., 2003; Gourgoulis et al., 2003; Koch et al., 2003; Rixon et al., 2007; Seitz et al., 2014a). In support of these findings, large statistically significant correlations of  $r = 0.50$  (Terzis et al., 2009),  $r = 0.76$  (Duthie et al., 2002),  $r = 0.775$  (Seitz et al., 2014a), and  $r = 0.805$  (Koch et al., 2003) between strength measures and subsequent performance measures have been indicated according to the scale developed by Hopkins (2014). Furthermore, Miyamoto et al. (2013) indicated that an individual can enhance their ability to potentiate after getting stronger.

It is possible that greater levels of strength will coincide with the ability to dissipate fatigue faster when using SPPCs, allowing stronger subjects to display an enhanced subsequent performance earlier as compared to weaker subjects (Jo et al., 2010; Seitz et al., 2014a). In fact, it has been suggested that strength-power athletes, will develop fatigue resistance to high loads as an adaptation to repeated high load training (Stone et al., 2008). Therefore, it appears that higher levels of strength may benefit an individual who is considering using SPPCs in their training programs. As demonstrated by weightlifters, who are able to perform lifts with near-

maximal loads repeatedly, the rationale of heavy load warm-ups may extend to a wide variety of high power activities (Chiu et al., 2003). Specific levels of relative strength that appear to be necessary in order to harness the benefits of PAP have been identified by several authors. Some authors have noted that those with the ability to back squat at least twice their body mass will have a greater potential for PAP as compared to their weaker counterparts (Bullock & Comfort, 2011; Ruben et al., 2010; Seitz et al., 2014a). Similarly, Berning et al. (2010) indicated that a level of strength required to achieve greater magnitudes of potentiation is the ability to squat at least 1.7 times one's body mass. Collectively, it appears that much evidence exists in regard to the relationship between strength levels and an enhanced subsequent performance following a SPPC. While one study suggests that the ability to back squat at least 1.7 times one's body mass is a necessary baseline level of strength to display an enhanced performance following an SPPC, three more recent studies indicate that greater potentiation effects can be realized with the ability to squat 2.0 times one's body mass.

In contrast to the previously discussed literature, some research has displayed no statistically significant differences between subjects, regardless of their training background (Batista et al., 2011; Jensen & Ebben, 2003; McBride et al., 2005). In fact, previous research has indicated that normalized strength values do not allow practitioners to identify which individuals will respond to a SPPC (Mangus et al., 2006; Witmer et al., 2010). Strength levels in the squat, snatch, bench press, incline bench press, and body composition did not correlate with an increase in performance (Terzis et al., 2012). Furthermore, previous research displayed a large statistically significant correlation ( $r = -0.55$ ) between leg strength and change in peak leg power during several subsequent CMJs following three MVCs each lasting three seconds in

international level fencers, indicating that stronger subjects may have greater decrease in peak leg power (Tsolakis & Bogdanis, 2011).

Sale et al. (1988) suggested that the full activation of motor units of specific muscles requires maximum voluntary effort and is more likely to be achieved when well trained. It appears that differences in the ability to harness the benefits of PAP relate to the training status of the participant. Thus, practitioners should consider the training status of their participants before implementing an SPPC that uses PAP to improve performance. Although the majority of the above literature supports the notion that stronger, well-trained participants can harness the PAP mechanism more effectively, this topic requires further research. When considering a previously unused SPPC, researchers should consider recruiting subjects with different training backgrounds or divide the subjects into strong and weak based on their relative strength, to determine if each group responds to the stimulus in the same manner.

### Athletes vs. Non-Athletes

Another relationship that potentiation research has examined is the difference between athletes and non-athletes in how they respond to certain PAP protocols. A recent meta-analysis by Wilson and colleagues (2013) indicated statistical differences in potentiation ability between untrained ( $d = 0.14$ ) and athletes ( $d = 0.81$ ) and between trained ( $d = 0.29$ ) and athletes ( $d = 0.81$ ). Supporting these findings, Hamada et al. (2000a) indicated that Canadian national team triathletes displayed statistically greater peak torque during MVCs in both elbow extensors and plantarflexors as compared to sedentary subjects following maximal twitch contractions. Similarly, Koch et al. (2003) indicated that Division I track and field athletes (sprinters and jumpers) performed broad jumps statistically better than college students in a resistance training

class following either a high force squat warm-up, high power squat warm-up, eight min of static stretching, and no activity. Another study by Chiu et al. (2003) examined the potentiation effect of five sets of one repetition of the back squat at 90% 1RM on rebound and concentric-only jump squat performance between athletes and recreationally trained subjects. Their results indicated that athletes potentiated peak power to a greater extent than their recreationally trained counterparts during both rebound and concentric-only jump squats (large effect sizes indicated by authors). In support of the previously discussed studies, Khamoui et al. (2009) indicated that the potentiation-fatigue balance favors potentiation in trained athletes following a heavy-load back squat intervention, while the opposite may exist with recreationally trained men using the same loading stimulus.

Collectively, these studies indicate that potentiation favors athletes as compared to non-athletes. Beyond performance measures, there is a paucity of research that has examined how physical attributes differ between athletes and non-athletes in regard to potentiation. However, as previously indicated, it is likely that the strength levels between athletes and non-athletes may dictate the ability of the subject to use potentiation to enhance subsequent performance. However, other factors that must be considered in regard to potentiation are the strength level, sex, and fiber type dominance of the subjects.

### Men vs. Women

Practitioners seek training methods that will provide their athletes with training stimuli that will lead to gains in a variety of performance characteristics (e.g. muscle mass, strength, power, etc.). When it comes to the PAP phenomenon, several studies have been conducted to

determine if certain potentiating stimuli display sex differences in the ability of males and females to potentiate.

A study by Staron and colleagues (2000) examined the fiber type composition of 55 women and 95 men (~21 years old) and compared the results between sexes. With the exception of fiber Type IC, no statistical differences were found between men and women for muscle fiber type distribution of the vastus lateralis muscle. Specifically, the vastus lateralis muscle in men and women contained approximately 41% I, 1% IC, 1% IIC, 31% IIA, 6% IIAB, and 20% IIB. In contrast, Terzis et al. (2009) indicated that male physical education students had a statistically greater percentage and cross-sectional area of Type II fibers as compared to female students. Supporting their findings, Rixon et al. (2007) indicated that men possess a greater Type II fiber cross-sectional area and have shorter twitch contraction times compared with women. In addition, the authors indicated that women may exhibit greater fatigue resistance due to lower twitch/tetanus ratios. Based on this evidence, the fiber distribution of males and females should allow similar relative results in subsequent performances following a potentiating stimulus. However, if differences do exist between sexes, they may be attributable to the shorter twitch contraction times or greater fatigue resistance characteristic of men and women, respectively.

Witmer et al. (2010) examined the effects of a squatting protocol culminating with three repetitions with a load of 70% 1RM on vertical jump performance in males and females. Their study indicated that no differences in jump height and vertical stiffness existed between sexes or how they responded to the stimulus. Tsolakis et al. (2011) examined CMJ lower body power in male and female fencers following three, 3s maximal isometric knee extensions. Although the male fencers displayed statistically greater lower body power as compared to the females, leg power only decreased after an isometric protocol in male fencers while the female fencers



displayed no change. Similarly, O'Leary et al. (1998) showed that potentiation of twitch force in dorsiflexor muscles after a brief, high-frequency tetanic stimulation, is similar in young women (42%) and men (45%) in the first several min after tetanus. However, statistically significant sex differences in fatigability during 7s of tetanic stimulation (women: 12%; men: 18%) and the twitch/tetanus ratio existed, which are factors known to influence potentiation. Comyns et al. (2006) examined CMJ flight time and peak ground reaction force changes following five repetitions of the back squat with a load of 87% 1RM. The entire subject group and the female participants statistically decreased flight time 30s and six min following the squatting protocol. However, no sex differences existed between male and female subjects. Male subjects displayed a statistical improvement in jump performance after four min, while female subjects did not. In a similar study, Jensen et al. (2003) compared male and female athletes who participated in anaerobic sports and how a 5RM squat affected subsequent CMJs. No statistical difference in the gender x repetition interaction existed, suggesting that the effects of CT are similar in both men and women. McCann and colleagues (2010) examined a variety of protocols involving both back squats and hang cleans and their effects on vertical jumps in both male and female Division I volleyball players. Their study showed that changes in vertical jump height and peak ground reaction forces were not affected by sex. Another study by Radcliffe and Radcliffe (1996) indicated that males statistically improved their horizontal jump distance following four sets of four repetitions of the power snatch, while females did not. Similarly, Terzis et al. (2009) indicated that drop jumps statistically improved underhand front shot throws in men, but not women.

While the distribution of fiber type between males and females appears to be similar within certain muscles, differences in the ability to potentiate may be based on twitch contraction

times or fatigue resistance. Currently, contrasting evidence exists in regard to the ability of male and female subjects to potentiate while using the same SPPCs. If the purpose of an SPPC is to produce a state of “readiness” for subsequent activity, it may be challenging to design a protocol that is effective for both males and females. However, it is clear that only a handful of studies have investigated sex differences within the potentiation literature as compared to the number of different SPPCs that have been examined. It is also clear that further research on this topic is warranted.

### Muscle Fiber Type and Composition

The muscle fiber type and composition that an individual possesses may dictate whether or not he or she will potentiate following a potentiating stimulus. In fact, previous research has indicated that fiber type and composition of the muscles used during an SPPC has a stronger influence on PAP than an individual’s strength level (Mangus et al., 2006; Terzis et al., 2009). Because fiber type and composition appears to be an important facet of potentiation literature, a number of studies have investigated the relationship between fiber type and the performances associated with SPPCs. Previous research has indicated that fast twitch (Type II) dominant muscles show greater degrees of potentiation than slow-twitch (Gullich & Schmidtbleicher, 1996; Hamada et al., 2000b). Furthermore, a number of studies have indicated that PAP is stronger in human muscles with shorter twitch contraction time and a higher proportion of Type II fibers (Hamada et al., 2000b; O’Leary et al., 1997; Vandenboom et al., 1993, 1995; Vandervoort et al., 1983). Although being examined in transgenic mice, Ryder et al. (2007) indicated that myosin regulatory light chain phosphorylation plays a prominent role in skeletal muscle force potentiation of Type IIb fibers but not Type I or IIa fibers. Terzis et al. (2009)

showed that a large statistically significant correlation ( $r = 0.76$ ) between Type II muscle fiber area and the percent change in underhand shot throw distance. Similarly, Bellar et al. (2012) indicated that stronger athletes with potentially higher percentages of Type II fiber may be able to take advantage of PAP effects to increase performance in track and field throwing events.

Although certain facets within the extant potentiation literature contain contrasting findings, this does not appear to be the case with the information regarding fiber type and composition. It appears that the existing literature supports the notion that Type II fibers within muscle are better able express potentiation as compared to Type I fibers. Furthermore, the extant literature supports the view that individuals who possess a greater percentage of Type II fibers are more likely to potentiate, and potentiate to a greater extent than those who are Type I fiber dominant.

Much of the literature supports the notion that stronger subjects are more likely to potentiate and do so to a greater extent than their weaker counterparts. However, a smaller body of conflicting literature exists. In addition, the current literature supports the view that potentiation favors athletes as compared to non-athletes. While some literature suggests that men and women can both potentiate and potentiate to similar extents, conflicting evidence also exists. Although conflicting evidence may exist in many other facets of potentiation literature, it is clear that those who are Type II (fast twitch) dominant are more likely to potentiate and potentiate to a greater extent as compared to those who are Type I (slow twitch) dominant. Because conflicting and limited literature exists with certain subject characteristics within potentiation literature, it is clear that further research is warranted on these important aspects of the potentiation equation.

## Electromyography

A final aspect that has been investigated within potentiation research is the electromyography (EMG) or muscle activation of various muscles. Within this scope, researchers are interested in determining if the EMG of certain muscles differs following various SPPCs as well as if the EMG differs between various rest intervals and baseline measures. The EMG of muscles is typically used to assess the level of motor neuron excitability (Jones & Lees, 2003). If an SPPC can raise the excitation level of motor neurons, there is a greater probability of greater motor unit activity, which may then lead to an enhanced performance. By investigating this topic with various SPPCs, researchers will provide strength and conditioning practitioners with knowledge that will allow them to prescribe or not prescribe various SPPCs within their resistance training regimens.

Despite the plethora of SPPCs within the potentiation literature, only a handful of studies have examined the EMG of lower body musculature before and after a potentiating stimulus. This may be in part to the mixed results that currently exist within the literature or the lack of availability of EMG equipment. Table 2.7 summarizes the studies that investigated EMG differences following a baseline measurement and SPPC.

*Table 2.7 Studies that Examined EMG of Various Muscles Following a Potentiation Protocol*

Author	n (training status)	Intervention	Rest interval	Results
Bergmann et al. (2013)	12 (RT)	8 x 10 maximal bilateral hops with 30s between sets	Imm, 30s between sets	↑ DJ height after hops No change in V-waves or EMG of SOL, lateral G, TA, VM, and BF after hops No difference in DJ contact time or ankle and knee angles between hops and control
Cochrane et al. (2014)	12 (RT)	10, 8, and 5 body weight squats with WBV at 26Hz with 6.4mm amplitude with 60s between sets	30s and 2.5 min	No difference in EMG of VL, BF, or gluteus maximus between the WBV, deadlift warm-up, and Control conditions.
Cormie et al.	9 (RT)	30s WBV at 30Hz	Imm, 5, 15, 30	↑ CMJ height Imm after WBV

Table 2.7 (continued)

(2006)		with 2.5mm amplitude in half-squat position	min	compared to sham treatment
Etnyre & Kinugasa (2002)	12 (NS)	3s MVC of knee extension	0.5, 1, 2, 3s	No differences in iEMG of VL, VM, and BF between protocols ↑ reaction, processing, muscle contraction time
Fukutani et al. (2014)	8 (TR)	Heavy: 1 x 3 at 90% 1RM Moderate: 1 x 3 at 75% 1RM	60s	↑ Twitch torque in both Heavy and Moderate conditions, but greater ↑ after Heavy ↑ CMJ height after both Heavy and Moderate conditions, but greater ↑ after Heavy No effect on M-wave amplitude or root mean squared for any muscle in either condition
Hazell et al. (2007)	10 (RT)	Static and dynamic squat with WBV at 25, 30, 35, 40, and 45Hz with 2 and 4mm amplitude	EMG activity recorded during squats	↑ VL and BF muscle activity with WBV during static squat ↑ VL and BF muscle activity with WBV during dynamic squat
Jones et al. (2003)	8 (TR)	1 x 5 at 85% 1RM	Imm, 3, 10, 20 min	No main effects for CMJ performance or EMG activity No main effects on DJ performance ↑ BF activity during propulsive phase of DJ
Masiulis et al. (2007)	8 (UT)	30s MVC of knee extension 60s of 50% MVC using electrical stimulation	Imm, 1 min, 3 min	↑ Potentiation during 30s MVC condition Imm and after 1 min recovery ↑ Half relaxation time after 50% MVC condition ↑ 10Hz force after 30s MVC condition No differences in VL EMG at 3 min for either condition
McBride et al. (2010)	19 (RT)	6 x 30s WBV at 30Hz with 3.5mm amplitude (1 <sup>st</sup> 3 sets bilateral squat, 2 <sup>nd</sup> 3 sets for each leg: unilateral squats)	Imm, 8, 16 min	↑ Peak force after WBV Imm and at 8 min. No difference in average iEMG, max H-reflex/M-wave ratio, or rate of force development
Mitchell & Sale (2011)	11 (TR)	1 x 5 at 5RM	4 min	↑ CMJ height and peak twitch No change in M-wave amplitude of VM during peak twitch torque in either twitch session
Mina et al. (2014)	16 (RT)	2 x 3 at 85% 1RM 2 x 3 at 85% 1RM with variable resistance elastic bands	5 min	No differences in peak or mean EMG between protocols during warm-ups No difference in peak or mean EMG during eccentric or concentric squat phases during testing repetitions

Table 2.7 (continued)

Miyamoto et al. (2010)	9 (RT)	10s MVC of plantar flexion	Imm, 1, 2, 3, 4, 5 min	<p>↑ Twitch torque Imm after MVC compared to 5 min</p> <p>No effect of time or condition for M-wave amplitude</p> <p>↑ Isokinetic peak torque at 1, 2, 3 min in MVC condition</p> <p>↓ Medial G EMG activity Imm after MVC</p>
Roelants et al. (2006)	15 (NS)	High, low, and one-leg squats with or without WBV at 35Hz	EMG activity recorded during squats	<p>↑ RF, VL, VM, and G EMG after WBV during high, low, and one-leg squat compared to no WBV</p>
Rønnestad et al. (2012)	12 (TR)	<p>1 x 3 half-squat with 65kg with 50Hz WBV</p> <p>1 x 3 half-squat with 100kg with 50Hz WBV</p> <p>1 x 1 half-squat with 92% 1RM with WBV</p> <p>1 x 1 half-squat with 1RM with WBV</p>	3, 10 min	<p>↑ Power output during 3 reps half-squat at 65 and 100kg</p> <p>↑ EMG VM, VL, and RF EMG starting and peak values</p> <p>No difference in 1RM parallel back squat</p>
Sortiropoulos et al. (2014)	12 (TR)	1 x 6 JSs at 70%, 100%, or 130% of load that maximized mechanical power	1, 3, 5, 7, 10 min	<p>No difference in repeated JS height across time within or between any protocol</p> <p>↑ JS mechanical power with 130% protocol compared to 100% and control at 5min</p> <p>↑ JS mechanical power with 70% protocol compared with control at 7min</p> <p>↑ Quadriceps EMG after 130% protocol compared to control at all times, 100% protocol at 1 and 5min, and 70% protocol at 1 and 3min</p> <p>↑ Quadriceps EMG after 70% and 100% protocols compared to control at 3, 5, 7, and 10min</p>
Sotiropoulos et al. (2010)	26 (TR)	<p>1 x 5 at 25% 1RM, 1 x 5 at 35% 1RM (A)</p> <p>1 x 5 at 45% 1RM, 1 x 5 at 65% 1RM (B)</p>	3 min	<p>No difference between groups A and B in CMJ height or power</p> <p>No changes in RF or VM EMG</p> <p>↑ VL in total sample, after A, and after B</p> <p>↑ Average of VL, VM, and RF in total sample and after B</p>

**Note:** BF, biceps femoris; CMJ, countermovement jump; DJ, drop jump; EMG, electromyography; G, gastrocnemius; iEMG, integrated electromyography; Imm, immediately following intervention; NS, training status not specified; RF, rectus femoris; RFD, rate of force development; RM, repetition maximum; RT, subjects reported as recreationally trained; SJ, squat jump; TR, subjects reported to be those who have trained at least twice per week for one year or athletes; UT, untrained subjects who have not participated in any resistance training over the previous year; VJ, vertical jump; VL, vastus lateralis; VM, vastus medialis; WBV, whole-body vibration

Despite the varying methodology and mixed results, EMG is a valuable tool that is underutilized in regard to PAP research. In order to provide strength and conditioning practitioners with information concerning performance following an SPPC, there is a need to examine the EMG of the musculature involved in the movements being trained. By assessing the EMG of musculature during performance, researchers can provide practitioners with important information about what exercises and intensities can be effective in increasing muscle activation while using SPPCs. Thus, training, and furthermore performance, may be enhanced.

