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Post-activation Potentiation in Moderately Heavy Squats following a Heavy Pre-load Squat

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Abstract

Post-activation potentiation (PAP) is a phenomenon where force output is acutely enhanced following muscular contraction. Previous research has documented enhanced performance in power-type light exercise following a heavy pre-load, such as vertical jumps following heavy squats. To date, the effect of PAP on moderately heavy exercise following a heavy pre-load has not been investigated. **Purpose:** The purpose was to examine whether PAP could be elicited in moderately heavy squats following a heavy squat pre-load, and if so, what intensity (as percentage of one repetition-maximum [1RM]) of pre-load elicited the highest PAP effect (measured as mean power, mean force and number of repetitions performed). **Subjects**: Seventeen resistance-trained males (age 24±2 years, length 182±8 cm, body mass 84.7±13.1 kg, squat 1RM 147.6±29.6 kg) with at least 2 years of experience of the squat exercise. **Methods:** After testing parallel squat 1RM at a separate session, subjects performed three testing sessions in a randomized order in a cross-over design; performance test at 80% of parallel squat 1RM (control), one repetition at 85% of 1RM followed 8 minutes later by the same performance test (PAP85), and one repetition at 93% of 1RM followed 8 minutes later by the same performance test (PAP93). Sessions were separated by six days. Force and power output was recorded using a linear encoder. Friedman's test was used to reveal differences between conditions, and a Wilcoxon signed rank test was used to identify these differences. **Results**: There was an increase in number of repetitions performed for PAP85 (p=0.009) and PAP93 (p=0.001) compared to control, but not for mean power or mean force. There was no significant difference between PAP85 and PAP93 for number of repetitions (p=0.091). **Conclusion:** PAP can be elicited to improve performance in moderately heavy squats following a heavy squat pre-load in trained subjects, but only measured as number of repetitions performed, not force or power. PAP could therefore be useful not only for designing power training, but also for strength and hypertrophy training.
KEYWORDS: squat, post-activation potentiation, PAP, strength, power, hypertrophy.

Introduction

The squat exercise is commonly used in a variety of sports to increase lower-body strength and power. There is a strong correlation between strength and power, where an increase in power follows increased maximal strength. Therefore, sport-specific training programs typically aim at developing both qualities (Baker, 2003; Robbins, 2005; Ebben & Watts, 1998). A heavy pre-load has been shown to increase power production in subsequent exercise through a phenomenon known as post-activation potentiation (PAP) (Weber, Brown, Coburn & Zender, 2008; Mitchell & Sale, 2011). This has been exploited when designing power training, so that a heavy strength exercise preceeds a lighter power exercise, resulting in increased power output. To date, the effect of PAP on moderately heavy exercise following a heavy pre-load has not been investigated. Therefore, this study will investigate whether PAP can be elicited to improve performance in moderately heavy squats following a heavy squat pre-load. If proven successful, it could be beneficial not only for designing power training, but also for strength and hypertrophy training.

Background

Post-activation potentiation and the squat

Muscular activity can result in neuromuscular fatigue, defined as an observed decrease in force after repeated muscular action (Hodgson, Docherty & Robbins, 2005), as well as a facilitated volitional force production – a phenomenon known as post-activation potentiation (PAP). Potentiation and fatigue can coexist (Hodgson, Docherty & Robbins, 2005; Docherty & Hodgson, 2007; Hamada, Sale, MacDougall & Tarnopolsky, 2000), and the net force output of a muscle following contractile activity depends on the balance between these processes that enhance and decrease force development, respectively (Kilduff, Bevan, Kingsley, Owen, Bennett, Bunce, Hore, Maw & Cunningham, 2007; Robbins, 2005; Hodgson, Docherty & Robbins, 2005; Docherty & Hodgson, 2007). Fatigue dissipates faster than potentiation, resulting in a period of time where the force-producing capabilities of a muscle are temporarily enhanced (Mitchell & Sale, 2011; Sale, 2004; Docherty & Hodgson, 2007).

Using heavy squats as the pre-load, previous research has been able to elicit PAP and improve subsequent performance in vertical jumps (Robbins, 2005; Lowery , Duncan, Loenneke, Sikorski, Naimo, Brown, Wilson & Wilson, 2012) , counter-movement jumps (CMJ) (Lorenz, 2011; Esformes & Bampouras, 2013; Hirayama, 2014; Robbins, 2005; Esformes, Cameron & Bampouras, 2010; Smilios, Pilianidis, Sotiropoulos, Antonakis & Tokmadikis, 2005) sprinting (Rahimi, 2007) and loaded jump squats (Chiu, Fry, Weiss, Schilling, Brown & Smith, 2003). Similarly, for the upper body, heavy bench presses have improved subsequent medicine ball throw height (Matthews, O'Conchuir & Comfort, 2009). There are, however, a number of studies who have failed to show any improvements in performance in sprinting (Guggenheimer, Dickin, Reyes & Dolny, 2009), vertical and horizontal jumps (Duthie, Young & Aitken, 2002) and jump squats (Scott & Docherty, 2004) using a PAP protocol.

One of the factors potentially explaining the disagreements in previous research is the fashion in which the squat exercise is performed, or rather, the lack of standardization. Previous research has used several different types of heavy squats, which makes comparability difficult, since force output and muscle activation differs greatly depending on execution (Caterisano, Moss, Pelling, Woodruff, Lewis, Booth & Khadra, 2002; Swinton, Lloyd, Keogh, Agouris & Stewart, 2012; Gorsuch, Long, Miller, Primeau, Rutledge, Sossong & Durocher, 2013; McCaw & Melrose, 1998; Bryanton, Kennedy, Carry & Chiu, 2012). Some of the different types of squats that have been used in previous research are quarter squats (Mitchell & Sale, 2011), half squats (Hirayama, 2014; Esformes & Bampouras, 2013; Esformes, Cameron & Bampouras, 2010; Rixon, Lamont & Bemben, 2007; Scott & Docherty, 2004), parallel squats (Esformes & Bampuras, 2013; Kilduff et al, 2007; Chiu et al, 2003; Chiu, Fry, Schilling, Johnson & Weiss, 2004), using smith machines (Duthie, Young & Aitken, 2002; Rixon, Lamont & Bemben, 2007) and concentric-only squats (De Villareal, González-Badillo & Izquierdo, 2007). In addition, some studies have not explained how the squats were performed at all (Weber et al, 2008).

