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| | **Title and Abstract (5%)**<br>Title to include: A concise indication of the research question/problem.<br>Abstract to include: A concise summary of the empirical study undertaken. |
| | **Introduction and literature review (25%)**<br>To include: outline of context (theoretical/conceptual/applied) for the question; analysis of findings of previous related research including gaps in the literature and relevant contributions; logical flow to, and clear presentation of the research problem/ question; an indication of any research expectations, (i.e., hypotheses if applicable). |
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**CARDIFF SCHOOL OF SPORT**

**DEGREE OF BACHELOR OF SCIENCE (HONOURS)**

**SPORT CONDITIONING, REHABILITATION AND MASSAGE**

**2014-5**

# The Effect of Different Conditioning Contraction Loading on Post-Activation Potentiation

**(Dissertation submitted under the SCRAM area)**

**Blake Penny**

**ST20026316**

# THE EFFECT OF DIFFERENT CONDITIONING CONTRACTIONS ON POST-ACTIVATION POTENTIATION

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## Abstract

A muscle's ability to generate force and velocity is determined by several components which are a consequence of its contractile history; however, this has been shown to be acutely yet significantly influenced following an exercise activity. A positive influence will lead the muscle to a potentiated state called Post-activation Potentiation (PAP) where the ability of the muscle to generate power is enhanced for a period of time. Although the use of a heavy resistance pre-contraction is well documented to elicit a potentiated state, little research has been completed on optimal or submaximal loading used as a medium to attain PAP in an individual. The purpose of the present study was to determine whether a light load contraction would produce a more potentiated state, cause a decrease in subsequent power performance, or provide the same effect as heavy loaded contractions on an athlete's counter movement jump (CMJ) performance over two trials. Eight male subjects, aged 19-22, from different sporting backgrounds and one repetition maximum (1RM) squat strength (mean ± standard deviation: 131Kg ± 28Kg 1) completed in a blocked randomized order a squat intervention set (SIS) on the first trial, either; three repetitions at 90% 1RM or six repetitions at 65% 1RM. The second trial day consisted of the opposite SIS to the first trial day and both trial days included a baseline CMJ measurement as well as a CMJ measurement following eight minutes rest after the SIS where peak power (PP), peak velocity (PV), average power (AP) and average velocity (AV) were recorded. No significant differences were found with any of the variables measured between the baseline and post-contraction CMJ for either SIS. However, a trend was observed with both interventions; where the light SIS generally showed a slight decrease in performance, whereas the heavy SIS displayed a general increase in performance.

# CHAPTER 1

# INTRODUCTION

## 1.0 Introduction

Post-activation potentiation (PAP) may be defined as an increase in muscle performance as a result of a conditioning contraction (CC) which may be a maximal voluntary contraction or submaximal exercise for example (Xenofondos et al,. 2010). It is thought that PAP occurs due to neural and muscular mechanisms that are not presently well understood (Xenofondos et al,. 2010). However two processes have been identified by Hodgson et al,. (2005) to explain the PAP phenomena including; an increase in calcium (Ca2) sensitivity in the myofilaments of a muscle (Metzger et al,. 1989) leading to an increase in twitch potentiation , muscle isometric force, decrease in time to peak contraction and an increase in muscle rate of force development (RFD) (O'Leary et al,. 1997). Capaday (1997) investigated the second proposal; reflex potentiation (H-reflex) which is an increase in muscle potentiation due to increased spinal excitability including synaptic transmission between 1a afferent fibres and alpha motor neurones. However the reflex potentiation is unclear as Hodgson et al,. (2008) found that PAP occurred in the absence of reflex potentiation although this supports the first proposal. These findings were supported in Iglesias-Soler et al,. (2011)'s study when measuring the effect of isometric CC on the improvement of explosive plantar flexion's of their participant's ankles. In contrast; previous studies support the H-reflex PAP such as Folland et al,. (2008)'s that examined different CC types which produced changes in spinal excitability and would therefore support the notion that the methodology used to produce a PAP may elicit different results.

