Manipulating a Conditioning Activity to Enhance Potentiation and its Application to Jumping and Sprinting Performance.

Mathew W. O'Grady

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Faculty of Health

Federation University Australia

P.O. Box 663

University Drive, Mount Helen

Ballarat Victoria 3353

Australia

Abstract

Post-activation potentiation (PAP) is the phenomenon where contractile history of a muscle may acutely increase voluntary performance of future contractions that are biomechanically similar (72). In order to exploit the PAP phenomenon, a conditioning activity (CA) is performed to enhance the performance of a subsequent skill. Throughout the literature, a common example of a CA is sets of heavy-loaded squats in order to potentiate subsequent jumping (31,33,39,57,83,116,151,163) or sprinting performance (15,28,39,99). Post-activation potentiation can be used either in a warm-up to acutely enhance performance for competition, or used within a resistance training session to enhance speed-strength, with the intention of producing a greater training stimulus for chronic adaptations.

The major issue with the PAP literature is the inconsistent results from study to study. There are many examples within the research that show the positive effects of PAP (44,54,57,62,83,102,133,163), whilst many others have failed to find any increase in performance (42,47,56,81,112,123,141). The results have been inconsistent as the methodology between studies has varied dramatically. These differences include the warm-up used prior to testing sessions, changes in the type of CA (30,54,163), the intensity or load of the CA (19,21,33) and the rest period allocated between the CA and the performance of the skill. Furthermore, it seems that certain individuals respond better to a CA, with most of the literature suggesting that participant strength has a positive correlation with a potentiating response (15,31,44,116,128,129,163). Due to the vast differences in methodologies used throughout the potentiation literature, it is hard for coaches to identify the best practice in order to elicit a positive potentiating effect. Therefore, four studies were designed to address these current gaps within the potentiation literature in order to establish the best methodology to elicit a potentiating response.

The first study sought to investigate whether a heavy half-squat CA could further improve jumping after an individualised optimal warm-up. As many of the warm-ups used prior to the baseline measurement in the potentiation research have been insufficient (30,44,69,71,88,102,111,115,140,143,158), it is plausible to suggest that improvements after a CA could be due to general mechanisms of a warm-up, rather than PAP. To investigate this, participants performed six different volumes of warm-ups on six separate days, followed by CMJ and DJ testing. After each participant completed the six warm-ups, their individual optimum warm-up was identified as the warm-up that produced the greatest CMJ relative peak power (RPP). On two separate sessions, a CA of four half-squats at a 5RM load was then added to each individual's optimum warm-up and a sub-optimum warm-up. Countermovement jump tests were performed before the CA (pre) and then four and eight minutes after the CA. Drop jump testing was performed before the CA (pre) and then six and 10 minutes after the CA. When examining each post-test separately, no improvements in CMJ performance were identified. Furthermore, for both the optimum and sub-optimum warm-up conditions, DJ performance significantly decreased at all post-tests ($p < 0.05$). When each individuals best recovery period was considered (post-best), both the maximum and mean CMJ jump height significantly increased above baseline measures for the optimum warm-up condition. No other CMJ or DJ variable displayed any significant change after the addition of the CA for either condition. As significant increases in CMJ jump height were identified, the four half-squat CA with a 5RM load was used in the next investigation. Although each individual's optimum warm-up volume varied, the moderate warm-up volume produced sufficient CMJ performance for all individuals. Considering the time required identifying each individuals optimum warm-up, the moderate warm-up was deemed sufficient and was used for the following studies.

The second study of this thesis investigated the acute response of two different CA strategies. Both CAs included four half squats at a 5RM load, however, in one condition participants were instructed to perform the squat in a controlled manner, whilst in the second condition, they were instructed to lift the bar as fast as possible without losing contact with the ground. At any post-time (including post-best), no significant improvement were identified for any CMJ variable in either condition. Furthermore, DJ performance significantly decreased at all post-tests for the explosive CA condition. Although no significant improvements were identified, when each individual's optimum recovery period was considered, CMJ jump height increased by 2.6% in the explosive CA condition, as opposed to 0.9% in the controlled CA condition. Because of this difference within the means of each condition, for the future studies throughout this thesis, participants were instructed to lift the bar as fast as possible during a heavy half-squat CA.

The third study of this thesis compared different volumes of plyometric CAs (rebound jumps) to a CA involving heavy half-squats and assessed the effect each had on potentiating CMJ and sprinting performance. Past research had often used small amounts of plyometric contacts to potentiate future contractions (23,30,143,146,151), however, due to their short duration; they were often not successful in improving performance. For one condition, this study increased the repetitions of plyometric contacts in the CA, so that its duration matched the time under tension exhibited by the four half-squats with a 5RM load. Furthermore, two other plyometric CA conditions were included; one that matched half of the time under tension of the half-squats and one that involved only four repetitions of the rebound jump (match the amount of repetitions of the half-squat). No CA (plyometric or half-squat) displayed statistical significant improvements in CMJ or sprint performance at any post-test interval. For CMJ performance, although it did not significantly improve performance, generally the heavy half-squat CA had smaller decrements in performance than the plyometric CAs, hence the final investigation of this thesis focussed upon different heavy dynamic CAs in order to potentiate CMJ performance.

The final study of this thesis firstly aimed to investigate the effect of three different types of half-squat CAs had on potentiating CMJ performance. This study also aimed to explore why certain individuals respond positively to a CA, whilst others respond in a negative manner. At the beginning of this study, participants completed a number of fitness performance tests, to assess each individual's performance. Participants then assessed the effect of three different CAs on CMJ performance. These CAs included three repetitions of the half-squat with a 3RM load (3 @ 3RM), four repetitions with a 5RM load (4 @ 5RM) and then five repetitions with a 5RM load (5 @ 5RM). In terms of the entire population of the study, after each of the CAs, post-CMJ performance typically decreased across all rest periods, whilst any improvement in particular CMJ variables were considered to only be trivial in terms of effect size magnitudes. Despite this, multiple statistically significant positive correlations were evident between particular fitness qualities (absolute strength, CMJ RPP and aerobic capacity) and the change scores between pre and post-best CMJ performance after certain CAs. Therefore, the participants were median split in terms of each of the following fitness qualities to assess the relationship each quality has on potentiating CMJ performance.