The squat exercise

The ability to produce force in the squat exercise seems to differ with joint angles of the hip and knee, with greater knee and hip angle toward the top of the squat movement being more biomechanically advantageous and allowing higher force and power output (Israetel, McBride, Nuzzo, Skinner & Dayne, 2010). Furthermore, bar placement higher or lower on the back results in less or more forward lean of the torso, respectively. More forward lean of the torso allows for a more vertical shin, and results in a posterior shift of the centre of mass, and subsequently greater peak joint moments in the hip, and smaller in the knees. A more upright torso position causes more anterior displacement of the knees and an anterior shift of the centre of mass, resulting in higher peak joint moments in the knees, and smaller in the hip (Swinton et al, 2012). The box squat exercise, a common practice in the sport of powerlifting where the individual sits down on a box in the bottom position of the squat, allows for even more vertical shin position and posterior shift of the centre of mass, resulting in even higher peak joint moments in the hips, and less in the knees. This pause on the box in the bottom position also breaks up the eccentric-concentric chain, limiting the use of the stretch-shortening cycle (SSC). This is reflected by significantly lower force and power output during the box squat than traditional squats, but 3-4 times higher rate of force development (RFD), indicating that new force has to be generated when less is stored from the SSC (Swinton et al, 2012). Muscle activity measured by electromyography (EMG) also differs depending on how the exercise is executed (Esformes & Bampouras, 2013). While foot position doesn't seem to influence muscle activity in the quadriceps significantly (Caterisano et al, 2002), a wider stance is associated with increased activity of the gluteal muscles (Swinton et al, 2012; McCaw & Melrose, 1998). The most influential variable for muscle activity seems to be squat depth, with deeper (inguinal fold parallel to or lower than the knee) squats resulting in increased activity of both quadriceps and gluteals (Bryanton et al, 2012) as well as erector spinae (Gorsuch et al, 2013).

Mechanisms of post-activation potentiation

While the relative joint angles affect the force production in the squat, the contractile history of a muscle also determines its force-producing capabilities, and subsequently the performance. As of today, all mechanisms behind the phenomenon of PAP are not fully understood. Some of the most established mechanisms are phosphorylation of myosin regulatory light chain (MRLC) (Rixon, Lamont & Bemben, 2007; Sale, 2004; Tillin & Bishop, 2009; Hodgson, Docherty & Robbins, 2005; Grange, Vandenboom & Houston, 1993), and neural factors such as increased recruitment and excitability of higher-order motor units (MUs) (Hodgson, Docherty & Robbins, 2005; Tillin & Bishop, 2009; Stone, Sands, Pierce, Ramsey & Haff, 2008). Other suggested mechanisms that have not been studied as extensively include desensitization of the Golgi tendon organ (GTO) and Renshaw cells (Baker & Newton, 2006; Scott & Docherty, 2004), increased H-reflex (Hodgson, Docherty & Robbins, 2005; Chiu et al, 2003; Ebben & Watts, 1998; Tillin & Bishop, 2009) as well as increased activity of synergist muscles (Scott & Docherty, 2004).

Phosphorylation of myosin regulatory light chain

Phosphorylation of MRLC seems to improve force production during submaximal contractions or when fatigued by increasing the rate of which myosin cross-bridges move from a non-force producing state to a force producing state, as well as increasing the number of force-producing cross bridges. It has also been shown that MRLC phosphorylation makes the interaction between myosin and actin more sensitive to myoplasmic Ca2+ (Hamada et al, 2000a, Stone et al, 2008; Grange, Vandenbom & Houston, 1993). Because of this, MRLC phosphorylation has the greatest effect when concentrations of Ca2+ are low (<50% of maximum), such as during low-frequency contractions (Tillin & Bishop, 2009; Behm et al, 2004; Grange, Vandenboom & Houston, 1993) or fatigue (Behm et al, 2004). In contrast, increased Ca2+ sensitivity has no measureable effect at saturated Ca2+ levels, such as during high-intensity conctractions (Hodgson, Docherty & Robbins, 2005). Hence, when Ca2+ levels are saturated, maximal force output is not increased by MRLC phosphorylation, only RFD. At unsaturated Ca2+ levels, however, force output increases as a result of MRLC phosphorylation (Esformes, Cameron & Bampouras, 2010; Tillin & Bishop, 2009; Hodgson, Docherty & Robbins, 2005; Grange, Vandenboom & Houston, 1993).

Neural factors

A heavy-pre load is also thought to enhance the force-producing capabilities of a muscle through: improving MU excitability by increasing MU recruitment and synchronization, decreasing pre-synaptic inhibition, increasing central drive to the motor neuron (Kilduff et al, 2007; Weber et al, 2008; Baker, 2003) and increasing post-synaptic potentials (Esformes, Cameron & Bampouras, 2010). Furthermore, delivery of neurotransmitters over the synaptic junctions is improved; greater quantities of neurotransmitters are released, their efficacy is improved, and pre-synaptic release matches post-synaptic uptake (Tillin & Bishop, 2009). These mechanisms subsequently result in greater cross-bridge attachments in the muscle, improving force production (Weber et al, 2008). The increased excitability of MUs could also enhance performance by recruiting high-threshold type II-fibres with high force-producing capabilities that normally would not be recruited (Hamada, Sale & MacDougall, 2000).

The H-wave (H-reflex) amplitude is a function of the amount and size of recruited MUs. With a constant submaximal stimulation of the motorneuron, an increased H-wave could represent increased levels of presynaptic Ca2+ as well as improved neurotransmitter function at synaptic junctions, resulting in increased recruitment of higher order MUs. Since MUs are recruited in accordance with the size principle (Henneman, Somjen & Carpenter, 1965), the next MUs to be recruited would be the larger, more powerful, high-threshold fibres. PAP has been shown to increase H-wave amplitude, suggesting this is one of the working mechanisms behind improved performance (Hodgson & Docherty, 2005; Tillin & Bishop, 2009).