Tillin & Bishop (2009) Argue that changes in muscle pennation may contribute to the PAP effect and therefore act as a third mechanism; however this requires further investigation. Because muscle pennation reflects the fibre orientation in relation to the tendon; it affects force transmission to tendons and bones (Tillin & Bishop, 2009). Mahlfeld et al., (2004) found a decrease in muscle pennation angle of the vastus lateralis between three and six minutes following isometric Conditioning Contractions which would equate to an increase in force transmission to the tendons; meaning that it is possible for muscle pennation angle to affect PAP. However; Tillin & Bishop (2009) argue that conditioning contractions are also likely to increase connective tissue/tendon compliance which may counter any increase in force transmission cause by the decrease in muscle pennation angle. Therefore it is unclear whether muscle pennation should be considered a mechanism of PAP.

# CHAPTER 2

# LITERATURE REVIEW

# 2.0 Literature Review

## 2.1 PAP and Mechanical Power

Robbins (2005)'s study states that it has been hypothesized that a short-term enhancement of power performance may be realised when exploiting PAP in an individual; and therefore increase overall athletic performance. Robbins (2005)'s study also implies that a chronic adaptation may be realised due to inducing PAP when training an athlete and thereby improve performance over a longer period however this is not the direction that the current study will be examining. Tillin & Bishop (2009) show that PAP may aid in increasing an athlete's ability to produce power by enhancing either one or both of the following factors; the force generation a muscle is able to achieve at a given velocity or increasing the athlete's muscle contractile velocity. This study also implied that there is little evidence that PAP can increase the maximal force that a muscle or athlete is capable of; meaning that the benefits may be realised when acting upon sub-maximal loads. This is because PAP has been shown to increase a muscle's RFD of contractions elicited at any frequency; which results in a greater force producing capability for a specific velocity or vice versa. However many studies show that in order for PAP to cause an increase in power it must supersede the fatigue cause by the CC; otherwise this will cause a decrease in subsequent performance (Robbins, 2005).

## 2.2 PAP VS Fatigue

Contractile activity is thought to cause fatigue as well as elicit a PAP effect; it is the balance of this continuum which determines whether the subsequent muscle performance becomes enhanced, unchanged or diminished (Robbins, 2005). The balance is dependent on the recovery time an individual undergoes as to whether a PAP effect is still present at the time when fatigue is dissipated (Robbins, 2005). Tillin & Bishop (2009) argue that fatigue is most dominant in the early stages following the CC which leads to a decrease in performance; however fatigue seems to diminish at a faster rate than PAP. This means that a potentiation in performance may be realised during the later stages of recovery. Kilduff et al,. (2008) illustrates this when a decrease in performance was observed 15 seconds after the CC, which is attributed to the muscle fatigue outweighing the excitability of the muscle; as heavy resistance training has been shown to acutely influence the neuromuscular process responsible for PAP as well as the fatigue mechanism of a muscle. Concluding that muscle performance following a heavy CC is a result of the balance between fatigue and excitability.

Conversely, some studies such as Gourgoulis et al,. (2003) and French et al,. (2003) resulted in an increase of lower body power performance immediately after the CC. The contrasting results of the literature suggest that the PAP-fatigue relationship is dependent on the contractile history or CC that the muscle undergoes. Several variables are thought to affect this relationship and as a result; the effect that the CC may have on subsequent performance. These variables include; Volume of CC as expressed in sets and repetitions, rest interval between the CC and following performance, intensity of CC as expressed in load (i.e. 60% 1RM) and CC type (dynamic, isometric etc…) (Tillin & Bishop, 2009).

**2.3 Conditioning Contraction Volume**

Kovačić et al., (2010)'s study confirm that PAP occurs when an exercise consisting of fast or explosive qualities is preceded by maximal loading of an exercise structurally identical to that of the main activity. The participants of this study consisted of nine elite, senior, healthy tennis players; of which all were experienced in strength training.