### Summary

Strength and conditioning professionals use a variety of training methods in order to improve lower body muscular power. The phenomenon of PAP has become increasingly popular within the scientific literature. The most examined underlying physiological mechanisms that are thought to produce a potentiated state are increased myosin light chain phosphorylation, increased neuromuscular activation, changes in pennation angle, and increased muscle stiffness. However, two other factors that may affect PAP, changes in joint characteristics and bilateral force production symmetry, have not been previously examined.

The phenomenon of PAP is based on CT principles. In order to investigate the effects of PAP, a large number of SPPCs have been investigated. Specific protocols have included MVCs, back squats, half-squats, quarter-squats, front squats, WBV, plyometrics, weightlifting exercises and their variations, running and/or cycling, throwing implements, weighted vests, intermittent exercise, and the leg press. Despite the abundance of protocols, only one study has examined the potentiating effects of heavy concentric-only half-squats. Moreover, no research has examined the differences between ballistic and non-ballistic exercise that uses the same movement leaving

existing questions on how the type of movement performed affects the magnitude and timing of potentiation.

The primary purpose of an SPPC is to bring about a state of fitness or “preparedness” for subsequent physical activity. Part of an SPPC involves either implementing a single or multiple rest intervals in order to determine if potentiation existed or when the optimal rest interval where the greatest potentiation existed. Both short and long rest intervals have been examined to determine if a potentiated state was present at that particular time. As previously mentioned, limited research exists while investigating an SPPC that includes heavy concentric-only half-squats. Furthermore, no previous research has examined multiple rest intervals when using an SPPC that involves heavy concentric-only half-squats.

As displayed in the deterministic model above, the other half of the potentiation equation involves the subject and their characteristics. Previous research has examined potentiation differences between strong and weak subjects, athletes and non-athletes, men and women, and individuals who are fast twitch dominant or slow twitch dominant. Much of the literature supports the notion that stronger subjects are more likely to potentiate and potentiate to a greater extent than their weaker counterparts. However, some conflicting evidence exists. The current literature supports the view that potentiation favors athletes as compared to non-athletes. While some literature suggests that men and women can both potentiate and potentiate to similar extents, conflicting evidence also exists. Conflicting evidence may exist in many other facets of potentiation literature; however, it is clear that those who are Type II (fast twitch) dominant are more likely to potentiate and potentiate to a greater extent as compared to those who are Type I (slow twitch) dominant. Because conflicting and limited literature has examined specific subject



characteristics, it is clear that further research is warranted on these important aspects of the potentiation equation.

It is believed by many that a potentiated state will produce increases in EMG or muscle activation, ultimately resulting in an improved performance. Much of the extant literature suggests that either an increase or no change in EMG will result from an SPPC. It is interesting that an abundance of SPPCs exist, however very little research has examined EMG changes in comparison. Clearly, EMG is underutilized within potentiation research. The information from EMG recordings provides valuable information about the underlying mechanisms of PAP and further research is needed.

## CHAPTER 3

### RELATIONSHIPS BETWEEN POTENTIATION EFFECTS FOLLOWING BALLISTIC HALF-SQUATS AND BILATERAL SYMMETRY

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## **ABSTRACT**

The purposes of this study were to examine the effect of ballistic concentric-only half-squats (COHS) on subsequent squat jump (SJ) performances at various rest intervals and to examine the relationships between changes in SJ performance and bilateral symmetry at peak performance. 13 resistance-trained men performed a SJ immediately and every minute up to 10 minutes on dual force plates after two ballistic COHS repetitions at 90% of their 1RM COHS. SJ peak force, peak power, net impulse, and rate of force development (RFD) were compared using a series of one-way repeated measures ANOVAs. The percent change in performance at which peak performance occurred for each variable was correlated with the symmetry index scores at the corresponding time point using Pearson's correlation coefficients. Statistical differences in peak power ( $p = 0.031$ ) existed between rest intervals; however no statistically significant pairwise comparisons were present ( $p > 0.05$ ). No statistical differences in peak force ( $p = 0.201$ ), net impulse ( $p = 0.064$ ), and RFD ( $p = 0.477$ ) were present between rest intervals. The relationships between changes in SJ performance and bilateral symmetry after the rest interval that produced the greatest performance for peak force ( $r = 0.300$ ,  $p = 0.319$ ), peak power ( $r = -0.041$ ,  $p = 0.894$ ), net impulse ( $r = -0.028$ ,  $p = 0.927$ ), and RFD ( $r = -0.434$ ,  $p = 0.138$ ) were not statistically significant. Ballistic COHS may produce an enhanced SJ performance; however the changes in performance were not be related to bilateral symmetry.

**Keywords:** *squat jump, half-squat, strength-power potentiation complex*

## **Introduction**

Complex training has been described as a method of training that involves completing a resistance exercise prior to performing a plyometric exercise that is biomechanically similar (Comyns, Harrison, Hennessy, & Jensen, 2007; Hodgson, Docherty, & Robbins, 2005; Robbins, 2005). The basis of complex training is thought to be a phenomenon called postactivation potentiation. Postactivation potentiation (PAP) has been defined as an acute enhancement of muscle performance based on the contractile history (Robbins, 2005). By using PAP in training, participants may be able to perform power exercises at a higher intensity, thus creating a superior training stimulus (Docherty, Robbins, & Hodgson, 2004). Furthermore, it has been suggested that training with potentiation complexes may result in superior chronic adaptations in comparison to normal training (Docherty, et al., 2004; Ebben, 2002; Ebben & Blackard, 1997).

A number of potentiation complexes have been investigated within the scientific literature. Many of the protocols have examined the acute potentiation effects of different squatting variations such as back squats (Bevan et al., 2010; Comyns, et al., 2007; Kilduff et al., 2007; McBride, Nimphius, & Erickson, 2005; Weber, Brown, Coburn, & Zinder, 2008), half-squats (Bogdanis, Tsoukos, Veligekas, Tsolakis, & Terzis, 2014; Chaouachi et al., 2011; Dechechi, Lopes, Galatti, & Ribeiro, 2013; Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003; Young, Jenner, & Griffiths, 1998), and quarter-squats (Crum, Kawamori, Stone, & Haff, 2012; Ebben, Wurm, Garceau, & Suchomel, 2013; Esformes & Bampouras, 2013; Mangus et al., 2006). Of the previously listed studies, only three have examined concentric-only muscle actions (Bogdanis, et al., 2014; Crum, et al., 2012; Dechechi, et al., 2013). Moreover, no study has examined the effect of loaded ballistic concentric-only muscle actions on squat jump (SJ)

performance. Because potentiation complexes should include biomechanically similar exercises, the combination of a loaded ballistic concentric-only movement and a SJ form a logical pair. Although specificity within the potentiation complex may play a role in whether or not potentiation occurs, there are a number of underlying mechanisms that must be considered.

There have been several proposed physiological mechanisms of PAP that include an increase in the phosphorylation of myosin regulatory light chains (Palmer & Moore, 1989; Ryder, Lau, Kamm, & Stull, 2007; Vandenboom, Grange, & Houston, 1995), an increase in the level of neuromuscular activation (Suzuki, Kaiya, Watanabe, & Hutton, 1988; Trimble & Harp, 1998), changes in muscle pennation angle (Mahlfeld, Franke, & Awiszus, 2004), and an increase in muscle stiffness (Chu, 1996; Hutton & Atwater, 1992; Shorten, 1987). A potential factor of PAP that has not been previously examined is the subject's bilateral symmetry during jumping.

Bailey et al. (2013) indicated that athletes who have less asymmetry during an isometric mid-thigh pull jumped higher than those with greater asymmetry. It is possible that changes in jump height may be attributable to changes in bilateral symmetry during a potentiation complex. For example, if the potentiating exercise results in an acute change for the individual to become more symmetrical, individuals may jump higher. If this situation were to occur, the relationship between jump performance and bilateral symmetry could not be ignored as a factor of PAP.

Although previous research has outlined an increase phosphorylation of myosin light chains, increased neuromuscular activation, and change in pennation angle as primary mechanisms of PAP (Tillin & Bishop, 2009), no previous research has examined the relationship between bilateral symmetry and the change in performance following a potentiation protocol. In order to

establish whether or not bilateral symmetry may influence PAP, further research is warranted. Therefore, the primary purpose of this study was to examine the relationship between the change in squat jump (SJ) performance following ballistic concentric-only half-squats (COHS) and bilateral symmetry at peak performance. A secondary purpose was to examine the effect of ballistic COHSs on subsequent SJ performance.

## **Methods**

### *Subjects*

Thirteen resistance-trained males participated in this study (age =  $23.9 \pm 2.3$  years, height =  $178.3 \pm 9.3$  cm, body mass =  $86.6 \pm 9.8$  kg, one-repetition maximum (1RM) back squat =  $170.1 \pm 44.0$  kg, relative 1RM back squat =  $1.9 \pm 0.4$  kg/kg, RM COHS =  $205.8 \pm 52.3$  kg, relative 1RM COHS =  $2.4 \pm 0.4$  kg/kg). Inclusion criteria required that each subject had been regularly training with the back squat exercise a minimum of once per week for the previous three months prior to participation in this study. Each subject read and signed a written informed consent form. This study was approved by the East Tennessee State University Institutional Review Board.

### *Experimental Design*

A repeated measures design was used to test our hypotheses and determine the relationships between the change in SJ performance and bilateral symmetry of peak force, peak power, net impulse, and rate of force development. Each subject participated in a 1RM back squat testing session, 1RM COHS testing session, and potentiation testing session. The 1RM testing sessions and potentiation testing session were each separated by one week.

### *1RM Back Squat Testing Session*

The primary purpose of the 1RM back squat testing session was to determine each subject's 1RM back squat, while a secondary purpose was to establish the half-squat starting position for the 1RM COHS testing session. Prior to the 1RM test, each subject performed a general warm-up that included two minutes of cycling at 50 W at approximately 70 rpm on a stationary bike (SCIFIT Systems, Inc., Tulsa, OK). The subjects then completed a dynamic warm-up that included stretches each covering a distance of 10 meters: forward walking lunge, backward walking lunge, lateral lunge, straight leg march, and walking quadriceps stretch, and five repetitions each of slow bodyweight squats and fast bodyweight squats. After the warm-up was completed, the bar height and safety bar heights in the squat rack were adjusted as necessary. Subjects then performed a 1RM back squat test using a protocol modified from McBride et al. (2002). Each subject completed a back squat warm-up that consisted of five repetitions at 30%, five repetitions at 50%, three repetitions at 70%, and one repetition at 90% of their self-determined 1RM. Subjects were provided with two minutes of recovery following the warm-up sets at 30% and 50% of the subject's self-determined 1RM and four minutes of recovery following the warm-up sets at 70% and 90% of the subject's self-determined 1RM. Following the recovery period, each subject completed 1RM back squat attempts, with four minutes of recovery between attempts, at progressively increasing loads until a failed attempt occurred. The loads were determined by the primary investigator and research assistants based on the subject's previous 1RM attempt. A minimum increase of 2.5 kg was required. All subjects achieved their 1RM back in four attempts or fewer. Subjects were required to squat to a depth where their hip crease dropped below their patella for all repetitions to be ruled successful.

After a self-selected recovery time, each subject was asked to squat down to a 90° knee with a 20kg barbell to determine the bar height that would be used for the COHS 1RM test during the second 1RM COHS testing session. The knee angle was verified by the primary investigator using a manual goniometer and the safety bars were raised to the corresponding height. Each subject then stepped under the barbell that rested on the newly adjusted safety bar height to confirm the half-squat position that would be used for the COHS 1RM test was correct.

### *1RM Concentric-only Half-Squat Testing Session*

Subjects returned one week later for the 1RM COHS testing session. The purposes of this session were to determine the subject's 1RM COHS, determine the loads that would be used during the testing sessions, and to familiarise the subjects with the ballistic COHS protocol. Following the same warm-up protocol described above, the subject performed warm-up COHS repetitions using the same protocol used in the previous 1RM back squat testing session. Briefly, the subjects performed five, five, three, and one warm-up repetition(s) at 30%, 50%, 70%, and 90% of their estimated 1RM COHS, respectively. The loads for this session were based on previous pilot testing, which indicated that the 1RM COHS of each subject was approximately 1.2 times that of their respective 1RM back squat. The same recovery periods were used following each warm-up set (i.e. two minutes following 30% and 50% of the subject's estimated 1RM COHS and four minutes following 70% and 90% of the subject's estimated 1RM COHS). After the recovery period, each subject completed maximal COHS attempts, with four minutes of recovery between attempts, at progressively heavier loads until a failed attempt occurred. Similar to the 1RM back squat, each subsequent increase in load was determined by the primary investigator and research assistants based on the subjects' previous 1RM attempt. A minimum



increase of 2.5 kg was required between maximal attempts. All COHS repetitions were performed with the barbell resting on the safety pins of the power rack with the subject starting with a 90 degree knee angle. The subjects then performed a concentric-only motion to complete each repetition, similar to Dechechi et al. (2013) (Figure 3.1). The 1RM COHS of each subject was determined in four attempts or fewer.



*Figure 3.1* Concentric-only half-squat repetition

Following a self-selected amount of rest, subjects completed one set of the potentiation condition to become familiar with the testing procedure. The potentiation condition required the subjects to perform two COHSs with 90% of their previously established 1RM COHS in a ballistic manner. Specifically, the subjects were instructed to finish each COHS repetition explosively onto the balls of their feet. In addition, subjects were instructed to “reset” between repetitions in

order to ensure proper positioning. Strong verbal encouragement was provided during each repetition to simulate testing procedures and to ensure maximal effort.

### *Potential Testing Session*

Upon arrival for the potentiation session, subjects completed the general warm-up described above. Following the general warm-up, subjects were given final instructions before completing their baseline SJs on the force platform. Warm-up SJs were performed at the subject's perceived 50% and 75% of maximum effort. Following the warm-up jumps, subjects performed two SJs with maximum effort with one minute of rest between jumps. Two minutes after the maximal baseline jumps, subjects completed the same dynamic warm-up as previously described.

Following two minutes of recovery, the subjects began the COHS potentiating protocol, which consisted of five repetitions at 30%, three repetitions at 50%, three repetitions at 70%, and culminated with two repetitions at 90% 1RM of the subject's previously established 1RM COHS. Two minutes of recovery was provided between the warm-up sets at 30% and 50% 1RM and four minutes of recovery was provided following the warm-up set at 70% 1RM. Following the final repetition of each potentiation condition (i.e. 90% 1RM COHS), subjects stepped out of the squat rack and onto a set of dual force plates, and performed a SJ immediately (~15 seconds) and every minute up to 10 minutes on. All SJ repetitions were performed on a dual force plate setup (2 separate 45.5 x 91 cm force plates; RoughDeck HP, Rice Lake, WI) sampling at 1,000 Hz while the subjects held a near weightless (< 1 kg) PVC pipe on their upper back, similar to a high bar back squat position. Subjects squatted down to a knee angle of 90°, received a countdown, and jumped as high as possible.

### *Data and Statistical Analyses*

The SJ data were collected and analyzed using a customised LabVIEW program (2012 Version, National Instruments Co., Austin, TX, USA). Voltage data obtained from the force plates were filtered using a digital low-pass Butterworth filter with a cutoff frequency of 10 Hz in order to remove any noise from the signal. Peak values of force and power were extracted from the force-time and power-time data, respectively from each individual force plate. Net impulse was calculated as the summation of all positive and negative impulses from each plate. Rate of force development was calculated as the average rate of force development from the onset of the SJ to peak force from each force plate. The average values of each variable were calculated between the two baseline repetitions and compared with the values obtained during the SJs at each post-stimulus rest interval (i.e. immediately and 1-10 minutes) during each testing condition. Symmetry index (SI) scores for peak force, peak power, net impulse, and rate of force development were calculated using the equation below (Sato & Heise, 2012; Shorter, Polk, Rosengren, & Hsiao-Wecksler, 2008).

$$SI = [(Larger Value - Smaller Value) \cdot (Sum of Values)^{-1}] \cdot 100$$

Intraclass correlation coefficients (ICC) were used to determine the test-retest reliability of peak force, peak power, net impulse, rate of force development, and the symmetry index scores for peak force, peak power, net impulse, and rate of force development variables in question during the baseline SJs during each testing session. Pearson product-moment, zero order correlations were calculated between the percent change in performance at the time of peak performance from baseline, and the corresponding symmetry index scores of each variable at the same time

interval. A series of one-way repeated measures ANOVAs were used to compare baseline peak force, peak power, net impulse, and rate of force development with the performance at each rest interval. If the assumption of sphericity was violated, Greenhouse-Geisser adjusted values were reported. When necessary, *post hoc* analysis was completed using the Bonferroni technique. Partial eta squared effect sizes ( $\eta^2_p$ ) and statistical power ( $c$ ) were calculated for all main effect comparisons. Effect sizes were interpreted as small, moderate, and large if  $\eta^2_p$  values were 0.01, 0.06, and 0.14, respectively (Cohen, 1988). All statistical analyses were performed with SPSS 22 (IBM, New York, NY) and statistical significance for all analyses was set at  $p \leq 0.05$ .