Golgi tendon organ and Renshaw cells

Heavy pre-loading is also suggested to decrease the sensitivity of GTO and Renshaw cells, who act as peripheral and central inhibitory mechanisms, respectively. The GTO is sensitive to the level of tension produced in the muscle and its main function is to protect the muscle from potentially dangerous overload, by inhibiting neural input if necessary. The Renshaw cell is a central feedback loop that also moderates the force output of muscle by regulating neural drive to the MUs. Decreased inhibitory feedback of these mechanisms would thus result in enhanced central drive to, and subsequently increased force output in the working muscle (Baker & Newton, 2005; Scott & Docherty, 2004).

Strength and power exercises

In previous research, typically a slow strength exercise is used as the conditioning stimulus, followed by a power exercise (Matthews, O'Conchuir & Comfort, 2009), but plyometric exercise has also been used as the conditioning stimulus, followed by heavy exercise (Masamoto, Larson, Gates & Faigenbaum, 2003). What differentiates between these two classifications of strength or power exercises is primarily movement velocity and acceleration. Power exercises allow acceleration throughout the range of motion, resulting in high lifting velocities and power output, such as CMJs. Strength exercises are defined by heavy resistances and high force outputs but also pronounced periods of deceleration resulting in lower lifting velocities and subsequently lower power outputs, like heavy squats (Baker, 2003).

Strength levels and training experience

The effect of PAP has been shown to be greater in subjects with training experience, compared to untrained subjects (Rixon, Lamont & Bemben, 2007; Robbins, 2005; Chiu et al, 2004; Stone et al, 2008; Duthie, Young & Aitken, 2002). In some studies, untrained subjects even showed reduced performance following PAP (Chiu et al, 2003). Since the PAP mechanism is based on the delicate relationship between fatigue and potentiation, it is possible that this can be explained by subjects with training experience being more resistant to the induced fatigue, and therefore being able to better utilize the potentiation (Fry, Schilling, Staron, Hagerman, Hikida & Thrush, 2003a; Wilson, Duncan, Marin, Brown, Loenneke, Wilson, Jo, Lowery & Ungrinowitsch, 2013; Lowery et al, 2012). Optimal performance has been shown to occur when the fatigue has subsided but the potentiation effect still exists (Kilduff et al, 2007; Robbins, 2005; Matthews, O'Conchuir & Comfort, 2009; Docherty & Hodgson, 2007). Higher maximal strength has also been shown to be positively correlated with the size of the potentiation, as the magnitude of the potentiation effect is larger in stronger subjects (Kilduff et al, 2007; Hirayama, 2014; Robbins, 2005; Hodgson, Docherty & Robbins, 2005; Duthie et al, 2002). Furthermore, a higher degree of potentiation has been demonstrated in type II fibres (Lorenz, 2011; Rixon, Lamont & Bemben, 2007; Hamada et al, 2000a; Hamada, Sale & MacDougall, 2000b; Stone et al, 2008), which can be explained by the greater capacity for MRLC phosphorylation in these fibres compared to type I fibres (Tillin & Bishop, 2009; Docherty & Hodgson, 2007; Hamada et al, 2000a; Grange, Vandenboom & Houston, 1993). As the relative percentage of type II fibres is also correlated with higher strength (Tillin & Bishop, 2009; Fry et al, 2003a; Fry, Webber, Weiss, Harber, Vaczi & Pattison, 2003b) and is found to a larger extent in trained subjects (Hodgson, Docherty & Robbins, 2005, Fry et al, 2003a; Fry et al, 2003b), this could explain the fact that experienced subjects with higher strength levels achieve larger potentiating effect than less experienced subjects with lower strength levels. There seems to be some evidence for gender differences in fibre type composition, with men having more type II fibres. It is possible that this could explain the observations of greater degree of potentiation in men (Rixon, Lamont & Bemben, 2007). Furthermore, apart from sex, fibre type composition and strength levels, the magnitude and time course of potentiation seems to be highly individual (Robbins, 2005; Matthews, O'Conchuir & Comfort, 2009).

Post-activation potentiation protocols

While heavy loads, such as 80-95% of 1RM have repeatedly been used (Weber et al, 2008; Robbins, 2005; Esformes, Cameron & Bampouras, 2010; Esformes & Bampouras, 2013; Chiu et al, 2003) and found to elicit PAP to a greater magnitude (measured as performance improvement in percentage) than lighter loads, such as 30% of 1RM (De Villareal, González-Badillo & Izquierdo, 2007), some studies have found a potentiating effect at 60% (Matthews, O'Conchuir & Comfort, 2009), 65% (Smilios et al, 2005) and 70% of 1RM (Chiu et al, 2004). Regardless of load used as conditioning stimulus, all of the above mentioned studies used protocols where the performance measure was a lighter load than the pre-load. If moderately heavy squats (80% of 1RM) are selected to be the performance test, the pre-load seems to need to be heavier than that. This is thought to be related to the size principle of MU recruitment (Henneman, Somjen & Carpenter, 1965). Since type II-fibres are recruited at loads of 80% of 1RM or more (Hirayama, 2014), this is heavy enough a load to recruit these high-threshold MUs immediately during the pre-load (Bryanton et al, 2012).

Recently, a meta-analysis of the currently available literature on PAP was done by Wilson et al. (2013) in order to summarize the current state of the research. This analysis suggests that in trained subjects, optimal potentiation is achieved through multiple rather than single sets, at 60-85% of 1RM and using rest periods of 7-10 minutes. Lowery et al. (2012) did, however, show that when controlled for total volume, both moderate (70% of 1RM) and high (93% of 1RM) intensities for the squat pre-load elicited PAP in subsequent VJ in experienced subjects.

While previous investigations have indeed found improvements in performance during low-load tasks following a heavy pre-load, the effectiveness of these protocols has not been studied in performance tests with a higher load (>30% of 1RM) (Chiu et al, 2003; Matthews, O'Conchuir & Comfort, 2009). The effect of PAP in heavy pre-loading followed by a moderately heavy exercise has, to the author's knowledge, not yet been examined. Loads of approximately 80% of 1RM are suggested for optimal hypertrophy training (Shimano, Kraemer, Spiering, Volek, Hatfield, Silvestre, Vingren, Fragala, Maresh, Fleck, Newton, Spreuwenberg & Häkkinen, 2006; Rixon, Lamont & Bemben, 2007; Bryanton et al, 2012) and loads of 80-100% of 1RM are recommended for strength development (Bryanton et al, 2012; Smilios et al, 2005), with loads in the range of 80% of 1RM anecdotally being commonly used in the sport of competitive powerlifting. Therefore, performance in the squat exercise with a load of 80% of 1RM is of interest for coaches and athletes in several sports. 80% of 1RM is a heavier load than has previously been used as a performance measure when assessing the effect of PAP, and should therefore be investigated.