When the population was split in terms of absolute strength, the stronger participants significantly improved CMJ performance at their best recovery period after the performance of the 5 @ 5RM CA (three out of the four CMJ variables assessed significantly improved), whilst the weaker individuals showed no significant improvements. A similar trend was exhibited when the population was split in terms of CMJ RPP, with the more powerful individuals improving by small to moderate effect size magnitudes after the 5 @ 5RM CA, whilst the less powerful group did not.

From the studies presented in the thesis, it can be concluded that certain recreationally resistance trained males can acutely enhance CMJ performance with the use of a heavy dynamic CA, even after pre-test performance has been optimised by a general warm-up. The optimum recovery period for the individual does need to be considered, as individuals require different amounts of rest to allow for an improvement in performance. Furthermore, the individual needs to have sufficient strength of the lower limbs in order to improve future contractions via the use of the heavy dynamic CA, as individuals with less strength do not improve post-CMJ performance after a CA.

In terms of the type of CA used, heavy half-squat seem to be more effective than rebound jumps in order to potentiate CMJ performance. Furthermore, five repetitions with a 5RM load seems more effective than heavier CAs (3 @ 3RM) or ones that have less repetitions (4 @ 5RM) for this particular population.

Statement of Authorship

Except where clear reference is made, this thesis contains no material published elsewhere or extracted any part from a thesis that has been previously completed. No other person's work has been used without due acknowledgement within the text or reference list of this thesis.

Signed: ______	Signed: ______
Date: 25/10/17	Date: 25/10/17
Mathew O'Grady	Associate Professor Warren Young
Candidate	Principal Supervisor

Dedication

I dedicate this thesis to my parents, Michael and Leigh, my sister Katie, and my girlfriend Coralie. I am forever grateful for your love and patience throughout my candidature. This thesis would not have been possible without your unwavering support.

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List of Abbreviations

1RM = One repetition maximum

3RM = Three repetition maximum

5RM = Five repetition maximum

CA = Conditioning activity

CMJ = Countermovement jump

CT = Contact time

DJ = Drop Jump

JH = Jump height

LPT = Linear position transducer

PAP = Post-activation potentiation

PF = Peak force

PV = Peak velocity

RFD = Rate of force development

RJ = Reactive jump

RPP = Relative peak power

RSI = Reactive strength index

W.U = Warm-up

Publications from Thesis

Peer Reviewed Conference Proceedings

O'Grady, M., Young, W. Acute increases in performance: post-activation potentiation or general warm-up effects? A review of the literature. Poster presentation at the Australian Strength and Conditioning Association 2013 International Conference on Applied Strength and Conditioning. Melbourne, Australia.

O'Grady, M., Young, W. A biomechanical comparison of controlled and explosive back squats. Poster presentation at the Australian Strength and Conditioning Association 2014 International Conference on Applied Strength and Conditioning. Melbourne, Australia.

O'Grady, M., Young, W., Talpey, S. A comparison of smith machine & barbell half squats to elicit potentiation in countermovement jump performance. Poster presentation at the Australian Strength and Conditioning Association 2015 International Conference on Applied Strength and Conditioning. Gold Coast, Australia.

Chapter 1: Introduction

1.1 Background

In elite sport, both athletes and coaches are always seeking to further improve their physical capabilities and hence overall sporting performance. Many sports are based upon the basic skills of sprinting and jumping, where the development of speed-strength is extremely important to increase performance in these basic skills. Often muscular power is a variable of speed-strength performance. Power can be defined as the rate at which work is performed (power = force x distance/time) (85) and can be improved by increasing the force produced and the speed at which it can be applied. In past research, the term muscular power has been misused (155), as the term power has described high velocity high force movements (for example, jumping activities). Due to the biomechanical definition of mechanical power, this thesis uses peak power (PP) as one variable of the CMJ, whilst the term “speed-strength” will be used to explain movements with a high force and velocity component. Other measures of speed-strength include measures of the counter-movement jump (CMJ), including jump height, movement velocity and rate of force development (RFD). Rate of force development is especially important, as it has been reported to be a more sensitive indicator of neuromuscular properties than maximal force (93). All of the measurements have been considered variables of speed-strength in this thesis, as previous research has identified that each particular variable represents independent qualities of speed-strength (159).

Training for speed-strength generally involves movements that not only focus on great amounts of force being produced, but also movements that maximise the speed of the contraction throughout the movement (43,160). Examples of this may involve resistance training with an emphasis on fast lifting (jump squats or power cleans) (35,145), or plyometric activities which can involve jumping, bounding or throwing where the aim is to produce as much force as possible in minimal amounts of time (30,146).

Another method to enhance athlete speed-strength is complex training, where participants combine lighter training sets (with a speed emphasis) with sets of heavy strength training (43,101). Past research has shown that performing a heavy strength activity can enhance subsequent performance acutely due to post-activation potentiation (PAP) (31,39,63,107). Post-activation potentiation is the phenomenon where contractile history of a muscle may acutely increase voluntary performance of future contractions that are biomechanically similar (72). To exploit the PAP phenomenon, a conditioning activity (CA) (heavy resistance lift) is performed to improve the performance of a subsequent power specific skill. An example of this would be performing a set of heavy-loaded half-squats as a CA, to potentiate subsequent countermovement jump (CMJ) performance (72,83,163).