Lima et al,. (2011) studied the effect of drop jumps as a pre-activation exercise by conducting an intervention study measuring counter movement jump height (CMJ) and 50 metre sprint time (50m). The participants were of similar age to Kovačić et al., (2010)'s consisting of ten males that represented a Brazilian city in track and field events respectively. The results of Lima et al,. (2011)'s study concluded that the drop jump potentiation protocol (two sets of five repetitions) was effective in causing a PAP effect and enhancing performance in both CMJ and 50m. Although this study also concluded that timing after the potentiating exercise proves a factor for inducing maximal PAP effect with the 50m time decreasing after ten minutes and CMJ performance increasing after 15 minutes following the CC. This study opposes Kovačić et al., (2010)'s view that only maximal loading is able to induce PAP by showing that submaximal loads may be used to evoke a PAP effect on power performance.

Kilduff et al,. (2008)'s participants noticed maximal PAP effects on increasing CMJ performance following three sets of three squat repetitions of 87% one repetition maximum (1RM). The participants in this study consisted of twenty male rugby players playing at professional level; meaning that this study may have a high level of reliability due to the large sample group.

Masiulis et al,. (2007)'s sample group included eight healthy, untrained but physically active males aged between 23-27 years. The main finding of this study was that PAP effect can be observed following maximal and submaximal CC providing the mechanical work done is equal. Furthermore this study concluded that the more intensively exercise is performed, the more PAP offsets fatigue immediately after the CC whereas PAP becomes more evident following a recovery period after submaximal exercise. This study is unique in that the exercise measured is an isometric knee extension (isolated movement) whereas the majority of research has been conducted measuring compound movements such as the squat or CMJ. Therefore the application of this study to the sporting environment may be limited due to the nature of the movements measured and the small, sedentary sample group.

## 2.4 Muscle Strength

It is thought that some adaptations to strength training may enhance PAP prompted by a conditioning activity such as the ability to activate the high threshold 'fast' motor units; of which exhibit the muscle fibres that show the greatest PAP (Sale, 2002). Sale (2002) argues that secondary adaptation likely to increase PAP within strength trained athletes may be an increase in 'fast' myosin light chains in the muscle fibres which could increase the capacity for myosin light chain phosphorylation; the primary mechanism for PAP. The majority of research suggests a positive correlation between strength and PAP which would imply that stronger athletes may be better equipped to benefit from PAP that weaker athletes (Young et al,. 1998 & Duthie et al,. 2002). Finally, a strong positive linear relationship has been found between subject's strength and type II muscle fibres meaning that these subjects may consequently have a larger number of high order motor units reserved which could be activated due to a CC (Tillin & Bishop, 2009).

## 2.5 Fibre Type Distribution

Hamada et al,. (2000) argue that the most important quality of a muscle with regard to PAP is the fibre type distribution. In this study, fibre type was directly measured in the four (of twenty) subjects that had the highest time to peak torque (HPAP) and the four with the lowest (LPAP) in the knee extensor muscles via percutaneous needle biopsy of the vastus lateralis. The study concluded that subjects with HPAP had a significantly greater percentage of type II muscle fibres that the LPAP subjects. Hamada et al,. (2000) also state that two features of PAP (other than time to peak torque) include; shortening of twitch contraction time and amplification of muscle action potential also correlate with muscle fibre type distribution.

### 2.6 Training Level

Chiu et al,. (2003)'s study agrees with the limitation of Masiulis et al,. (2007)'s study by suggesting that subjects training at higher levels of resistance would adapt to develop fatigue resistance due to intensive training regimes and more likely to realise PAP. This study found a decrease in CMJ performance for the untrained sample group contrary to the increase in CMJ performance realised by the trained sample groups following the CC; suggesting that Masiulis et al,. (2007)'s may only be applied to untrained individuals