Aim of the study

The aim of this study was to investigate whether PAP can be elicited by a heavy pre-load squat (85 and 93% of 1RM) preceding a performance test with moderately heavy squats (80% of 1RM) in trained subjects, and if so, what intensity of the pre-load (85 or 93% of 1RM) elicited the highest PAP effect measured as number of repetitions performed at 80% of 1RM mean power and mean force.

Hypothesis

Based on previous research, the author's hypothesis was that using 80% of 1RM as the performance test, PAP could be elicited by both 85% and 93% of 1RM pre-load, with 85% being the superior pre-load because of less fatigue being caused by the lower load.

Method

Subjects

Nineteen healthy, young male subjects volunteered to participate in the study. Of these, seventeen completed the study while two selected to discontinue their participation because of unrelated injuries. Subjects were mean (±SD) 24 (±2) years old, 182 (±8) cm tall and weighed 84.7 (±13.1) kg. All subjects had at least two years experience of resistance training, and specifically performing the squat exercise. Exclusion criteria were any injury, illness or inability to perform the squat exercise to at least parallel depth. No distinction was made between sexes for participation, but no females with sufficient training experience volunteered, resulting in an all-male sample.

Equipment and set-up of measurements

For performing the squat exercise, a powerlifting barbell, squat rack and Olympic weight plates (Eleiko, Halmstad, Sweden) were used. In order to register force, velocity, distance, power and number of repetitions, the MuscleLab linear encoder (Ergotest, Langesund, Norway) was used. The MuscleLab linear encoder has previously been validated as a reliable tool for registering power output (Ravier, 2011; Hansen, Cronin & Newton, 2011). The linear encoder was attached to the end of the barbell and placed at the floor directly underneath it, in order to make as vertical a line as possible. Calibration of the linear encoder was performed before each testing session, according to the manufacturer's instructions. The positioning of the linear encoder was adjusted between each set of every subject, in order to register data as accurately as possible. The height of the squat rack was adjusted to suit each subject's preference before commencing the testing at each occasion.

Power and force measurements

In the performance tests, peak power and peak force was registered during the concentric phase for each repetition, and divided by the total number of repetitions performed, in order to attain mean power and force values. These mean values were used instead of the single highest peak value because of the great difference between the power values of the first and last repetition when performing repetitions to exhaustion. A mean value of all repetitions was determined to be a better reflection of the eventual net increase in force and power. This was also determined to better suit the purpose of the study, since previous research has already shown that peak power can be improved by PAP (Kilduff et al, 2007). The MuscleLab also allows for registration of the distance the bar travels. This value was compared for all repetitions for each subject, serving as an additional control that the range of motion for each squat was as close to identical as possible.

Exercise execution

In order for the results to be comparable between subjects, the execution of the exercise had to be standardized. Competition rules for the squat provided by the International Powerlifting Federation were used. These rules state that required depth is when the hip crease is parallel with or under the highest point of the knee (IPF Technical Rules Book, 2014, p18). This required depth of the squats was standardized using a box of weight plates, placed at the floor slightly behind and between the legs of the subjects. The purpose of the box was to serve as a depth gauge without interfering with the subjects' habitual movement pattern; during the downward motion, the subjects' thighs or buttocks eventually touched the box, giving physical feedback that sufficient depth was reached and subjects could stand back up. The height of the box was individually adjusted for each subject and used for all squats throughout the study (see Figure 1). A similar depth gauge was used in the protocol of Chiu et al. (2003). Repetitions that failed to reach this required depth were not counted. Subjects were instructed to maximally accelerate out of the bottom position every repetition, but not to bounce off or sit down on the box of weight plates, only touching it softly and then immediately reversing the motion. Subjects were instructed to use their preferred style of squatting (regarding placement of the barbell on the back and stance width), and the use of weightlifting belts and shoes was allowed, provided that the subject then used them continuously throughout the study.

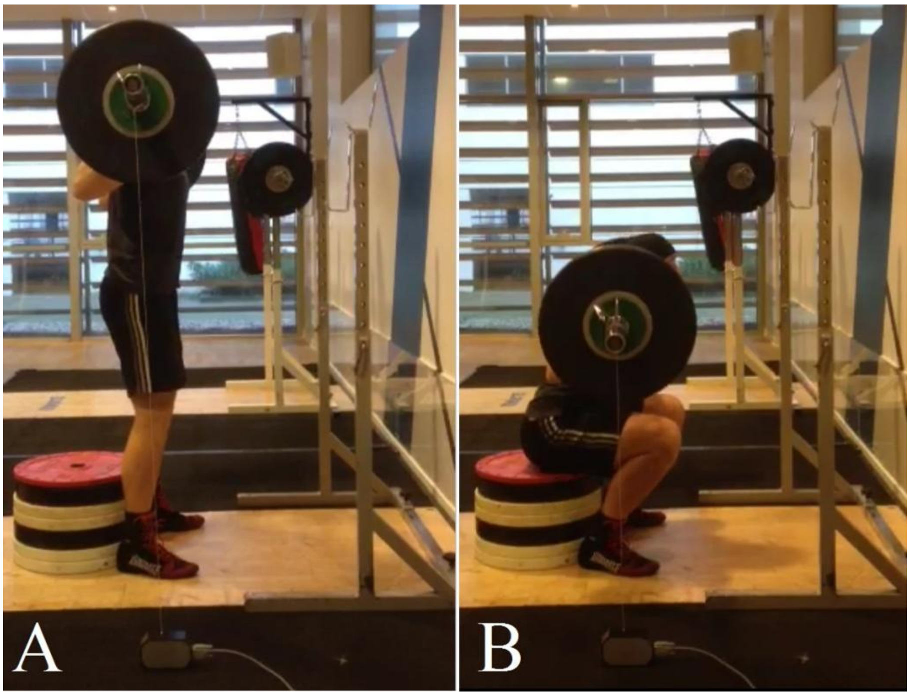

Figure 1: Start (A) and bottom (B) position of the parallel squat.