There are two main ways that coaches attempt to use PAP to improve athletic performance. These include:

1. Using a CA within a warm-up to enhance a particular skill or performance within competition (99,116).
2. Contrasting heavy and lighter sets within a resistance training session to enhance muscular power output, with the intention of producing a greater training stimulus for a chronic adaptation (43,98,101)

The major issue with the past literature on PAP, is the inconsistent results identified by researchers. Much research has produced evidence to suggest the positive effect of PAP (15,44,54,57,63,102,133,163) whilst other research has failed to find any statistically significant or meaningful improvements in performance (42,47,56,81,112,123,141). The vast differences in results have been attributed to many different factors, including the type and intensity of the CA used (131), the rest period between the CA and the performance of the skill (69) and the physical capabilities (strength and predominant muscle fibre type) and training history of the athlete (31,44).

Post-activation potentiation can be assessed by complex neurophysiological techniques (84,132), but the authors of most applied literature assume that the PAP mechanism is operating if there is an improvement in performance. Due to the applied nature of this project, a delimitation of this study will be that the mechanisms of PAP will not be measured. The term "potentiation" will be used to describe an enhancement of muscular or sports performance following a CA, assumed to be due to PAP.

1.2 Statement of the Problem

The literature has suggested many reasons for the inconsistencies in the PAP research; however, there are many other variables that still need to be investigated as they could also affect a potentiating response. The effect of Warm-up (W.U) prior to the performance of a CA has never been considered as a confounding variable in PAP research. This is evident from the many different warm-ups used throughout the literature. If a warm-up is insufficient or too fatiguing in its intensity, pre-test values within the research are not going to be optimised for participants. Therefore, it is not clear whether any increase in post-test performance is due to the CA eliciting potentiation, or whether performance has simply increased due to the general mechanisms of a warm-up.

Half-squats have been used as a common CA throughout the PAP literature (57,107,131,163), with researchers focussing on the ideal load (33,57,91) and number of repetitions (26,30,91) to maximise performance. One variable that the literature has failed to focus on, is the instructions on how to perform the half-squats during the CA. If a participant performs a set of half-squats in a controlled manner (for both the eccentric and concentric phase), the kinetic and kinematic variables from the squat could potentially be different than if they were instructed to squat with the intention to move the bar as fast as possible (14). Despite the fact that changing the intention of the squat could change the nature of the CA, no previous research has compared the two lifting strategies and their effectiveness as a CA to elicit a potentiating response.

Past research has focussed on different types of CA, with recent literature suggesting heavy-loaded contractions (for example squatting) are more effective than isometric or plyometric CAs (146,154). Despite this, many heavy strength based CA would not be practical to perform in a warm-up, as large pieces of equipment may not be available. Plyometric activities could be more appropriate for these situations, as minimal equipment is required and they could potentially be performed on-field. Although past research concluded that plyometric activities were not as effective as other methods as a CA, the short duration of muscle activation during these plyometric activities was not considered. If the amount of repetitions of plyometric activities is increased in a CA, there is a possibility that they could cause more of a potentiating effect.

Previous literature has tried to explain the inconsistencies within the PAP literature, that participants require a relatively high level of muscular strength to be able gain the potentiating benefits of a CA (15,31,44,116,125,129,163). Similar to this theory, individuals with greater fast-twitch muscle fibre composition also respond better in creating a potentiating effect (128). Despite this suggestion about predominant muscle fibre type, no previous research has investigated whether any other fitness performance qualities are associated with a potentiating effect (for example: sprint speed or speed-strength). Furthermore, an individual that has greater muscular fatigue resistance may be of benefit to exploiting potentiation (66), therefore, strength-endurance may be an especially important quality for benefiting from a CA.

The depth and detail of the literature about PAP is extensive, however, many aspects that could influence its implementation have not been explored. Further research is required to better understand the ideal protocol to enhance a potentiating effect. This project will look to address these gaps in the literature and suggest practical applications on how to best create a positive potentiating response. Once the best methodology to create potentiation is established, further research can focus upon the effects that a CA may have on more complex skills.

1.3 Aim and Research Questions

The aim of this research project was to investigate how different manipulations to a CA influence potentiation and subsequent performance in speed-strength (jumping and running).

The overall research questions for the project are:

Study 1

The main research questions for study 1 were:

1. What is the optimum warm-up (WU) volume for CMJ performance?

2. Does the addition of a CA of four half-squats at a 5RM load potentiate CMJ or drop jump (DJ) performance after an optimum and sub-optimum WU?

The following specific research questions were also addressed:

1. Is a particular WU volume optimal for all/most participants?

Study 2

The main research questions for study 2 are:

1. Does the intention to maximise bar velocity during the concentric phase of a CA of four half-squats at a 5RM load have an effect on potentiating CMJ and DJ performance?

The following specific research question were also addressed throughout this study:

1. What are the kinematic differences between squatting to maximise bar velocity compared to squatting in a controlled manner?

Study 3

The main research questions were:

1. Can an increased volume of rebound jumps be an effective CA to elicit potentiation in either CMJ or sprinting performance?

2. Does a CA of four half-squats at a 5RM load potentiate CMJ or sprinting performance?

The following specific research questions were also addressed throughout study 3:

1. Did a particular duration of rebound jumps have a greater effect on any post-CMJ and sprinting variables?

2. Which type of CA (plyometric vs. heavy squat) had the greater effect on potentiating CMJ and sprinting performance?

Study 4

The main research questions for study 4 were:

1. Did any of the three CAs have an effect on CMJ performance?
2. Does any particular fitness component have an influence on whether a CA potentiates CMJ performance?

1.4 Significance of the Thesis

Sports coaches and athletes are always striving to improve athletic performance, whether this is by creating a better stimulus in training or competition. As explained above, the body of literature focused upon PAP is inconsistent. These inconsistencies throughout the literature have caused confusion in what methodology is best to elicit the greatest potentiating effect. The following project aimed to provide substantial information to clarify the optimum way to structure training designed to exploit PAP, therefore enhancing peak power development and sports performance. The following research aimed to add to the body of literature by:

- Identifying the impact of a thorough warm-up before a CA and its effect on PAP (Study 1).
- Identifying which lifting method (high velocity intent squat motion or controlled) was the most effective in eliciting potentiation (Study 2).
- Identifying whether an increased volume of plyometric activities was a successful CA in eliciting potentiation and hence be more practical for many sporting situations. (Study 3).
- Identifying what fitness qualities affect whether an individual can enhance performance by eliciting potentiation (Study 4).