## Results

Peak force, peak power, net impulse, and rate of force development all displayed high test-retest reliability with ICC values of 0.99, 0.99, 0.99, and 0.83, respectively. With the exception of the net impulse symmetry index score (ICC = 0.85), the test-retest reliability of symmetry index scores for peak force, peak power, and rate of force development were less reliable displaying ICC values of 0.21, 0.62, and 0.68, respectively.

The descriptive peak force, peak power, net impulse, and rate of force development data are displayed in Table 3.1. Statistically significant differences in peak power were found between rest periods ( $F_{5,481, 65.768} = 2.563$ ,  $p = 0.031$ ,  $\eta^2_p = 0.176$ ,  $c = 0.79$ ); however no statistically significant pairwise comparisons existed ( $p > 0.05$ ). In contrast to peak power, no statistically significant differences existed between rest periods for peak force ( $F_{4,265, 51.178} = 1.542$ ,  $p = 0.201$ ,  $\eta^2_p = 0.114$ ,  $c = 0.46$ ), net impulse ( $F_{11, 132} = 1.779$ ,  $p = 0.064$ ,  $\eta^2_p = 0.129$ ,  $c = 0.84$ ), or rate of force development ( $F_{4,956, 59.466} = 0.915$ ,  $p = 0.477$ ,  $\eta^2_p = 0.071$ ,  $c = 0.30$ ).

Table 3.1 Descriptive peak force, peak power, net impulse, and rate of force development data at baseline and each rest interval (mean  $\pm$  SD; n = 13).

Time	Performance Variable			
	Peak Force (N)	Peak Power (W)*	Net Impulse (Ns)	RFD (N/s)
Baseline	2094.6 $\pm$ 282.8	4763.0 $\pm$ 826.0	224.7 $\pm$ 33.5	3349.0 $\pm$ 679.3
~15s	2113.3 $\pm$ 275.3	4816.9 $\pm$ 839.6	225.7 $\pm$ 34.4	3363.0 $\pm$ 830.3
1min	2094.2 $\pm$ 246.4	4821.4 $\pm$ 807.7	227.2 $\pm$ 35.5	3214.4 $\pm$ 623.5
2min	2140.4 $\pm$ 267.1	4931.1 $\pm$ 796.6	229.0 $\pm$ 34.5	3433.8 $\pm$ 913.7
3min	2101.4 $\pm$ 281.0	4879.7 $\pm$ 894.5	228.8 $\pm$ 36.9	3413.2 $\pm$ 719.1
4min	2111.2 $\pm$ 261.7	4857.9 $\pm$ 771.4	227.4 $\pm$ 33.0	3493.0 $\pm$ 815.3
5min	2127.5 $\pm$ 284.0	4904.7 $\pm$ 836.8	227.9 $\pm$ 33.4	3155.2 $\pm$ 645.9
6min	2116.3 $\pm$ 283.5	4899.6 $\pm$ 860.8	228.8 $\pm$ 35.0	3583.6 $\pm$ 1182.4
7min	2108.9 $\pm$ 264.6	4882.2 $\pm$ 841.3	228.6 $\pm$ 34.9	3485.7 $\pm$ 756.3
8min	2092.0 $\pm$ 274.1	4800.9 $\pm$ 807.4	226.3 $\pm$ 33.3	3236.8 $\pm$ 699.1
9min	2077.3 $\pm$ 275.4	4739.6 $\pm$ 824.8	224.8 $\pm$ 34.1	3296.5 $\pm$ 789.0
10min	2099.7 $\pm$ 283.0	4876.7 $\pm$ 886.4	228.8 $\pm$ 35.5	3310.2 $\pm$ 897.9

Notes: \* = statistically significant main effect; RFD = rate of force development

Table 3.2 Symmetry index score descriptive data for peak force, peak power, net impulse, and rate of force development at baseline and each rest interval (mean  $\pm$  SD; n = 13).

Time	Performance Variable			
	Peak Force SI (%)	Peak Power SI (%)	Net Impulse SI (%)	RFD SI (%)
Baseline	1.24 $\pm$ 0.50	4.40 $\pm$ 2.54	2.75 $\pm$ 2.05	6.58 $\pm$ 3.89
~15s	0.92 $\pm$ 0.69	6.00 $\pm$ 3.09	3.31 $\pm$ 2.57	8.55 $\pm$ 7.80
1min	1.02 $\pm$ 0.71	5.11 $\pm$ 2.65	3.82 $\pm$ 2.27	6.92 $\pm$ 5.57
2min	0.80 $\pm$ 0.87	6.02 $\pm$ 4.59	3.89 $\pm$ 4.13	8.60 $\pm$ 7.95
3min	0.96 $\pm$ 0.81	4.66 $\pm$ 3.07	1.90 $\pm$ 1.78	5.31 $\pm$ 3.15
4min	1.24 $\pm$ 0.69	4.12 $\pm$ 2.82	3.22 $\pm$ 2.80	6.76 $\pm$ 4.59
5min	1.02 $\pm$ 1.06	5.15 $\pm$ 3.33	3.30 $\pm$ 2.52	9.29 $\pm$ 8.81
6min	1.46 $\pm$ 0.70	5.32 $\pm$ 2.33	3.50 $\pm$ 2.24	8.28 $\pm$ 6.09
7min	1.28 $\pm$ 0.68	6.36 $\pm$ 4.32	3.07 $\pm$ 1.57	8.70 $\pm$ 6.60
8min	1.07 $\pm$ 0.80	4.15 $\pm$ 3.35	3.02 $\pm$ 2.49	8.33 $\pm$ 6.00
9min	1.25 $\pm$ 0.70	7.04 $\pm$ 5.81	2.93 $\pm$ 1.60	9.18 $\pm$ 7.40
10min	0.82 $\pm$ 0.86	3.83 $\pm$ 2.84	3.46 $\pm$ 2.37	9.35 $\pm$ 6.99

Notes: SI = symmetry index score; RFD = rate of force development

As displayed in Table 3.1, the greatest peak force, peak power, and net impulse performance occurred two minutes following the potentiation protocol, while the greatest rate of force development performance occurred six minutes following the potentiation protocol. No statistically significant relationships ( $p > 0.05$ ) existed between the percent change in

performance at peak performance and the corresponding symmetry index score as displayed in Figures 3.2-3.5.

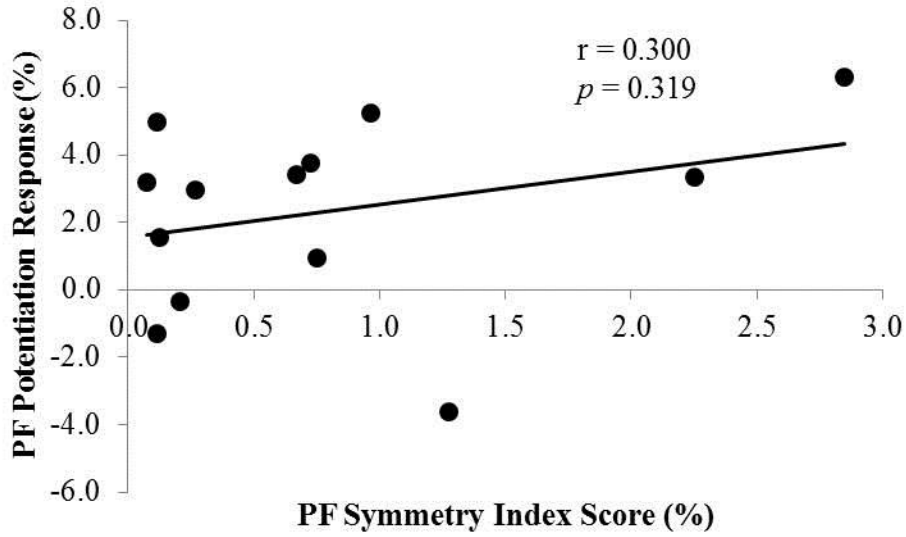


Figure 3.2 Relationship between peak force (PF) symmetry index score and potentiation response at two minutes post-stimulus

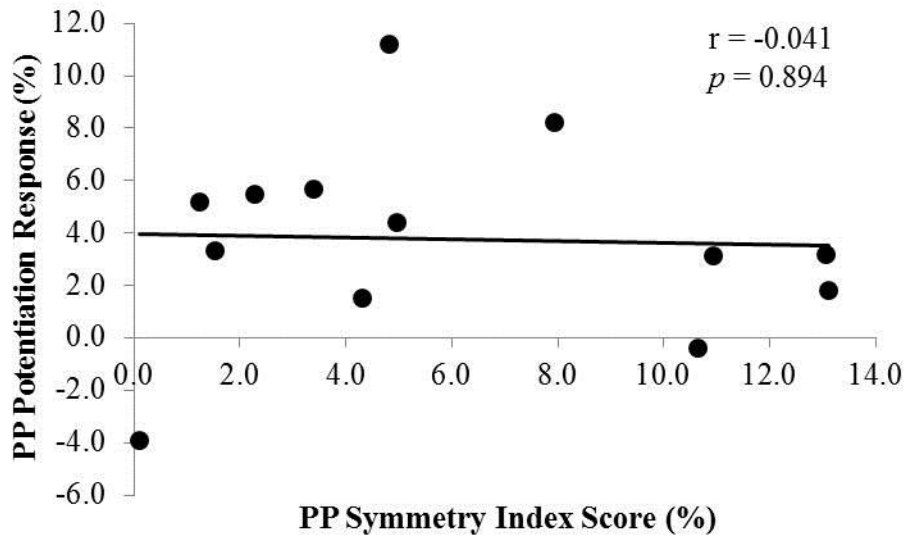


Figure 3.3 Relationship between peak power (PP) symmetry index score and potentiation response at two minutes post-stimulus

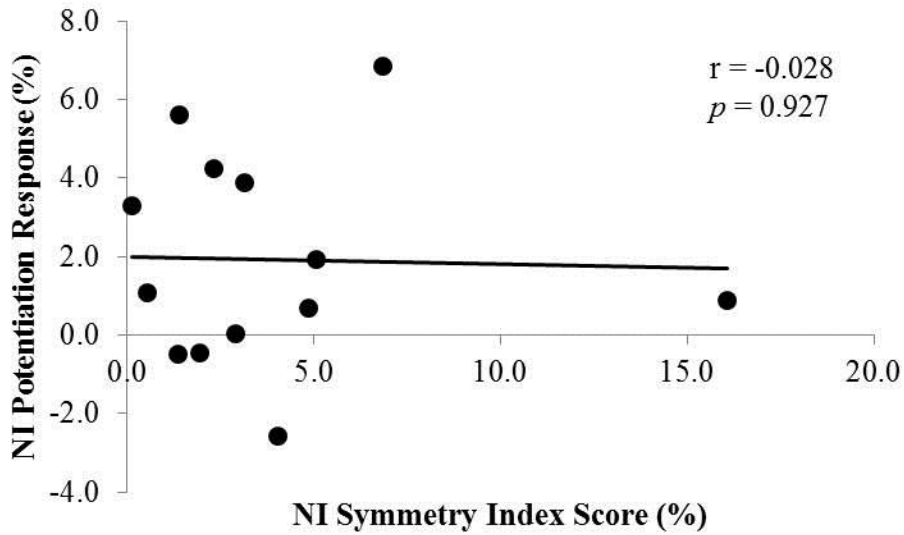


Figure 3.4 Relationship between net impulse (NI) symmetry index score and potentiation response at two minutes post-stimulus

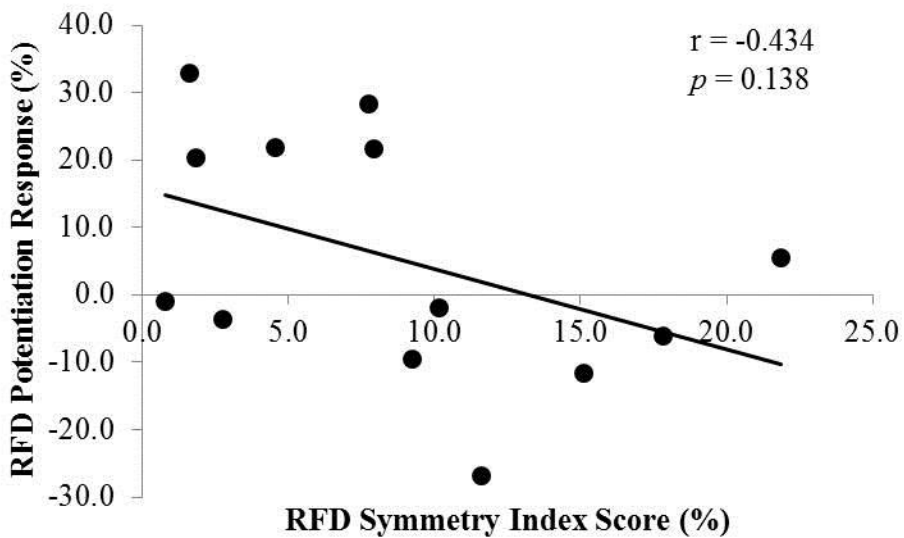


Figure 3.5 Relationship between rate of force development (RFD) symmetry index score and potentiation response at six minutes post-stimulus

## Discussion

The current study examined the effect of ballistic COHSs on subsequent SJ performances and evaluated the relationships between change in SJ performance and bilateral symmetry at the time of peak performance. The primary findings of this study are as follows: Statistically significant

differences in peak power existed between the examined time points, while the magnitudes of peak force, net impulse, and rate of force development were not statistically different following ballistic COHSs. However, large and moderate effect sizes existed for peak power and peak force, net impulse, and rate of force development, respectively. None of the relationships between the percent change in performance at the time of peak performance and the corresponding symmetry index scores for peak force, peak power, net impulse, or rate of force development were statistically significant.

The greatest SJ performance with regard to peak force, peak power, and net impulse occurred two minutes following the potentiation protocol. However, the greatest SJ performance with regard to rate of force development occurred at six minutes post-stimulus. Although statistically significant differences were only seen with peak power, it should be noted that practical significance was present as large and moderate effect sizes for peak power and peak force, net impulse, and rate of force development were present, respectively (Cohen, 1988). Recent meta-analyses by Gouvêa et al. (2013) and Wilson et al. (2013) indicated that the greatest potentiation magnitudes occurred at 8-12 minutes and 7-10 post-stimulus, respectively. From a practical standpoint, it appears that the ballistic protocol used within the current study may elicit an enhancement at a much earlier rest interval. Thus, practitioners may consider implementing ballistic COHS as part of a potentiation complex as they may produce enhanced peak power magnitudes much earlier as compared to previous literature.

Several physiological mechanisms have been purported to contribute enhanced performances following potentiation complexes. For a review, readers are directed to Tillin et al. (2009).



Some of the proposed mechanisms include an increase in the phosphorylation of myosin regulatory light chains (Palmer & Moore, 1989; Ryder, et al., 2007; Vandenboom, et al., 1995), an increase in the level of neuromuscular activation (Suzuki, et al., 1988; Trimble & Harp, 1998), changes in muscle pennation angle (Mahlfeld, et al., 2004; Tillin & Bishop, 2009), and an increase in muscle stiffness (Chu, 1996; Hutton & Atwater, 1992; Shorten, 1987). Prior to the current study, no previous research had investigated how changes in performance following a potentiation complex related to the bilateral symmetry of the same performance variables. As a result, sport scientists could not rule out bilateral symmetry as a contributing factor of jump potentiation. The results of the current study indicate that the changes in performance following a potentiation complex that included ballistic COHSs are not related to the bilateral symmetry of the subjects during SJs.

Previous research has indicated that an individual's absolute strength may play a large role in the jumping asymmetry of an athlete (Bailey, Sato, Burnett, & Stone, 2014). Specifically, a stronger athlete may display less asymmetry as compared to a weaker athlete. However, Bazylar et al. (2014) indicated that increases in strength may only decrease asymmetry to a certain extent. Several potentiation studies have indicated that strong relationships exist between an individual's strength levels and their potentiation response (Duthie, Young, & Aitken, 2002; Koch et al., 2003; Seitz, de Villarreal, & Haff, 2014; Terzis, Spengos, Karampatsos, Manta, & Georgiadis, 2009). It is possible that bilateral symmetry may be related to an individual's potentiation response based on their level of strength. Although outside the scope of this study, future research may consider examining the relationships between change in performance and bilateral symmetry in strong and weak subjects.

There are two primary limitations to note within this study. The test-retest reliability of the symmetry index scores of most of the examined variables was poor, with the only exception being net impulse. These results call into question the consistency of asymmetry measures for an individual in a practical setting. It should be noted that once the subjects stepped onto the force plates no additional instruction was provided with regard to foot placement. Future research may consider investigating jump asymmetries over the course of a series of jumps to determine its consistency for an individual in a practical setting. Differences in asymmetry between strong and weak subjects following potentiating exercise were not examined in the current study. Because the absolute strength levels of subjects may dictate their level of asymmetry (Bailey, et al., 2014), but may change following training (Bazyler, et al., 2014), future research may consider examining the differences in asymmetry between strong and weak subjects following a potentiation protocol.

## **Conclusion**

Ballistic COHSs may acutely enhance subsequent SJ performance at various rest intervals; however the changes in performance may not be related to bilateral symmetry. The greatest improvement in SJ performance following ballistic COHSs may occur two minutes post-stimulus. From a practical standpoint, improvements in performance seen at such an early rest interval makes the examined protocol much more feasible to use in a training setting as compared to potentiation complexes whose optimal rest interval is much longer. However, further researching examining the potentiation effects of COHSs is needed before conclusive statements of their effectiveness or ineffectiveness can be made. The test-retest reliability of symmetry index scores for peak force, peak power, and rate of force development may be

questionable and thus it is suggested that future research should examine the consistency of bilateral symmetry in a practical setting.