### 2.7 CC Type (Dynamic etc…)

Tillin & Bishop (2009) state that although any type of contraction (dynamic, isometric, isokinetic ect…) may cause an activation of the mechanisms responsible for PAP, the amount of potentiation observed is likely dependent on which type of contraction is selected. For example; Pasquet et al,. (2000) found that the ankle dorsiflexors had a higher degree of potentiation following a series of 30 eccentric maximal voluntary contractions (MVC's) as opposed to concentric contractions, although both contractions did cause some degree of potentiation. Baudry & Duchateau (2004)'s study show that PAP is not related to the type of CC and therefore suggest that the findings by Pasquet et al,. (2000) may be due to the competing effects of fatigue on potentiation; as opposed to the type of contraction causing a more potentiated effect. Fatigue was not a factor in Baudry & Duchateau (2000)'s study and this may be because the contractions used to elicit a potentiated effect were not of a high enough intensity to accumulate fatigue. This may have resulted in a quicker dissipation of the PAP effect observed at a mean time of 2.17 minutes within their sample group. On the other hand, Kilduff et al,. (2008)'s study utilised higher intensity conditioning contractions and found the optimal recovery time to maximise PAP following heavy resistance was eight minutes. Kilduff et al,. (2008)'s study subsequently shows that exercises incorporating both eccentric and concentric muscle contraction (such as the squat) may provide a PAP effect in line with that of Lima et al,. (2011) and Kovačić et al., (2010)'s studies. Furthermore this study is similar to that of Kovačić et al., (2010)'s in that the squat exercise meets the 'structurally identical' criteria suggested by Kovačić et al., (2010).

Kovačić et al., (2010)'s study concluded that the implementation of maximum isometric contraction as a pre-activation exercise enables possible performance enhancement of speed and power in an athlete. Although this study examined the effects of PAP following a maximal isometric CC there is no consideration of other CC's such as concentric, eccentric or submaximal loading.

Sale (2002) concluded that there is some evidence suggesting that PAP can improve high velocity strength and power performance; however the gap in the research is found when trying to determine the optimal strategy to induce PAP. Therefore this study will aim to provide direction of optimal loading of the CC in order to induce PAP to ultimately aid athletes and coaches in preparation for sporting performance. The majority of research studies maximal loading of the athlete (>80% 1RM) of which is primarily focussed on isometric contraction as a pre-load to induce PAP however this is not practical for games athlete's as they may not have access to necessary equipment to meet the maximal isometric CC guidelines found in previous research. The proposed study will aim to study effects of submaximal loading which may be more practical and beneficial for the athlete when aiming to induce a PAP effect for improved performance.

# CHAPTER 3

# METHODOLOGY

# 3.0 Methodology

## 3.1 Experimental Approach to the Problem

The main aim of the present study was to compare the effects of differing back squat load that may be incorporated routinely into training practise as a PAP stimulus on subsequent explosive performance (CMJ). Eight, club level, male athletes from different sporting backgrounds performed a CMJ proceeded by a five minute rest. Following this, the athletes then performed a single set of back squats at the respective load and repetitions calculated using there 3RM load whereby the athletes would then rest for eight minutes before completing another CMJ. A counterbalanced randomised order was designed and incorporated in order to avoid potential order bias. A paired T-test was employed to compare each of the CMJ variables (PP, AP, PV, AV) between the baseline and post CC CMJ of each athlete as well as each load used. All participants in this study were tested for their counter movement jumps pre and post squat interventions; which incorporated different loading (either light or heavy load) of the proposed set. All participants were required to attend three testing sessions; starting with a three repetition maximum (3RM) test, followed by two experimental sessions.

## 3.2 Subjects

Eight male athletes participating in a variety of sports including; Rugby, Hockey, Basketball and Parkour took part in this study and all had volunteered, without pressure, to participate. Each subject was in current training which included a minimum of three resistance exercise sessions a week; training with loads varying between 50% and 95% 1RM. The criteria that deemed the participants suitable for this study was that they had a minimum of two years resistance training experience and could competently perform a back squat with adequate technique. The athletes had been asked to refrain from consuming caffeine or alcohol 24 hours before testing and also asked to not eat two hours before testing.  The subjects had been informed of the potential risks and benefits of participating in this study, provided written consent, and the procedure was approved by Cardiff Metropolitan University before any testing was completed. The written consent form example and participant information sheets example are shown in the appendix.