1.5 Thesis Structure

This thesis has been structured so that many of the current issues surrounding the PAP research can be investigated, potentially identifying future practical applications for both coaches and research. The next chapter (Chapter 2) consists of a thorough review of the literature, focussing on the mechanisms of PAP and current suggestions of the optimum methodology to exploit a potentiating effect. Chapter three explores optimising an individual's warm-up prior to a CA, to identify if an improvement in post-CA jumping performance increases due to potentiation, or general warm-up effects. The results from chapter three (in terms of the optimum warm-up) are used throughout the remainder of the studies, so that all warm-ups used prior to any testing session are sufficient. Chapter four investigates whether a high velocity intent half-squat CA has an effect on improving post-jumping performance. The results from that investigation then influence the instruction used for a CAs that involve the half-squat technique. Chapter five compares a CA of heavy half-squats to CAs that include different volumes of plyometric rebound jumps, to examine which is most effective at potentiation jumping and sprinting performance. Considering no plyometric CA displayed improvement in jump or sprinting performance, only squatting CAs would be considered for the final study in chapter six. Chapter six explores the relationship between multiple fitness components and whether they have an effect on an individual's ability to improve performance after a CA. The final chapter summarises the major findings from the preceding chapters and provides conclusions that suggest certain practical applications and implications for future research in the area of PAP. All practical applications and suggestions for future research are presented in this final concluding chapter.

1.6 Assumptions

For the four studies involved in this thesis, the following assumptions were made:

1. Participants performed all activities within testing sessions with maximum intensity and to the best of their ability.

2. The participants carried out the instruction to avoid consuming any caffeine prior to any of the testing sessions.

3. The participants carried out the instruction to not perform and lower body exercise 48 hours prior to any testing session.

4. All participants were honest when providing researchers a score out of 10 for "how the feel" upon the day of testing.

5. All instructions provided throughout all studies were fully understood by the participants.

1.7 Delimitations

The following delimitations were identified for the four studies:

1. Due to strength requirements for participation, only males were recruited.

2. The participants used within the studies were "recreationally trained."

3. Only single sets of half-squats were used as the CA, rather than multiple sets. This was due to the cohort being "recreationally trained" and it was suggested by Wilson et al. (154) to only use single sets as the CA.

4. The following studies did not investigate any of the complex mechanisms of PAP, as the following thesis aims to focus on the practical applications for future research and coaches.

1.8 Limitations

The following limitations were considered before any analysis of the results from the following studies:

1. Participants availability was restricted to the academic calendar; therefore, any data collection periods were restricted to six weeks.

2. Due to the availability of participants, some testing conditions were conducted in the morning, whilst others were completed in the evening. To keep testing protocols consistent, those participants who preferred testing in the mornings, were restricted to only test in the morning, whilst participants who preferred the evening time were restricted to those times only.

3. Although participants did not complete any lower body resistance training 48 hours to a testing session, the training for sports that participants competed in was not controlled during the testing periods.

4. The sample sizes for chapter 4 through to 6 did not meet the suggestions from the statistical power analysis, as it was not feasible to recruit that number of participants. Due to the following studies not meeting the statistical power analysis requirement, the chance for a type 1 error would be increased. The sample sizes for these particular studies did however; match the number of participants used in similar investigations within the literature (31,57,83).

Chapter 2: Literature Review

2.1 Overview of the literature review

The following chapter is a complete review of the current literature about the PAP phenomenon. Firstly, brief information is provided about the traditional methods to train for speed-strength, before discussing the topic of PAP. In order to better understand PAP, the discussion throughout the review will focus on what PAP is, followed by the physiological mechanisms that explain why it occurs. Further emphasis is placed on the best methods to elicit a potentiating response, by investigating the type and intensity of CAs, the rest periods after a CA as well as the physical attributes of the participants used throughout the research. The literature review concludes with summary tables of examples from the literature that have successfully potentiated jumping, sprinting, throwing and other sporting performances, as well as examples from the literature that have found no increases in performance after a CA.

2.2 Speed-strength

Speed-strength is the ability of a particular muscle group to exert large amounts of force in a small amount of time (160). It is a fitness quality that is derived from both maximal strength and speed (85). Due to the importance of both fitness qualities in relation to speed-strength, the force-velocity relationship (Figure 2.1.) is often used to determine the explosiveness a particular movement or contraction (144). The force-velocity relationship suggests that as the force of a concentric contraction increases, the velocity of the movement will decreases, and conversely as velocity of movement increases, the maximal force will decrease (144). Considering speed-strength is a combination of force and velocity, peak power production will be maximised at a sub-maximal force in conjunction with velocity (36,37,64).

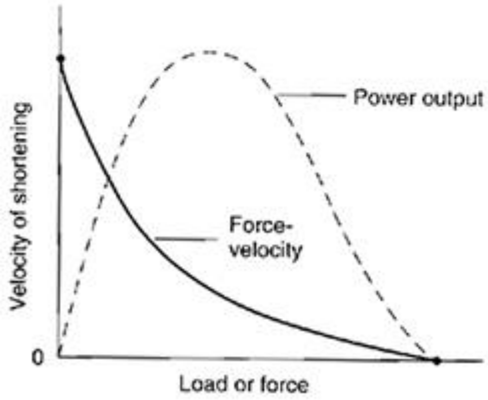

Figure 2.1. An adaption of the proposed force-velocity and power relationship by Toji & Kaneko (144).

In terms of the lower body, speed-strength is often assessed via the performance of a jump (35,159). From performing a jump, many different variables of speed-strength can be calculated. Peak power measured in Watts is commonly used as a variable to represent moderate-high force and velocity movements, but other variables such as jump height, velocity of movement and rate of force development (RFD) can also be used to express this physical quality. Although it has been shown that each of the following qualities are independent to certain speed-strength performance (159), peak power production has commonly been used as a measure of explosive performance (5,40).

