2014

Repeated post-activation potentiation (PAP) effect on sprint performance

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REPEATED POST-ACTIVATION POTENTIATION (PAP) EFFECT ON SPRINT PERFORMANCE

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A Master's Thesis presented to the Faculty of the
Graduate Program in Exercise and Sport Sciences
Ithaca College

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In partial fulfillment of the requirements for the degree
Master of Science

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by

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December 2014

Ithaca College
School of Health Sciences and Human Performance
Ithaca, New York

CERTIFICATE OF APPROVAL

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MASTER OF SCIENCE THESIS

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This is to certify that the Thesis of
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Submitted in partial fulfillment of the requirements for the degree of
Master of Science in the School of Health Sciences and Human Performance
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ABSTRACT

This study investigated the recurring effects, over multiple sets, of heavy back squats on repeated sprint times. It has been found in prior studies that performing a few repetitions (reps) of a heavy, multi-joint, lower body exercise can increase performance in events that rely on peak muscular power output. Single effort jump and sprint performances have been improved in athletic subjects following performance of heavy back squats. In the current study, a partially randomized, counterbalanced, repeated measures design, 29 college-aged NCAA male varsity lacrosse players, possessing a minimum of 12 months of strength and sprint experience, participated in control and experimental sprint testing sessions. Subjects performed four reps of back squats (experimental = 90% 1RM, control = 20% 1RM), rested 8 min, performed repeated sprint sets of four reps (55 s inter-rep rest period) and rested for 9 min after completion of the last sprint rep. This testing set was performed two more times, for a total of three sets (of four sprints) performed 20 min apart. Sprint performance was measured by timing gates positioned at 10 and 40 m from the start line. Reaction time was also recorded for each sprint rep. Performance was analyzed using 2x3 (Condition x Sets) and 2x4 (Condition X Reps) repeated measures ANOVA for sprint and reaction time. Subjects ran significantly faster ($p = 0.014$) after completing heavy back squats compared to light squats used in the control condition. Specifically, sprint times were faster for the first two sprint reps across sets after heavy squats. These findings suggest that post-activation potentiation, using heavy back squats, can be repeated successfully over the course of a single session. This finding should be of interest to coaches and athletes looking to maximize performance.

ACKNOWLEDGEMENTS

The completion of this thesis is due, in large part, to everyone who has contributed their advice and support throughout the entire process. In particular, I would like to thank Dr. Gary Sforzo for pushing me to undertake this challenge in the first place. It was his guidance that led to my discovery of, and subsequent interest in, this topic. His constant and constructive feedback was a key factor in my ability to finish this project. I would also like to thank Dr. Deborah King for her invaluable assistance. Her expertise with all things related to statistics and navigating the difficulties of certain software packages was of great help to me. The time and effort Drs. Sforzo and King dedicated to advising and supporting me every step of the way was immeasurably helpful and greatly appreciated.

A thank you to Dr. Jeff Ives who allowed me to borrow the electronic timing gate equipment that was crucial to achieving accurate and precise measurements for data collection.

I would also like to thank Jeff Long for his backing of the use of his athletes for this study and every member of the IC Men's Lacrosse team who participated for being excellent subjects. Coach Long was very supportive in allowing me access to his players for the physical testing in this study outside of their already busy training schedule. The lacrosse athletes had great attitudes about participating in a study requiring them to wake up early to squat and sprint a dozen times. Thank you for allowing the data collection process to go smoothly.

A special thanks to Kate Daniels for her patience with me while this was a work in progress. Her moral support has kept me going through numerous frustrations and difficulties, and her proof reading skills have saved at minimum, a handful of small trees. Thank you, Katie.

DEDICATION

To my parents, without whom I would not have had the myriad opportunities that allowed me to even consider undertaking this thesis.

Thanks, guys.

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INTRODUCTION

Post activation potentiation (PAP) is a phenomenon in which an intense activity performed prior to an explosive activity increases muscular power. Exploiting this effect may be highly beneficial for athletes who participate in sports that rely on quick, explosive movements such as sprinting or long jumping. Numerous studies have examined many key variables that affect PAP including training status, gender, intensity, exercise volume, rest period, and movement type (Wilson et al., 2013). This current body of literature is equivocal on the efficacy of PAP, primarily due to the highly varying methodological nature of studies (Hanson, Leigh & Mynark, 2007; Hodgson, Docherty & Robbins, 2005; Kilduff et al., 2007). However, recent reviews established similarities between studies that demonstrate significant effects of PAP on performance (DeRenne, 2010; Wilson et al., 2013). The training level has been found the most important factor in determining response to PAP, with experienced strength trained subjects benefitting the most (Wilson et al., 2013). Trained athletes are able to blunt fatiguing effects of the intense exercise used to elicit PAP while maximizing the potentiation (Hodgson et al., 2005; Wilson et al., 2013). The critical determinant for a performance enhancing effect is the subjects' ability to perform a PAP exercise with minimal fatigue to the muscle fibers (DeRenne, 2010).

Performance enhancement found by previous studies focused on trials in which only one PAP exercise was completed, followed by a performance test typically occurring within 10 min (Chiu et al., 2003; Kilduff et al., 2007; McBride, Nimphius & Erickson, 2005). There are no data on the effect of multiple series of PAP exercises and performance tests over a period of time. Many sports, such as football, soccer, and basketball have durations of 60 min or longer and athletes have to perform maximal effort activities (i.e., sprinting or jumping) numerous times over the course of a contest. Track and field athletes (specifically multi- event athletes) may be required to perform in multiple heats and events in the same competition over many hours. A single PAP prior to competition may have little or no benefit after a certain time, therefore it could benefit an athlete to perform multiple PAP efforts at specific times throughout competition (e.g., in between quarters, or 10 min prior to each heat/event). Establishing if multiple PAP exercises confer a performance benefit, when used over the course of a prolonged session of intense activity, may be a step towards understanding and being able to better apply PAP in sport-specific situations.

Statement of Purpose

The primary purpose of this study was to investigate if PAP effects can be elicited repeatedly. Specifically the purpose was to determine if three separate but successive applications of PAP exercise prior to sprinting over the course of a prolonged session would enhance sprint performance throughout the entire session by decreasing reaction and sprint time. Another purpose was to investigate if these PAP effects remain during repeated maximum effort sprints performed with minimal rest within multiple sets of PAP exercise.

Hypotheses

The experimental hypotheses for this study were:

1. Performing PAP exercise pre-sprint would result in significantly lower mean sprint times for each of three sprinting sets compared to the sprint times after completing the control condition.
2. Performing PAP exercise pre-sprint would result in significantly lower mean reaction times for each of three sprinting sets compared to the reaction times after completing the control condition.

3. Performing PAP exercise pre-sprint would result in significantly lower mean sprint times for each of the four repeated sprints in each sprinting set compared to the sprint times for each repeated sprint after completing the control condition.
4. Performing PAP exercise pre-sprint would result in significantly lower mean reaction times for each of the four repeated sprints in each sprinting set compared to the reaction times for each repeated sprint after completing the control condition.
5. Performing PAP exercise would result in slower sprint times for the second and third sprint sets compared to the first set.

Assumptions

The assumptions for this study were:

1. The subjects were representative of athletes competing in sports necessitating repeated muscular power efforts.
2. The subjects were sufficiently experienced with high intensity strength training necessary to take advantage of, and possibly maximize, PAP effects.
3. Compound core exercises of intensities at 85% 1RM or greater were necessary to stimulate enhancement of motor unit recruitment and increased phosphorylation of myosin regulatory light chains, therefore preparing the musculature for a potential PAP effect.
4. The subjects were honest concerning any activities or physical conditions that contraindicated their participation in the study.

Definition of Terms

The terms used in this study are:

1. Post Activation Potentiation (PAP) – Physiological response to high intensity resistance training which increases muscular power.
2. Muscular Power – Generation of force by the muscles to move the body or an external object over a unit of time. Measured in Watts.
3. Power Sports – Sports in which successful performance relies heavily on repeated bouts of maximal effort such as sprinting, jumping, quickly accelerating or decelerating the body to move in a different direction, or events that require the athlete to exert maximal force on an external object.
4. 1RM – Maximum weight that can be lifted for one complete repetition (rep) following proper technique. Used to assess maximal force production.
5. Sprint Performance – Time to sprint a fixed linear distance (40 meters). Lower times indicate faster velocity and thus better sprint performance.
6. Reaction Time – Time between the presentation of the command to sprint and the subject coming out of the starting stance to initiate forward movement as measured by photocell timing gates.
7. Strength Training – A periodized resistance training protocol in which participants engage in compound lifts such as the back squat to improve muscular force and power production.
8. Interval Sprint Training – Repeated maximal effort sprints with rest intervals between reps. Rest intervals for training power and force are typically performed at a ratio of work to rest of 1:5 – 1:6.

9. Dynamic Warm-up – Warm-up protocol which uses dynamic mobility exercises to stretch muscle groups in order to prepare them for the demands of competition. Static stretching of any kind is not utilized.
10. Counter Movement Jumps (CMJ) – Vertical jump in which the participant utilizes a quick eccentric cocking movement of hip flexion to engage the stretch shortening cycle for maximal power production during the concentric phase of motion.
11. PAP Exercise – Any resistance exercise which is used prior to performance testing or competition in order to elicit a PAP effect.
12. Maximum Voluntary Isometric Contraction (MVIC) – Action which requires subject to attempt a maximum effort contraction against an immovable object.

Delimitations

The study was delimited to:

1. Male, college-aged athletes participating in collegiate varsity lacrosse.
2. Athletes with more than 12 consecutive months of resistance training.
3. Athletes with more than 12 consecutive months of interval sprint training.
4. Athletes with experience performing 1RM testing in the back squat exercise.
5. 40 m sprint time and reaction time as measures of performance.
6. Back squats at 90% of 1RM for PAP activity.
7. Eight min rest period used between PAP activity and sprint testing and 9 min rest period between the end of the last sprint rep in each set and beginning of the next PAP.
8. Rest of 55 s between each sprint rep.

9. Repeated pre-exercise PAP and sprint testing sets 20 min in length and repeated three times to examine PAP effects over a 60 min period.

Limitations

There were several limitations to the study.

1. The results may only be generalized to male collegiate athletes competing in team or field sports at the NCAA Division III level with minimum 12 consecutive months experience in resistance and sprint training.
2. Detection of performance enhancement due to PAP may only apply to 40 m linear sprinting and sprint-start reaction time.
3. There may be potential test-retest interactions with results due to the repeated measures design of the study.
4. The results may only be generalizable to use of back squat as the PAP exercise at an intensity of 90% 1RM and a volume of 4 reps.
5. The results may only be generalizable to the 8 min resting period used between PAP and sprinting, the 3 min sprint testing and the 9 min rest period between sprinting and next PAP.
6. The results may only be generalizable for three sets of PAP and sprint testing conducted over a 60 min period.
7. Use of four interval sprints with a 55 s inter-rep rest time are more ecologically valid to projecting PAP uses for sports performance, but may influence the balance of fatigue and potentiation effects.
8. Potential effects will only be detectable during the 3 min window beginning at 8 min post-PAP with the start of sprint testing and ending at 11 min with the last sprint.

9. The results may only be generalizable to the precise work:rest ratio for PAP activity and sprint testing used in this study.

Chapter 2

REVIEW OF LITERATURE

Introduction

The ability to generate power is a crucial ability in athletic events which rely on sprinting, change of direction, jumping or exerting maximal force on an external object such as a ball. Specific PAP protocols have demonstrated a significant influence on the muscles ability to generate power, and this may improve performance in the context of a competitive event. This review will summarize the physiological basis for PAP, outline the key variables previous studies have used to develop methodologies, and establish specific parameters shared between successful protocols.

Physiologic Mechanisms of PAP

Tillin and Bishop (2009) discuss the phosphorylation of myosin regulatory light chains and the recruitment of higher order motor-units as the two distinct primary mechanisms through which PAP acts to improve explosive performance. However, intense effort necessary to stimulate a PAP effect may potentially fatigue muscle fibers. It is thought that decreased concentration of Ca^{2+} is partly responsible for force attenuated post-muscular contractions (Rassier & MacIntosh, 2000). Eliciting a performance benefit from a PAP exercise thus becomes a balancing act of mitigating the impact of fatigue and maximizing the potentiate effect on force production.