### 3.3 Experimental Procedure

Initially the subjects visited the laboratory to become familiar with the testing procedure and complete a 3RM back squat measurement as well as record each individuals mass. After this procedure, the subjects attended two testing sessions (one heavy and one light load). The first session was completed a minimum of 48 hours post 3RM testing to ensure all fatigue had dissipated. The following sessions were at least 24 hours apart for this same reason as well as at least 24 hours post-strenuous exercise. During each testing day the subjects were required to complete a standardised five minute warm up of light intensity cycling, after this, the participants completed various stretches of the muscle groups involved in the squat and CMJ.

The first testing day started with the standardised warm up and stretching of the relevant musculature the participant used when squatting, followed by familiarisation with the equipment used to measure CMJ and the CMJ itself. 3RM testing of the back squat was completed after this procedure; following Kilduff et al,. (2008)'s protocol which determined 3RM as the heaviest load the participant could squat with adequate technique, without aid.

The second testing day initialised with the subjects completing the standardised warm up and stretching, followed by a five minute rest before the baseline measurement of their CMJ was taken. After resting for ten minutes; the subjects would then complete either a light or heavy (as determined by percentage of 1RM) set of back squats, rest for 8 minutes, then attempt a final CMJ. This protocol was also followed on the third testing day; however the participant's back squat intervention would be the opposite i.e. if they completed a light set on the previous test day, they would complete a heavy set for the third testing day and vice versa. The squat interventions included either one set of three repetitions at 90% 1RM (heavy intervention) or one set of six repetitions at 65% 1RM (light intervention). All squat sets were completed using a squat rack, Olympic barbell and free weight plates as well as having experienced spotters present for safety. These spotters also aided in assessing squat technique i.e. squat depth criteria was such that the athlete must descend to a point at which the inguinal groove passed the patella. This was to ensure each athlete was completing their squats through full ROM, however each subject's CMJ consisted of their own self-selected depth and each testing session was separated by a period of no less than 24 hours. Verbal encouragement was provided throughout all testing procedures in order to aid the athletes to provide maximal effort, as well as enabling the subjects to consume water during each test day.

**3.4 Measurements**

*Strength Testing:* In the first familiarisation day 3RM testing of the back squat was completed using an Olympic barbell (Eleiko Sport, 2015) following Kilduff et al,. (2008)'s procedure (using approximations of the subject's 1RM) of; three warm up sets at 50% of the athlete's 1RM, four repetitions at 70% 1RM, 2 repetitions at 80% 1RM. Following this the athlete would complete three repetitions of a set load and repeat with increasing load until the participant is unable to complete all three unaided repetitions through full range of motion (ROM). A five minute rest between all 3RM attempts was allowed in order for the participant to recover energy stores. The subject's 3RM scores were then used to calculate their 1RM according to the tables provided by Beachle & Earle (2000). The back squat technique was set to that of the International Powerlifting Federation rules (International Powerlifting Federation, 2015).

*Counter Movement Jump:* Average power (APO), average velocity (AV), peak power (PPO) and peak velocity (PV) were measured using a TENDO-unit (TENDO-Units, 2015) which is a type of linear position transducer (LPT). The subjects were required to wear a standardised belt in order to attach the TENDO via the Velcro provided on the TENDO string and stand directly above the TENDO so that the string was perpendicular to the floor. Then the participants completed a CMJ with the instruction to jump as high as possible without any prior movements i.e. rising onto their toes before the initial movement. This procedure preceded the squat intervention, to provide a baseline; this was also completed eight minutes after the squat intervention in order to compare results.

The TENDO-Unit LPT calculates each variable previously mentioned utilising the displacement of the string between the initial taught static position and the final peak height reached. Garnnacho-Castano et al,. (2015)'s study was completed to determine the reliability and validity of; peak power, average power, peak velocity and average velocity calculated by a linear position transducer (in this case a TENDO). In this study, the TENDO was compared with another system (T-force dynamic measurement system) which determined the same variables and fulfils the criteria of consistency or agreement of one or more measurement systems. Garnnacho-Castano et al,. (2015) concluded that the TENDO LPT possesses high test-retest reliability and adequate concurrent validity; therefore emerging as a suitable tool to measure and asses performance.