2.3 Traditional training methods to enhance speed-strength

Maximal strength is the ability to produce the highest amount of force against a set resistance (85). Considering speed-strength is a product of both force and velocity, research has shown that by increasing the force producing capability of an individual (via strength training) will also improve the capacity of the individual to produce explosive contractions (7,35). Therefore, traditional training to enhance muscular strength will also provide a stimulus to increase power production. This suggestion is supported by the research of Cormie, McBride & McCaulley (35), as they showed stronger participants in the 1RM back squat also produced significantly greater relative peak power compared to a lower performing population in terms of 1RM back squat performance. Cormie et al. (35) also showed that strength training enhances power development in relatively untrained (low strength training age) individuals. However, it is generally believed a highly strength trained athlete will get limited gains in speed-strength by doing further strength training. Therefore, individuals with a greater strength training age must focus upon speed-strength exercises to specifically enhance peak power (14).

Using ballistic movements like medicine ball throws or jump squats have also been suggested within the literature as effective training to enhance power development (1,92). By either jumping or throwing an object, maximal acceleration can be maintained throughout the entire ROM of an exercise (do not have to decelerate at the end of movement) leading to higher outputs of peak power (110). Ballistic movements are also ecologically valid as they are primarily used in applied power and speed sport situations. As ballistic movements have unique motor control patterns such as the triphasic activation (agonist-antagonist-agonist coupling), such training is important for improved movement coordination and efficiency (10). Newton, Kraemer & Hakkinen (109) provide evidence for this, as they identified significant improvements in elite volleyball players vertical jump performance ($p < 0.01$, 5.9% improvement) after eight weeks of ballistic jump squat training. Plyometric activities are a type of ballistic movement that have also led to significant improvements in muscular power (1,29,92).

Plyometric activities aim to improve speed-strength by making the stretch-shortening cycle (SSC) more efficient (87,134). Typical plyometric exercises involve contacts with the ground where the aim is to maximise height or force with minimal ground contact time (53). Plyometric activities improve performance by training the neuro-muscular system to decrease the time of the SSC, whilst maximising the force it produces (114).

2.4 Complex or Contrast training

Complex or contrast training is the combination of heavy strength-based sets of training with lighter explosive-based sets, with the emphasis to create a chronic adaptation in speed-strength. Duthie, Young and Aitken (44) explained that contrast training involved alternating sets of heavy and lighter loads throughout a session, whilst complex training involves multiple strength sets followed by lighter more explosive-based sets. Both complex and contrast methods attempt to take advantage of the PAP phenomenon, in that the heavier strength based set will elicit greater amounts of power production in the subsequent lighter sets that follow.

Table 2.1. Example of the structure of sets for both complex and contrast training. HS = heavy set (for example squats with load > 80% 1RM), LS = light set (for example body weight jumps)

Type of sets	Structure of Set
Contrast sets	HS, LS, HS, LS, HS, LS
Complex sets	HS, HS, HS, LS, LS, LS

2.5 What is the PAP phenomenon?

Post-activation potentiation is the heightened voluntary response after the performance of a previously relatively similar contraction (72) (i.e. squats to jumps). It is created by the performance of a CA, which allows a "window of opportunity" to further improve performance in a similar skill if the rest period is appropriate (119). Previously CAs have successfully been used throughout research to acutely improve jumping (19,31,33,39,54,107,146,163), sprinting (15,28,99,125,126) and throwing performance (3,4,48,80,82), however, many other examples have failed to identify this positive effect of performance after a CA (42,47,56,81,112,123,141). Further research is still required to investigate the PAP phenomenon to identify potential explanations for the inconsistencies throughout the present literature.

2.6 Mechanisms of PAP

Post-activations potentiation occurs due to three main mechanisms. The first proposed mechanism is phosphorylation of the regulatory chains (RLC) on the myosin head (72,119,142). The second is a greater amount of higher order motor neuron recruitment (62,142) and the third is changes into the structure of the muscle, specifically changes in pennation angle (94). A brief discussion of each of the mechanisms will follow.

2.6.1 Phosphorylation of the regulatory light chains on the myosin head

The phosphorylation of the RLC is believed to enhance muscular performance by changing the configuration of the myosin head and moving it away from the backbone of the filament (142). This revised configuration places the myosin head closer to the actin active sites permitting a higher rate of cross-bridge interactions. Tillin and Bishop (142) also suggested that RLC phosphorylation potentiates subsequent contractions by making the actin and myosin interaction more sensitive to Ca2+ in the myoplasm. This particular finding was also suggested by Klug, Botterman and Stull (84), who concluded myosin RLC increased calcium sensitivity and lead to a more powerful contraction.

The relationship between an increase in RLC phosphorylation and twitch potentiation has been reported in many studies using animals (96,148), as well as human studies (59,74,136,149). Stuart et al. (135) reported significantly elevated phosphate levels of the RLC in the vastus lateralis muscle after performing a CA of a 10-second isometric maximum voluntary contraction (MVC) of the knee extensors. Researchers also reported a significant potentiation of the twitch tension in the knee extensors following the MVC, leading to the conclusion that the twitch potentiation occurred due to the phosphorylation of the RLC. Smith and Fry (132) similarly analysed muscle biopsies and leg extension performance seven minutes after performing a 10 second isometric MVC. Despite the similarities in methodology, when the group as a whole was analysed, there was no significant effect, but when the "responders" were isolated (n = 7), they were found to exhibit an increase in the phosphorylation of the RLC. This study represents an example of variability of responses to a CA. Considering this, more research is required to identify certain reasons as to why variability of response to a CA occurs (discussed further later in this review).