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## CHAPTER 4

### POTENTIATION EFFECTS OF HALF-SQUATS PERFORMED IN A BALLISTIC OR NON-BALLISTIC MANNER

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## ABSTRACT

This study examined and compared the acute effects of ballistic and non-ballistic concentric-only half-squats (COHS) on squat jump performance. 15 resistance-trained men performed a squat jump two minutes following a control protocol or two COHS at 90% of their 1RM COHS performed in a ballistic or non-ballistic manner. Jump height (JH), peak power (PP), and allometrically-scaled peak power (PPa) were compared using three 3 x 2 repeated measures ANOVAs. Statistically significant condition x time interaction effects existed for JH ( $p = 0.037$ ), PP ( $p = 0.041$ ), and PPa ( $p = 0.031$ ). *Post hoc* analysis revealed that the ballistic condition produced statistically greater JH ( $p = 0.017$  and  $p = 0.036$ ), PP ( $p = 0.031$  and  $p = 0.026$ ), and PPa ( $p = 0.024$  and  $p = 0.023$ ) than the control and non-ballistic conditions, respectively. Small effect sizes for JH, PP, and PPa existed during the ballistic condition ( $d = 0.28$ - $0.44$ ), while trivial effect sizes existed during the control ( $d = 0.0$ - $0.18$ ) and non-ballistic ( $d = 0.0$ - $0.17$ ) conditions. Large statistically significant relationships existed between the JH potentiation response and the subject's relative back squat 1RM ( $r = 0.520$ ,  $p = 0.047$ ) and relative COHS 1RM ( $r = 0.569$ ,  $p = 0.027$ ) during the ballistic condition. In addition, large statistically significant relationship existed between JH potentiation response and the subject's relative back squat strength ( $r = 0.633$ ,  $p = 0.011$ ), while the moderate relationship with the subject's relative COHS strength trended toward significance ( $r = 0.483$ ,  $p = 0.068$ ). Ballistic COHS produced superior potentiation effects compared to COHS performed in a non-ballistic manner. Relative strength may contribute to the elicited potentiation response following ballistic and non-ballistic COHS.

**Keywords:** *postactivation potentiation, concentric-only half-squat, squat jump, power, relative strength*

## **INTRODUCTION**

Strength and conditioning practitioners often seek training modalities that will produce superior results in competition. A topic that has received much attention as a training modality is postactivation potentiation. Postactivation potentiation (PAP) has been defined as an acute enhancement of muscular performance as a result of contractile history and is considered the basis of complex training (27). A large portion of PAP literature has focused on the development of potentiation complexes whose primary goal is to enhance a subsequent high power or high velocity movement. However, currently there are a limited number of potentiation complexes that may be implemented effectively in a practical setting due to the long rest period needed to produce an enhanced performance (13, 39) and the cost of additional equipment in the weight room (e.g. whole-body vibration platforms). Thus, the ability to effectively implement potentiation complexes within strength training programs may be challenged.

Partial range of motion exercises are frequently prescribed in strength training programs (6, 7, 14, 32). These movements allow for the use of supramaximal loads that cannot be lifted through a full range of motion. Previous research has indicated that using supramaximal loads with partial lifts may enhance maximal force production via reduced neuromuscular inhibition (38). In addition, Zatsiorsky (40) indicated that training with partial lifts may enhance peak force, rate of force development, and impulse in the range of motion being trained as compared to only training with full range of motion lifts. Previous potentiation research has used partial lifts such as the concentric-only half-squat (COHS) and eccentric-only half-squat (3, 9) and concentric-only quarter-squat (8) in order to enhance subsequent explosive performances. Although two studies indicated that no potentiation effect was produced (3, 8), Dechechi et al. (9) indicated that

COHS performed at 90% 1RM produced superior sprint performance as compared to eccentric-only half-squats. Despite the above results, no previous research has investigated whether or not different potentiation effects are produced from performing the same potentiating exercise with maximal velocity (ballistic) or without maximal velocity (non-ballistic). A comparison between COHS performed in ballistic and non-ballistic manner is warranted and may have important training implications with regard to partial squatting movements.

The use of ballistic exercise as part of a potentiation complex is well documented (21). A ballistic exercise is characterized as an exercise that includes the intention to complete the movement with maximal velocity and accelerating throughout the entire movement (10, 25). Previous research has used a variety of ballistic exercises such as depth jumps (34), tuck jumps (36), countermovement jumps (26), and weightlifting movements such as hang clean (23), power clean (30), and snatch pulls (5) in order to potentiate subsequent exercise. The underlying physiological mechanism of PAP when using ballistic exercise is centered on an increase in neuromuscular activation. Ballistic exercise causes the threshold of recruitment of given motor units to be lower as compared to slower, ramped contractions (10, 37). Moreover, the large neural drive associated with ballistic movements can allow for the motor neuron pool to be activated to its fullest extent within milliseconds (11).

Henneman's size principle indicates that the use of heavier loads will produce superior activation of Type II fibers as compared to lighter loads (15). Moreover, an exercise performed in a ballistic manner may produce greater power outputs than the same exercise performed in a non-ballistic manner (19). It would appear that an ideal potentiation complex would combine a

heavily loaded movement performed in a ballistic manner. Despite the number of potentiation complexes that have been examined in the previous literature, limited research has compared the potentiation effects of the same exercise performed in a ballistic or non-ballistic manner.

Previous studies by Andrews et al. (1) and Seitz et al. (30) touched on this concept by comparing the potentiation effects of a ballistic exercise (i.e. hang clean or power clean) and non-ballistic exercise (i.e. back squat). Both studies indicated that the ballistic exercise produced superior potentiation effects compared to the non-ballistic exercise with regard to vertical and sprint performance, respectively. It should be noted however, that both studies used different loads for each of the exercises examined, resulting in the use of much different loads for each exercise. To the authors' knowledge, no previous research has examined the potentiation differences following ballistic and non-ballistic exercises that use the same mechanics and absolute loads.

It appears that research examining the potentiation effects of a heavily loaded exercise performed in a ballistic and non-ballistic manner is warranted. Therefore, the purpose of this study was to examine and compare the acute effects that ballistic and non-ballistic COHS have on subsequent squat jump (SJ) performance. It was hypothesized that ballistic COHS would produce greater potentiation effects as compared to non-ballistic COHS.

## **METHODS**

### **Subjects**

This study included 15 resistance-trained males (age =  $24.3 \pm 4.4$  years, height =  $179.7 \pm 10.2$  cm, body mass =  $85.8 \pm 9.9$  kg, one-repetition maximum (1RM) back squat =  $161.4 \pm 29.4$  kg, relative 1RM back squat =  $1.9 \pm 0.3$  kg/kg, 1RM COHS =  $195.0 \pm 28.1$  kg, relative 1RM COHS

=  $2.3 \pm 0.3$  kg/kg). Inclusion criteria required that each subject had been regularly training with the back squat exercise a minimum of once per week for the previous three months prior to participation in this study. This study was approved by the East Tennessee State University Institutional Review Board. All subjects were informed of the possible risks of involvement in the study and provided written informed consent.

## **Procedures**

All subjects participated in two 1RM testing sessions (i.e. 1RM back squat and 1RM COHS) and three jump testing sessions (i.e. Control, Ballistic, and Non-ballistic). The 1RM testing sessions and first jump testing session were each separated by one week and the jump testing sessions were separated by 72-96 hours. The order of the jump testing sessions was randomized to prevent an order effect.

### *1RM Back Squat Testing Session*

The purposes of the 1RM back squat testing session were to determine each subject's 1RM back squat and to establish the half-squat starting position for the 1RM COHS testing session. Prior to testing, each subject performed a standardized general and dynamic warm-up. The general warm-up consisted of two minutes of stationary cycling at 50 W (approximately 70 rpm; SCIFIT Systems, Inc., Tulsa, OK), and the dynamic warm-up included dynamic stretches (e.g. forward walking lunge, straight leg march, walking quadriceps stretch, etc.) and five repetitions each of slow bodyweight squats and fast bodyweight squats. Two minutes following the dynamic warm-up, subjects then completed a 1RM back squat test using a protocol modified from McBride et al. (22). Briefly, subjects performed five, five, three, and one warm-up repetition(s) at 30%, 50%,

70%, and 90% of their self-determined 1RM, respectively. Two minutes of recovery were provided following the warm-up sets at 30% and 50% of the subject's self-determined 1RM while four minutes were provided following the warm-up sets at 70% and 90% of the subject's self-determined 1RM. The subject then completed maximal back squat attempts, with four minutes of recovery between attempts, at progressively increasing loads until a failed attempt occurred. The loads were determined by the primary investigator and research assistants based on the previous 1RM attempt by the subject and a minimum 2.5 kg increase was required. Each subject's 1RM was achieved in four maximal attempts or fewer. All back squat repetitions were performed to a depth where the subject's hip crease dropped below their knee.

Following the 1RM back squat, a self-selected recovery time was given to each subject prior to establishing the bar height that would be used for the COHS 1RM test during the 1RM COHS testing session. Subjects were asked to squat down to a 90° knee angle with a 20kg barbell while the primary investigator and research assistants determined the safety bar height. The subject's knee angle was verified by the primary investigator by using a manual goniometer and the safety bars were raised to the corresponding height. Each subject then stepped under the barbell that rested on the newly adjusted safety bar height to verify that the half-squat position that would be used for the COHS 1RM test was correct.

#### *1RM Concentric-Only Half-Squat Testing Session*

Subjects returned one week later for the 1RM COHS testing session. The goals of this session were to determine the subject's 1RM COHS, determine the loads that would be used during the testing sessions, and to familiarize the subjects with the ballistic and non-ballistic COHS

conditions. Following the same general and dynamic warm-up performed in the previous testing session, the subject began performing warm-up COHS repetitions using a similar protocol as the 1RM back squat testing session. The subjects performed five, five, three, and one warm-up repetition(s) at 30%, 50%, 70%, and 90% of their estimated 1RM COHS, respectively. The loads for this session were based on previous pilot testing, which indicated that the 1RM COHS of each subject was approximately 1.2 times that of their respective 1RM back squat. The same recovery periods were provided to the subjects with two minutes following the warm-up sets at 30% and 50% of the subject's estimated 1RM COHS and four minutes following the warm-up sets at 70% and 90% of the subject's estimated 1RM COHS. Following the last warm-up set, the subject performed maximal COHS attempts, with four minutes of recovery between each attempt, at progressively heavier loads until a failed attempt occurred. The increases in load for subsequent repetitions were determined by the primary investigator and research assistants based on the subjects' previous 1RM attempt. All COHS repetitions were performed with the barbell resting on the safety pins of the squat rack with the subject starting with a 90° knee angle. The subjects then performed a concentric-only motion to complete each repetition. The 1RM COHS of each subject was determined in four maximal attempts or fewer.

Following the 1RM COHS test, subjects were provided with a self-selected recovery period before completing one set each of the potentiation conditions. The familiarization sets were used to have the subject experience the culminating exercise set during the ballistic and non-ballistic testing sessions. Each potentiation condition required the subjects to perform two COHS with 90% of their previously established 1RM COHS. During the non-ballistic condition, subjects completed two repetitions of the COHS finishing the movement without plantar flexion (Figure



4.1). Subjects were instructed to “stand up” with the load. Following a self-selected recovery period, subjects completed a familiarization set of the ballistic condition with the same load as the previous set. During the ballistic condition, subjects were instructed to finish each COHS repetition explosively onto the balls of their feet (Figure 4.2). Subjects were instructed to “reset” between each repetition during both familiarization sets in order to ensure proper positioning. Strong verbal encouragement was provided during each repetition to simulate testing procedures and to ensure maximal effort.



*Figure 4.1* Sequence of non-ballistic concentric-only half-squat



*Figure 4.2* Sequence of ballistic concentric-only half-squat

### *Control Testing Session*

Upon arrival for the control testing session, subjects completed the general warm-up described above. Following the general warm-up, subjects were given final instructions before completing their baseline SJs on the force platform. Warm-up SJs were performed at the subject's perceived 50% and 75% of maximum effort. Following the warm-up jumps, subjects performed two SJs with maximum effort with one minute of rest between jumps. Two minutes after the baseline jumps, subjects completed the control condition protocol which consisted of the same dynamic warm-up as performed during the familiarization sessions. Upon completion, subjects performed a SJ two minutes following the dynamic warm-up. Briefly, subjects squatted down to a knee angle of 90°, received a countdown, and used a concentric-only movement to jump as high as possible while holding a near weightless (< 1 kg) PVC pipe on their upper back, similar to a high bar back squat position (Figure 4.3).



*Figure 4.3 Squat jump performance sequence*

### *Ballistic and Non-Ballistic Testing Sessions*

The following two testing sessions were completed in a similar manner. Subjects first completed the general warm-up followed by the warm-up SJs at 50% and 75% of the subject's perceived

maximal effort, and two maximal SJs with maximum effort. After two minutes of recovery, subjects completed the same dynamic warm-up as previously described. Following two minutes of recovery, the subjects began the COHS potentiating protocol, which consisted of five repetitions at 30%, three repetitions at 50%, three repetitions at 70%, and culminated with two repetitions at 90% 1RM of the subject's previously established 1RM COHS. Two minutes of recovery was provided between the warm-up sets at 30% and 50% 1RM and four minutes of recovery was provided following the warm-up set at 70% 1RM. Based on the testing session, subjects either completed all repetitions in a ballistic or non-ballistic manner as previously described. Strong verbal encouragement was provided to promote maximal effort. Following the final repetition of each potentiation condition (i.e. 90% 1RM COHS), subjects performed a SJ after two minutes of recovery as previously described.

### **Data and Statistical Analyses**

All SJ repetitions were performed on dual force plates (2 separate 45.5 x 91 cm force plates; RoughDeck HP, Rice Lake, WI) sampling at 1,000 Hz. The SJ data were collected and analyzed using a customized LabVIEW program (2012 Version, National Instruments Co., Austin, TX, USA). Voltage data obtained from the force plates were filtered using a digital low-pass Butterworth filter with a cutoff frequency of 10 Hz in order to remove any noise from the signal. Jump height was calculated based on the flight time of the center of mass using previously established methods (20). Allometrically-scaled peak power was equal to the product of peak power and the subject's body mass raised to the 0.67 power. The average value of each variable was calculated between the two baseline repetitions and compared with the values obtained during the SJs at two minutes following each testing condition.

A series of 3 (condition) x 2 (time) repeated measures ANOVA were used to compare the differences in JH, PP, and PPa between the different testing conditions and rest intervals. When necessary, *post hoc* analyses were completed using the Bonferroni technique. In addition, partial factorial ANOVAs were used to investigate statistically significant interaction effects. Cohen's *d* effect sizes were calculated for the difference between means. When the Cohen's *d* value was 0.0, 0.2, 0.6, 1.2, 2.0, and 4.0, effect sizes were interpreted as trivial, small, moderate, large, very large, and nearly perfect, respectively (17). Statistical power (*c*) for main effects was also calculated. Pearson's zero order, product-moment correlation coefficients (*r*) were used to examine the relationships between the JH potentiation response and relative strength during both the ballistic and non-ballistic testing conditions. Correlation values of 0.0, 0.1, 0.3, 0.5, 0.7, 0.9, and 1.0 were interpreted as trivial, small, moderate, large, very large, nearly perfect, and perfect, respectively (17). Intraclass correlation coefficients (ICC) were used to determine the test-retest reliability of JH, PP, and PPa during the baseline SJs of the control, ballistic, and non-ballistic testing sessions. The ICCs ranged from 0.94 – 0.99, 0.95 – 0.99, and 0.97 – 0.99 for all variables during the control, ballistic, and non-ballistic testing sessions, respectively. All statistical analyses were performed with SPSS 22 (IBM, New York, NY) and statistical significance for all analyses was set at  $p \leq 0.05$ .

## **RESULTS**

The descriptive JH, PP, and PPa for each condition are displayed in Table 4.1. There were statistically significant condition x time interaction effects for JH ( $F_{2, 28} = 3.726$ ,  $p = 0.037$ ,  $c = 0.634$ ), PP ( $F_{2, 28} = 3.592$ ,  $p = 0.041$ ,  $c = 0.617$ ), and PPa ( $F_{2, 28} = 3.929$ ,  $p = 0.031$ ,  $c = 0.659$ ). *Post hoc* interaction-contrast analysis indicated that the ballistic condition produced statistically

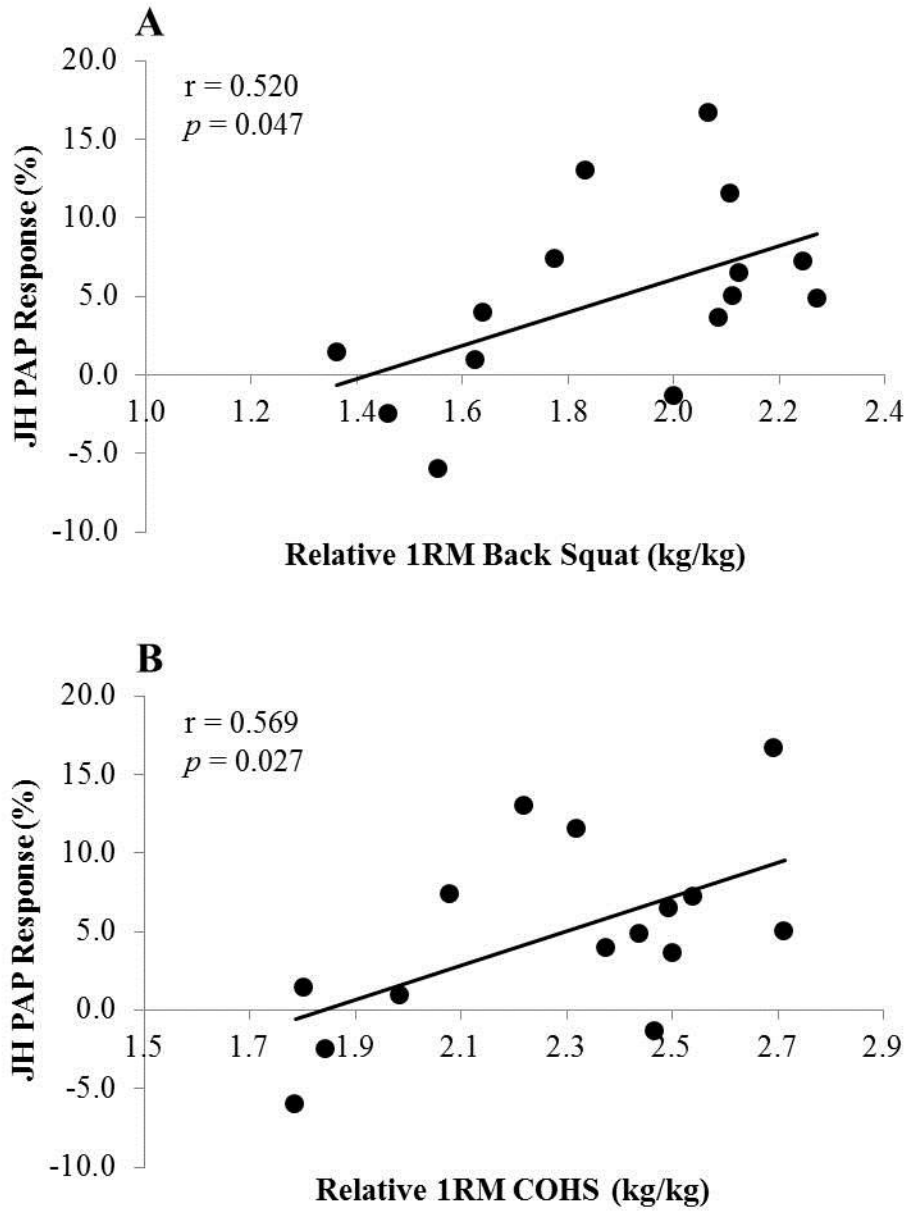
greater JH potentiation effects as compared to the control ( $F_{1, 14} = 7.263, p = 0.017$ ) and non-ballistic conditions ( $F_{1, 14} = 5.373, p = 0.036$ ). In addition, the ballistic condition produced statistically greater PP potentiation effects as compared to the control ( $F_{1, 14} = 5.736, p = 0.031$ ) and non-ballistic conditions ( $F_{1, 14} = 6.177, p = 0.026$ ). Finally, the ballistic condition produced statistically greater PPa potentiation effects as compared to the control ( $F_{1, 14} = 6.442, p = 0.024$ ) and non-ballistic conditions ( $F_{1, 14} = 6.556, p = 0.023$ ). No statistically significant differences existed between the control and non-ballistic conditions for any performance variable ( $p > 0.05$ ).