### 3.5 Statistical Analysis

The normality of the raw data and delta values (Δ) were calculated using the Kolmogorov-Smirnov's test. A Wilcoxon Rank Test was then employed to compare pre-squat and post-squat CMJ data; for all CMJ variables previously mentioned. This was also used to compare pre CC and post CC CMJ delta values which include heavy vs light intervention. All data presented are as mean ± SD (standard deviation) unless stated otherwise, the significance value was set at <0.05 and finally, all statistical analyses of data was completed using SPSS v20.

# CHAPTER 4

# RESULTS

## 4.0 Results

Table 1 shows that, with the exception of peak velocity, all measured variables of the post CC CMJ decreased following the light loading intervention. Average power was the variable that decreased the most in the test subjects; by -63.75 watts on average, whereas average velocity decreased the least (-0.04 m/s) and a slight increase in peak velocity was observed (0.02 m/s). This table also shows that all measured variables increased following the heavy loading intervention; with peak power improving by the highest margin of 75.88 Watts and average velocity increasing by a minimal amount (0.04 m/s). Although the data show both increases and decreases in specific variables with regard to a squat intervention, this data is not significant ($p > 0.05$).

**Table 1.** Performance variables scores (mean ± SD) for CMJ. Showing both pre and post CC for light and heavy interventions. Finally showing Δ values (difference between pre and post CC).

| | Light | | | Heavy | | |
|---|---|---|---|---|---|---|
| **Variables** | **Pre-CC CMJ** | **Post-CC CMJ** | **Δ** | **Pre-CC CMJ** | **Post-CC CMJ** | **Δ** |
| **Peak Power (W)** | 2821.38 ± 580.00 | 2769.88 ± 535.09 | -51.50 ± 369.36 | 2704.38 ± 617.68 | 2780.25 ± 318.95 | 75.88 ± 497.42 |
| **Average Power (W)** | 1513.38 ± 262.41 | 1449.63 ± 165.26 | -63.75 ± 196.02 | 1453.00 ± 262.81 | 1463.63 ± 167.99 | 10.63 ± 232.92 |
| **Peak Velocity (m/s)** | 3.36 ± 0.38 | 3.37 ± 0.44 | 0.02 ± 0.28 | 3.30 ± 0.47 | 3.44 ± 0.43 | 0.13 ± 0.18 |
| **Average Velocity (m/s)** | 1.81 ± 0.10 | 1.77 ± 0.10 | -0.04 ± 0.11 | 1.76 ± 0.11 | 1.80 ± 0.15 | 0.04 ± 0.12 |

# CHAPTER 5

# DISCUSSION

# 5.0 Discussion

The objective of the current study was to provide an insight into the optimal load, relative to 1RM, of an individual's back squat as a CC to elicit maximum PAP in a CMJ. The results show a slight trend that the light load CC decreased CMJ performance in all variables; where the power variables observed the largest decrement; however, a slight increase in PV was noted. Whereas a trend was also noted with the heavy load CC which increased each variable, especially the power variables, with PP increasing considerably on average throughout the subjects and velocity values remained similar to baseline measurements. Although these results were determined non-significant (p >0.05), changes in performance were observed following both interventions, therefore the results of this study prove inconclusive as to whether conditioning contraction load has an effect on PAP. The results of this study are in contrast to previous findings of those such as; Esformes & Bampouras (2013), Rahimi, (2007) as well as Kilduff et al,. (2008)'s study which is in direct contrast with the present study because it was concluded that a significant increase in peak power output was observed when following a heavy back squat CC with the same recovery time as the present study. However, the present study's findings were in agreement with Esformes et al,. (2010)'s study which observed an increase in CMJ performance following a heavy squat CC, yet the results were not deemed significant; this was also the case when compared to light loads (or plyometrics in this instance) where no significant differences were found in CMJ performance. This may be due to the subject group used in Esformes et al,. (2010)'s study where the requirement for resistance training experience was a minimum of two years and the athletes are from different sporting backgrounds; similar to the present study. This study's findings are also in disagreement with Baker's (2003) study which determined a small yet significant increase in the participant's power output following a light CC using the same load and repetitions as the present study, however the recovery time differed.