Myosin Regulatory Light Chains

A molecule of myosin is composed of two heavy chains each possessing two regulatory light chains (RLC) (Tillin & Bishop, 2009). The enzymatic reaction which results in RLC phosphorylation is regulated by Ca^{2+} release from the sarcoplasmic reticulum during muscle fiber excitation. According to Hodgson et al. (2005) the phosphorylation of RLC via myosin light chain kinase elicits a favorable conformational change in myosin allowing greater rate of force production. Type 2 fibers exhibit a higher degree of RLC phosphorylation and the PAP effect appears greater in subjects and/or muscles with a higher percentage of fast twitch fibers (Hodgson et al., 2005; Sweeney, Bowman & Stull, 1993). Thus, RLC phosphorylation may be a primary mechanism for the potentiation effect.

Motor Unit Recruitment

It might be possible to enhance motor unit recruitment with use of pre-activity voluntary contractions that decrease neurotransmitter failure (Tillin & Bishop, 2009). Proposed mechanisms for this effect are an increase in neurotransmitter quantity released into the synapse, an increase in transmitter efficacy, or lessening failure rates of afferent nerve fibers (Tillin & Bishop, 2009). Hodgson et al. (2005) attributed more efficient motor unit recruitment to tetanic contractions which elevated CA^{2+} concentration in the presynaptic neuron.

Fatigue

Fatigue is an expected response to muscle contractions that occur close to maximal effort. Stores of ATP and phosphocreatine are consumed by high intensity muscular contractions and need time to be replenished. Besides substrate availability, Ca^{2+} concentration is paramount. Low Ca^{2+} concentrations and decreased Ca^{2+} sensitivity are thought to be primary mechanisms of muscle fatigue (Rassier & MacIntosh, 2000). Wilson et al. (2013) noted that in addition to decreased substrate and Ca^{2+} availability, there is also mechanical breakdown of myofibrils and increased hydrogen ion concentration following an intense resistance conditioning protocol. Regardless of the precise mechanism, the probability of a positive PAP effect occurring is likely diminished when fatiguing events are present or initiated.

Treatment Variables and Potentiation Efficacy

The subjects and methodology for PAP studies are highly varied. Investigators have reported disparate effects using similar protocols but different subject populations and vice-versa. This section is a discussion of the major methodological variables found in PAP studies and explores the commonalities between methods that elicited a successful PAP.

Training Status

Wilson et al. (2013) performed a meta-analysis on PAP studies that divided subjects into three classifications depending on their training level. They found a significant difference in effect size between athletes (d = 0.81) and untrained (d = 0.14), as well as athletes and trained (d = 0.29). Athletes were classified as having 3 years or more of strength training experience and having NCAA, Pro or competitive power lifting experience. Trained subjects had a minimum one year of strength training experience while untrained subjects were active but not currently strength training. The findings therefore suggested that athletes who are experienced with resistance exercise are able to optimize PAP while minimizing fatigue effects. This success was likely due to strength training adaptations and familiarity with intense workloads. Brandenburg (2005) used recreationally trained subjects and found no PAP effect. Another study used non-athletes with one year of resistance training experience and found no significant improvements in countermovement jump (CMJ) height or peak force and peak power when comparing a control protocol to a maximum voluntary isometric contraction (MVIC) conditioning protocol (Robbins & Docherty, 2005). Hanson et al. (2007) utilized subjects who had at least one year of resistance training experience and reported no significant differences between control and PAP testing.

However, when PAP was investigated using Division III football players familiar with strength training, there was a significant improvement in 40 m sprint time (McBride et al., 2005). Chiu et al. (2003) had athletes and recreationally trained subjects complete the same PAP protocol and tested performance in weighted squat jumps. Only the athletic population showed significant increases in performance while the performance of the recreationally trained subjects either did not improve or decreased. Gourgoulis, Aggeloussis, Kasimatis, Mavromatis and Garas (2003) tested CMJ performance before and after the use of back squat as a PAP warm-up. A between groups analysis was performed on vertical jump height and maximum strength, with subjects in the stronger group increasing jump height 4.01% compared to the weaker groups increase of .42%. Kilduff et al. (2007) effectively elicited upper and lower body PAP with Rugby professionals who averaged 3.1 ± 1.6 years of resistance training experience. Performing a PAP warm-up exercise seems more likely to lead to the desired result in athletes or individuals with higher levels of maximum strength as calculated by 1RM testing.

Intensity and Volume of PAP Activity

Brandenburg (2005) investigated PAP protocols at 50, 75 and 100% of 5RM bench press and its effect on upper body explosiveness measured by concentric only bench press throws. Subjects completed a pre-test of three bench press throws, the 5RM PAP exercise, and then a post-test of three bench press throws. This protocol did not generate PAP; the subjects may not have been experienced enough to derive benefits from PAP at the higher intensities and the lower intensities may not be adequate to elicit PAP.

Hanson et al. (2007) had subjects complete both a low intensity high velocity load (40% 1RM) and a high intensity low velocity load (80% 1RM) in two separate testing sessions. Subjects performed multiple PAP exercise sets of the back squat with the Smith Machine. The low intensity group performed two sets of 10 reps before performing eight reps at 40% intended to elicit PAP. The high intensity group performed two warm-up sets of five reps each before performing four reps at 80%. There was no difference found in net impulse or vertical ground reaction force produced by vertical jump attempts after PAP compared to baseline. It is possible both exercise selection and intensity played a role in this. Four reps at 80% 1RM may be too little volume at this specific intensity level to produce PAP. Successful studies using only four reps have used intensities at or above 90% 1RM (McBride et al., 2005). There also might be a difference between performing a back squat with the Smith Machine as compared to an unassisted free weight back squat. Yetter and Moir (2008) had subjects perform five reps at 30% 1RM, 4 x 50%, and 3 x70%, yielding a total volume of 12 reps over the course of three sets of increasing intensity. This protocol produced significantly faster velocities when subjects performed the experimental condition in 40 m sprinting tests. This was the only study to elicit PAP effects using intensities lower than 80% 1RM.

Weber, Brown, Coburn and Zinder (2008) compared performance in squat jumps after subjects completed a squat-jump control or a PAP exercise of five reps of back squat at 85% of 1RM. The effects of this protocol resulted in increased jump height for the back squat condition (pre: 41.6 ± 6 5.3 cm; post: 43.9 ± 6 5.1 cm) but a decrease for the squat-jump control condition (pre: 42.7 ± 6 5.8 cm; post: 41.4 ± 6 5.1 cm). Mathews, Mathews and Snook (2004) had professional rugby players perform one set of back squats at 5RM prior to 20 m sprint. Intensity level for 5RM is calculated to be equivalent to 87% of 1RM by the NSCA (Baechle & Earle, 2008). Subjects performed both control and experimental sessions 7 days apart in a repeated measures design. They found that 20 m sprint times were decreased by 3.3% following PAP compared to the control of performing no activity prior to sprinting. McBride et al. (2005) and Chiu et al. (2003) both utilized 90% of 1RM in the back squat. McBride et al. (2005) reported an average decrease of 0.05 ± 0.34 s in 40 m sprint times using a rep scheme of 3 x 90%. Chiu et al. (2003), using a 5 x 90% rep scheme found that athletes, but not recreational subjects, increased squat-jump average and peak power, supporting the PAP effect found by McBride et al. (2005) at the same intensity of 1RM. Linder et al. (2010) studied sprint performance in females using a 4RM (NSCA equivalent of 90% 1RM) half squat. This PAP intervention decreased 100 m sprint time by 0.19 s on average and lends further support for eliciting PAP by use of intensities at 90% of 1RM. In a study with a design similar to Yetter and Moir (2008), Gourgoulis et al. (2003) used a back squat PAP of five sets. The first set was performed at 20% of 1RM and subsequent sets increased intensity to 40%, 60%, 80% and 90% of 1RM. Subjects performed two reps for each set. This protocol increased CMJ height by 2.4% compared to baseline taken before the PAP exercise. Kilduff et al. (2007) utilized one set of 3RM in bench press and back squat as PAP conditioning, highly similar in volume and intensity to the aforementioned studies. The NSCA 1RM % chart estimates a 3RM to be 93% of a 1RM load. Peak power output increased in CMJs and bench press throws at this rep scheme. Chatzopoulos et al. (2007) used 10 sets of a 90% 1RM load as PAP exercise to test sprint performance in 10 and 30 m sprints and found significant improvements compared to baseline.

In summary, it appears that while there is a degree of variance between exact repetition schemes and PAP results, some similarities exist. A number of investigators that reported significant effects utilized PAP intensities at or above 90% 1RM performed as a single set of three to five repetitions; one study was successful using a higher volume at the same intensity. Studies that used various repetitions schemes at intensities lower than 90% were much less likely to generate PAP effects with the exception of Yetter and Moir (2008). It should be noted all subjects in Yetter and Moir (2008) were athletes experienced with strength training and the back squat was performed with free weights and not the Smith Machine protocol McBride et al. (2005) used.

Gender

DeRenne (2010) and Wilson et al. (2013) found that both male and females benefit from potentiation effects and there is no apparent significant difference between genders. However, PAP studies have been performed predominantly on male subjects. In studies that used male and female participants, however, investigators chose to pool data into the same group due to assumptions that there was no difference between genders. Linder et al. (2010) assessed 100 m sprint time in female college students with at least one year of resistance training with the back squat and found that sprint times were decreased significantly after a 4RM back squat compared to a control session with no exercise performed prior to sprinting. Performance benefits from PAP effects do not appear to be gender specific. The fact that most studies have used male subjects seems to reflect the likelihood that males comprise a larger percentage of the pool of strength trained athletes from which to recruit subjects.

Rest Period

Muscles must be stimulated by intense loads to undergo the theorized physiologic priming that elicits the performance enhancing effect of PAP. However, muscles must not be fatigued when the performance occurs, which is a likely acute effect of an intense compound strength exercise used for PAP. Therefore careful attention must be given to rest periods in any PAP protocol. The rest periods must strike a balance in which enough time has elapsed to allow recovery but not too much time has passed for the muscle to lose any beneficial changes.

Brandenburg (2005) had subjects perform a PAP protocol 2 min after a bench press pre-test and then perform the bench press post-test 4 min later, and found no significant differences in average power of concentric bench press throws. Robbins and Docherty (2005) had subjects perform a CMJ 4 min after completion of a 7 s maximal voluntary isometric contraction (MVIC) in a squat position and found peak power output was decreased. Hanson et al. (2007) separated warm-up sets (conducted prior to the PAP exercise intended to elicit PAP) by 3 min and the PAP set by 5 min from the post-test for CMJ performance. They found no significant improvements.

Chatzopoulos et al. (2007) found improved sprint performance in the session in which subjects had 5 min rest (between PAP exercise and sprinting) compared with a separate session in which they had only 3 min rest. Subjects performed otherwise identical PAP protocols. McBride et al. (2005) found significantly faster sprint times for subjects who had a 4 min walking recovery after performing a PAP exercise and before performing the 40 m sprint post-test. Chiu et al. (2003) had subjects rest for 2 min in between each of five sets of the PAP exercise and then began performance of squat-jumps 5 min after the conclusion of the intervention. There was an improvement in jump performance for athletes. Linder et al. (2010) had subjects rest for 9 min after a PAP exercise of 4RM half squat and found a PAP effect evidenced by decreased sprint times. Mathews et al. (2004) used a 10 min rest period between PAP exercise and 20 m sprint testing and found a significant decrease in 20 m sprint times (0.098 s). Kilduff et al. (2007) observed increased peak power in upper and lower musculature at the same time intervals as Mathews et al. (2004). Kilduff et al. (2007) had subjects perform separate testing sessions for upper and lower body with a rest period of 48 h between those sessions. Power measurement was assessed by CMJ and bench press throws 15 s after PAP exercise was performed. Testing repeated every 4 min for 20 total min. Performance decreased at 15 s for both movements and there was no significant difference in lower body power after 4, 16 or 20 min, but lower body peak power was significantly higher at 8 and 12 min compared to baseline (4,568 ± 509 W vs. 4,862 ± 485 W). The highest recorded power output occurred at 12 min (4911 ± 444 W vs. 4,568 ± 509 W). Analysis of upper body power output found the same trends, with power peaking at 12 min. In summary, studies which allow participants to rest for at least 4 min have been considerably more successful in showing a performance boosting effect, though it appears amount of rest necessary for successful PAP is mediated by training status, volume and intensity.