Table 4.1 Squat jump performance prior to and 2 minutes after a control protocol and two potentiation protocols (mean  $\pm$  SD;  $n = 15$ ).

SJ performance variable	Protocol	Baseline	2 min	Effect size ( $d$ )
JH (m)	Control	0.32 $\pm$ 0.04	0.32 $\pm$ 0.04	0.00
	Ballistic	0.32 $\pm$ 0.04	0.34 $\pm$ 0.05	0.44
	Non-ballistic	0.32 $\pm$ 0.03	0.32 $\pm$ 0.04	0.00
PP (W)	Control	4598.5 $\pm$ 565.4	4663.2 $\pm$ 528.0	0.12
	Ballistic	4699.5 $\pm$ 624.9	4873.2 $\pm$ 616.2	0.28
	Non-ballistic	4659.8 $\pm$ 564.9	4726.0 $\pm$ 590.1	0.11
PPa (W/kg <sup>0.67</sup> )	Control	232.8 $\pm$ 19.3	236.1 $\pm$ 17.1	0.18
	Ballistic	237.7 $\pm$ 21.8	246.7 $\pm$ 23.4	0.40
	Non-ballistic	235.8 $\pm$ 18.7	239.3 $\pm$ 22.2	0.17

Notes: SJ = squat jump; JH = jump height; PP = absolute peak power; PPa = allometrically-scaled peak power

Large statistically significant relationships existed between the JH potentiation response and the subject's relative back squat 1RM ( $r = 0.520, p = 0.047$ ) and relative COHS 1RM ( $r = 0.569, p = 0.027$ ) during the ballistic condition (Figure 4.4). In addition, a large statistically significant relationship existed between JH potentiation response and the subject's relative back squat 1RM ( $r = 0.633, p = 0.011$ ), while the moderate relationship between the JH potentiation response and relative COHS 1RM trended toward significance ( $r = 0.483, p = 0.068$ ) during the non-ballistic condition (Figure 4.5).



*Figure 4.4* Relationships between jump height potentiation response during the ballistic condition and A) relative back squat 1RM and B) relative concentric-only half-squat 1RM

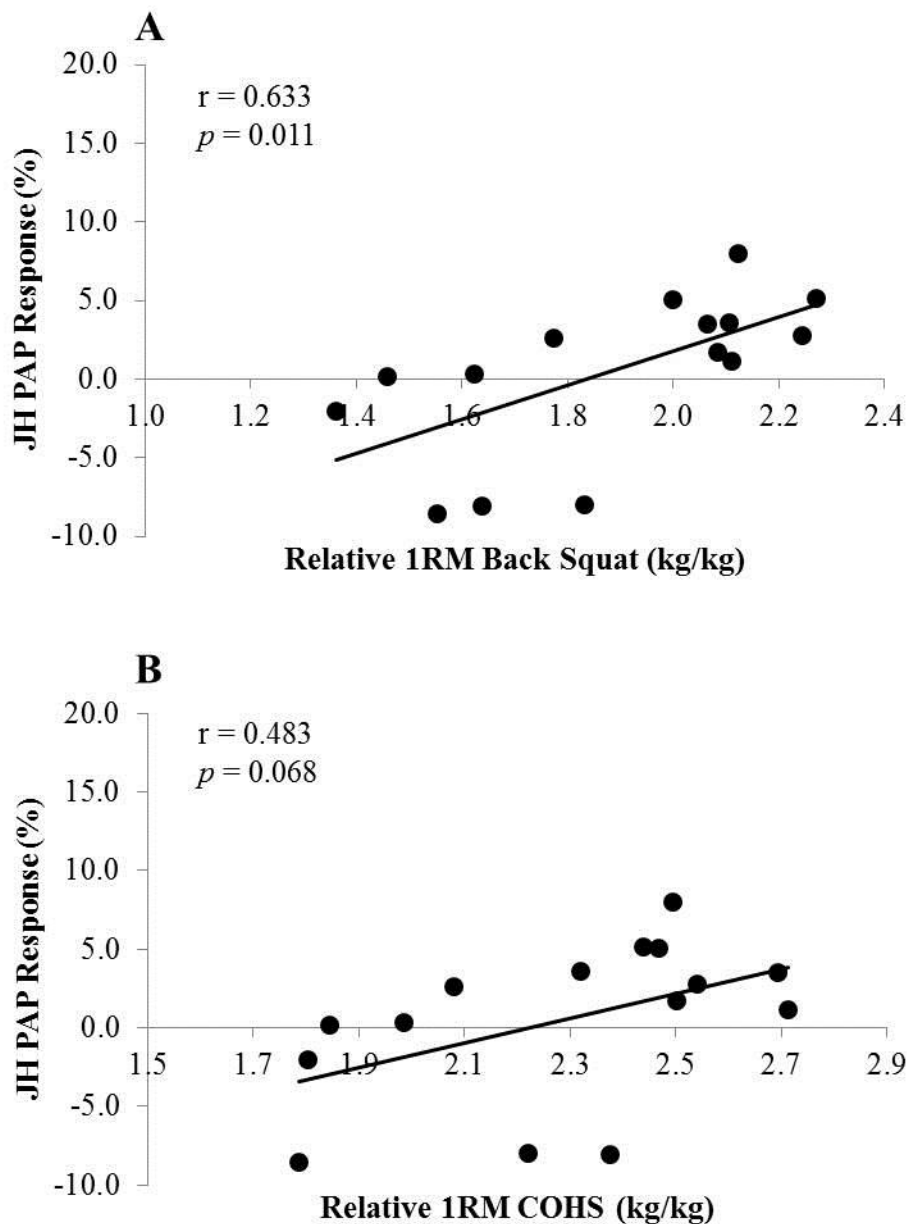


Figure 4.5 Relationships between jump height potentiation response during the non-ballistic condition and A) relative back squat 1RM and B) relative concentric-only half-squat 1RM

## DISCUSSION

The current study examined and compared the acute effects that ballistic and non-ballistic COHS had on subsequent SJ performance. The primary finding of this study was that ballistic COHS produced a superior potentiation effect as compared to the control and non-ballistic protocols. A

secondary finding demonstrated that the potentiation response of each subject was strongly correlated with their relative strength during both the ballistic and non-ballistic protocols.

Ballistic COHS potentiated SJ performance with regard to JH, PP, and PPa to a greater extent than non-ballistic COHS and a control protocol. These findings are in agreement to previous research that has indicated that ballistic movements produce greater power outputs than the same exercise performed in a non-ballistic manner (19). Previous studies by Andrews et al. (1) and Seitz et al. (30) compared the potentiation effects of either hang cleans or power cleans and back squats. Both studies indicated that the ballistic exercise (i.e. hang clean or power clean) produced superior potentiation effects as compared to the non-ballistic exercise (i.e. back squat). The rationale behind why the ballistic condition potentiated SJ performance to a greater extent than the non-ballistic condition may be due to an increase in neuromuscular activation of the involved musculature. Although the current study did not measure muscle activation during the potentiation complexes, Newton et al. (25) indicated that ballistic movements increase the duration of positive acceleration leading to an increase in muscle activation and force output. Future research may consider examining the muscle activation of the active musculature during SJs following ballistic and non-ballistic COHS to determine if an increase in neuromuscular activation is a primary mechanism of enhanced performance.

The effectiveness of a potentiation complex on a subsequent performance may be contingent on several factors (35). One factor that may be overlooked is the design of the potentiation complex. Many potentiation complexes involve completing resistance exercise prior to performing a plyometric exercise that is biomechanically similar (16). Previous research used



concentric-only squatting motions in an attempt to potentiate a countermovement jump, but failed to produce an enhanced performance (3, 8). One of the research groups noted that the lack of eccentric component may have led to their findings (8). Thus, the specificity of the previous potentiation complexes comes into question. The current study used COHS that started from a 90° knee angle to potentiate SJs that were performed from the same starting knee angle. However, the ballistic COHS mimicked the subsequent SJs to a greater extent because the subject accelerated through the entire COHS in a jumping motion, whereas the non-ballistic COHS required the subject to accelerate and decelerate the load to perform a COHS without plantar flexion. In order to effectively train sport specific movements (i.e. jumping, sprinting, etc.) with potentiation complexes that include COHS, it is suggested that a ballistic motion should be used as compared to a non-ballistic motion. Furthermore, the subsequent activity that the practitioner hopes to potentiate must be biomechanically similar, including the eccentric/concentric nature, and joint angles involved.

Many explosive movements in sports are initiated from a knee angle of approximately 90° (e.g. sprinters in the blocks, linemen in football, weightlifters, etc.). Thus, it appears that a training modality that emphasizes explosiveness from this position may be beneficial to practitioners and athletes. Strength training programs often include partial range of motion lifts, such as partial squats (6, 7, 14, 32). Partial squats, such as the COHS examined in the current study, may allow for the use of heavier training loads that an individual may not be able to use if performing a full range of motion squat. Wilson et al. (38) indicated that partial lifts that use these heavier training loads may lead to an increase in maximal force production via reduced inhibition. Moreover, Zatsiorsky (40) indicated that training with partial lifts may lead to positive peak force, rate of

force development, and impulse adaptations in the range of motion being trained as compared to training with full range of motion lifts exclusively. It should be noted that the use of partial squats in training may be exclusive to the goals of the training block. For example, previous literature has indicated that potentiation complexes and partial squats may be exclusively used during training periods where the primary goals are enhanced rate force development and explosive speed development (31). The ballistic COHS examined in the current study appears to be an effective potentiating stimulus and may be used in training programs. However, if practitioners elect to use ballistic COHS in a potentiation complex, it is suggested that the complexes should be incorporated into a strength-power and/or explosive speed training block.

A plethora of potentiation complexes have been investigated within the scientific literature. A reoccurring issue with many of the designed protocols is the lack of practicality with regard to their use in training or competition. For example, two recent meta-analyses by Gouvêa et al. (13) and Wilson et al. (39) indicated that the optimal rest interval for potentiation complexes is between 8-12 minutes and 7-10 minutes, respectively. From a practical standpoint, sport scientists and practitioners should question if using potentiation complexes that require long rest periods (i.e. 7-12 minutes) are feasible to use in training. The training time for athletes may be limited based on university requirements and governing bodies such as the National Collegiate Athletic Association, which forces practitioners to make sure that athletes get the most out of the training time available. The ballistic protocol examined in this study may be viewed as more practical compared to other protocols in the sense that an enhanced performance was seen at an early rest interval (i.e. two minutes). It is suggested that a future focus of potentiation research should be on developing potentiation complexes that are more practical in nature and display an

enhanced performance much earlier than 7-12 minutes as indicated by meta-analyses (13, 39). Researchers may consider using the current study, and those by other research groups who have found positive potentiation effects in four or fewer minutes post-stimulus, as examples in the development of practical potentiation complexes.

The current study indicated that large relationships existed between a subject's potentiation response two minutes following ballistic and non-ballistic potentiation complexes and their relative 1RM back squat and relative 1RM COHS. These findings are in agreement with previous literature that has also displayed large relationships between a subject's strength and subsequent performance (12, 18, 29, 34). As indicated above, a potentiated response two minutes post-stimulus is a relatively early time effect as compared to previous potentiation literature. In fact, this early time interval may favor stronger subjects. Seitz et al. (29) also indicated that stronger subjects displayed an enhanced subsequent performance earlier as compared to weaker subjects. This may be due to an individual's ability to develop fatigue resistance to high loads as an adaptation to repeated high load training (33). Additional research has indicated that subjects who took part in a strength training program enhanced their potentiation ability (24). Moreover, previous research has indicated that the ability to back squat 1.7 times one's body mass (2) or 2.0 times one's body mass (4, 28, 29) will result in greater likelihood of an enhanced subsequent performance following a lower body potentiation complex. Future research may consider examining the temporal profile of strong and weak subjects during the ballistic and non-ballistic potentiation complexes examined in this study.

## **PRACTICAL APPLICATIONS**

The findings of this study may assist practitioners in implementing partial squats within strength training programs and provide insight on the potentiation effects between ballistic and non-ballistic movements. Ballistic COHS produced superior potentiation effects compared to COHS performed in a non-ballistic manner at two minutes post-stimulus. It is suggested that if ballistic COHS potentiation complexes are prescribed, they should be incorporated into a strength-power and/or explosive speed training block. Increasing relative strength may contribute to a greater potentiation response following ballistic and non-ballistic COHS.

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## CHAPTER 5

### POTENTIATION FOLLOWING BALLISTIC AND NON-BALLISTIC COMPLEXES: THE EFFECT OF STRENGTH

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## ABSTRACT

The purpose of this study was to compare the temporal profile of strong and weak subjects during ballistic and non-ballistic potentiation complexes. Eight strong (relative back squat =  $2.1 \pm 0.1$  times body mass) and eight weak (relative back squat =  $1.6 \pm 0.2$  times body mass) males performed squat jumps immediately and every minute up to 10 minutes following potentiation complexes that included ballistic or non-ballistic concentric-only half-squats (COHS) performed at 90% of their 1RM COHS. Jump height (JH) and allometrically-scaled peak power (PPa) were compared using a series of 2 x 12 repeated measures ANOVAs. No statistically significant strength level main effects for JH ( $p = 0.442$ ) or PPa ( $p = 0.078$ ) existed during the ballistic condition. In contrast, statistically significant main effects for time existed for both JH ( $p = 0.014$ ) and PPa ( $p < 0.001$ ); however no statistically significant pairwise comparisons were present ( $p > 0.05$ ). Statistically significant strength level main effects existed for PPa ( $p = 0.039$ ), but not for JH ( $p = 0.137$ ) during the non-ballistic condition. *Post hoc* analysis revealed that the strong subjects produced statistically greater PPa as compared to the weaker subjects ( $p = 0.039$ ). Statistically significant time main effects existed for time existed for PPa ( $p = 0.015$ ), but not for JH ( $p = 0.178$ ). No statistically significant strength level x time interaction effects for JH ( $p = 0.319$ ) or PPa ( $p = 0.203$ ) were present for the ballistic or non-ballistic conditions. Practical significance via effect sizes and relationships between maximum potentiation and relative strength suggest that stronger subjects potentiate earlier and to a greater extent than weaker subjects during ballistic and non-ballistic potentiation complexes.

**Keywords:** *temporal profile, rest interval, relative strength, half-squat, squat jump, power*

## **INTRODUCTION**

An enhanced muscular performance as a result of acute contractile history has been termed postactivation potentiation (PAP) (27). Because the interest of using PAP as a training modality has grown in recent years, researchers have designed exercise complexes that pair a high force or high power movement with biomechanically similar movement. These complexes have been termed strength-power potentiating complexes (27, 31). Within each of these potentiation complexes an optimal rest interval may exist where the greatest amount of PAP may be expressed. For example, previous research has indicated that a state of fatigue and potentiation are produced following a potentiating stimulus (8, 14, 25, 29). This may be modeled acutely based on the fitness-fatigue paradigm (38). It is believed that fatigue may dominate over potentiation in the early stages of recovery (34); however several studies have indicated that fatigue dissipates faster than potentiation (16, 26, 35). Thus, it is up to sport scientists and practitioners to determine the optimal rest interval for individuals completing the potentiation complex. If the rest interval following the potentiating exercise is too short, fatigue may mask the benefits of potentiation (9, 36). However, if the rest interval is too long, the greatest potentiation effects may dissipate, leading to no change in performance. The optimal rest interval following potentiating exercise may be specific to the protocol (22), but may also be altered based on the characteristics of each individual being tested (2, 6, 20, 25, 28). The way an individual responds to the potentiating exercise may be based on their physical and physiological characteristics.

Primary factors that may affect the elicitation of PAP are the characteristics of the individuals being tested. For example, previous research has indicated that the subject's training status,

training age, chronological age, genetics (i.e. fiber type and composition), sex, relative strength, and absolute strength may all affect the magnitude of PAP expressed (5, 14, 19, 29, 31, 34).

Although sport scientists and practitioners cannot manipulate a number of the previously listed characteristics, a subject's strength levels (relative and absolute) can be enhanced with regular strength training. In fact, previous research has indicated that subjects who took part in a strength training program enhanced their ability to express PAP (24). Additional research has displayed strong relationships between a subject's strength levels and potentiated performance (7, 18, 30, 32), further indicating the importance of strength with regard to PAP.

Previous research has indicated that stronger individuals may potentiate earlier and to a greater extent compared to their weaker counterparts (17, 30). This may be due to the ability of stronger individuals to develop fatigue resistance to high loads as an adaptation to repeated high load training (3, 31). In addition, it has been indicated that stronger individuals display greater myosin light chain phosphorylation (12, 34) and have a greater percentage of Type II muscle fibers as compared to their weaker counterparts (1, 23, 33). Because Type II fibers display greater potentiation effects compared to Type I fibers (11, 12), it is logical that individuals who display greater levels of strength would also display earlier and greater levels of potentiation.