Test protocol

Subjects attended four sessions at four separate occasions, with 6 days between sessions. They were asked to refrain from alcohol or heavy training the day before, and from caffeine or other stimulants on the day of each session. No attempt was made to standardize diet or sleep during the duration of the study. During the first sessions, subjects performed a 1RM test in the squat exercise. During the second session, subjects performed the performance test in the squat exercise. During the third and fourth trials, subjects performed a pre-load consisting of one repetition at 85% and 93% of 1RM, respectively, followed by the same performance test from the second session. During sessions two, three and four mean power and force were recorded in the repetition test. Each subject attended the sessions at approximately the same time of day every session. The order of sessions two, three and four was randomized for each subject in a cross-over design, in order to avoid a learning effect (Scott & Docherty, 2004). An overview of the test protocol can be seen in table 1, and the exact order in which each subject performed the sessions can be seen in table 2. All subjects were strongly encouraged verbally throughout the study. Two to three spotters were present at all times, ensuring the safety of the subjects and making it possible for the subjects to keep exerting themselves until exhaustion. Although several sets seem to elicit a greater PAP response (Wilson et al, 2013) and increasing loads in an ascending order during the warm-up seems to benefit power performance (Baker & Newton, 2005), caution has to be taken with using excessive volume, resulting in unnecessary fatigue that can impair the results (Chiu et al, 2003; Chiu et al, 2004). Based on this, the number of repetitions in the warm-up protocol used in this study was reduced from the original protocol of McArdle, Katch & Katch (2010), and the pre-load consisted of a single repetition at 85% and 93% of 1RM, instead of several repetitions (McArdle, Katch & Katch, 2010, p492-495).

Session 1: 1RM test

Subjects were informed of the desired execution of the squat exercise and proper height of the box was measured and used for all subsequent squats throughout the study. Subjects were allowed to do any self-selected mobility routine and were instructed to do the same routine every session. Subjects then performed a standardized warm-up protocol consisting of five repetitions at 20, 40, and 60 percent of estimated 1RM, and one repetition at 70 and 80 percent. The subjects then performed one repetition at a successively increasing load, with an increase of 2.5-10kg per set with 3-5 minutes of rest between sets, until they reached their 1RM (McArdle, Katch & Katch, 2010, p492-495).

Session 2: Performance test (control)

Subjects performed the same standardized warm-up protocol from session 1. In order to control for total volume between sessions two, three and four, subjects also performed one additional repetition at 80% of 1RM at the end of the warm-up protocol. After 8 minutes of rest, subjects then performed as many repetitions as possible at 80% of previously established 1RM. Subjects were instructed to keep going until voluntary failure, i.e. failure to lift the load, or if the last successful repetition was extremely heavy with no hope of completing the next one, to stop there. Number of performed repetitions, mean power and force was recorded and used for comparison with the subsequent trials. Since no pre-load was done before this performance test, the result from this session was regarded as the subjects' baseline level of performance and served as the control condition when investigating improvements from the experimental conditions.

Session 3: PAP test: 85% + performance test (PAP85)

Subjects performed the same standardized warm-up protocol. They then performed one pre-load repetition at 85% of 1RM. After 8 minutes of rest, subjects performed the same performance test again (80% 1RM for as many repetitions as possible).

Session 4: PAP test: 93% + performance test (PAP93)

Subjects performed the same standardized warm-up protocol. They then performed one pre-load repetition at 93% of 1RM. After 8 minutes of rest, subjects performed the same performance test again.

Table 1: Summary of sessions.

Session 1: 1RM test	Session 2: Performance test	Session 3: PAP 85% + Performance test	Session 4: PAP 93% + Performance test
Depth standardization	Standardized warm-up	Standardized warm-up	Standardized warm-up
Standardized warm-up	80% of 1RM x 1	85% of 1RM x 1	93% of 1RM x 1
1RM test	80% of 1RM x max*	80% of 1RM x max*	80% of 1RM x max*

* denotes when force and power was registered using a linear encoder device.

Table 2: Overview of the order in which subjects performed trials 2, 3 and 4.

Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Session 2	3	1	2	2	1	2	3	1	2	1	3	2	3	3	1	2	2
Session 3	1	3	3	3	3	1	1	3	1	2	2	3	1	2	3	1	1
Session 4	2	2	1	1	2	3	2	2	3	3	1	1	2	1	2	3	3

Ethical and social considerations

Before the start of the study, subjects were informed of the study design, methods used and possible risks involved with participating and that ethical principles were to be followed. Ethical approval was applied for from the ethics committee. Subjects read and signed an informed consent (see Appendix 1) informing them that participation is voluntary and can be discontinued at any time. Subjects were informed that this research is of importance for designing safe and efficient training programs for both athletes and recreationally active individuals. In a recent position stand by the American College of Sports Medicine, all adults are recommended to engage in resistance training 2-3 times per week in addition to cardiorespiratory, flexibility and neuromotor exercise training (Garber, Blissmer, Deschenes, Franklin, Lamonte, Lee, Nieman & Swain, 2011).

Statistical analysis

When checking for normality using the Shapiro-Wilks test, data were found to deviate from normal distribution. Thus a Friedman's test was used to examine differences between sessions 2 (control), 3 (PAP85) and 4 (PAP93) for all performance measures (number of repetitions, mean power, mean force). A Wilcoxon's signed rank test was used to identify between what sessions there was a difference. Significance was set at $p<0.05$. Data were analyzed using statistical software from IBM SPSS v.20. While not normally distributed, data were presented as mean (±SD) in order to be more comparable with previous research.

Results

The mean (±SD) 1RM for the sample was 147.64 (±29.56) kg, equaling 1.75 (±0.27) times body weight. A statistically significant difference between all sessions was revealed (Friedman's test) for number of repetitions (p=0.000), but not for mean power (p=0.561) or mean force (p=0.360). Wilcoxon's signed rank test revealed that PAP85 significantly increased the number of repetitions compared to control (p=0.009), as did PAP93 (p=0.001). There was, however, no statistically significant difference between the number of repetitions performed with PAP85 and PAP93 (p=0.091). The number of repetitions at control was 11.18 (±3.89), with PAP85 and PAP93 increasing this number to 13.18 (±5.45) and 15.13 (±5.11) repetitions, respectively (table 3).