Exercise Type

A number of exercises are performed to generate PAP, the most common being variations of the back squat, loaded countermovement jump, and bench press. Hanson et al. (2007) had subjects perform back squats to a depth of 90 degrees of knee flexion using a Smith Machine and did not detect any differences in power output of a CMJ. McBride et al. (2005) and Chiu et al. (2003) had subjects perform a back squat with free weights at a depth of thighs parallel to the floor. Sprints were faster after subjects performed heavy back squats (Chiu et al, 2003; McBride et al., 2004). Linder et al. (2010) had subjects perform the half back squat and they reported a significant decrease in 100 m sprint times after using this exercise for a PAP activity.

Yetter and Moir (2008) further investigated exercise selection and the effect on PAP for 40 m sprint performance. Subjects in the study performed (in separate testing sessions) front squats, back squats, and a third control session. The aim was to determine if there was an interaction between movement patterns in the two different squat exercises and performance in each 10 m split. Yetter and Moir hypothesized that sprinting performance is a convergence of different biomechanical factors whose influence is loosely delineated by 10 m splits, thus use of an exercise which emphasizes patterns similar to the sprint mechanics displayed during a given split will generate a greater effect in that split compared to an exercise with mechanics that differ from that same split. Findings indicated no significant difference between 0 – 10 and 20 – 30 m but a significantly higher average velocity for back squat (7.57 ± 0.28 m $\cdot$ s^{-1}) compared to control (7.46 ± 0.26 m $\cdot$ s^{-1}) at the 10 – 20 m split was reported. No differences between back or front squat were reported at this interval. At the 30 – 40 m split back squat produced an average velocity 0.24 m $\cdot$ s^{-1} faster than front squat, and 0.18 m $\cdot$ s^{-1} faster than the control

Kilduff et al. (2007) utilized the bench press as the PAP exercise with subjects performing ballistic bench press throws in order to assess PAP effects in upper body power output, and found that power output increased. Brandenburg (2005) also utilized bench pressing as an exercise to examine PAP effects in the upper body but did not find that it improved performance in bench press throws.

Robbins and Docherty (2005) had subjects perform a MVIC in the squat position for a length of 7 s but found no significant improvements in CMJ performance. French, Kraemer and Cooke (2003) also investigated the use of MVIC to elicit a PAP in the knee extensors. Subjects in this study performed three knee extensions and held the contraction for 3 s. It was found that drop-jump height increased by 5.03% and peak torque in isokinetic knee extensions improved by 6.12%.

Outcome Measures

Various measures of performance have been used as dependent variables in PAP studies. The most common activities used to measure outcome for lower body power enhancement have been sprinting and jumping. Studies investigating upper body power enhancement have typically utilized variations of the bench press.

<u>Jumping</u>

Jumping has been a popular outcome measure for detecting PAP. The findings of Kilduff et al. (2007) suggest that PAP manifests in jumping actions via increased power production from lower body muscles stimulated by an exercise of sufficient intensity and volume. Successful vertical jump attempts require the subject to produce a maximal effort power movement. If PAP enables the muscles to produce more force, power output will improve and vertical jump performance will improve after PAP exercises. Moreover, jumping and similarly powerful movements such as cutting are ubiquitous in athletic competition, so they are a good practical measure of performance. Lastly, jumping is a convenient measure because it requires small amounts of time and space to test and can be tested to highly accurate degrees with the use of force plates, which also allow the calculation of power output.

Robbins and Docherty (2005) used a force plate to record performance in CMJs. They analyzed vertical jump height, peak force, peak power, rate to peak force, peak acceleration and peak velocity. Hanson et al. (2005) also used a force plate to measure vertical ground reaction forces for CMJ. Neither Hanson et al. (2005) or Robbins and Docherty (2005) found any significant improvement in jump performance. Gourgoulis et al. (2003) measured vertical jump height by calculating impulse of the vertical ground reactive force and found that there was an improvement in jump performance.

<u>Sprinting</u>

Studies on PAP frequently use sprint performance as a measure to determine if increases in power production are caused by PAP exercise. Like jumping, sprinting (distances between 20 – 100 m) requires the athlete to engage in maximal effort force production in order to accelerate the body over a given distance in the shortest time possible. Sprinting is universal to all major field sports (e.g., football, soccer, lacrosse, field hockey, rugby). Sprinting distances which rely almost exclusively on muscular power and alactic anaerobic energy system, as opposed to the lactic anaerobic or aerobic energy systems, are often 10 – 15 s or less, making them relatively easy markers of performance to test.

McBride et al. (2005) tested sprint speed at the length of 40 m, in addition to observing 10 and 30 m split times. Measurement was made by an infrared timing system. Sprint times were faster for a heavy back squat condition compared to control condition. Yetter and Moir (2008) also utilized 40 m sprints. Split times were calculated for every 10 m split from 0 to 40. Photocells were used to record average split time and obtain velocity for each of the splits. They reported faster split velocities for the squat conditions compared to control. Both of these studies were conducted at indoor track facilities and had athletes assume a three point sprinters stance. Linder et al. (2010) utilized a distance of 100 m to assess PAP in their protocol. Time was collected by photocell timing gates positioned at the start and end lines. They found that sprint performance improved following a heavy back squat compared to the control condition.

Bench Press Throws

Studies that have explored PAP effects in the upper body musculature have most commonly used bench press throws to assess power production. Bench press throws have some degree of similarity to the actions used by football linemen, and the bench press is one of the most common strength training exercises. It would be expected that similar to jumping and sprinting, almost all potential subjects would have familiarity with the correct way to perform the exercise.

Brandenburg (2005) had subjects perform concentric only bench press throws. The bar was placed 5 cm above the sternum and subjects were instructed to explosively push the bar and release at the highest point to limit deceleration. The bar was arrested by spotters and 30 s of rest were given before the next attempt. A total of three attempts were made at an intensity of 45% of their bench press 1RM. Kilduff et al. (2007) utilized a similar protocol in rugby players. Forty percent of their 1RM was used as the load for measuring upper body peak power output. Throws in this study were conducted at baseline, 15 s post PAP, and every 4 min post up to 20 min. An increase in power was seen 12 min post PAP exercise. A system utilizing a potentiometer connected to a digital analog converter was used to capture voltage differences as the bar moved through the range of motion. Software then computed the voltage differences into displacement data allowing calculation of power output for the bench press throws. The reliability for this method of calculation had been assessed previously (Alemany et al., 2005), with a correlation coefficient of 0.93. Investigators found that bench press throw performance improved after the PAP exercise.

All previous outcome measures aim to detect performance differences due to effects on muscular force and power production of the muscles following PAP exercise. Performing CMJ's on force plates allows the most direct calculation of power output. Assessing power via sprint performance on a track is indirect but may be more applicable to sport competition depending on the sport or athlete in question. Sprint studies have relied upon either velocity or sprint time as measures of performance. Bench press throws which utilize only the concentric part of the movement have been established as the only method so far of testing power output in the upper body related to PAP.

Summary

The two physiologic processes which have been identified as the most likely mechanisms through which PAP takes place are phosphorylation of myosin RLC and enhanced motor recruitment. Fatigue is a key physiologic factor which appears to mediate the potentiation effect.

Most studies that successfully demonstrate a potentiating effect share two key factors. First, is subjects who are active high level athletes (college or beyond) familiar with performing maximal weight lifting efforts and explosive movements. There has been some success with recreationally active subjects who are experienced with strength training but not to the same degree as athletes. As Wilson et al. (2013) explained, this is likely due to the condition of athletes who have multiple years of experiencing high intensity exertion, allowing them to be more fatigue resistant than untrained or even noncompetitive athletes. Thus PAP is an effect that will only be distinguishable in those who are very highly trained. Furthermore, there is evidence that the potentiating effect is activated more thoroughly by higher intensity PAP exercises. People who do not specifically train at high intensities (around 90% of 1RM) may not be able to properly complete a protocol resulting in the desired PAP effects. A second key factor in generating PAP is volume of the conditioning intervention. A majority of the studies reporting PAP effects were performed with subjects back squatting 90% of their 1RM for three to 10 reps. Most studies that have used lower intensities or volumes do not report effective PAP.

While it has been demonstrated that PAP can improve performance in a single event, there has been no work exploring if the PAP effect is repeatable for multiple events in one day. Many sports require athletes to perform at close to maximal exertion numerous times, for duration of an hour or more. It may be beneficial for track athletes, and their coaches, who have multiple sprint or throwing events throughout the course of a day to understand how best to prepare for these events and if the PAP effect recurs after repeated PAP exercises and performance activities.

Chapter 3

METHODS

This chapter details the procedures used in this study. The aim of this study was to determine if multiple PAP exercises can increase repeated sprint performance performed every 20 min. This time frame is similar to the demands of field sports and track events that require lower body maximum power output over the duration of competition. Determining the effect of PAP on RT was also an aim of this study. Subsections for this chapter include subjects, experimental design, procedures, and data analysis.

Subjects

The subjects for this study were 29 recruited volunteers from Ithaca College who were all active NCAA varsity athletes at the time of data collection. Subjects were required to have 12 months of resistance training and sprint training experience with no more than three consecutive weeks of inactivity. Subjects must have had at least 12 months experience with the back squat at or above 90% of 1RM intensity. Subjects with any illnesses or injuries that prevented them from giving maximum effort in any of the activities required for the study were precluded from participating. This study was approved by the Ithaca College Human Subjects Review Board and subjects had the risks and benefits of their participation made aware to them prior to providing written informed consent (Appendix A).

Experimental Design

Subjects reported for three separate sessions. The first session was used to test and establish 1RM in the back squat as well as familiarize subjects with the procedure for sprinting sessions. The second and third sessions were for the control and PAP conditions for sprint testing, respectively. Subjects underwent a counterbalanced, repeated measures design, with partially random assignment. The structure of the sprinting trials was identical for both control and PAP sessions. The control session consisted of a protocol in which a very low intensity back squat was performed prior to sprinting. The PAP session utilized heavy back squat exercise prior to sprinting. Counterbalancing had half the subjects performing the control condition for the second session and PAP condition for the third session while the other half performed the PAP condition at their second session and the control condition during the third.

Procedures

Subjects attended the first session and completed the testing procedure to establish 1RM in the back squat. After completing the first session subjects attended the second and third sessions to test sprint performance, one with a control condition, and the other with the PAP condition.

1RM Testing Session

Testing for 1RM back squat was carried out in accordance with NSCA guidelines (Baechle & Earle, 2008). Subjects performed a dynamic warm-up prior to lifting. Subjects performed warm up sets of 10 reps at 35%, 5 reps at 55%, 3 reps at 75%, and 1 rep at 90% before 1RM attempts. Between each attempt subjects rested for a period of 5 min. The testing was performed using free weights in a squat rack with spotters. For a successful attempt, subjects had to keep their feet flat against the platform and thighs had to reach a parallel position relative to the platform at the end of the eccentric movement. A minimum of two days rest was given to subjects before they reported for sprint testing.

Sprint Testing Sessions

Participants reported for two sprint testing sessions with no less than 48 h and no more than 10 days between sessions. Subjects were asked not to consume caffeine or alcohol within 24 h of testing. They were also asked not to engage in any heavy intensity endurance training, sprinting, or lower body resistance training within 48 h of testing. Subjects were asked to wear the same shoes for each testing session and report at the same time of day for both the control and experimental sessions. The testing was conducted at a temperature controlled indoor track facility during the late morning to early afternoon. The session began with a standardized warm-up consisting of light cycling, self myofascial release and dynamic exercises for 10 min (Appendix B). After the warm-up, subjects were directed to begin the control or PAP back squat exercise. Subjects were given 8 min rest between completion of back squats and the first sprint of the four repeated sprints to be performed each set. Subjects performed four 40 m sprints with an inter-sprint rest period of 55 s. At conclusion of the last sprint of the repeated sprints, subjects rested for 9 min. That concluded the first 20 min set. Two more sets were performed. At the end of the 9 min post-sprint rest period, subjects began back squats again, initiating the next set. The total time for subjects to perform all three sets was 51 min due to subjects not needing the 9 min rest period after the third and final set of repeated sprints.

PAP Protocol

Subjects performed four reps of the back squat at 90% of their 1RM as established by preliminary testing. Subjects performed a full back squat until thighs were parallel to the weight platform during the eccentric motion and fully extended their hips during the concentric motion. Back squats were performed on a half rack platform with barbells and free weights.