2.6.2 Higher order motor unit recruitment

The second mechanism of PAP is that the CA causes an increase in the recruitment of higher order motor units (62,119). Previous contractions have been shown to elevate the transmission of action potentials at the spinal cord, hence, increasing the recruitment of motor neurons (142). Research conducted on humans has measured the H-wave amplitude to assess the effects of a CA on motor neuron recruitment. H-reflexes illustrate the extent of afferent excitability of the spinal motoneuron (46). It has been suggested that an increase in H-wave amplitude leads to a decrease in transmission failure at the synaptic junction due to a greater amount of action potentials present, leading to a greater recruitment of higher order motor units (142). Gullich and Schmidtbleicher (62) measured the changes of H-wave amplitude in the gastrocnemius before and after participants performed a CA which involved a five second maximal voluntary contraction (MVC) of the plantar flexors. Initially, the H-wave amplitude decreased by 24% one minute after participants completed the CA. However, after 5-13 minutes rest, the H-wave amplitude increased by 20%, suggesting a greater recruitment of motor neurons had occurred due to the CA.

2.6.3 Changes in Pennation Angle

It has also been suggested that changes in muscle pennation angle cause potentiation. The pennation angle of a muscle refers to the orientation of the muscle fibres in relation to the connective tissue or tendon, with a smaller pennation angle leading to a greater transmission of force from the muscle to a tendon due to the more direct line of force transmission (142). In a study conducted by Mahlfield et al. (94), researchers found no change in participant's vastus lateralis pennation angle immediately after they performed a three second MVC, however, after three to six minutes rest, the pennation angle had decreased significantly by 14.4º. Despite the identification of the change in pennation angle, it must be noted that no post-test of muscle function occurred in this particular research, suggesting it was unclear if the change in pennation angle actually led to an acute enhancement of performance. The researchers suggested that such a change in pennation angle would have a small improvement in the transmission of force between the muscle and tendons. Although more research is required to explain the effect that the change in pennation angle has on potentiation, it must still be considered as a possible mechanism that contributes to potentiating response.

2.7 PAP vs. Fatigue

Much literature has concluded that potentiation and fatigue co-exist (9,11,78,119); suggesting the rest period after a CA is vital in optimising a net potentiating effect. Directly after the performance of a CA, fatigue outweighs the potentiation created, equating to a decrease in performance (83,119). During the recovery period however, fatigue dissipates faster than the potentiation, leading to a "window of opportunity" where the potentiation is greater than the fatigue, therefor producing a state where power performance is heightened above normal levels (119) (Figure 2.2).

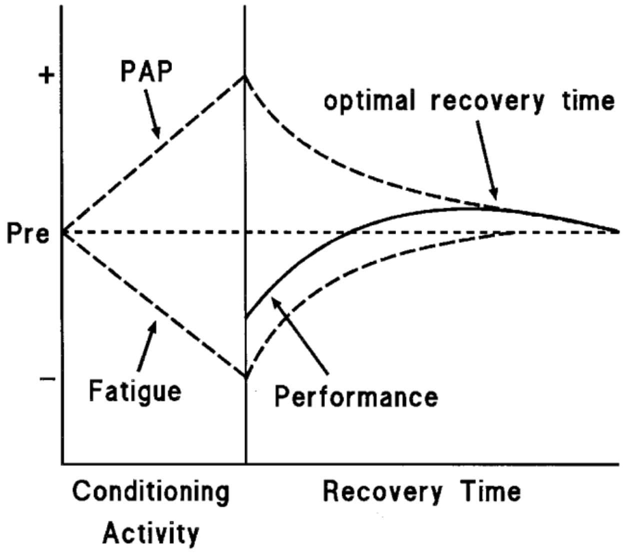

Figure 2.2. Representation of the relationship between fatigue and potentiation following a CA presented by Sale (119).

Despite the above suggestion of Sale (119), Tillin and Bishop (142) suggested that there could be two rest periods where a positive potentiating response can be exploited. They initially suggest that if a CA is low in its volume and fatigue is relatively low, then an improvement in performance can be seen almost directly after the CA. Secondly, if the CA is higher in its volume leading to greater fatigue, then a more substantial rest period after the performance of the CA will be required to see an enhancement in performance (Figure 2.3) (142).