Table 3: Summary of results from sessions 2 (control), 3 (PAP85) and 4 (PAP93), n=17. Differences between groups analyzed for variables only where Friedman's test ≤0.05.

Variable	Control (Mean±SD)	PAP85 (Mean±SD)	PAP85 vs. control p-value*	PAP93 (Mean±SD)	PAP93 vs. control p-value*	PAP85 vs. PAP93 p-value*
Number of repetitions	11.18±3.89	13.18±5.45	0.009	15.13±5.11	0.001	0.091
Power (W)	800.49±220.64	820.96±222.44	na	772.17±211.86	na	na
Force (N)	1902.47±298.69	1867.90±220.11	na	1851.84±197.77	na	na

*Wilcoxon signed rank test

na=not applicable (no differences between the three sessions was found with Friedman's test why further analysis was not performed)

Discussion

Results discussion

There was a difference in the number of repetitions performed between PAP85 and control, and PAP93 and control, but not between PAP85 and PAP93. There were no differences in mean power or mean force for any of the conditions. The hypothesis was that PAP could be elicited in moderately heavy squats following heavy squats, and PAP85 would result in a greater magnitude of potentiation and thus better performance than PAP93 because of less fatigue produced. The hypothesis was partially confirmed. PAP could indeed be elicited in moderately heavy squats following heavy squats, but only measured as number of repetitions performed, not mean power or mean force. There was no statistical difference between PAP85 and PAP93, indicating that neither one was superior to the other in improving performance through PAP. There was, however, a trend for increase in repetitions for PAP93 compared to PAP85 ($p=0.091$).

In the present study a potentiating effect could be demonstrated using moderately heavy squats (80% of 1RM) as the performance test. To the author's knowledge, this is the first study to investigate and report this. Previous research has reported increased performance with light loads (≤30% of 1RM) after a heavy (80-95% of 1RM) pre-loading with the magnitude of increased performance being 4.5% higher power output (Robbins, 2005) and 1.0-6.8% increase in jump height (Mitchell & Sale, 2011; Masamoto et al, 2003; Robbins, 2005; Esformes, Cameron & Bampouras, 2010) in trained subjects. In this study, no increase in mean power was observed for any of the conditions. This can be partially explained by the performance test not being designed for producing high power outputs, as 80% of 1RM is much heavier load than 30-60% of 1RM that is normally recommended for optimal power training (Smilios et al, 2005). Even if an increase in mean power had been observed for some of the conditions in this study, because of the higher load and subsequent slower velocity, the power values are much lower than the ones obtained from typical power exercises, such as vertical jumps or jump squats, making them difficult to compare. Furthermore, these traditional power protocols entail one or a few repetitions in one or a few sets with the intent of producing as much power as possible (Chiu et al, 2003), while the protocol in this study entailed performing as many repetitions as possible in a single set. It is possible that the subjects, although instructed to accelerate the load as fast as possible on all repetitions, did subconsciously conserve some energy to perform more repetitions by not accelerating them as fast as possible. This would further explain the low power values observed. Last, with mean power being recorded and not peak power, the resultant values will naturally be lower.

This study found significant increases in number of repetitions, but not in force and power. There are other studies that have found increases in power using a PAP protocol (De Villareal, González-Badillo & Izquierdo, 2007), but also some that have not (Guggenheimer et al, 2009; Scott & Docherty, 2004; Duthie, Young & Aitken, 2002). Guggenheimer et al. (2009) used male track and field athletes and found no significant improvement in 40m sprint times following three repetitions of power cleans with 90% of 1RM (Guggenheimer et al, 2009). Scott & Docherty (2004) reported no difference between pre- and post-test scores for VJ and horizontal jumps, when using one set of 5RM half-squats as conditioning stimulus with resistance-trained men (Scott & Docherty, 2004). Duthie, Young & Aitken (2002) had female subjects perform jump squats before half-squats, half-squats before jump squats, and alternating sets of jump squats and half-squats. No difference in jump height was found for any of the conditions (Duthie, Young & Aitken, 2002). It is possible that this could be explained by not controlling for factors such as strength levels, training experience and sex, as well as methodological differences in warm-up protocol, total volume of the conditioning stimuli, load and type of conditioning stimuli as well as length of recovery periods (Behm et al, 2004, Docherty & Hodgson, 2007; Tillin & Bishop, 2009; De Villareal, González-Badillo & Izquierdo, 2007, Sale, 2004). The protocol of Guggenheimer et al. (2009) used one minute of rest between the three repetitions of power cleans at 90% of 1RM and two 40m sprints, and since adequate recovery between the conditioning stimulus and performance test is crucial, it is plausible that the outcome could have been different if a sufficient recovery period (7-10 minutes) had been used (Wilson et al, 2013). Furthermore, when the subjects in the study of Duthie, Young & Aitken (2002) were split in to high- and low-strength groups, a significant difference between the groups was revealed; the stronger subjects increased their jump height when alternating jump squats and half-squats, reinforcing the importance of the subjects having sufficient and similar strength levels (Duthie, Young & Aitken, 2002). Scott & Docherty (2004) did, however, use equally and sufficiently strong subjects (half-squat 5RM 196.9±23.0 kg) and adequate rest periods (5 minutes) but still found no improvements (Scott & Docherty, 2004). It is possible that the use of half-squats as pre-load could explain this. Recently, Esformes & Bampouras (2013) found that parallel squats resulted in greater magnitude of PAP effect than quarter squats, possibly indicating that the RoM of the pre-load is a determining factor for subsequent performance, with greater RoM being superior

(Esformes & Bampouras, 2013). It is possible that the use of parallel squats instead of half-squats as the pre-load would have yielded different results, as this study found significant improvements using parallel squats.