While previous research has examined the temporal effects between strong and weak subjects following heavy non-ballistic back squats (17, 30), no previous research has examined the temporal profile of potentiation between strong and weak subjects following ballistic exercise.

Although ballistic exercise has been shown to promote the recruitment of Type II muscle fibers (6), it is currently unknown if stronger individuals will potentiate earlier and to a greater extent following a ballistic exercise. Therefore, the purpose of this study was to compare the temporal

profile of strong and weak subjects during ballistic and non-ballistic potentiation complexes. It was hypothesized that stronger subjects will potentiate squat jump (SJ) performance earlier and to a greater extent than weaker subjects during the ballistic and non-ballistic potentiation complexes.

## **METHODS**

### **Subjects**

Sixteen resistance-trained males who regularly trained with the back squat exercise volunteered to participate in this study. Within this sample, there were eight strong subjects (age =  $23.5 \pm 1.9$  years, height =  $175.5 \pm 3.0$  cm, body mass =  $85.1 \pm 5.3$  kg, 1RM back squat =  $181.1 \pm 16.6$  kg, relative 1RM back squat =  $2.1 \pm 0.1$  kg/kg, 1RM COHS =  $214.6 \pm 17.9$  kg, relative 1RM COHS =  $2.5 \pm 0.1$  kg/kg) and eight weak subjects (age =  $25.1 \pm 5.7$  years, height =  $183.3 \pm 12.9$  cm, body mass =  $83.7 \pm 15.5$  kg, 1RM back squat =  $134.5 \pm 25.5$ kg, relative 1RM back squat =  $1.6 \pm 0.2$  kg/kg, 1RM COHS =  $167.9 \pm 22.1$  kg, relative 1RM COHS =  $2.0 \pm 0.2$  kg/kg). Prior to participation, all subjects read and signed a written informed consent form. This study was approved by the East Tennessee State University Institutional Review Board.

### **Procedures**

The subjects participated in two 1RM testing sessions (i.e. 1RM back squat and 1RM COHS) and two potentiation testing sessions (i.e. Ballistic and Non-ballistic). The 1RM testing sessions and first potentiation session were separated by one week while the potentiation sessions were separated by 72-96 hours.

### *1RM Back Squat Testing Session*

The 1RM back squat testing session was primarily used to establish each subject's 1RM back squat, but was also used to establish the half-squat starting position for the 1RM COHS testing session. Prior to testing, each subject performed a standardized general warm-up that consisted of two minutes of stationary cycling (SCIFIT Systems, Inc., Tulsa, OK) at 50 W at approximately 70 rpm. This was followed by a dynamic warm-up that consisted of dynamic stretches each covering a distance of 10 meters: forward walking lunge, backward walking lunge, lateral lunge, straight leg march, and walking quadriceps stretch, and five repetitions each of slow bodyweight squats and fast bodyweight squats. Following the warm-up, two minutes of recovery were provided before the subject started the 1RM back squat test protocol. The warm-up protocol consisted of five repetitions at 30%, five repetitions at 50%, three repetitions at 70%, and one repetition at 90% of the subject's self-determined 1RM. Two minutes of recovery were provided following the warm-up sets at 30% and 50% and four minutes of recovery were provided following the warm-up sets at 70% and 90%. Following the last warm-up set, the subject performed maximal back squat attempts, with four minutes of recovery between attempts, at progressively increasing loads until a failed attempt occurred. The loads were determined by the primary investigator and research assistants based on the previous 1RM attempt by the subject and a minimum 2.5 kg increase was required. All subjects achieved their 1RM back in four attempts or fewer. All back squat repetitions were performed to a depth where the subject's hip crease dropped below their patella.

Following a self-selected rest period, subjects were asked to squat with a 20 kg barbell to a knee angle of 90° in order to determine the safety bar height for the 1RM COHS that would be

performed during the following 1RM COHS session. The knee angle was verified through the use of a manual goniometer and the safety bar heights were adjusted accordingly. After the safety bars were adjusted, the subject squatted under the bar to confirm that the subject's position for the COHS 1RM test was correct.

#### *1RM Concentric-Only Half-Squat Testing Session*

The 1RM COHS testing session took place one week following the 1RM back squat session. The purposes of this session were to determine the subject's 1RM COHS, determine the loads that would be used during the testing sessions, and to familiarize the subjects to the ballistic and non-ballistic COHS testing conditions. Prior to testing, subjects performed the same warm-up protocol as described above. Following a two minute rest period, the subject began performing warm-up COHS repetitions using a similar protocol as the 1RM back squat testing session. The warm-up protocol consisted of five repetitions at 30%, five repetitions at 50%, three repetitions at 70%, and one repetition at 90% of the subject's estimated 1RM COHS. Based on previous pilot testing, the 1RM COHS of each subject was approximately 1.2 times that of their respective 1RM back squat and thus the warm-up loads were based on this calculation. Two minutes of recovery were provided following the warm-up sets at 30% and 50% of the subject's estimated 1RM COHS and four minutes of recovery were provided following the warm-up sets at 70% and 90% of the subject's estimated 1RM COHS. Following the last warm-up set, the subject completed maximal COHS attempts, with four minutes of recovery between attempts, at progressively increasing loads until a failed attempt occurred. The loads for the subsequent maximal attempts were determined by the primary investigator and research assistants based on the previous 1RM attempt made by the subject. All COHS repetitions were performed with the



barbell resting on the safety pins of the squat rack with the subject starting with a 90° knee angle. The subjects then performed a concentric-only motion to finish each repetition. Each subject's 1RM COHS was determined in four attempts or fewer.

After the 1RM COHS of each subject was established, subjects were given a self-selected recovery period prior to completing one familiarization set of each potentiation condition. Each familiarization set required the subjects to perform two COHS with 90% of their previously established 1RM COHS. The first condition required the subjects to perform two repetitions of the COHS finishing the movement without plantar flexion (non-ballistic condition). Subjects were instructed to “stand up” with the load. During the other condition, subjects completed two repetitions of the COHS finishing the movement explosively onto the balls of their feet or jumping if possible (ballistic condition). Subjects were instructed to “reset” between each repetition during both familiarization sets in order to ensure proper positioning. Strong verbal encouragement was provided during each repetition to simulate testing procedures and to ensure maximal effort.

#### *Potentiation Testing Sessions*

The order of the ballistic and non-ballistic testing sessions was randomized. Upon arrival for the first testing session, subjects completed the general warm-up described above. Following the general warm-up, final instructions were given to the subjects before they completed their baseline SJs on the force platform. Subjects performed warm-up SJs at 50% and 75% of their perceived maximum effort. Following the warm-up jumps, subjects performed two SJs with maximum effort with one minute of rest between jumps. Following two minutes of recovery,

subjects completed the same dynamic warm-up as performed during the 1RM testing sessions. Two minutes following the dynamic warm-up, subjects began the COHS potentiating protocol, which consisted of five repetitions at 30%, three repetitions at 50%, three repetitions at 70%, and two repetitions at 90% 1RM of the subject's previously established 1RM COHS. Based on the testing session, subjects either completed all repetitions in a ballistic or non-ballistic manner as previously described. The subjects received two minutes of recovery following the sets at 30% and 50% 1RM and received four minutes of recovery following the set at 70% 1RM. Immediately following the final repetition of each potentiation condition, each subject walked out of the squat rack and stepped onto the force plates. The subjects were instructed to squat down to the "ready position" (i.e. 90° knee angle) and received a countdown. The subjects then performed a SJ using a concentric-only movement to jump as high as possible while holding a near weightless (< 1 kg) PVC pipe on their upper back, similar to a high bar back squat position. Subsequent SJs were performed in the same manner every minute up to 10 minutes following the completion of the potentiation protocol.

### **Data and Statistical Analyses**

All SJ repetitions were performed on a dual force plate setup (2 separate 45.5 x 91 cm force plates; RoughDeck HP, Rice Lake, WI) sampling at 1,000 Hz. The SJ data were collected and analyzed using a customized LabVIEW program (2012 Version, National Instruments Co., Austin, TX, USA). Voltage data obtained from the force plates were filtered using a digital low-pass Butterworth filter with a cutoff frequency of 10 Hz in order to remove any noise from the signal. Squat jump JH was calculated based on the flight time of the center of mass using previously discussed methods (20). Allometrically-scaled peak power was calculated as the

product of peak power and body mass raised to the 0.67 power. The average values of each variable were calculated between the two baseline repetitions and compared with the values obtained during the SJs at each post-stimulus rest interval (i.e. immediately and 1-10 minutes) during each testing condition.

Intraclass correlation coefficients (ICC) were used to determine the test-retest reliability of JH and PPa for the strong and weak subjects during the baseline SJs during the ballistic and non-ballistic testing sessions. A series of 2 (Strength Level) x 12 (Time) repeated measures ANOVAs were used to compare the JH and PPa of the strong and weak subjects during SJs performed immediately and every minute up to ten minutes following the ballistic and non-ballistic potentiation protocols. If the assumption of sphericity was violated, Greenhouse-Geisser adjusted values were used. When necessary, *post hoc* analyses were completed using the Bonferroni technique. Cohen's *d* effect sizes and 95% confidence intervals (CI) were calculated for the difference between means. Effect sizes were interpreted as trivial, small, moderate, large, very large, and nearly perfect when Cohen's *d* was 0.0, 0.2, 0.6, 1.2, 2.0, and 4.0, respectively, based on the scale by Hopkins (15). In addition, statistical power (*c*) was also calculated. Relationships between the subject's maximum JH potentiation response during the ballistic and non-ballistic testing conditions and relative strength were assessed using Pearson's zero order, product moment correlation coefficients (*r*). The relationships were interpreted as trivial, small, moderate, large, very large, nearly perfect, and perfect if the correlation values were 0.0, 0.1, 0.3, 0.5, 0.7, 0.9, and 1.0 (15). All statistical analyses were performed with SPSS 22 (IBM, New York, NY) and statistical significance for all analyses was set at  $p \leq 0.05$ .

## RESULTS

### *Ballistic Condition*

The ICC values for JH and PPa ranged from 0.95 – 0.98 and 0.93 – 0.97 for the strong subjects and weak subjects during the ballistic testing session, respectively. The temporal profiles for the JH and PPa of strong and weak subjects during the ballistic condition are displayed in Figures 5.1 and 5.2, respectively. No statistically significant main effects for strength level existed for JH ( $F_{1,7} = 0.663, p = 0.442, c = 0.11$ ) or PPa ( $F_{1,7} = 4.246, p = 0.078, c = 0.43$ ) during the ballistic condition. In contrast, statistically significant main effects for time existed for both JH ( $F_{11,77} = 2.363, p = 0.014, c = 0.93$ ) and PPa ( $F_{11,77} = 3.715, p < 0.001, c = 0.99$ ). However, *post hoc* analysis revealed no statistically significant pairwise comparisons for JH or PPa ( $p > 0.05$ ). There were no statistically significant strength level x time interaction effects for JH ( $F_{11,77} = 1.174, p = 0.319, c = 0.59$ ) or PPa ( $F_{11,77} = 1.373, p = 0.203, c = 0.68$ ) during the ballistic condition.

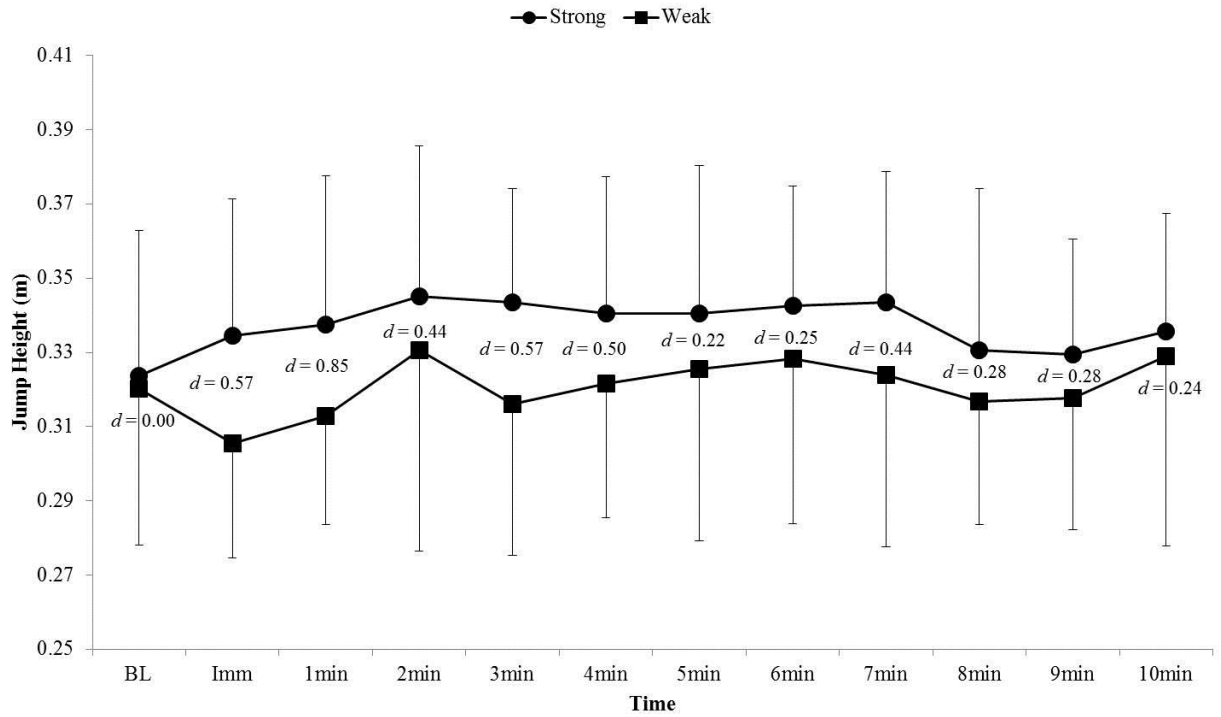


Figure 5.1 Jump height temporal profiles for strong and weak subjects following the ballistic potentiation protocol. Cohen's *d* effect sizes indicate differences between groups

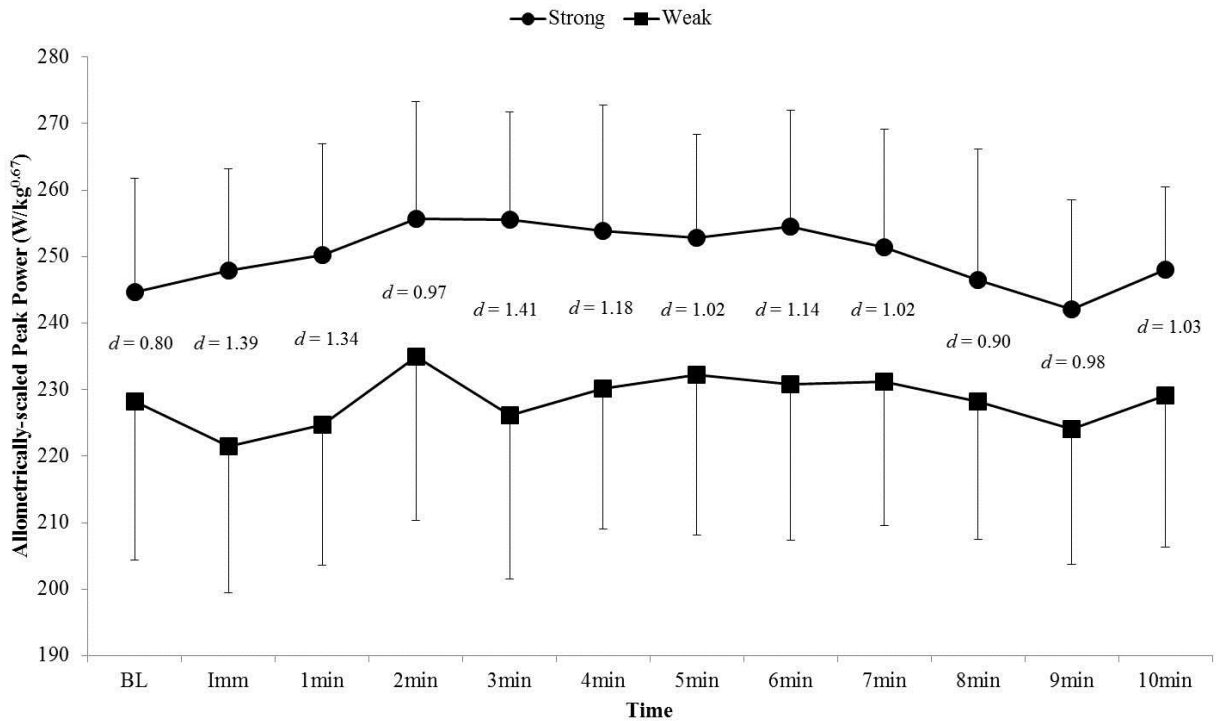


Figure 5.2 Allometrically-scaled peak power temporal profiles for strong and weak subjects following the ballistic potentiation protocol. Cohen's *d* effect sizes indicate differences between groups

Statistically significant relationships existed between the subjects' maximum potentiation response following the ballistic potentiation complex and their relative back squat 1RM ( $p = 0.007$ ) and relative COHS 1RM ( $p = 0.001$ ). The relationships are displayed in Figure 5.3.