Control Protocol

Subjects performed four reps of the back squat at 20% of their 1RM as established by preliminary testing. Subjects performed a full back squat until thighs were parallel to the weight platform during the eccentric motion and fully extended their hips during the concentric motion. Back squats were performed on a half rack platform with barbells and free weights.

Repeated Sprint Protocol

Subjects began with tips of the fingers at the starting line, feet behind the starting gate and line in a three point sprinter stance. Subjects placed their rear foot on the pressure foot pad used to measure RT. The starting gate emitted an audible starting cue to signal subjects to take off through the starting gate. Subjects were instructed to run through the end gate at full speed before decelerating. Rest time of 55 s was given as subjects returned to the same starting point before beginning the next sprint. Subjects were told to reset to the sprint-start position with 3 s remaining. Each set of sprints consisted of four repetitions. The audible cue signaled from a random range of .05 – 1.5 s prior to the end of the 55 s rest period on each rep so that subjects could not anticipate the starting signal. Sprint times were recorded by SmartSpeed (Fusion Sport, Australia) timing gates. Gates were set at 0, 10 and 40 m. The timing gates recorded reaction time from the audible start signal to toe off of the foot pad, time from toe off to the 10 m gate and the complete time for subjects to sprint 40 m.

Data Analysis

Data were analyzed using SPSS (IBM, NY) version 21. Descriptive statistics were calculated for set sprint and reaction times. Set sprint times were calculated for each of the three sets by averaging each of the set's four reps, yielding a mean set sprint time. Set reaction times were calculated in the same manner. Rep times were calculated for each of the four reps by averaging times for a given rep in all three sets. Rep reaction times were calculated in the same manner. A 2x3 repeated measures ANOVA (Condition x Sets) of set sprint times compared differences between conditions (PAP and control) and between sets (1, 2, and 3). A 2x3 repeated measures ANOVA was also performed to analyze set reaction times. A 2x4 repeated measures ANOVA (Condition x Reps) of rep sprint times compared differences between conditions (PAP and control) and reps (1, 2, 3, and 4). Alpha was set to .05. Post-hoc paired samples t-tests were used to test for sprint time differences for significant Condition x Reps interactions.

Chapter 4

RESULTS

This chapter details results from investigating how repeated PAPs affect sprint performance and reaction time. Statistical analysis of the average set and repetition sprint time and reaction time data for PAP and control condition are presented. Raw data can be found in Appendix C.

Subjects

Subjects (n = 29) were members of the Ithaca College varsity (DIII) Men's Lacrosse team (Table 1). Two subjects were dropped from the study due to injury sustained at lacrosse practice that prevented full study participation. All subjects were experienced and proficient at performing parallel back squats, and every rep at 90% was completed (Table 2).

Table 1

Anthropometric and Demographic Values ($\overline{X}$ ± SD)

	Age (Years)	Height (cm)	Weight (kg)	Experience (Years)
Mean	19.4 ± 1.4	178 ± 6	80.2 ± 7.9	4.9 ± 1.6

Table 2

Back Squat Strength Values ($\overline{X}$ ± SD)

	1RM (kg)	90% (kg)	20% (kg)
Mean	126.8 ± 23	114.5 ± 20.8	25.6 ± 4.7

Note. 1 RM (Squat 1 repetition maximum)

Sprint Performance

Average times for each sprint across subjects are provided in Table 3. From these data, average sprint time for each set (across the four reps) was calculated and average sprint time for each rep (across three sets) was calculated. Average set times and average rep times were used for further analysis.

Average Set Sprint Time

Mauchly's test indicates assumption of sphericity was met for both main effects, sets, $\chi^2(2) = 1.04$, $p > .05$, and condition (perfect sphericity due to only 2 conditions). Sphericity was violated for the interaction of condition and sets, $\chi^2(2) = 9.43$, $p < .05$. Corrected degrees of freedom were obtained from Greenhouse-Geisser estimates ($\varepsilon = .01$ for the interaction of Condition x Sets).

The 2x3 repeated measures ANOVA (Condition x Sets) demonstrated no significant interaction for average set sprint time between condition and sets, $F(1.52, 39.57) = .09$, $p > .05$. There was a significant main effect of condition on sprint times, $F(1, 26) = 6.89$, $p < .05$ (Table 4). PAP sprints were faster (.053 ± .02 s) than the control sprints over the entire three set trial (Figure 1). There was a significant main effect of set on sprint times, $F(2, 52) = 15.56$, $p < .05$. Set 1 had a faster time than Set 2 ($p < .01$) or Set 3 ($p < .001$). Sprint times for sets 2 and 3 were not significantly different from each other.

Table 3

Sprint and Reaction Time ($\overline{X}$ ± SD)

	Sprint Time		Reaction Time	
	PAP (s)	Control (s)	PAP (s)	Control (s)
Set 1				
Rep 1	5.609 ± .24	5.693 ± .18	0.621 ± .31	0.525 ± .18
Rep 2	5.668 ± .25	5.705 ± .20	0.521 ± .19	0.521 ± .10
Rep 3	5.680 ± .24	5.723 ± .18	0.509 ± .11	0.570 ± .20
Rep 4	5.715 ± .22	5.734 ± .22	0.536 ± .23	0.527 ± .16
Set 2				
Rep 1	5.703 ± .26	5.803 ± .26	0.519 ± .09	0.489 ± .08
Rep 2	5.743 ± .26	5.793 ± .23	0.525 ± .13	0.512 ± .14
Rep 3	5.744 ±.23	5.814 ± .27	0.488 ± .09	0.469 ± .09
Rep 4	5.765 ± .27	5.766 ± .23	0.669 ± .80	0.537 ± .18
Set 3				
Rep 1	5.737 ± .31	5.838 ± .25	0.514 ± .11	0.487 ± .12
Rep 2	5.762 ± .27	5.897 ± .43	0.497 ± .11	0.494 ± .12
Rep 3	5.814 ± .27	5.829 ± .24	0.511 ± .16	0.498 ± .10
Rep 4	5.774 ± .32	5.755 ± .25	0.513 ± .18	0.484 ± .14

Table 4

Two-Way Repeated Measures ANOVA Summary Table of Sprint Time (Condition x Sets)

	SS	df	MS	F	*p*-value
Condition	0.114	1	0.114	6.890	0.014*
Error (Condition)	0.432	26	0.017		
Sets	0.341	2	0.170	15.555	0.000*
Error (Sets)	0.570	52	0.011		
Condition*Sets †	0.001	1.522	0.001	0.093	0.861
Error (Condition*Sets)†	0.570	39.569	0.008		

Note. *p ≤ 0.05. † Greenhouse-Geisser estimate for sphericity correction.

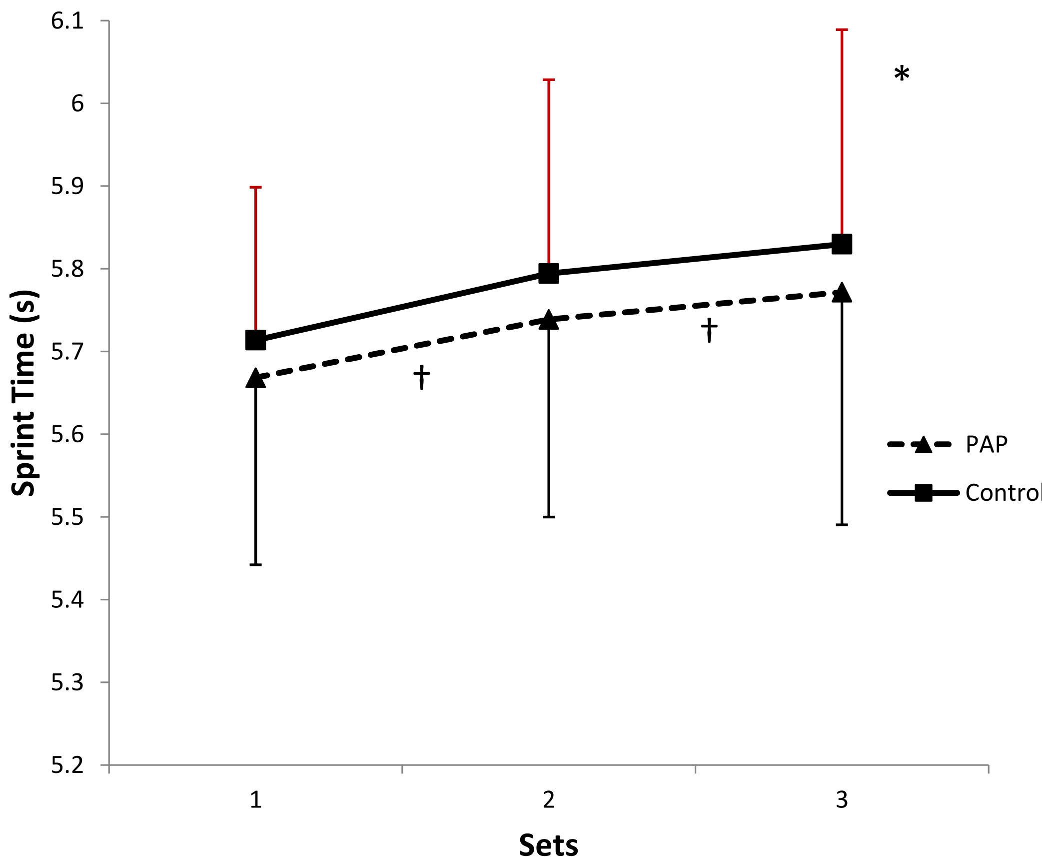

Figure 1. Sprint time across three sets. Means and standard deviations of sprint performance in seconds. *The main effect of condition showed a significant difference ($p \leq .05$) with PAP being faster overall than the control condition. †The main effect of sets showed a significant difference ($p \leq .05$) with set 1 being faster than either set 2 or 3.

<u>Average Repetition Sprint Time</u>

The main effect of sprint reps did not meet sphericity assumptions, $\chi^2(5) = 16.93$, $p < .05$, Greenhouse-Geisser estimates were used as corrections ($\varepsilon = .74$). The condition main effect and condition and sprint rep interaction, $\chi^2(5) = 3.24$, $p > .05$, both satisfied Mauchly's test for sphericity assumptions.

The 2x4 repeated measures ANOVA demonstrated a significant interaction for average rep sprint time between condition and reps $F(3, 78) = 5.47$, $p < .05$ (Table 5). Post-hoc *t*-tests looking at differences between conditions for each rep indicated PAP rep 1 (*M* = 5.68, *SE* = .05) and 2 (*M* = 5.72, *SE* = .05) were significantly faster than control rep 1 (*M* = 5.79, *SE* = .04) and 2 (*M* = 5.8, *SE* = .05) ($t(26) = 3.86$, $p < .05$, and $t(26) = 2.35$, $p < .05$), respectively. The difference between sprint time for control rep 3 (*M* = 5.79 *SE* = .05) and PAP rep 3 (*M* = 5.75, *SE* = .05) ($t(26) = 2.02$, p = .053) approached significance. There was no significant difference between PAP rep 4 and control rep 4, (*M* = 5.75, *SE* = .05, and *M* = 5.75, *SE* = .04 respectively) ($t(26) = .05$, p = .98). These results indicate a decreasing PAP effect occurring after rep 2 (Figure 2).

Post-hoc *t*-tests looking at differences between each rep within conditions indicated that control rep 4 was faster than control rep 2 ($t(26) = -2.1$, $p = .045$) and 3 ($t(26) = -3.11$, $p = .005$) but was no different than control rep 1 ($t(26) = -1.38$, $p = .18$). PAP rep 1 was significantly faster than PAP rep 2 ($t(26) = -2.79$, $p = .01$) PAP rep 3 ($t(26) = -3.95$, $p = .001$) and PAP rep 4 ($t(26) = -3.12$, $p = .004$). There was no difference between PAP rep 2 and 3 or rep 3 and 4. The main effect of sprint reps approached, but did not reach significance, $F(2.23, 58.01) = 3.02$, $p > .05$.

Table 5

Two-Way Repeated Measures ANOVA Summary Table of Sprint Time (Condition x Reps)

	SS	df	MS	F	*p*-value
Condition	0.152	1	0.152	6.890	0.014*
Error (Condition)	0.575	26	0.022		
Reps †	0.042	2.231	0.019	3.024	0.051
Error (Reps) †	0.364	58.016	0.006		
Condition*Reps	0.069	3	0.023	5.474	0.002*
Error (Condition*Reps)	0.328	78	0.004		

Note. *p ≤ 0.05. † Greenhouse-Geisser estimate for sphericity correction.