Optimal recovery times following PAP seem to be related to the strength of the subjects. Thus, including subjects with varying strength levels and adjusting recovery times to optimize every subject's performance makes standardization of the protocol difficult. In the present study, all subjects were of comparable strength levels (Squat 1RM 147.6±29.6kg), meaning the same recovery times could be used (Hirayama, 2014; Weber et al, 2008; Wilson et al, 2013). Including experienced subjects who were familiar with 1RM testing made the 1RM test more reliable and the chance of acquiring a true 1RM value is increased (Kilduff et al, 2007). Similarly, experience with performing the squat exercise with heavy loads allowed subjects to exert themselves to a greater degree than would subjects who lack efficient motor skills for the task (Chiu et al, 2004; Hamada et al, 2000b). In previous research, relative strength levels of squat 1RM equaling 1.5-2.5 times bodyweight have been recommended in order for subjects to be able to benefit the most from PAP (Chiu et al, 2003; Scott & Docherty, 2004; Ebben & Watts, 1998). The relative strength levels (squat 1RM = 1.75 times bodyweight) and experience of the subjects in this study fall within these recommendations. Previous studies that have used subjects with comparable strength levels have reported positive results of PAP in low-load performance measures (Chiu et al, 2003; Esformes & Bampouras, 2013; Kilduff et al, 2007), suggesting that similarly high strength levels increase the magnitude of PAP in both low and high-load performance tests.

The performance of the subjects in this study is comparable with previous research. The amount of repetitions performed at the control session (11.2±3.9) is comparable with that of Shimano et al. (2006), who reported a mean of 12.3±2.5 repetitions at 80% of 1RM ($p>0.05$). These subjects were also experienced with similar absolute strength levels (squat 1RM 140.1±25.2 kg compared to 147.6±29.6 kg in this study), and the relative strength levels between the two samples are also comparable, 1.62 and 1.75 times bodyweight in the study by Shimano and this, respectively. They did, however, not specify how the squats were performed any more than stating that "a strength and conditioning specialist verified the subjects' technique as being proper before the start of the study" (Shimano et al, 2006). Without knowing how the squats were executed, it is difficult to compare the results with the ones from this study, as will be discussed later.

Based on the results of this study, it seems that the same recommendations concerning recovery periods, volume and intensity for optimal PAP in subsequent light exercise can also be applied to moderately heavy squats (80% of 1RM). The recovery periods, volume and intensity used in this study was based on the current consensus of the literature (Wilson et al, 2013; Lowery et al, 2012), and are comparable with what has been done in other studies successfully eliciting a potentiating effect in light exercise (≤30% of 1RM) following heavy pre-load (Kilduff et al, 2007).

Methods discussion

While subjects were instructed to refrain from alcohol and heavy training the day before testing sessions, and stimulants such as caffeine at the day of testing sessions, no attempt was made to control other dietary factors or sleep. It is possible that nutritional and hydration status, as well as amount of sleep, differed between each session. Since not all subjects were able to perform the testing sessions at the exact same time of day all four sessions due to work, studies and transportation, there is a risk of everyday events such as workload and stress levels differing between sessions and interfering with optimal performance, skewing the results.

It has been shown that individuals having a low power-to-strength ratio, that is, exhibit lower power values than would be expected based on their strength levels, benefit more from PAP (Tillin & Bishop, 2009). Therefore, it would have been interesting to have subjects perform a biomechanically similar power test, such as vertical jumps or jump squats, at a separate testing session before the onset of the study. These power values could then have been compared to the subjects' strength (measured as squat 1RM) and the magnitude of their PAP response (increase in number of repetitions, power and force values) to see if the subjects that experienced the greatest increase in performance after PAP did indeed exhibit the lowest power values.

While the mechanisms of PAP were not examined directly, the increase in number of repetitions performed during PAP85 and PAP93 compared to control, could represent PAP compensating for low-frequency fatigue, allowing the activity to continue. 80% of 1RM performed for as many repetitions as possible does represent a submaximal load with fatigue increasing throughout the activity, both of which are conditions under which PAP has the greatest influence on performance (Sale, 2004; Behm, Button, Barbour, Butt & Young, 2004).

Thus, 80% of 1RM used in this study seems to still be light enough a load to represent unsaturated Ca2+ levels and benefit from MRLC phosphorylation.

While subjects were not allowed to sit on or bounce off the box, the need to touch the box every repetition disabled some use of the SSC. Some subjects were used to utilize and rely heavily on the SSC in the beginning of the concentric phase of the lift, and had to change their execution of the lift somewhat. While not a large change, it is possible that this affected the performance to some degree as subjects were not completely able to use their preferred squatting style. This is unfortunate, but in the author's opinion, the standardization of depth was necessary to make the results comparable. Chiu et al. (2003) presented an alternative solution to the same problem by using a rubber cord between two stands as the depth gauge. This effectively eliminated any chance of bouncing against the material, while still allowing the subjects to continue using their habitual squatting style, such as relying on the SSC. It is possible that using a similar method in this study could have resulted in a different outcome. Results of this study are however, as already stated, comparable with those of Shimano et al. (2006), implying that the use of a box likely did not influence performance severely. The rubber cord used by Chiu et al. (2003) could, however, only be adjusted to the nearest inch (2,5cm), while using weight plates to build a box allowed for adjustments of millimeters by switching plates. This made it possible to attain the specific individual box height with very high precision. Another aspect of the execution of the lift is the tempo at which the exercise is performed. It has been shown that for optimal performance, the tempo of the exercise needs to be self-selected, as a pre-determined cadence not only obviously influences power values, but a 2-second concentric and 4-second eccentric phase has been found to significantly reduce the number of repetitions performed compared to a self-selected cadence (Rixon, Lamont & Bemben, 2007; Bruce-Low & Smith, 2007).

PAP has previously been examined using evoked twitches following maximal voluntary contractions, where increases in RFD have been observed (Robbins, 2005). Such isometric tests are generally isolated muscle tests, making the practical applications on real world sports performance difficult (Baker & Newton, 2004; Wilson & Murphy, 1996). However, isometric testing allows for studying the mechanisms of potentiation and fatigue in the neuromuscular system, without the influence of motor control and skill that is inevitable with dynamic testing. Varying level of skill for the actual task may interfere with observing the effect (Chiu et al, 2004). Furthermore, studies using dynamic exercise as the post-stimulus performance test are much more unequivocal than are studies examining twitch contractile properties (Robbins, 2005). Because the practical applications and potential benefit for athletic performance, and not the actual mechanisms behind PAP have been the main interest for this thesis, only studies using dynamic contractions have been taken into consideration when designing the protocol and methodology.

There was a trend for increase in repetitions for PAP93 compared to PAP85 (p=0.091). It is possible that this difference would have been significant if the sample size had been larger. A power calculation states that a sample size of 54 subjects would be needed to result in a significant difference between PAP93 and PAP85 (Appendix 2).