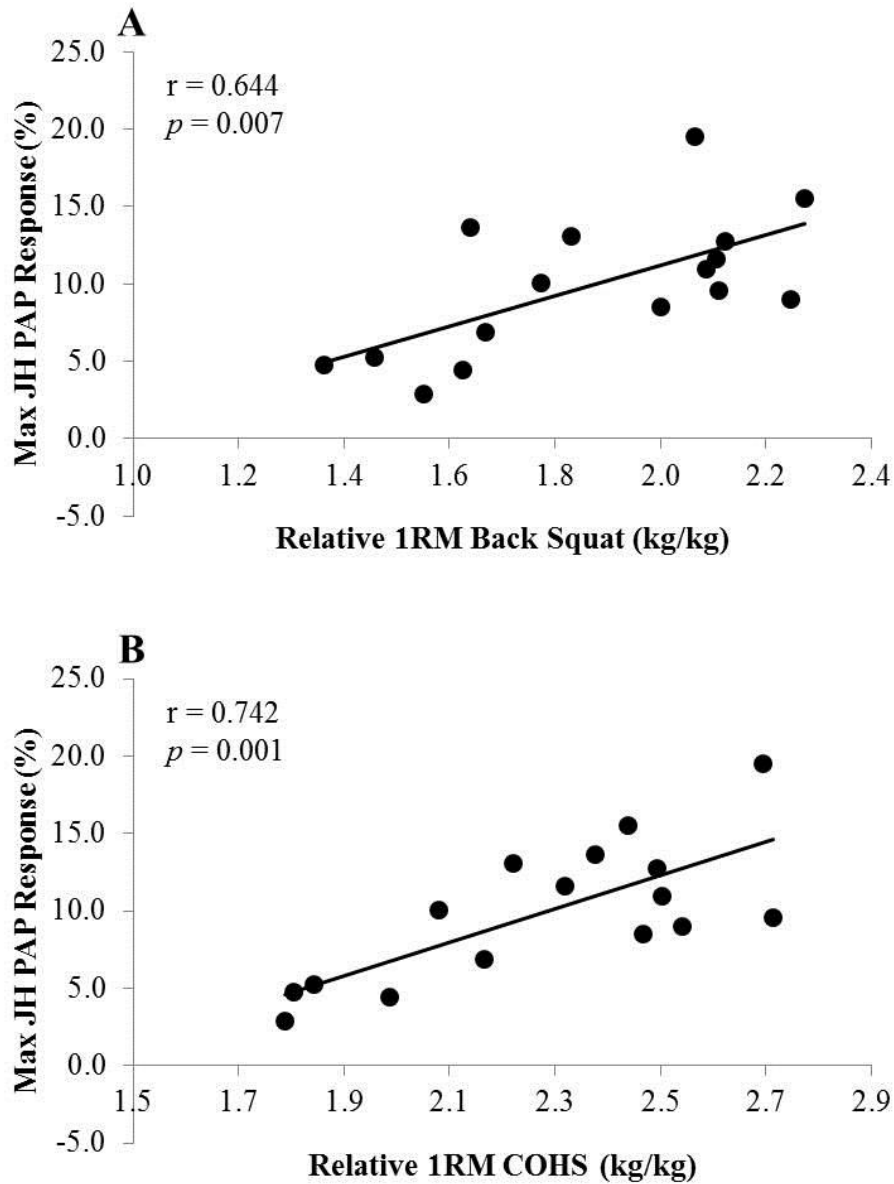


Figure 5.3 Relationship between the subjects' maximum jump height potentiation response following the ballistic potentiation protocol and their A) relative 1RM back squat and B) 1RM concentric-only half-squat

### *Non-Ballistic Condition*

The ICC values for JH and PPa were both 0.97 and ranged from 0.95 – 0.98 for the strong subjects and weak subjects during the non-ballistic testing session, respectively. The temporal profiles for the JH and PPa of strong and weak subjects during the non-ballistic condition are displayed in Figures 5.4 and 5.5, respectively. Statistically significant strength level main effects existed for PPa ( $F_{1,7} = 6.400, p = 0.039, c = 0.59$ ), but not for JH ( $F_{1,7} = 2.820, p = 0.137, c = 0.31$ ) during the non-ballistic condition. *Post hoc* analysis revealed that the strong group produced statistically greater PPa as compared to the weaker subjects ( $p = 0.039, CI = 1.477 - 43.747$ ). Statistically significant time main effects existed for time existed for PPa ( $F_{11,77} = 2.337, p = 0.015, c = 0.92$ ) during the non-ballistic condition, but not for JH ( $F_{11,77} = 1.428, p = 0.178, c = 0.70$ ). *Post hoc* analysis revealed that the PPa at three minutes following the non-ballistic protocol was statistically greater than the PPa at nine minutes ( $p = 0.029, CI = 0.599 - 12.891$ ). No other statistically significant pairwise comparisons were present ( $p > 0.05$ ). There were no statistically significant strength level x time interaction effects for JH ( $F_{11,77} = 0.924, p = 0.522, c = 0.47$ ) or PPa ( $F_{11,77} = 0.732, p = 0.705, c = 0.37$ ) during the non-ballistic condition.

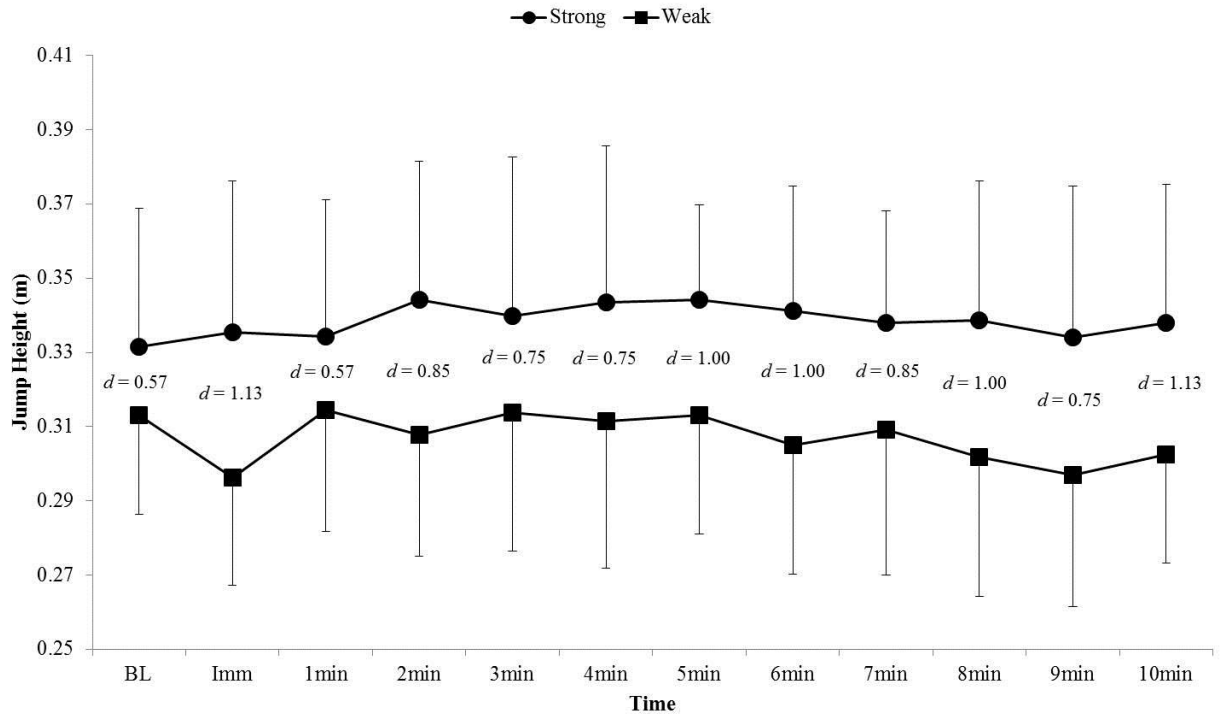


Figure 5.4 Jump height temporal profiles for strong and weak subjects following the non-ballistic potentiation protocol. Cohen's  $d$  effect sizes indicate differences between groups

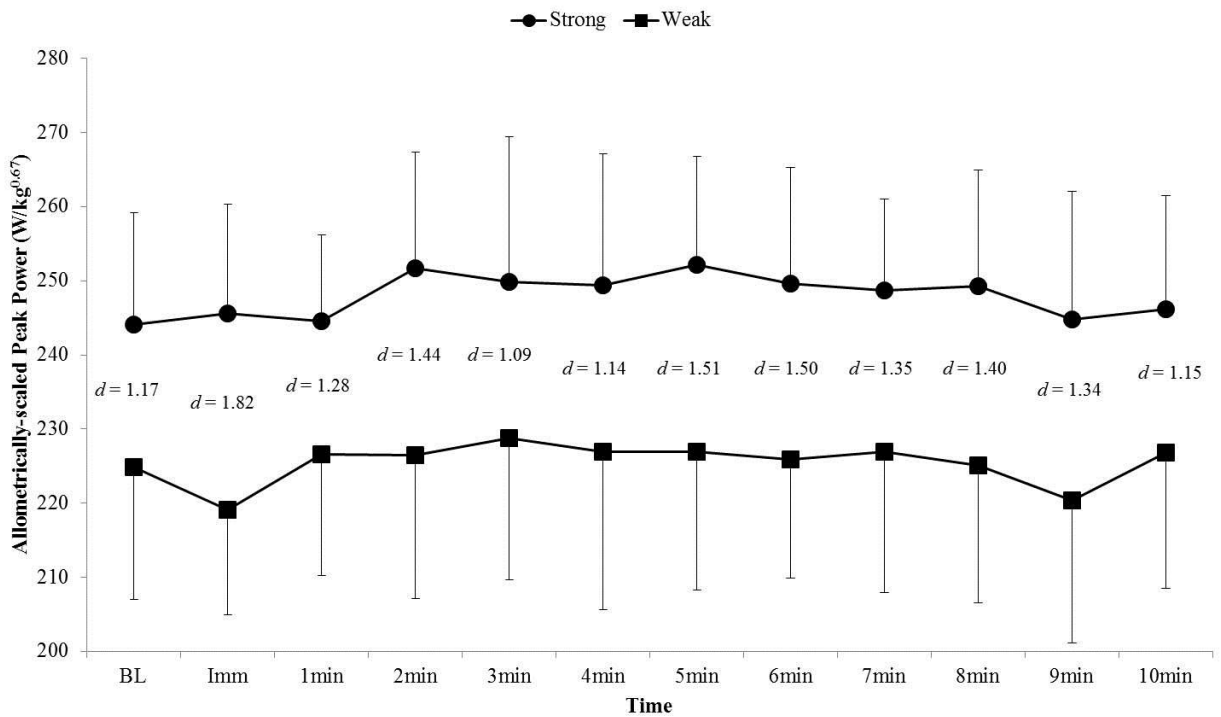


Figure 5.5 Allometrically-scaled peak power temporal profiles for strong and weak subjects following the non-ballistic potentiation protocol. Cohen's  $d$  effect sizes indicate differences between groups



A statistically significant relationship existed between the subjects' maximum potentiation response following the non-ballistic potentiation complex and their relative back squat 1RM ( $p = 0.033$ ), while the relationship between the maximum potentiation response and the subjects' relative COHS 1RM trended toward statistical significance ( $p = 0.065$ ). The relationships are displayed in Figure 5.6.

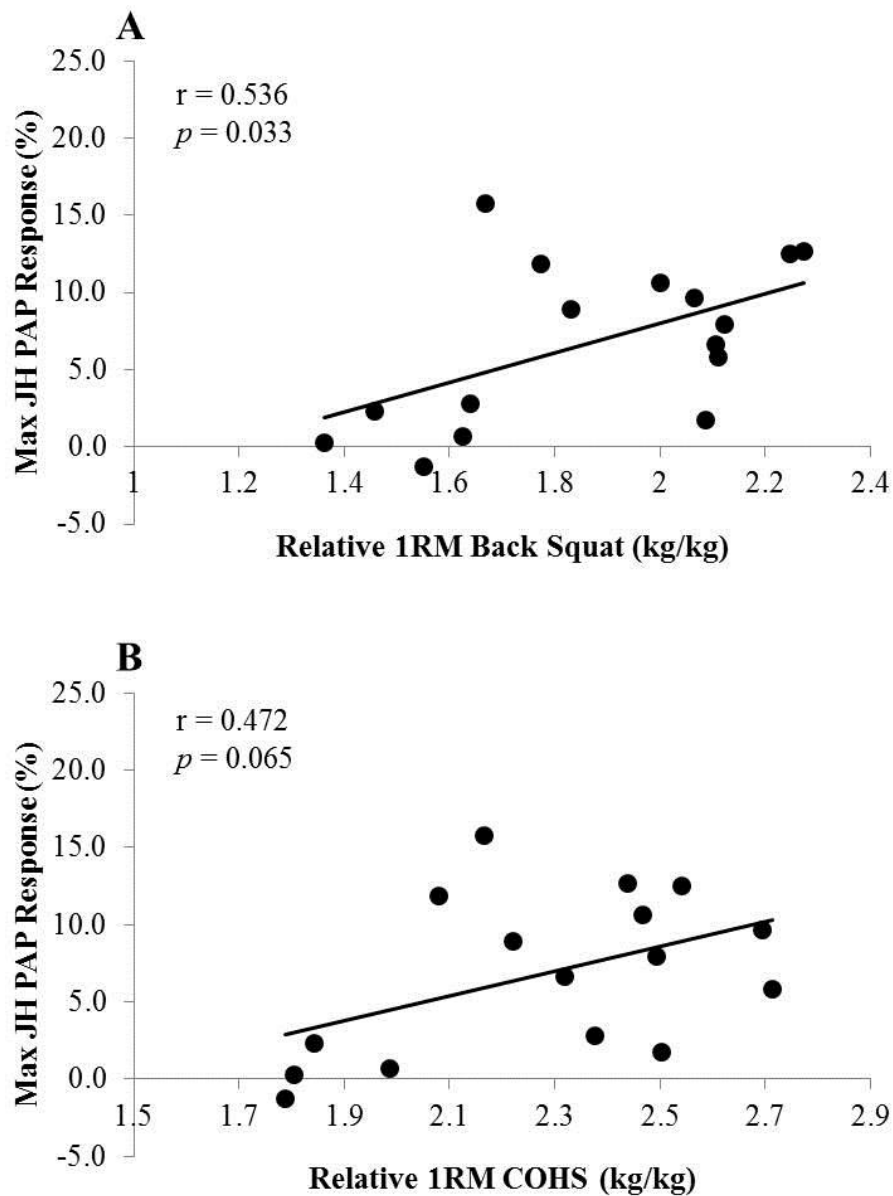


Figure 5.6 Relationship between the subjects' maximum jump height potentiation response following the non-ballistic potentiation protocol and their A) relative 1RM back squat and B) 1RM concentric-only half-squat

## **DISCUSSION**

This study examined the temporal profiles of strong and weak subjects following potentiation complexes that included ballistic and non-ballistic COHSs. The primary findings of this study are as follows. No statistically significant strength level main effects existed for JH or PPa during the ballistic condition; however statistically significant main effects for time existed for both JH and PPa. Statistically significant strength level main effects existed for PPa during the non-ballistic condition and indicated that stronger subjects produced statistically greater PPa as compared to the weaker subjects. However, no statistically significant strength level main effects existed for JH. Statistically significant time main effects existed for time existed for PPa, but not for JH. Finally, there were no strength level x time interaction effects for JH or PPa for the ballistic and non-ballistic conditions.

Although few statistically significant differences existed within this study, the practical significance indicated by effect sizes may provide more valuable information to sport scientists and practitioners regarding the temporal profiles of strong and weak subjects. Stronger subjects enhanced their performance immediately following the potentiation protocols as compared to weaker subjects whose performance decreased initially (Figures 1, 2, 4, and 5). These findings are in agreement with previous research that has indicated that stronger subjects potentiate earlier than their weaker counterparts (17, 30). The ability of the stronger subjects to potentiate immediately after the COHS may be due to their ability to resist fatigue. Previous research has indicated that stronger subjects may develop fatigue resistance to high loads as an adaptation to repeated high load training (3, 4, 17, 31). It is possible that the familiarity of the stronger

subjects with heavier loads allowed them to dissipate any potential fatigue rapidly before producing a potentiated performance.

A unique aspect of this study is the examination of potentiation at different rest periods in strong and weak subjects following two different potentiation protocols. Two recent meta-analyses have indicated the greatest effects of potentiation protocols are produced between 7 and 12 minutes of recovery (10, 37). Interestingly, both strong and weak subjects displayed their greatest performance two minutes after the ballistic protocol. However, stronger subjects were able to maintain a similar performance up to the seven minute recovery interval, while the performance of the weaker subjects dropped off after two minute and never reached a similar magnitude. The non-ballistic protocol yielded similar findings where the stronger subjects produced their greatest performance two minutes post-stimulus and maintained a similar performance to approximately six minutes post-stimulus. It should be noted that the greatest performance by weak subjects occurred one minute post-stimulus for JH, albeit a negligible increase of 0.001 meters. In contrast, the greatest PPa performance of weak subjects following the non-ballistic protocol occurred three minutes post-stimulus.

This is the first study to examine the temporal profile of strong and weak subjects following a potentiation protocol that included ballistic exercise. Our results indicate that the stronger subjects within this study increased their performance to a greater extent as compared to weaker subjects. Specifically, the strong group increased their JH and PPa by 6.4% and 4.4% at peak performance, respectively, while the weak group increased their JH and PPa by 3.2% and 3.0% at peak performance, respectively. The improvements shown in this study are similar to those

displayed in a recent review that documented the use of ballistic exercise within potentiation complexes (i.e. 2-5%) (21). The combination of a heavy load and a ballistic movement likely contributed to the recruitment of Type II muscle fibers (6, 13), which may have led to the performance enhancements displayed. However, because stronger individuals display greater myosin light chain phosphorylation (12, 34) and have a greater percentage of Type II muscle fibers compared to weaker subjects (1, 23, 33), it is not surprising that the stronger subjects within this study improved their performance to a greater extent than the weaker subjects during the ballistic protocol. Further evidence supporting the notion that stronger subjects responding differently to the ballistic potentiation protocol as compared to weaker subjects is indicated by the practical significance between groups. A moderate practical effect at baseline ( $d = 0.80$ ) became large practical effect immediately following the potentiating exercise ( $d = 1.39$ ) (15).

The non-ballistic protocol investigated in this study yielded similar results to the ballistic protocol. The strong group in the current study increased their JH and PPa performance by 3.7% and 3.3% at peak performance, respectively, while the weak group only increased their JH and PPa by 0.4% and 1.7% at peak performance, respectively. Moreover, the stronger subjects increased their performance immediately following the potentiating exercise, while the weaker subjects displayed a decreased performance initially. Our findings are similar to previous research that also investigated the potentiation effects of a heavy squatting movement (17, 30). The effect sizes indicated that a moderate practical effect existed at baseline ( $d = 1.17$ ), but grew to a large practical effect immediately following the potentiating exercise ( $d = 1.82$ ) (15), further indicating differences in how the strong and weak subjects responded to the potentiating exercise.