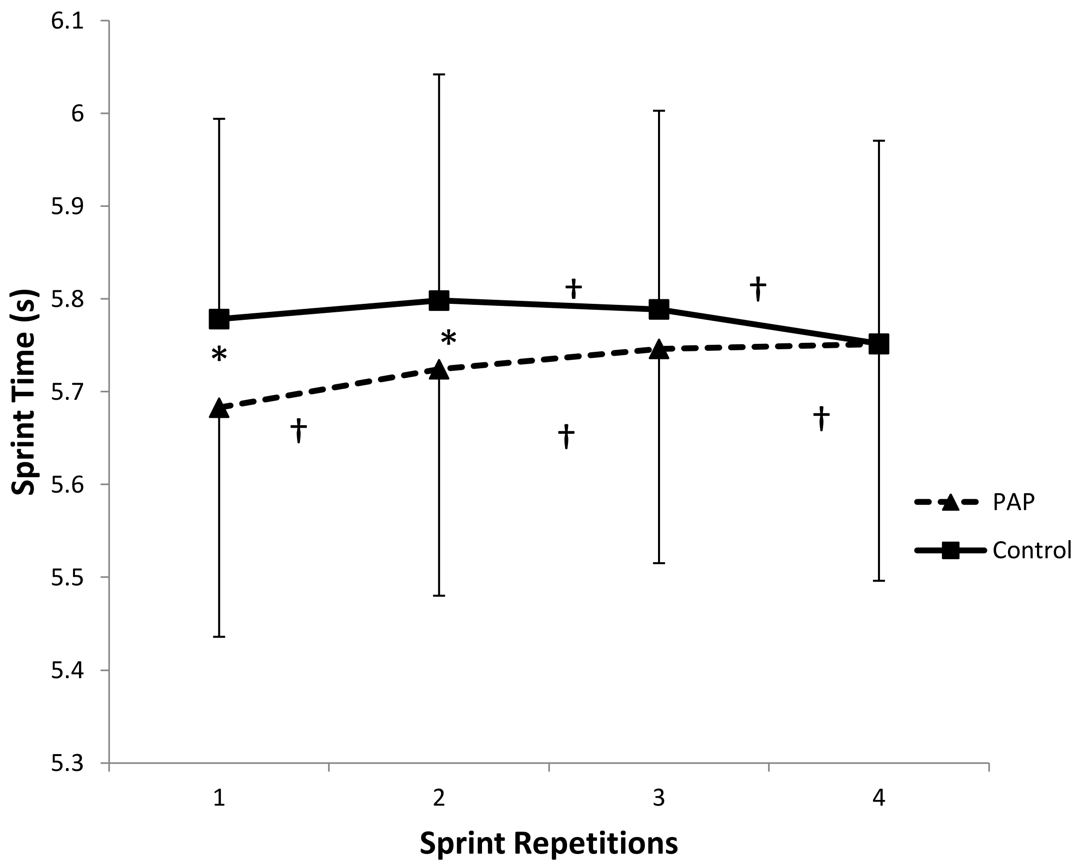

Figure 2. Sprint time across four repetitions. Means and standard deviations of sprint performance in seconds. *There was an interaction, with a significant difference ($p \leq .05$) of faster sprint times for PAP reps 1 and 2 versus control. †Within conditions, PAP rep 1 was faster than PAP reps 2, 3, and 4 while control rep 4 was faster than control reps 2 and 3 ($p \leq .05$).

Average Set Reaction Time

The main effect of sets and the interaction of sets and condition violated assumptions of sphericity, $\chi^2(2) = 13.21$, $p < .05$, $\chi^2(2) = 13.59$, $p < .05$ (Table 6 and Figure 3), respectively. Greenhouse-Geisser estimates were used for correction ($\varepsilon = .71$, $\varepsilon = .71$). The interaction was not significant ($F(1.41, 36.64) = .56$, $p = .52$). There was no significant main effect for condition ($F(1, 26) = 1.83$, $p = .19$) or sets $F(1.42, 36.87) = 1.86$, $p = .18$).

Average Repetition Reaction Time

Assumptions of sphericity were violated by the main effect of sprints and the interaction of condition and sprints ($\chi^2(5) = 52.46$, $p = .00$, and $\chi^2(5) = 57.3$, $p = .00$). Greenhouse-Geisser estimates were used for correction ($\varepsilon = .47$, and $\varepsilon = .44$ respectively). The interaction was not significant ($F(1.33, 34.5) = 1.27$, $p = .28$). Neither the condition ($F(1, 26) = 1.83$, $p = .19$) nor rep ($F(1.4, 36.3) = 1.2$, $p = .31$) main effect was significant (Table 7, Figure 4).

Summary

The dependent variable of sprint time was significantly faster for the PAP condition than the control in reps 1 and 2, and approached significance for rep 3. Across conditions, set 1 was significantly faster than either set 2 or 3. Overall, the sprint times were generally faster for the PAP condition. There were no statistically significant differences for RT.

Table 6

Two-Way Repeated Measures ANOVA Summary Table of Reaction Time (Condition x Sets)

	SS	df	MS	F	*p*-value
Condition	0.027	1	0.027	1.828	0.188
Error (Condition)	0.381	26	0.015		
Sets †	0.047	1.418	0.033	1.855	0.179
Error (Sets) †	0.664	36.868	0.018		
Condition*Sets †	0.011	1.409	0.008	0.556	0.519
Error (Condition*Sets)†	0.503	36.639	0.014		

Note. † Greenhouse-Geisser estimate for sphericity correction.

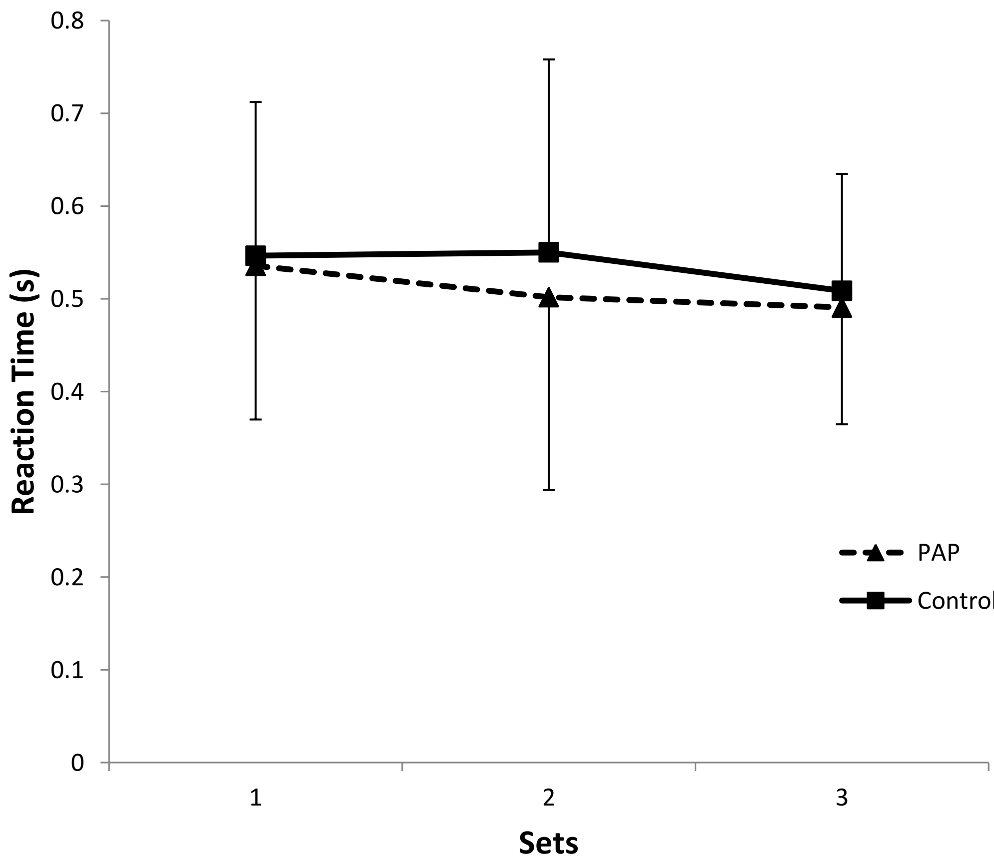

Figure 3. Reaction time across three sprint sets. Means and standard deviations of reaction time in seconds.

Table 7

Two-Way Repeated Measures ANOVA Summary Table of Reaction Time (Condition x Reps)

	SS	df	MS	F	*p*-value
Condition	0.036	1	0.036	1.828	0.188
Error (Condition)	0.508	26	0.020		
Reps †	0.044	1.398	0.031	1.155	0.309
Error (Reps) †	0.989	36.335	0.027		
Condition*Reps †	0.043	1.325	0.033	1.272	0.280
Error (Condition*Reps)†	0.885	34.455	0.026		

Note. † Greenhouse-Geisser estimate for sphericity correction.

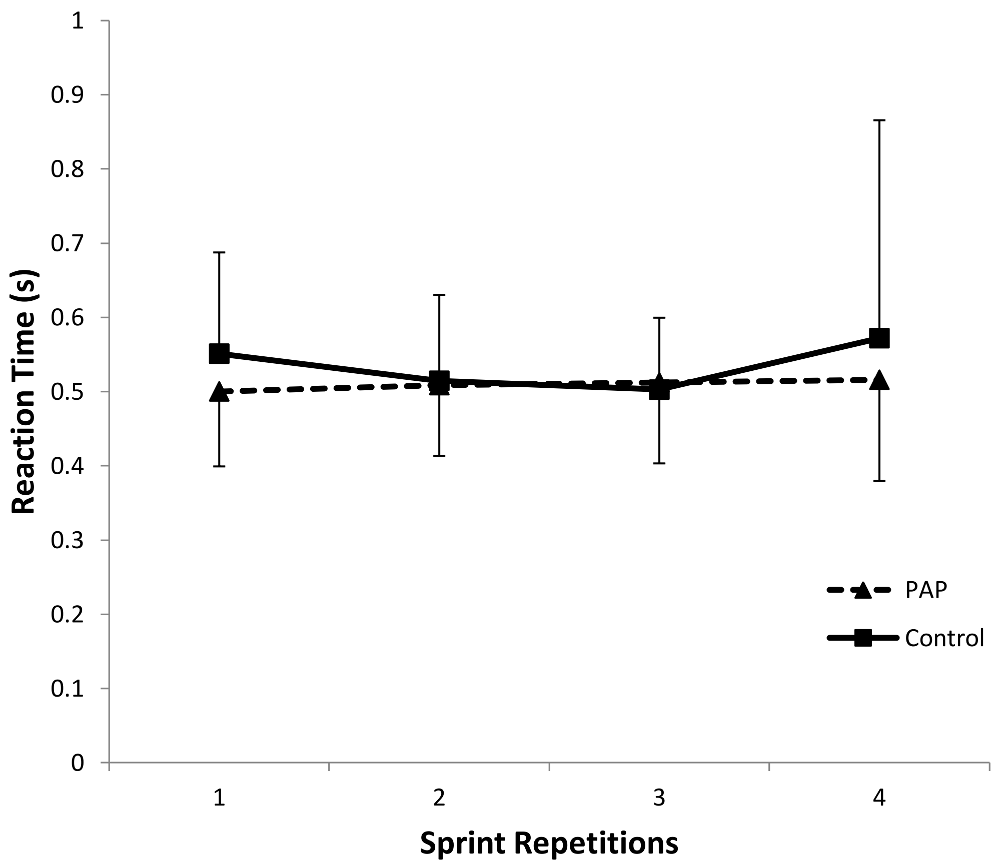

Figure 4. Reaction time across four sprint repetitions. Means and standard deviations of reaction time in seconds.

Chapter 5

DISCUSSION

The purpose of this study was to investigate if PAP can be elicited multiple times within the same session. Prior studies have found that single preparatory PAP can have a performance enhancing effect on one maximum effort sprint or jump (Kilduff et al., 2007; Linder et al., 2010; Yetter & Moir, 2008). There have been no studies to investigate whether this effect is repeatable with the use of preparatory PAP efforts prior to each performance within a single session. Moreover, the effect of repeated sprints following a single preparatory PAP has not been investigated. In this chapter the results are discussed in the subsections: (1) sprint performance, (2) reaction time, (3) limitations, and (4) implications for enhancing performance.