## 5.1 Muscle Strength

The majority of the research completed on PAP identifies a positive correlation between an individual's maximal strength and PAP realisation (Young et al,. 1998; Duthie et al,. 2002; Wilson et al,. 2013). Each of the subjects involved in the current study compete in different sports which require diverse athletic profiles; and therefore differing levels of maximal strength in order to be successful. Wilson et al,. (2013) argues that the correlation between strength and PAP may be attributed to an increased fatigue resistance via buffering capacity, in a stronger individual, when compared to an untrained or lesser trained individual; meaning that the balance between fatigue and potentiation is more favourable with increased training. This may play a role as to why the results in this study were deemed non-significant, because the present study used an identical recovery period following each CC intervention to Kilduff et al,. (2008)'s study. However, one of the fundamental differences is that Kilduff et al,. (2008) observed PAP on individuals with a considerably greater mean 1RM squat (201Kg ± 41Kg) as opposed to the weaker participants of the current study (131Kg ± 28Kg). This implies that the participants of the current study may not have the strength levels necessary to realise PAP when preceded by a strenuous CC or that the PAP benefits/detriments were too similar to the individual's baseline measurements to be significantly affected by either CC load. Gourgoulis et al,. (2003)'s study showed a considerable increase in jump performance following heavy (>80% 1RM) squat interventions; specifically in the stronger test subjects, that squat over 160kg 1RM, with an increase in 4.01% jumping ability, as opposed to the weaker group (<160kg squat 1RM) which improved by 0.42%. The participants of Gourgoulis et al,. (2003)'s study had a mean 1RM squat of 160kg; indicating that the participants were well trained and much stronger than the subjects of the current study and therefore this study also illustrates that stronger individuals are more likely to realise PAP as well as the positive correlation between strength and amount of potentiation available.

Many studies have found significant increases in performance following multiple sets of conditioning contractions as opposed to single set interventions (Kilduff et al,. 2008; Chiu et al,. 2003; Smilios et al,. 2005) whereas the present study included a single set intervention. However it has also been speculated that stronger individuals, which possess a minimum of three years lifting experience, would benefit more from multiple sets as opposed to individuals with less than this; not only due to buffering capacity, but due to resistance to skeletal muscle damage (Wilson et al,. 2013). As found in Gourgoulis et al,. (2003)'s study where each participant completed five squat sets of two repetitions at increasing intensities starting at 20% 1RM and finishing with 90% 1RM with a rest period of five minutes between each set and the final CMJ measurement.

Baker (2003)'s study found a small, yet significant increase in power output following one set at 65% 1RM using the same intervention as the present studies light load methodology. However the present study included a longer recovery time of eight minutes which may have been too long for a light CC; causing the PAP effect to be missed and the results to be deemed insignificant. Whereas Baker (2003) utilized a recovery time of three minutes which could have been long enough for the fatigue to dissipate in his subjects but not the potentiation; resulting in a significant increase in power output.

### 5.2 Heavy VS Light Load

Similar to the present study; Hanson et al,. (2007) found no significant difference in CMJ performance of their participants following either a light squat intervention set (SIS) of 40% 1RM or a heavy SIS of 80% 1RM. The subjects used in this study were similar to the present study in that they were relatively untrained with only one year's resistance training experience minimum required (less than the present study) and are from differing sporting backgrounds. It is thought that other variables also contributed to the non-significant results found in Hanson et al,. (2003)'s study. This includes the CC load in relation to recovery time where a standardised recovery period following both SIS loads of five minutes was incorporated; whereas many studies have found significant improvements in power output and jump performance following heavy conditioning contractions with stronger subjects such as Gourgoulis et al,. (2003)'s paper. McBride et al,. (2005)'s study observed a significant sprint time performance improvement following a heavy SIS (similar to that of the present study) which consisted of three repetitions at 90% 1RM with only a four minute walking recovery period, however, no significant differences were found between the light intervention used in this study when compared to the control group. This is thought to be because the volume of work was too little to induce PAP as well as too little to induce fatigue; where only one repetition of a loaded (30%) CMJ was performed (McBride et al,. 2005). The subjects used in this study all competed in the same sport, at the same level, where a 40 meter sprint was specific to their sport which may be why a significant change in performance was observed in McBride et al,. (2005)'s study as opposed to the present study. It has previously been shown that a correlation exists between CMJ and sprint performance as both are power based exercises (McBride et al,. 2005).