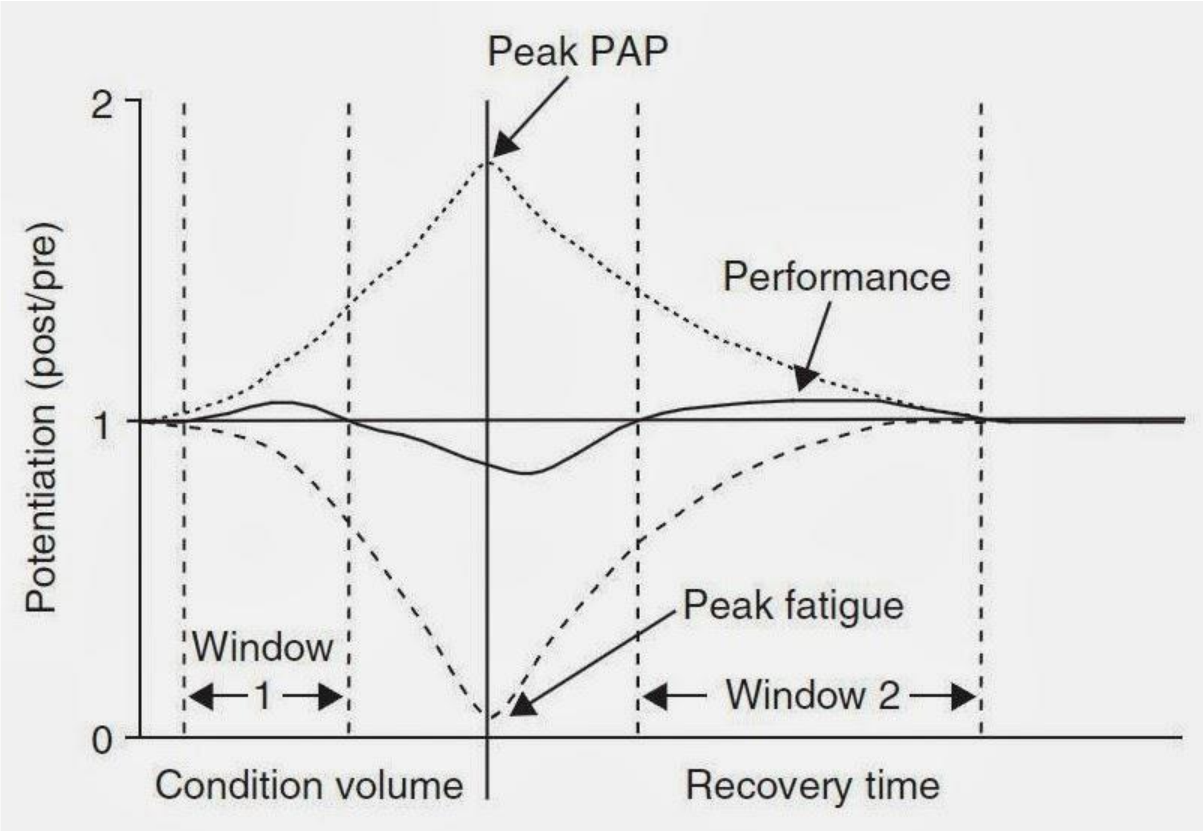

Figure 2.3. An explanation of from Tillin & Bishop (142) of the two "windows of opportunity" to elicit a positive potentiating response.

This suggestion comes from a few examples within the literature that found acute increases in performance directly after the performance of a CA (57,140,143). Gourgoulis et al. (57) used a CA of five sets of two repetitions of the half-squat with the load increasing incrementally throughout the sets (20, 40, 60, 80 & 90% of participant 1RM load) in order to potentiate CMJ performance. Participants performed their post-CMJ test directly after the last set of half-squats and significantly increased their CMJ jump height by 2.6% ($p < 0.05$). This CA of multiple sets of two repetitions of half-squats is an example of the low volume CA suggested by Tillin & Bishop (142), that may lead to a potentiating response directly after the CA. Furthermore, Terzis et al. (140) identified significant acute enhancements in underhand throwing performance immediately after the CA. Participants firstly performed a baseline underhand throw for maximum horizontal distance, before performing a CA of five repetitions of the drop jump (DJ) from a 40 cm box. After performing the CA, throwing distance increased significantly by 4.6% ($p < 0.05$). Despite the evidence of the previous two examples, much of the literature has expressed no change or decreases in performance directly after the CA (39,56,83,86,91), although the CA activity volume in these instances may not be considered low. The evidence to suggest potentiation occurs directly after a CA is minimal; however, future research should focus upon establishing a particular protocol that allows a potentiating response to occur directly after a CA. If the PAP response occurred immediately, this would have greater practical applications to many situations, as people would not have to “waste” time waiting for a positive potentiating response to occur.

2.7.1 Different recovery periods in the PAP literature

As discussed previously, in order for a positive response in performance to occur after a CA, the potentiation created must be greater than the fatigue (119). Hence, the rest period allowed after the CA is paramount in order to observe an acute performance enhancement (83). Despite this, the optimum rest period for potentiation to occur after a CA has ranged from 0-16 minutes throughout the literature (58).

Much of the literature has found four minutes of recovery the best to potentiate performance (102,163), whilst others have suggested that eight minutes (16,83,125) or even greater than 12 minutes rest is optimum (48,82) in order to elicit a potentiating response. The most effective rest periods vary throughout the literature due to different types and intensities of CA, as well as the different physical attributes of the participants being used from study to study. Wilson et al. (154) conducted a meta-analysis on all PAP research to investigate the optimum conditions to elicit potentiation. The study concluded that a rest period between 7 – 12 minutes is optimum for athletes with one-year experience weight training, if the CA has a load between 60-85% of a participant's 1RM. Furthermore, a meta-analysis by Gouvea et al. (58) also suggested that rest periods should vary between 8 – 12 minutes after a CA to potentiate jump performance. It is suggested that future PAP research should follow the guidelines suggested by the two previous examples (58,154), in order to make the methodology used between studies more consistent.

2.7.2 Is the optimal recovery period after a CA individualistic?

A potential reason to explain why so many different ranges of rest periods have been suggested in previous literature, is that the optimal recovery period is different for certain individuals (26), or different after certain types of CAs . Seitz and Haff (124) stated that the optimal rest period varied depending on the CA, suggesting that 4-12 minutes rest was best for back squat CAs, 3-16 minutes was more suited to CAs that involved the bench press and seven minutes rest would be best for CAs that use the power clean exercise. Furthermore, Seitz, Vilarreal & Haff (129) suggested that participant strength also played a role in changing the optimal rest period to elicit the best potentiating response. They concluded that the best rest period was three minutes after the CA (back squat) for the stronger rugby players (relative 1RM strength > 2 x BW) whilst the optimum rest period was six minutes after the CA for the weaker players (relative 1RM strength < 2 x BW).

Considering the above suggestions, some of the literature has compared pre CA performance to each individual participant's best-post performance, in order to account for the differences between individuals in the amount of rest required. Even though multiple post-tests were performed, best-performance considers only the recovery period that produced the greatest result, rather than comparing results at set recovery times. Both Bevan et al. (15) and Crewther et al. (39) considered each participants best-post sprint and compared to baseline sprint performance. Both studies reported a significant improvement in the post-best sprint times compared to the baseline measurements. Future research should place more emphasis upon identifying other characteristics that may also explain why optimum rest periods vary between individuals.

2.8 Factors other than rest period that influence a potentiating response

The vast differences in potentiation research have been attributed to many other factors throughout the research, including the intensity and type of the CA (131) and the physical attributes and training history of the participants (31,44,116). In previous research, isometric MVC (21,54,63,76), heavy dynamic activities (for example loaded squats) (107,131,163) and plyometric activities (23,30,143,151) have all been used as CAs to assess if future power performance can be increased.