Sprint Performance

Previous research indicates that a preparatory PAP exercise can have a marked effect on performance in activities such as short distance sprinting and counter-movement jumps that require maximum muscular power output or an all-out effort (DeRenne, 2010; Wilson et al., 2013). The focus in previous literature was to establish parameters for a successful preparatory PAP exercise, such as the back squat. Parameters that have been manipulated include volume, intensity, and rest period. Multiple studies successfully demonstrated increasing sprint performance with a low volume, high intensity scheme for the back squat (Chatzopoulos et al., 2007; Linder et al., 2010; Matthews et al., 2004; McBride et al., 2005). This study utilized a very similar approach in regard to the parameters of the PAP activity prior to sprinting.

This study differs from previous PAP studies in regards to the use of repeated sprints rather than a single sprint effort, and the use of multiple sets of back squat and repeated sprints within one testing session. To date, no studies had examined PAP as a repeatable phenomenon, so the use of multiple sets of repeated sprints in this study is unique. The goal of structuring this study with multiple sets of repeated sprints within a single session was to establish if PAP is repeatable within a framework that mimics, to an extent, the demands of athletic competition. If athletes could successfully repeat PAP multiple times in the same event, it could create a performance advantage. Multiple sets of sprints 20 min apart were used to simulate the demand of a longer competition and test if PAP is a repeatable phenomenon.

The major finding of this study is that subjects ran significantly faster (0.92%) after completing a heavy squat (PAP) than they did after completing the control exercise of very light squats. The effect size of increased sprint performance was $d = 0.24$. This degree of improvement could be meaningful for any competitive event in which success is differentiated by tenths or hundredths of seconds, particularly at the distance of 40 m. This finding indicates that performing PAP every 20 min (and possibly longer intervals) can repeatedly improve sprint performance. This is the first study to show performance improvements are associated with using PAP over multiple sets of repeated sprints in the same session.

It is usually expected that performing multiple sets of heavy back squats and repeated sets of sprints in a single session will cause some degree of fatigue to occur. However, it was unknown if repeating heavy squats prior to second and third sets of sprints would yield a PAP effect due to the sensitivity of potentiation to fatigue and the increased volume of work leading to a fatigued state. The proposed mechanism for PAP is that phosphorylated RLC, a process regulated by Ca^{2+}, induces a favorable change in myosin which leads to increased force production (Hodgson et al., 2005; Tillin & Bishop, 2009). Muscle contractions also require the release of Ca^{2+}. The first concern is that as muscles contract repeatedly over a short period of time, the availability of Ca^{2+} may diminish which can lead to less efficient phosphorylation, resulting in a diminished or non-existent PAP. A second concern of fatigue is the potential damage to muscle fibers inherent to concentric and eccentric contractions performed at 90% 1RM intensity. Though, there does not appear to be any sign of this being an influential factor in diminishing PAP effect as both PAP and control conditions experienced the same trend of slower sprint times as sets progressed. A diminished amount of Ca^{2+} in the muscles might explain the diminished performance seen after the first set in both conditions. If Ca^{2+} concentration in the sarcoplasmic reticulum does not return to baseline levels before subjects initiate their second set of squats, and sprints, it is possible RLC phosphorylation would be less efficacious, resulting in decreased force output compared to the first set.

The PAP condition also exhibited significantly faster sprints than control for the first two sprints (across sets), while the third sprint was close to being significantly faster. It does not appear, with the distance (40 m) and rest time (55 s) used in this study, that an athlete will see improvement for more than three consecutive sprints after a single PAP. This study, however, is the first to demonstrate that the PAP effect can extend for at least two, and maybe three, high intensity efforts (i.e., 40 m sprints). Mean times for sprint reps 1, 2, and 3 respectively were 1.65%, 1.27%, and 0.74% faster with PAP than without PAP. This increase in sprint performance had an effect size of d = 0.4 for PAP rep 1 and 0.31 for PAP rep 2. This effect size represents a meaningful decrease in time taken to complete a 40 m sprint. The difference between times among athletes placed in the top three of a short distance sprint is often separated by hundredths of a second.

In the PAP condition, the first 40 m sprint was significantly faster (1.2%) than the last sprint, indicating a diminished PAP effect as repeated sprints progressed from one to four. No diminished performance was present in the control condition and by rep 4, mean time (5.75 s) was identical in both conditions. Diminished PAP effect seemed most pronounced after the second sprint in the PAP group, perhaps owing to fatigue from sprinting and heavy squats which may reduce the effectiveness of the PAP effect for subsequent sprints.

It is likely that the combination of repeated sprints and heavy squats were more taxing than repeated sprints and light squats, and may explain the diminishing of the PAP effect after the second PAP rep. Like the fatigue response after the first set, it is likely that within sets, there may be a point when Ca^{2+} concentration became inadequate to maintain a PAP effect and muscular force production subsequently decreases and performance returns to levels observed in the control condition. Additionally, Kilduff et al. (2007) found that PAP effects may wash out after 12 min in the lower body. After a 3RM back squat, their subjects performed CMJ's every 4 min, with significantly increased power at 8 and 12 min but not at 16 or 20 min. Though the fourth rep of the present study was performed at 11 min post PAP exercise, it may be that exertion over the course of repeated sprints accelerated the washing out of PAP faster than CMJs. Multiple contractions of the same muscle groups are required to perform a 40 m sprint, yet performing a CMJ requires only a single contraction per muscle group. Another difference that could have accelerated PAP wash out was that sprint reps in the present study were performed about every minute; while CMJ's in the Kilduff et al. (2007) study were performed every 4 min.

Factors such as phosphocreatine depletion during repeated sprints may explain why sprint reps subsequent to PAP showed a greater rate of fatigue than control. Heavy squats require more work and thus more energy expended by the muscles compared to light (control condition) squats. The 55 s rest between repeated sprints may not have been enough time for muscles to fully restore PCr levels when heavy squats preceded sprinting. Muscular force production could be attenuated by the lack of adequate PCr and/or Ca^{2+} as repeated sprints continue. Sprint times became slower as repeated sprints progressed in the PAP condition, which could be a result of decreased muscular force production. However, relative to control times, PAP sprints were never slower than control sprints. The slower times in successive reps in the PAP condition were likely due to the washing out of the PAP effect. PAP wash out may be influenced by exertion and duration of time post-PAP activity. After a certain period of time, the beneficial conformation of myosin may revert to its resting state. Exertion could influence PAP wash out by using up PCr and Ca^{2+} or requiring repeated contractions, causing the sarcomere to lengthen and shorten numerous times which may accelerate myosin's return to its normal conformation. This combination of factors attenuated the potentiation effect, removing the performance benefit of PAP. Heavy back squats did not have a negative influence on performance, an effect that was reported by Chiu et al. (2003).

Other studies have also found that sprint performance increases after PAP exercises (usually heavy squats). McBride et al. (2005) found that DIII football players improved their sprint time (0.87% in a single 40 m) after heavy squats. Linder et al. (2010) also found that mean sprint times improved by 1.12% in a 100 m sprint post-PAP exercise, versus 100 m sprint pre-PAP exercise. Matthews et al. (2004) found improvement as great as 3.3% for rugby players sprinting 20 m after PAP. These studies report sprint improvements following PAP that are closely in line with the 1% improvement seen here. The somewhat greater increase in performance found by Mathews et al. (2004) is perhaps explained by the high level athletic ability and training status of professional rugby players; as Wilson et al. (2013) noted, athletes with greater strength training experience may see greater improvements from PAP.

This study had the overall result of faster sprint time for the PAP condition, which agrees with the results found by previous studies using a similar design. Despite subjects having already completed a first set of four reps of back squats at 90% 1RM and four reps of 40 m sprints, the average times of all repeated sprints was shorter in the PAP condition. This finding seems to indicate that subjects' muscle fibers were not fatigued enough after a set of activity to counteract a subsequent PAP. In conclusion, repeated PAP can be effective at enhancing performance over the course of a session given enough time for recovery between sets.

Reaction Time

The effect of PAP on RT does not seem to have been investigated previously. RT is crucial to athletic performance any time there is a stimulus to process indicating the beginning of an action (jump, sprint, etc.). For example, enhancing sprint performance by shortening RT to initiate movement would be of great interest to a football player (e.g., a wide receiver who must wait for a signal to begin play) or a track sprinter reacting to the gun. However, in the current study PAP did not improve RT.

Reaction time as measured in this study, was primarily the response time for subjects to react to an audible stimulus. There has been no research to suggest PAP has any effect on the processing of stimuli by the nervous system. It is possible that a PAP exercise targeting the hip flexors, the primary muscle group responsible for driving the leg up and out of a sprinting start, might have an effect on the movement time component of RT (i.e., more forceful or faster knee drives). However, the back squat which was chosen for this study does not target the hip flexors. While on average, the RT was faster for the PAP group, the large variability of the data within and between subjects, and lack of statistical significance, makes it difficult to make any additional conclusions other than RT did not contribute to the difference in sprint times seen in this study.

Limitations

The results of this study cannot be generalized to those far outside the population examined in this study. PAP has been shown to be most effective in athletic, strength-trained populations, similar to the subjects in this study. These subjects had adequate experience performing the back squat at high intensities and were less likely than untrained subjects to experience rapid fatigue from the PAP exercise used in this study. Athletes of greater abilities (more training experience, higher percentage of fast twitch muscle fibers, better sprinting mechanics) might have the potential to benefit more from this type of protocol. Untrained, inexperienced subjects might not benefit or might even perform significantly worse after utilizing such a PAP in an attempt to enhance performance.

This study also used a very precise rest period in relation to the volume of work. The performance enhancing effect seen in this study might be altered by simply changing the number of repeated sprints per set or the time between sets and PAP exercises. The combination of fatigue and possible PAP washout effect discussed earlier appears to influence the degree of potentiation and thus performance enhancement. The rest period between PAP exercise and sprints would be expected to yield weaker results if altered too severely in either direction. This situation would be due to PAP wash out if the rest period is too long and no chance for recovery if the rest period is too short (Kilduff et al., 2007). Longer rest periods between sprints would have allowed more time for recovery but extended the amount of time between PAP and sprinting, while shorter rest periods would have placed more strain on the muscles and phosphocreatine system leading to higher fatigue. The final rest period variable was the time after sprinting (i.e., between sets) to beginning of the next PAP exercise. While there would be no drawback to increasing the time of this rest period, sets were intentionally made 20 min apart because that is generally the amount of time between halves in many field sports. Additionally, many track athletes might have a 20 min minimum period of rest between multiple events or heats. Shortening this rest period would likely increase fatigue effects on subsequent sets.

The volume of work performed in this study was also highly specific. Subjects performed a total of 12 reps of 40 m sprints and 12 back squats at 90% 1RM. Performing more reps at the same intensities would again increase the amount of fatigue expected, likely blunting or negating the PAP effect. Performing sprints or squat at higher intensities (e.g., 95% 1RM or 100 m) may also increase the expected fatigue due to the increased demand placed on the muscles to perform at more intense workloads.

Implications for Enhancing Performance

Athletes and coaches are always looking for new methods to maximize athletic performance and be successful. Previous studies clearly show that athletes experienced in strength training stand to benefit from PAP in single effort power events such as countermovement jumps and short distance sprints (McBride et al., 2005; Kilduff et al., 2007). However, there are virtually no instances in sport in which an athlete performs one single rep of a given activity and subsequently concludes participation in the competition. Even single event track athletes must make multiple attempts, in multiple heats or qualifying trials over the course of a meet. At the high school and collegiate levels, a short distance sprinter may run multiple individual events in addition to relays. Field athletes, such as jumpers, commonly compete in some combination of the triple, long and high jumps and therefore must make multiple attempts over the course of an entire meet that may last several hours.

The results of this study indicate that repeating a second and third set of PAP exercises can improve sprint times after each PAP activity separated by 20 min. Overall there was close to a 1% improvement, which could make the difference for athletes to finish within the top three and qualify for regional or national events. When looking at repeated sprints within sets, a significant performance boost was found for the first and second reps, with the third rep coming very close to being significantly faster in the PAP condition. This finding indicates that performing PAP every 20 min can improve speed for at least two subsequent maximum effort sprints. This outcome is encouraging for coaches and athletes looking to increase their performance over the course of an entire competition. There is no shortage of potential applications for such a performance aid.