The results of the current study indicated that subjects whose relative 1RM back squat was two times their body mass or greater potentiated earlier and to a greater extent than subjects whose relative 1RM back squat was less than two times their body mass. This is supported by the large relationships between relative strength measures and maximum potentiation that existed in this study (Figures 3 and 6). In order to increase the likelihood of an individual potentiating, it appears that relative strength that includes a back squat  $\geq 2.0$  times one's body mass is beneficial. This is supported by previous research that has also suggested that the ability to back squat 2.0 times one's body mass may result in an increased ability to enhance a subsequent performance following a lower body potentiation complex (2, 28, 30). Furthermore, Miyamoto and colleagues (24) have indicated that greater magnitudes of potentiation can be achieved following strength training.

## **PRACTICAL APPLICATIONS**

Practical significance via effect sizes and relationships between maximum potentiation and relative strength suggest that stronger subjects potentiate earlier and to a greater extent than weaker subjects during potentiation complexes that include ballistic and non-ballistic COHS. The ability to squat two times one's body mass may result in the ability to potentiate earlier and to a greater extent as compared to lower relative strength levels. In order to realize the greatest benefits following potentiating exercise, greater levels of relative strength should be sought. The differences between strong and weak subjects during the ballistic and non-ballistic potentiation complexes indicate that individualized protocols may be necessary based on an individual's strength level.

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## CHAPTER 6

### SUMMARY AND FUTURE INVESTIGATIONS

The purposes of this dissertation were to 1) To examine the effects of strength-power potentiating complexes on bilateral symmetry and how symmetry affects squat jump performance at various rest intervals, 2) To examine and compare the acute effects of ballistic and non-ballistic concentric-only half-squats on squat jump performance, and 3) To compare squat jump performance between strong and weak subjects at various rest intervals following a strength-power potentiating complexes that include ballistic and non-ballistic concentric-only half-squats.

Previous research has indicated that the primary physiological mechanisms of PAP are an increase in the phosphorylation of myosin regulatory light chains (Cochrane et al., 2010; Hodgson et al., 2008; Palmer & Moore, 1989; Rassier & Herzog, 2001; Ryder et al., 2007; Tillin & Bishop, 2009; Vandenkoorn et al., 1995), increase in the level of neuromuscular activation (Burkett et al., 2005; Hamada et al., 2000b; Suzuki et al., 1988; Tillin & Bishop, 2009; Trimble & Harp, 1998), changes in muscle pennation angle (Mahlfeld, et al., 2004; Tillin & Bishop, 2009), and an increase in muscle stiffness (Chu, 1996; Hutton & Atwater, 1992; Shorten, 1987). This is the first study to examine if bilateral symmetry may be considered as an underlying factor of PAP. The results of Study I indicate that no statistically significant relationships existed between the greatest peak force, peak power, net impulse, or rate of force development performance following ballistic COHS and the bilateral symmetry of each variable. Therefore, although ballistic COHS may acutely enhance subsequent squat jump performance at various rest intervals, the changes in performance do not appear to be related to bilateral symmetry. Thus,

the current study indicates that bilateral symmetry should not be considered as an underlying factor affecting PAP.

An abundance of SPPCs have been investigated within the scientific literature (see Chapter 2). However, only two studies have compared the potentiation effects of ballistic and non-ballistic exercise (Andrews et al., 2011; Seitz et al., 2014c). While these studies have compared a ballistic exercise (i.e. hang clean or power clean) with a non-ballistic exercise (i.e. back squat), Study II is the first study to compare ballistic and non-ballistic exercise using the same movement and loads. The results of Study II indicate that the ballistic protocol produced statistically greater potentiation effects two minutes post-stimulus, with regard to squat jump height, peak power, and allometrically-scaled peak power, compared to the control and non-ballistic protocols. In addition, statistically significant relationships between the jump height potentiation response of the subjects and their relative 1RM squat and COHS existed during both the ballistic and non-ballistic protocols. The findings of Study II may assist practitioners in implementing partial squats within strength training programs and provide insight on the potentiation effects between ballistic and non-ballistic movements. First, ballistic COHS appear to produce superior potentiation effects as compared to non-ballistic COHS. Second, increases in relative strength may contribute to a greater potentiation response following ballistic and non-ballistic COHS.

Previous research has indicated that stronger subjects may potentiate earlier and to a greater extent compared to their weaker counterparts following heavy non-ballistic back squats (Jo et al., 2010; Seitz et al., 2014a). However, a similar comparison had not been completed between strong and weak subjects following ballistic exercise. Study III examined the temporal profiles of strong and weak subjects following ballistic and non-ballistic potentiation complexes.

Although few statistically significant differences existed, practical significance via effect sizes indicated that stronger subjects potentiated earlier and to a greater extent compared to weaker subjects following both the ballistic and non-ballistic potentiation complexes. In support of these findings, statistically significant relationships between the peak jump height potentiation response of each subject and their relative 1RM squat and COHS existed during both the ballistic and non-ballistic protocols. Study III indicated the ability to squat two times one's body mass result in the ability to potentiate earlier and to a greater extent compared to lower relative strength levels. Thus, greater levels of relative strength should be sought to realize greater potentiation effects.

While this dissertation provided answers to some questions, it also raised more questions on the subject, indicating that further research on this topic is warranted. Based on the findings of this dissertation and the extant literature, recommendations for future research are as follows. Future research should consider investigating the muscle activation differences following ballistic and non-ballistic COHS. Another research focus should be to examine the acute effects of ballistic and non-ballistic COHS on other subsequent performances such as sprinting and back squats. Training studies using potentiation complexes are also warranted. The current study indicates that ballistic concentric-only half-squats produce a superior subsequent performance compared to non-ballistic COHS acutely. Training studies that use these potentiation complexes should be completed to determine if there are any longitudinal training effect differences between ballistic and non-ballistic potentiation complexes. Additional training studies should investigate the long-term training effects that result from using the above potentiation complexes in individuals with differing relative levels of strength.

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## APPENDICES

### APPENDIX A: ETSU Institutional Review Board Approval



East Tennessee State University  
Office for the Protection of Human Research Subjects • Box 70365 • Johnson City, Tennessee 37614-1707  
Phone: (423) 439-6053 Fax: (423) 439-6060

#### IRB APPROVAL – Initial Expedited Review

June 5, 2014

Timothy Suchomei

**Re:** The acute effects of ballistic vs. non-ballistic concentric-only half-squats on squat jump performance

**IRB#:** 0314.25s

**ORSPA #:**

The following items were reviewed and approved by an expedited process:

- reform new protocol submission, CV of PI, informed consent (version 3/7/2014)\*, Methods (protocol), data collection sheet

The item(s) with an asterisk(\*) above noted changes requested by the expedited reviewers.

On **June 3, 2014**, a final approval was granted for a period not to exceed 12 months and will expire on **June 2, 2015**. The expedited approval of the study *and* requested changes will be reported to the convened board on the next agenda.

The following **enclosed stamped, approved Informed Consent Documents** have been stamped with the approval and expiration date and these documents must be copied and provided to each participant prior to participant enrollment:

- Informed Consent Document (ICD version 5/27/14 stamped approved 6/3/2014)

Federal regulations require that the original copy of the participant's consent be maintained in the principal investigator's files and that a copy is given to the subject at the time of consent.

**Projects involving Mountain States Health Alliance must also be approved by MSHA following IRB approval prior to initiating the study.**

Unanticipated Problems Involving Risks to Subjects or Others must be reported to the IRB (and VA R&D if applicable) within 10 working days.



*Accredited Since December 2005*

Proposed changes in approved research cannot be initiated without IRB review and approval. The only exception to this rule is that a change can be made prior to IRB approval when necessary to eliminate apparent immediate hazards to the research subjects [21 CFR 56.108 (a)(4)]. In such a case, the IRB must be promptly informed of the change following its implementation (within 10 working days) on Form 109 ([www.etsu.edu/irb](http://www.etsu.edu/irb)). The IRB will review the change to determine that it is consistent with ensuring the subject's continued welfare.

Sincerely,  
Stacey Williams, Ph.D., Vice-Chair  
ETSU Campus IRB

cc: William A Sands

## APPENDIX B: Informed Consent Document

**Principal Investigator:** Timothy J. Suchomel

**Title of Project:** The acute effects of ballistic vs. non-ballistic concentric-only half-squats on squat jump performance.

### **SUBJECT CONSENT FORM FOR PARTICIPATION OF HUMAN SUBJECTS IN RESEARCH**

**Project Title:** **The acute effects of ballistic vs. non-ballistic concentric-only half-squats on squat jump performance.**

**Primary Investigator:** Timothy J. Suchomel, MS, Exercise & Sport Sciences, suchomel@goldmail.etsu.edu

**Faculty Advisor:** Kimitake Sato, PhD, Exercise & Sport Sciences, satok1@etsu.edu  
**Co-Investigator:** Michael H. Stone, PhD, Exercise & Sport Sciences, stonem@etsu.edu

**Co-Investigator:** Brad H. DeWeese, EdD, Exercise & Sport Sciences, deweese@etsu.edu

**Phone:** 423-439-4655 (Sport Science Lab; Mini-Dome E113)

#### **INTRODUCTION:**

You are being asked to participate in a research project. This informed consent will explain about being a participant of this research project. Please read this consent form carefully and decide if you wish to participate in this study.

#### **PURPOSES:**

The purposes of this study are:

- To examine the effects of strength-power potentiating complexes on bilateral symmetry and how symmetry affects squat jump performance at various rest intervals.
- To examine and compare the acute effects that ballistic and non-ballistic half-squats have on squat jump performance following various rest intervals.
- To compare squat jump performance between strong and weak subjects following various rest intervals following a strength-power potentiating complex that includes either ballistic or non-ballistic half-squats.
- To examine the relationships between subject size and shape and postactivation potentiation following either ballistic or non-ballistic half-squats.

#### **DURATION:**

Participation in this study would involve attending five total sessions lasting approximately 45 minutes each over a three week span.

#### **PROCEDURES:**

-You will be asked to participate in the 5 total sessions listed below.

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By the ETSU IRB

JUL 23 2014

By  Chair IRB

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Subject Initials \_\_\_\_\_

**Principal Investigator:** Timothy J. Suchomel

**Title of Project:** The acute effects of ballistic vs. non-ballistic concentric-only half-squats on squat jump performance.

-Subject characteristics and one repetition maximum (1RM) back squat testing session:

You will be asked for your age and your anthropometries (height, body mass, shank length, and leg length) will be measured. Your body composition will be assessed by completing a 7 site skinfold which will involve pinching small amounts of skin on the right side of your body (tricep, subscapula, midaxillary, chest, supralliac, abdomen, and thigh) and measuring them with a caliper. In addition, your right quadriceps (vastus lateralis) and hamstrings (biceps femoris) muscle characteristics (cross-sectional area, pennation angle, and fascicle length) will be assessed by using an ultrasound machine. Specifically, conductance gel will be place on your right thigh and digital pictures will be taken of your intact muscles. You will be asked to participate in a general and dynamic warm-up that consists of light stationary cycling and dynamic stretches, respectively. You will then complete a 1RM back squat test.

-1RM Half-squat and familiarization session:

You will be asked to complete the same general and dynamic warm-up and then complete a 1RM concentric-only half-squat test. After the 1RM test, you will be asked to complete a familiarization set of each potentiation condition that will be used during later testing sessions. Specifically, you will complete one set of two reps at 90% of your 1RM concentric-only half-squat with and without finishing on the balls of your feet.

-Control testing session:

You will be asked to complete the same general warm-up, perform submaximal squat jumps at 50% and 75% of your maximum effort and then two squat jumps at maximum effort. You will then complete the same dynamic warm-up as previously described and then perform one maximal squat jump immediately and at every minute up to 10 minutes following the dynamic warm-up.

-Non-ballistic (slow) half-squat testing session:

You will be asked to complete the same general warm-up, perform submaximal squat jumps at 50% and 75% of your maximum effort and then two squat jumps at maximum effort. You will then complete the same dynamic warm-up as previously described. Following the dynamic warm-up you will complete a concentric-only half-squat warm-up consisting of 1 set of 3 reps at 50% 1RM, 1 set of 3 reps at 70% 1RM, and 1 set of 2 reps at 90% 1RM). All of the reps will be performed without plantar flexion (without going onto the balls of your feet). You will then perform one maximal squat jump immediately and at every minute up to 10 minutes following the squat protocol.

-Ballistic (rapid) half-squat testing session:

You will be asked to complete the same general warm-up, perform submaximal squat jumps at 50% and 75% of your maximum effort and then two squat jumps at maximum effort. You will then complete the same dynamic warm-up as previously described. Following the dynamic warm-up you will complete a concentric-only half-squat warm-up consisting of 1 set of 3 reps at 50% 1RM, 1 set of 3 reps at 70% 1RM, and 1 set of 2 reps at 90% 1RM). All of the reps will be performed without plantar flexion (without going onto the balls of your feet). You will then perform one maximal squat jump immediately and at every minute up to 10 minutes following the squat protocol.

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Subject Intials \_\_\_\_\_

**Principal Investigator:** Timothy J. Suchomel

**Title of Project:** The acute effects of ballistic vs. non-ballistic concentric-only half-squats on squat jump performance.

**TRAINING PROGRAM:**

You will be asked to participate in a standardized training program for the duration of your participation in this study. The training program is listed below.

Exercise	Sets	Repetitions	% 1RM
Day 1			
Back squat	1 Warm-Up	5	50
	1 Warm-Up	5	65
	3	5	80
Push Press	3	5	80
Bench press	1 Warm-Up	5	50
	1 Warm-Up	5	65
	3	5	80
Day 2			
Midhigh pulls	3	5	80
SLDL	3	5	80
Bent over rows	3	5	80
Day 3			
Back squat	1 Warm-Up	5	50
	1 Warm-Up	5	55
	3	5	60
Push Press	3	5	60
Bench press	1 Warm-Up	5	50
	1 Warm-Up	5	55
	3	5	60

**POSSIBLE RISKS/DISCOMFORTS:**

No more than minimal risk is anticipated in this study. You may experience perspiration, an increased heart rate, an increased respiration rate related to physical exertion, fatigue, and mild muscle and joint discomfort following the physical activity within this study.

**POSSIBLE BENEFITS:**

There is no direct benefit to you as a participant in this study.

**CONFIDENTIALITY:**

Every attempt will be made to see that your identity and data are kept confidential. Hard copies of your subject data sheets will be kept in the locked office of the primary investigator (Mini-dome E110) and digital copies of your performance information will be stored on a password protected computer kept in the locked office of the primary investigator. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, ETSU IRB, and personnel particular to this research in the Exercise and Sports Science Department have access to the study records.

6/30/14

**APPROVED**  
By the ETSU IRB

**JUL 23 2014**

By   
Chair IRB Coordinator

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**DOCUMENT VERSION EXPIRES**

**JUN 02 2015**

ETSU IRB

Subject Initials \_\_\_\_\_





VITA

TIMOTHY JOHN SUCHOMEL

- Personal Data:                   Date of Birth: January 18, 1988
- Place of Birth: Madison, Wisconsin
- Marital Status: Single
- Education:                        Ph.D. S Sport Physiology and Performance – Sport Physiology  
  Track, East Tennessee State University, Johnson City,  
  TN, 2015
- M.S. Human Performance – Applied Sport Science Emphasis,  
  University of Wisconsin-La Crosse, La Crosse, WI, 2012
- B.S. Kinesiology – Strength and Conditioning Emphasis,  
  University of Wisconsin-Oshkosh, Oshkosh, WI, 2010
- Sun Prairie High School, Sun Prairie, WI, 2006
- Professional Experience:        Head Student Sport Scientist for Weightlifting and Doctoral  
  Fellow, Olympic Training Site, East Tennessee State  
  University, 2014-2015
- Sport Scientist and Assistant Strength and Conditioning Coach for  
  ETSU Baseball, East Tennessee State University, 2012-  
  2014
- Adjunct Faculty, King University, 2013
- Biomechanics Laboratory Graduate Research Assistant, University  
  of Wisconsin-La Crosse, 2010-2012
- Graduate Assistant Strength and Conditioning Coach, University  
  of Wisconsin-La Crosse, 2010-2011
- Publications:                    Suchomel, T.J., Comfort, P., and Stone, M.H. Weightlifting pulling  
  derivatives: Rationale for implementation and application.  
  *Sports Medicine*. Epub ahead of print February 18, 2015.
- Suchomel, T.J., Sole, C.J., Bailey, C.A., Grazer, J.L., and  
  Beckham, G.K. A comparison of reactive strength index-

modified between six U.S. collegiate athletic teams. *Journal of Strength and Conditioning Research* 29(5): 1310-1316, 2015.

Suchomel, T.J., Beckham, G.K., and Wright, G.A. Effect of various loads on the force-time characteristics of the hang high pull. *Journal of Strength and Conditioning Research* 29(5): 1295-1301, 2015.

Suchomel, T.J., Bailey, C.A., Sole, C.J., Grazer, J.L., and Beckham, G.K. Using reactive strength index-modified as an explosive performance measurement tool in Division I athletes. *Journal of Strength and Conditioning Research* 29(4): 899-904, 2015.

Suchomel, T.J. and Bailey, C.A. Monitoring and managing fatigue in baseball players. *Strength and Conditioning Journal* 36(6): 39-45, 2014.

Suchomel, T.J., DeWeese, B.H., Beckham, G.K., Serrano, A., and French, S. The hang high pull: A progressive exercise into weightlifting derivatives. *Strength and Conditioning Journal* 36(6): 79-83, 2014.

Suchomel, T.J., DeWeese, B.H., Beckham, G.K., Serrano, A.J., and Sole, C.J. The jump shrug: A progressive exercise into weightlifting derivatives. *Strength and Conditioning Journal* 36(3): 43-47, 2014.

Honors and Awards:

New Investigator Award Poster Finalist, "The use of reactive strength index-modified as an explosive performance measurement in male and female athletes." Presented at: XXXII<sup>nd</sup> International Society of Biomechanics in Sports, Johnson City, TN, July 12-16, 2014.

Suchomel, T.J., Ebben, W.P., Garceau, L.R., Harrison, A.P., Howe, M.I., Grazer, J.L., Goodin, J., and McBride, I.M. "The effect of verbal instruction on lower body power development during various plyometrics." Eighth Annual Coaches and Sport Science College, Johnson City, TN 2013. (1<sup>st</sup> Place award winner for Coach Education)

2012 Master's Student Research Award for Outstanding Poster Presentation, National Strength and Conditioning Association National Conference, Providence, RI, July 11-14, 2012.