Practical applications

Performing repetitions until voluntary failure in the squat exercise can be potentially dangerous if done without spotters or within a safety rack, and thus it is not a very common training method. The results of this study are, however, applicable to other, more commonly occurring training situations. If the maximal amount of repetitions that can be performed with 80% of 1RM without PAP is 11, and utilizing PAP can increase this number to 13 or 15, it is then reasonable to assume that performing only 11 repetitions in the potentiated state is not as physically demanding as doing it without potentiation. Since many training programs involve performing sets of fixed repetitions, for example 4 sets of 8 repetitions at 80% of 1RM, then these sets would be easier to perform if the individual is capable of doing 15 repetitions at that load, than if 11 repetitions is the maximum. Thus, PAP can be used to make these sets less taxing, and total volume (as in more sets) can be increased with little or no increase in perceived effort. Alternatively, a heavier load could be used and performed for the prescribed number of repetitions. Increased training volume and/or load without overriding the individual’s recovery capacities could over time result in greater training adaptation and increases in strength, power and hypertrophy.

Future research

Future research should investigate whether a similar protocol could elicit PAP in traditional upper-body strength exercises, such as the bench press. Additionally, a typical PAP protocol where a heavy pre-load precedes a power exercise with the aim of increasing power output should be done using a moderately heavy load (such as 80% of 1RM) as the performance measure, to see if power output can be acutely improved at such high intensity as well as light intensities. It would also be interesting to perform an intervention study comparing increases in strength, power and hypertrophy between two identical groups, but with the experimental group utilizing PAP in their otherwise identical training.

Conclusion

The main finding of this study is that in young trained male subjects, PAP can improve performance in moderately heavy squats following a heavy pre-load squat, but only measured as number of repetitions completed, not mean power or mean force. PAP can therefore be useful not only for power training, but also for strength and hypertrophy training. The practical application of these findings is that the number of repetitions that can be performed at a given load can be increased if preceded by a heavier load, potentially leading to greater training stimulus and, over time, gains in strength and hypertrophy. This information could be used by athletes and coaches when designing training programs and protocols.

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Appendix 1: Informed consent

Informationsblanket för deltagande i D-uppsats

Hej!
Mitt namn är Oscar Björk och jag studerar på Magisterprogrammet i Biomedicin med inriktning fysisk träning på Högskolan i Halmstad. Jag söker nu testdeltagare till denna studie som kommer att användas i min D-uppsats. Det huvudsakliga syftet med studien är att ta reda på om man kan få en bättre efterföljande prestation i knäböj (mätt i kraftutveckling och antal utförda repetitioner) om man först utför en tyngre, potentierande knäböj. Det andra syftet är att ta reda på hur tung den här potentierande knäböjen behöver vara för bästa resultat. Denna information kommer förhoppningsvis kunna användas för att designa träningsprogram för atleter och idrottare.

I praktiken kommer det att gå till så här:

Upplägg och tidsschema

Studien kommer att delas upp över fyra tillfällen, med ungefär en vecka emellan. Varje tillfälle kommer att ta ungefär en halvtimme. Testerna kommer utföras i gymmet på Idrottscentrum, och du behöver inte vara medlem där för att delta.

Testdag 1: Instruktioner för önskat utförande, test av 1RM i knäböj.

Testdag 2: Repetitionstest på 80% av 1RM. Kraftutveckling mäts med en s.k. linear encoder.

Testdag 3: Potentieringslyft på 85% av 1RM, följt av repetitionstest på 80% av 1RM. Kraftutveckling mäts med linear encoder.

Testdag 4: Potentieringslyft på 93% av 1RM, följt av repetitionstest på 80% av 1RM. Kraftutveckling mäts med linear encoder.

För att delta bör du:

Kunna utföra en fri knäböj med skivstång till parallellt djup (höften i samma höjd som knän sett från sidan), och ha erfarenhet av att utföra övningen knäböj (minst 2 år regelbunden träning).

Inte ha några skador eller sjukdomar som begränsar eller hindrar dig från att utföra övningen eller genomföra studien.

Kunna närvara vid samtliga fyra testtillfällen och utföra aktuella tester enligt instruktion.

Undvika att utföra hård träning dagen innan varje test.

Avstå från prestationshöjande kosttillskott som t.ex. koffein innan och under testtillfällena, eftersom detta kan påverka resultatet av studien.

Vad får du ut av deltagandet?

Din prestation testas under kontrollerade och säkra omständigheter. Du kommer få individuella tips och hjälp med ditt utförande för maximal prestation. Dessutom blir det 4 kostnadsfria träningspass på Idrottscentrum. =)

Jag vill uppmärksamma dig om:

Att det alltid finns en skaderisk vid fysisk aktivitet. För att minimera denna risk kommer jag som testledare att närvara vid alla tillfällen för att instruera och övervaka korrekt utförande av övningarna. Som deltagare kommer du aldrig utföra övningen ensam utan övervakning.

Att liknande testprotokoll använts innan i andra studier utan rapporterade skador.

Att du sannolikt kan uppleva träningsvärk efter testtillfällena.

Att deltagandet är frivilligt och när som helst kan avbrytas utan förklaring.

Alla resultat av studien och personliga uppgifter kommer att behandlas konfidentiellt enligt personuppgiftslagen §10. Data kommer att förvaras skyddat och inga obehöriga har tillgång till dessa data. Resultaten kommer att redovisas som medelvärden på gruppnivå, utan möjlighet att identifiera individer. På begäran raderas alla dina personliga data efter godkänd uppsats.

Vid frågor, vänligen kontakta:

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oscbjo10@student.hh.se

Appendix 2: Power calculation

- ◉ Calculate Sample Size (for specified Power)
- ○ Calculate Power (for specified Sample Size)

Enter a value for mu0:	13.18
Enter a value for mu1:	15.13
Enter a value for sigma:	5.11

- ○ 1 Sided Test
- ◉ 2 Sided Test

Enter a value for α (default is .05):	.05
Enter a value for desired power (default is .80):	0.80
The sample size is:	54

Obtained from http://www.stat.ubc.ca/~rollin/stats/ssize/n1.html.

Oscar completed his Bachelor's and Master's degrees in Sports and Exercise Science at the University of Halmstad. Being a competetive powerlifter and coach, the main subject of interest is improving human performance in sports.

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