Other studies using similar protocols have found that CMJ performance (peak power output) increases following a PAP exercise (Gourgoulis et al., 2003; Kilduff et al., 2007). If jumping performance can be enhanced over time, as sprint performance was found in this study, this finding may be applicable to sport specific contexts where a discrete, single, maximum effort movement is repeated, such as pitching a baseball. Baseball pitchers generate the foundation of their pitch velocity from the power generated in the lower body and have somewhat predictable down time between innings. However, pitching is not a purely sagittal plane lower body power output movement like sprinting or a CMJ and further study is needed.

Track events schedules are prepared in advance of the meet so each athlete will have a fairly accurate idea of when their events will take place and how much time they will have to prepare for a potential PAP exercise prior to competing. Athletes and coaches should begin experimenting with repeating PAP as a tool for acutely enhancing performance. However, it must be practiced before it can be trusted in any given application. There should be strong consensus on what the ideal parameters of PAP are before applying PAP in competition.

It is relatively easy in a controlled study environment with preset schedules to determine when athletes will be best suited to perform a PAP exercise. It is also much easier in a controlled study to access the appropriate facilities and equipment. In reality, facilities and access to training equipment can vary greatly at different competition locations. For PAP to become a widespread method to enhance training, or event performance, coaches and athletes must know they have the means to utilize PAP. Logistics may present a great challenge to applications of this nature. Even if free weights and squat rack equipment were available, this equipment placed in a convenient location to the field of play may be difficult. For this reason, weighted countermovement jumps or other activities might be the most promising form of PAP exercise. An appropriate weighted implement (vest, sandbag) could be transported fairly easily and potentially mimic the demand placed on the musculature during a 90% 1RM back squat. Studying more practical PAP exercises and ways to induce the proper load without Olympic lifting equipment could be a next step in investigating how PAP can benefit athletes.

Summary

This study found that power athletes (intermediate or advanced in strength training skill) stand to benefit from the repeated use of PAP exercise prior to bouts of maximal effort activity in which muscular power output is a major determinant of success. Sprint times after PAP were faster across all three sets and the effect was evident for the first two to three sprint reps within each sprint set. While there appeared to be a fatigue response or possible washout effect that diminished the PAP effect within sets as sprints progressed, PAP trials never yielded poorer performances than control trials. In other words, despite the PAP effect washing out, repeated PAP sets were effective in increasing performance for the first two reps and did not negatively affect performance in any sprint. These findings indicate athletes would benefit from repeated use of PAP in a single game or event so that they can maintain the acute performance boost that other studies have shown with single efforts. There was no indication that RT was affected by PAP. Within the context of this present study, RT probably does not contribute to the beneficial PAP effect on repeated sprint sets.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study examined the effect of heavy squats before three successive sets of repeated sprints performed every 20 min. Collegiate DIII athletes (n = 29) completed 1 RM testing in the back squat and two sprinting sessions consisting of three sets of four reps of 40 m sprints with a rest time of 55 s between sprints. Eight min prior to each repeated sprint set subjects completed four reps of the back squat at either 20% 1RM (control) or 90% 1RM (PAP) depending on the condition they were assigned after counterbalancing the sessions. Reaction time was measured by an audible signal cueing the beginning of each sprint and the time taken for subjects to initiate movement off the foot pad. Sprint times and RT were measured with electronic timing gate equipment.

Average set sprint and reaction times were analyzed by 2x3 repeated measures ANOVAs to compare both PAP and control conditions across the three sets. A main effect of condition and sets was found, indicating that overall PAP sprints were faster than control sprints, though set 1 was faster than sets 2 and 3. Average rep time across sets for sprint and reaction times were analyzed by 2x4 repeated measures ANOVAs to compare PAP and control conditions by sprint repetition. An interaction of reps and condition found that PAP sprints were faster than control sprints for the first two reps, and almost for the third. The results found in this study indicate that PAP can be effective at increasing performance over the course of a session lasting one hour. Athletes could use PAP to enhance performance on at least the first two subsequent efforts if performed within one min of each other. There were no significant results found with RT.

Conclusions

The major conclusion of this study is that performing PAP exercise multiple times over the course of a prolonged event may lead to increased sprinting performance for athletes compared to competitors not utilizing PAP. A second conclusion is that performance in repeated sprinting was increased after PAP exercise for at least two sprint reps over the course of three sets. There was no evidence to suggest change in RT influenced sprint times or that RT benefitted from PAP.

Recommendations

Future research should investigate the parameters that may make PAP practical and reliable for most, if not all, competitive situations when access to free weights may not be possible. The examination of new PAP exercises with more portable resistance equipment could be considered. Also investigating the effect on actual competitive tasks, such as long jump, 100 m sprint, and baseball pitching could be beneficial. Coaches and athletes are ultimately concerned with increasing odds of success in competition, so it would be practical to utilize competitive tasks as the outcome measure in future studies. These studies should also mimic the conditions of a particular competitive event as closely as possible. PAP exercise had no effect on RT but using a more sprint- start appropriate exercise, rather than the back squat, should be investigated to see if RT responds to PAP.

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APPENDICES

Appendix A

Informed Consent

Repeated Post-Activation Potentiation (PAP) Effect on Sprint Performance

Purpose of Study

We are conducting a study on the effects of back squats on running speed and movement time in sets of repeated sprints. We want to see if running speed and movement time during repeated sprints can be increased after performing a set of back squats at a given intensity and if this effect recurs after repeated applications.

Benefits of the Study

You will not receive direct benefits from participation but the results gained from this study have the potential to give coaches and athletes guidelines on optimal strategies to enhance explosive performance during athletic competition.

What you will be asked to do

There will be three sessions. You will be asked to consume no alcohol or caffeine 24 hours before reporting for testing. You will also be asked not to participate in high intensity strength training, sprinting or cardio within 48 hours of the testing sessions. To obtain accurate results it will be necessary for you to exert maximum effort in all testing. The first session is pre-testing and informational. 1RM testing in the back squat will be conducted during this session. In the second session you will perform a 10 minute warm-up and rest for 3 minutes, and then you will perform four reps of a pre-exercise back squat at intensity based on your 1RM. You will then rest for 8 minutes and perform a set of 4 40 meter sprints with a rest time of 55 seconds. After the last sprint you will rest for 9 minutes. You will repeat the squats and sprints 2 more times. The third session will be identical to the second session with the exception of the intensity of the back squat load. Rest time between sessions is a minimum of 48 hours and maximum of 10 days.

Time requirements for session one will be between 20-45 minutes. Time requirements for sessions two and three will be 75 minutes. Total time requirements for the study will range from 170 – 195 minutes.

Risks

The risks for this study are minimal. The pre-test involves a standard 1RM testing protocol for the back squat. It involves 12 total sprints and 12 total squats per testing session. The risks of physical injury are equivalent to the risks you face on a routine basis while training for your sport. Most common risks of injury during sprinting are muscle pulls; though other injuries are possible. These risks will be minimized by having you perform a dynamic warm-up prior to squat and sprint testing. We will also ensure that there are no pre-existing physical concerns that could amplify any injury potential before you participate.

Appendix A (continued)

Compensation for Injury
If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost for such care will be charged to you. You will be responsible to pay all costs not covered by your insurance. Ithaca College will not pay for an care, lost wages, or provide other financial compensation.

If you would like more information about the study
Please contact the principal investigator, Tristan McLaren. He can be reached at 631-745-6242 or tmclare1@ithaca.edu. Dr. Sforzo can be reached via email at sforzo@ithaca.edu.

Withdrawal from Study
I understand that I may withdraw from this study at any time without penalty. I may turn in a blank survey and I may skip the questions on the survey.

How Data will be Maintained in Confidence
Participation and data collected for this study will be kept confidential. You will receive a numeric code that will be utilized for identification purposes during all data collection tasks. All data collected will be entered directly into the principal investigators password locked computer which only he will have access to. Data files generated by the timing gate software will be coded and transmitted to this computer. Informed consent forms will be kept in the principal investigators home filing cabinet. A master file will contain the subject names and code numbers. Only the principal investigator will have access to these files. All data will be kept for at least 5 years.

I have read the above and understand its contents. I agree to participate in this study. I acknowledge that I am 18 years of age or older.

Print Name:______________________

Signature:________________________ Date:_______

Appendix B

Warm-Up Protocol

Bike Warm-up

3 Minutes @ 70 RPM @ 10 Resistance

Soft Tissue

Quad – 30 seconds/side

ITB – 30 seconds/side

Adductors – 30 seconds/side

Calves – 30 seconds/side

Dynamic Warm-up

Side Shuffle with Overhead Arm Swing – 10 M

Power Skip – 10 M

Back Pedal – 10 M

Carioca – 10 M

Frankenstein – 10 M

Knee to Chest Lunge Walk – 10 M

Squat to Stand – x6

Appendix C

Raw Data

Subject	Condition	ST 1x1	ST 1x2	ST 1x3	ST 1x4	RT 1x1	RT 1x2	RT 1x3	RT 1x4
1	C	5.872	5.792	5.800	6.011	0.968	0.614	1.232	0.915
	E	5.637	5.708	5.713	5.801	0.574	0.580	0.561	0.585
2	C	5.729	5.811	5.816	5.801	0.462	0.859	0.887	1.068
	E	5.688	5.765	5.820	5.774	0.928	1.268	0.711	1.426
3	C	5.300	5.234	5.212	5.228	0.630	0.587	0.663	0.642
	E	5.102	5.287	5.182	5.230	0.729	0.579	0.750	1.006
4	C	5.480	5.594	5.622	5.599	0.616	0.452	0.655	0.453
	E	5.335	5.440	5.502	5.680	0.461	0.623	0.543	0.445
5	C	-	-	-	-	-	-	-	-
	E	6.054	5.927	5.972	5.986	0.422	0.565	0.493	0.536
6	C	5.705	5.792	5.711	5.877	0.479	0.444	0.425	0.386
	E	5.748	5.728	5.917	5.760	0.374	0.417	0.372	0.440
7	C	5.567	5.517	5.683	5.662	0.468	0.500	0.468	0.497
	E	5.402	5.346	5.406	5.601	0.637	0.683	0.725	0.596
8	C	5.563	5.441	5.558	5.378	0.410	0.567	0.477	0.543
	E	5.460	5.622	5.613	5.556	0.543	0.405	0.374	0.430
9	C	5.777	5.540	5.659	5.571	0.411	0.514	0.395	0.391
	E	5.592	5.526	5.596	5.646	0.436	0.543	0.434	0.375
10	C	5.364	5.356	5.446	5.526	0.607	0.567	0.543	0.443
	E	5.493	5.426	5.477	5.517	0.412	0.498	0.470	0.440
11	C	5.940	6.071	6.122	6.109	0.424	0.458	0.399	0.354
	E	6.229	6.247	6.226	6.154	0.458	0.346	0.388	0.360
12	C	5.786	5.812	5.884	6.033	0.502	0.545	0.572	0.425
	E	6.008	6.184	6.108	6.294	0.384	0.369	0.521	0.480
13	C	5.650	5.655	5.745	5.747	0.406	0.438	0.450	0.428
	E	5.649	5.813	5.762	5.683	0.532	0.413	0.490	0.589
14	C	5.733	5.697	5.746	5.660	0.252	0.590	0.436	0.505
	E	5.512	5.512	5.439	5.842	0.481	0.374	0.468	0.393
15	C	5.856	5.827	5.713	5.752	0.342	0.323	0.444	0.466
	E	5.679	5.600	5.711	5.720	0.559	0.490	0.379	0.368
16	C	5.836	5.721	5.899	5.822	1.188	0.580	0.499	0.604
	E	5.625	5.788	5.694	5.690	1.756	0.666	0.553	0.626
17	C	5.426	5.561	5.540	5.546	0.651	0.532	0.625	0.632
	E	-	-	-	-	-	-	-	-
18	C	5.864	6.016	5.753	5.745	0.519	0.521	0.581	0.519
	E	5.541	5.516	5.528	5.564	0.639	0.186	0.639	0.592
19	C	5.697	5.777	5.757	6.026	0.568	0.500	0.546	0.409
	E	6.065	6.233	6.017	6.121	0.515	0.436	0.441	0.354
20	C	5.933	5.917	5.899	6.035	0.424	0.390	0.364	0.360
	E	5.443	5.541	5.534	5.725	0.520	0.431	0.528	0.402