Although Esformes et al,. (2010) and Hanson et al,. (2003)'s studies did not report significant findings through the use of light CC (<85% 1RM), both Baker (2001)'s studies found a significant increase in power output following light contractions. The optimal intensity found for upper body power represented loads between 55-59% 1RM however this was also the case for the second study of Baker (2001) where lower body power was maximised with similar loads and therefore implying that the upper body and lower body extremities both react similarly to training stimuli. These papers, however, utilised athletes that were well trained in both strength and power qualities; therefore indicating that although 55-59% 1RM generally maximises power output, a range of loads from 48-63% 1RM may be used to increase power output (Baker 2001). It may be because the athletes used in this study are well trained in strength and power that they generally find higher power output with the heavier range of the power bracket (Baker 2001). Moir et al,. (2011) 's study found that a heavy load CC protocol of three repetitions at 90% 1RM was more effective at increasing leg stiffness following a two minute recovery as opposed to a high volume CC protocol of twelve repetitions at 30%. This agrees with most research that heavy load contractions evoke a greater PAP response than submaximal loads; however the participants used had a minimum of 1 year resistance training which is unusual as PAP has been shown more evident in well trained athletes with multiple years of resistance training experience (Chiu et al,. 2003; Baker, 2001; Kilduff, 2008.).

**5.3 Limitations**

The main limitation of the present study was that the subjects used were all from different sporting backgrounds and therefore had extremely diverse strength profiles as well as training experience. This may have affected the results of the present study because some athletes may have responded to the pre-contraction stimuli positively, some negatively and some not at all. However, this would not be evident because the results were completed as a group average and therefore varied results would result in a non-significant finding.

**5.4 Practical Applications**

The majority of research has identified that a heavy load pre-contraction may benefit subsequent explosive performance as well as some research indicating that a performance enhancement may be observed following lighter loads. This depends on a variety of variables including the athlete's strength base; with most research showing that stronger athletes may realise PAP to a greater extent than weaker athletes. However these variables may be manipulated depending on the athlete in order to accommodate for their strength profile, for example, the research indicates that stronger athletes may require less recovery time following both a light and heavy CC due to their increased buffering capacity. This principle may be reversed for weaker athletes who may benefit from PAP following a longer rest time than the present study because they may accumulate excess fatigue which may take a longer time to dissipate than the stronger athletes. The research also shows that the CC load may also be manipulated in order to benefit an athlete's subsequent performance however the optimal load recommended by the majority or research is greater than 85% 1RM however, a performance increase may be realised utilizing lighter loads. Therefore, athletes may choose to implement a set (or several sets) of pre-contractions into their performance preparation, after manipulating the load and recovery time to suit their physiological attributes; in order to realise an explosive performance benefit.

### 5.5 Conclusion

Pervious literature has focussed mainly on maximally loading athletes (>85%) in order to generate a significant PAP effect and increase in subsequent power performance however the PAP response is often varied, if at all present. Although this is seemingly the case for lighter loading conditioning contractions (<80%), less research has been done on sub-maximal loading for a PAP response. Both light and heavy pre-loading depends on many variables as to whether a PAP effect will be observed, such as, but not limited to; strength profile of the subjects, sets and repetitions used and training experience. The majority of the research indicated that stronger and more powerful athletes are more likely to realise PAP with either a heavy or light loading protocol; however it has been observed that the protocol may be manipulated to accommodate for this such as Moir et al,. (2011)'s study. The recovery period is a main determinant of subsequent performance following a conditioning contraction because the research shows that fatigue is usually present immediately after the pre-contraction and this must dissipate to a level where PAP is more dominant in order for a positive adaptation in performance to occur. This window is also dependent on the subjects used and their buffering capacity as well as previously mentioned variables. In general the research shows that stronger individuals require less recovery time following a conditioning contraction than those who are untrained or recreationally trained.

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