Note. ST = Sprint Time, RT = Reaction Time, C = Control, E = Experimental/PAP, 1x2 = First set, second sprint

Appendix C (continued)

Subject	Condition	ST 1x1	ST 1x2	ST 1x3	ST 1x4	RT 1x1	RT 1x2	RT 1x3	RT 1x4
21	C	5.459	5.450	5.698	5.442	0.401	0.420	0.412	0.411
	E	5.286	5.387	5.275	5.490	0.458	0.409	0.455	0.386
22	C	5.499	5.618	5.515	5.515	0.508	0.533	0.484	0.521
	E	5.625	5.449	5.733	5.606	0.403	0.497	0.368	0.384
23	C	5.797	5.801	5.832	5.876	0.456	0.467	0.459	0.549
	E	5.768	5.834	5.769	5.684	0.670	0.509	0.505	0.425
24	C	5.593	5.651	5.467	5.583	0.614	0.600	0.625	0.592
	E	5.494	5.665	5.530	5.544	0.451	0.462	0.522	0.490
25	C	5.818	5.830	5.837	5.747	0.477	0.511	0.535	0.513
	E	5.680	5.666	5.761	5.683	0.554	0.508	0.484	0.511
26	C	5.892	5.912	5.846	5.774	0.502	0.661	0.761	0.670
	E	5.713	5.835	5.884	5.851	0.662	0.530	0.556	0.521
27	C	5.424	5.501	5.588	5.533	0.612	0.418	0.454	0.438
	E	5.431	5.490	5.598	5.549	0.480	0.690	0.489	0.428
28	C	5.840	5.897	5.904	5.950	0.485	0.506	1.036	0.513
	E	5.706	5.799	5.895	5.775	1.405	0.568	0.418	0.759
29	C	5.733	5.793	5.813	5.826	0.450	0.496	0.587	0.611
	E	5.536	5.635	5.678	5.759	0.748	0.607	0.588	0.623

Appendix C (continued)

Subject	Condition	ST 2x1	ST 2x2	ST 2x3	ST 2x4	RT 2x1	RT 2x2	RT 2x3	RT 2x4
1	C	6.054	6.032	5.969	6.007	0.592	0.989	0.558	0.714
	E	5.757	5.855	5.989	5.973	0.574	0.819	0.445	0.719
2	C	5.790	5.749	5.765	5.741	0.669	0.482	0.514	0.646
	E	5.718	5.692	5.573	5.755	0.703	0.612	0.500	0.833
3	C	5.366	5.392	5.258	5.268	0.593	0.640	0.694	0.877
	E	5.348	5.153	5.250	5.309	0.678	0.728	0.664	0.857
4	C	5.576	5.647	5.704	5.732	0.441	0.462	0.429	0.433
	E	5.487	5.668	5.664	5.620	0.478	0.481	0.507	0.582
5	C								
	E	6.052	6.021	5.985	5.975	0.545	0.504	0.484	0.526
6	C	5.903	5.887	5.846	5.885	0.418	0.454	0.406	0.404
	E	5.832	5.967	6.067	6.028	0.440	0.381	0.342	0.484
7	C	5.736	5.920	5.755	5.809	0.495	0.445	0.441	0.471
	E	5.413	5.509	5.499	5.544	0.616	0.537	0.569	0.459
8	C	5.511	5.515	5.539	5.404	0.520	0.491	0.392	0.425
	E	5.414	5.392	5.486	5.574	0.562	0.550	0.459	0.371
9	C	5.676	5.620	5.550	5.668	0.354	0.344	0.362	0.273
	E	5.531	5.550	5.596	5.539	0.487	0.397	0.374	0.360
10	C	5.439	5.418	5.378	5.491	0.508	0.534	0.590	0.538
	E	5.620	5.649	5.660	5.601	0.396	0.470	0.477	0.441
11	C	6.132	6.124	6.196	6.249	0.370	0.373	0.375	0.372
	E	6.213	6.059	6.079	6.173	0.338	0.416	0.418	0.356
12	C	6.193	6.006	6.273	6.262	0.368	0.447	0.370	0.402
	E	5.754	6.312	6.114	6.398	0.539	0.510	0.427	0.404
13	C	5.778	5.733	6.095	5.809	0.467	0.403	0.292	0.434
	E	5.964	5.611	5.655	5.755	0.442	0.538	0.486	0.506
14	C	5.813	5.686	5.867	5.828	0.408	0.553	0.433	0.486
	E	5.723	5.712	5.806	5.786	0.383	0.382	0.341	0.470
15	C	5.895	5.860	5.815	5.754	0.526	0.531	0.545	0.539
	E	5.738	5.697	5.690	5.648	0.450	0.529	0.528	0.582
16	C	6.171	5.917	5.905	5.934	0.555	0.632	0.563	0.824
	E	5.783	5.770	5.850	5.838	0.648	0.883	0.705	0.612
17	C	5.840	5.826	5.800	5.648	0.629	0.578	0.571	0.587
	E								
18	C	5.993	5.844	5.645	5.706	0.456	0.507	0.576	0.621
	E	5.770	5.574	5.849	5.508	0.568	0.685	0.506	0.667
19	C	6.004	6.093	6.132	5.745	0.594	0.372	0.382	0.495
	E	6.328	6.215	5.937	6.092	0.531	0.443	0.471	0.393
20	C	5.959	5.966	5.997	5.917	0.378	0.492	0.422	0.445
	E	5.677	5.716	5.822	5.897	0.459	0.421	0.439	4.620

Appendix C (continued)

Subject	Condition	ST 2x1	ST 2x2	ST 2x3	ST 2x4	RT 2x1	RT 2x2	RT 2x3	RT 2x4
21	C	5.307	5.595	5.627	5.626	0.424	0.480	0.356	0.376
	E	5.241	5.592	5.413	5.365	0.416	0.435	0.414	0.375
22	C	5.547	5.627	5.630	5.591	0.426	0.494	0.511	0.495
	E	5.497	5.723	5.542	5.564	0.571	0.389	0.506	0.524
23	C	5.960	5.998	6.069	5.792	0.482	0.500	0.507	0.501
	E	5.729	5.675	5.740	5.763	0.559	0.599	0.478	0.455
24	C	5.635	5.497	5.621	5.546	0.571	0.573	0.564	0.500
	E	5.598	5.676	5.585	5.619	0.481	0.476	0.455	0.548
25	C	5.885	5.900	5.969	5.871	0.517	0.523	0.417	0.526
	E	5.745	5.894	5.846	5.798	0.465	0.511	0.569	0.510
26	C	5.780	5.753	5.731	5.664	0.533	0.593	0.540	1.169
	E	5.616	5.751	5.775	5.842	0.650	0.533	0.533	0.555
27	C	5.562	5.464	5.524	5.540	0.446	0.411	0.417	0.467
	E	5.527	5.502	5.565	5.562	0.483	0.515	0.465	0.465
28	C	6.308	6.318	6.315	6.053	0.519	0.469	0.446	0.502
	E	6.276	6.271	6.236	6.308	0.545	0.460	0.635	0.494
29	C	5.725	5.857	5.803	5.797	0.576	0.829	0.572	0.562
	E	5.672	5.867	5.805	5.799	0.539	0.487	0.467	0.424

Appendix C (continued)

Subject	Condition	ST 3x1	ST 3x2	ST 3x3	ST 3x4	RT 3x1	RT 3x2	RT 3x3	RT 3x4
1	C	6.004	5.986	6.030	5.911	0.635	0.63	0.607	0.804
	E	5.926	5.920	6.153	6.107	0.803	0.686	0.768	0.450
2	C	6.046	5.915	5.828	5.826	0.810	0.608	0.603	0.781
	E	5.804	5.860	5.867	5.819	0.600	0.757	1.130	1.240
3	C	5.523	5.422	5.489	5.261	0.526	0.626	0.585	0.564
	E	5.123	5.210	5.205	5.203	0.756	0.663	0.692	0.715
4	C	5.548	5.703	5.621	5.568	0.533	0.440	0.527	0.458
	E	5.500	5.679	5.743	5.678	0.583	0.518	0.559	0.485
5	C								
	E	6.065	5.949	5.930	6.008	0.491	0.567	0.516	0.592
6	C	5.749	5.836	5.784	5.639	0.404	0.391	0.508	0.455
	E	5.870	5.958	5.896	5.842	0.385	0.361	0.359	0.373
7	C	5.839	5.656	5.727	5.555	0.508	0.449	0.420	0.431
	E	5.310	5.340	5.411	5.429	0.607	0.657	0.645	0.640
8	C	5.667	5.412	5.566	5.558	0.385	0.458	0.391	0.357
	E	5.467	5.576	5.605	5.516	0.508	0.400	0.383	0.463
9	C	5.758	7.237	5.845	5.873	0.391	0.076	0.349	0.474
	E	5.584	5.601	5.606	5.616	0.315	0.302	0.299	0.275
10	C	5.437	5.471	5.428	5.363	0.518	0.535	0.603	0.390
	E	5.433	5.463	5.509	5.292	0.591	0.554	0.489	0.521
11	C	6.149	6.919	6.220	6.201	0.359	0.343	0.409	0.449
	E	6.061	6.145	6.136	6.113	0.358	0.365	0.445	0.330
12	C	6.216	6.378	6.360	6.299	0.419	0.434	0.399	0.430
	E	6.590	6.386	6.341	6.508	0.416	0.437	0.443	0.521
13	C	5.662	5.610	5.638	5.706	0.490	0.535	0.529	0.446
	E	5.761	5.791	5.776	5.404	0.551	0.548	0.455	0.642
14	C	5.823	5.856	6.112	5.844	0.403	0.485	0.242	0.461
	E	5.963	5.774	5.879	5.873	0.476	0.422	0.462	0.420
15	C	5.902	5.887	5.830	5.807	0.362	0.467	0.510	0.572
	E	5.829	5.628	5.691	5.763	0.446	0.538	0.596	0.385
16	C	6.247	6.036	5.918	5.767	0.568	0.740	0.581	0.475
	E	5.993	5.903	5.994	5.814	0.542	0.537	0.547	0.609
17	C	5.951	6.062	6.021	5.994	0.547	0.502	0.554	0.538
	E								
18	C	5.959	6.049	5.903	5.835	0.487	0.506	0.626	0.565
	E	5.893	5.917	5.911	5.627	0.603	0.465	0.506	0.561
19	C	6.292	6.346	6.261	5.803	0.460	0.553	0.491	0.528
	E	6.046	6.075	6.211	6.415	0.355	0.421	0.403	0.493
20	C	5.891	5.982	5.887	5.906	0.448	0.449	0.472	0.415
	E	5.640	5.970	5.881	5.871	0.453	0.321	0.323	0.328

Appendix C (continued)

Subject	Condition	ST 3x1	ST 3x2	ST 3x3	ST 3x4	RT 3x1	RT 3x2	RT 3x3	RT 3x4
21	C	5.430	5.414	5.619	5.542	0.414	0.411	0.354	0.336
	E	5.378	5.552	5.574	5.572	0.451	0.364	0.449	0.380
22	C	5.667	5.547	5.628	5.408	0.484	0.532	0.516	0.418
	E	5.475	5.489	5.497	5.421	0.553	0.534	0.426	0.546
23	C	6.094	5.953	6.050	6.040	0.472	0.445	0.486	0.505
	E	5.931	5.798	5.752	5.835	0.497	0.477	0.458	0.419
24	C	5.666	5.607	5.658	5.552	0.490	0.536	0.518	0.534
	E	5.628	5.640	5.708	5.697	0.430	0.505	0.459	0.423
25	C	5.811	5.875	5.782	5.850	0.588	0.487	0.501	0.502
	E	5.609	5.735	6.067	5.891	0.544	0.640	0.535	0.512
26	C	5.756	5.794	5.776	5.609	0.655	0.717	0.742	0.634
	E	5.710	5.662	5.810	5.927	0.484	0.480	0.478	0.508
27	C	5.597	5.549	5.555	5.675	0.172	0.465	0.479	0.051
	E	5.492	5.519	5.677	5.609	0.605	0.486	0.514	0.421
28	C	6.128	5.929	6.123	6.096	0.599	0.498	0.455	0.534
	E	6.198	6.289	6.290	6.237	0.471	0.470	0.474	0.618
29	C	5.775	5.849	5.748	5.883	0.564	0.513	0.548	0.509
	E	5.675	5.690	5.790	5.819	0.494	0.509	0.511	0.564