2.8.1 Isometric CAs

Many studies have used isometric MVCs as a CA to potentiate future performance (21,54,63,76). French, Kraemer and Cooke (54) assessed the effect three sets of 3-second and 5-second isometric MVC's of the knee extensors had on subsequent drop jump performance. The three sets of 3-second isometric MVC's increased drop jump height significantly by 5.0% as well as the acceleration impulse of the drop jump by 9.5%. Conversely, no significant differences in drop jump performance were observed when participants performed three sets of 5-second MVC. Iglesius-Soler et al. (76) also used isometric contractions as a CA to potentiate power output during plantar flexion. Participants performed isometric contractions of the soleus muscle at 10% and 100% maximum effort for either seven or 10 seconds in duration. Power output increased significantly by 1.7% when participants performed the 10-second isometric contraction CA with 100% max effort. No other CA protocol significantly changed peak power output during the plantar flexion.

The previous findings suggest that an isometric CA needs to be maximum, or near maximum effort in order to potentiate future contractions. Conversely, both the research of Robbins and Docherty (117) and Till and Cooke (141) failed to show improvements in post-performance after a CA. Robbins and Docherty (117) used three sets of 7-second isometric MVC to assess the effect on CMJ performance, however, found no significant change in jump performance. Similarly, Till and Cooke (141) found no improvement in 10 metre; 20 metre or vertical jump performance after participants completed three repetitions of 3-second isometric MVC knee extensions.

With mixed results throughout the literature, it is unclear if isometric contractions are effective CA strategies in order to potentiate future contractions. One contributing factor to the inconsistent results is that it is hard to control the intensity of an isometric contraction

(154). Despite this, they do have an advantage as a CA, as they require minimal equipment to perform and could be practical for many sporting examples.

2.8.2 Heavy Dynamic CAs

A plethora of the current literature has successfully used heavy dynamic contractions as a CA, whether performing heavy squats (103,107,116,118,131,153,163) or bench press (3,4,48,83,97), to potentiate future contractions. To improve sprinting performance, Matthews, Matthews and Snook (99) used five back squats at a 5RM load to potentiate 20m sprinting performance. In the experimental protocol, participants significantly decreased their 20m sprinting time by 3.3% ($p < 0.001$) when compared to the control protocol. Rahimi (115) obtained similar results with a CA that involved two sets of four repetitions of back squats at a load of 85% of a participant's 1 RM. Forty-metre sprint time decreased significantly by 3.0 % ($p < 0.05$) when compared to the control, however, it must be noted that running times were recorded by the use of a stopwatch, which would definitely affect the reliability of the study.

Other studies have displayed a significant increase in jumping performance after a particular heavy dynamic CA. Young, Jenner and Griffiths (163) showed that loaded CMJ performance increased significantly by 2.8% ($p < 0.05$) after a CA of five half squats at a load of 5RM. These results were also supported by Kilduff et al. (82), who increased participants peak power, peak rate of force development (RFD) and jump height in the CMJ after performing a CA of three sets of three repetitions of back squats at a load of 87% of participants 1RM. Despite these results, Khamoui et al. (81) found contradicting results after a CA with heavy back squats. Khamoui et al. (81) used two, three, four and five repetition of back squats at 85% of 1 RM on separate occasions; however, no protocol had any significant change on vertical jump performance when compared to the control protocol. Scott and Docherty (123) also found that a 5 RM back squat did not potentiate vertical or horizontal jump performance. Both researchers concluded that the insufficient rest period and the strength and training history of the participants may have contributed to the null finding.

2.8.3 Plyometric CAs

There are examples in the previous literature that have attempted to use plyometric and ballistic activities as a CA in order to elicit potentiation. Chen et al. (30) used sets of drop jumps (DJs) from an individual's optimum height (20, 40 or 60 cm's) as a CA for CMJ performance. Individuals optimum drop height was the height that allowed for the highest reactive strength score. Participants either performed one set or two sets of five drop jumps. After two minutes rest, CMJ performance improved significantly for both DJ protocols when compared to the pretesting values ($p < 0.05$). However, this significant improvement was not maintained as the rest period increased above six minutes. It must also be stated that the warm-up procedure before the CA of this particular investigation was insufficient (5 minute cycle followed by static stretching), hence, any acute improvement in CMJ performance after the plyometric CA could be due to other warm-up mechanisms, rather than potentiation. Similarly to the above investigation, Bridgeman et al. (23) used five repetitions of the DJ in order to potentiate performance in the CMJ. This particular research differed to Chen et al. (30), as participants performed the DJs at body weight (BW), or BW plus 10, 20 or 30% (participants held dumbbells in each hand beside body). After the DJ BW + 20% CA, participants significantly increased CMJ height and peak power (PP) after two minutes rest. From these results, by increasing the load during a plyometric CA could further potentiate subsequent contractions.

Despite the above research providing some evidence for plyometrics as a CA, Villarreal et al. (151) used three sets of 5 DJs (from a participants optimum drop height) as a CA to assess acute responses in CMJ performance, DJ performance and loaded jump squats.

After performing the DJ CA, no significant improvements were identified for any of dependent variables when compared to the pre-test values. Turki et al. (146) used three sets of three tuck jumps after dynamic stretching to assess any improvements in CMJ performance after 15 seconds, 4, 8, 12, 16 and 20 minutes rest (this mix of dynamic stretching and plyometric activities was named the DS/PLYO condition). The DS/PLYO CA did not show significant improvements, however, the dynamic stretching only protocol (2.2 cm improvement) and a dynamic stretching plus three heavy deadlifts (2.71cm improvement) did display changes greater than the smallest worthwhile change.

Although plyometric activities have not been consistently successful throughout the potentiation literature, further research may still be required, as plyometric based CAs are the most practical in many sporting situations. For many sporting examples, heavy weights or devices to elicit a maximum isometric contraction cannot be used on-field just before an athlete performs; however, it is possible to employ a variety of plyometric activities. A preponderance of previous research has only focussed on a low volume of plyometric contacts (23,25,27,42,141,146), however, potentially an increase in the volume of the plyometric CA may lead to more substantial changes in post-performances. Tobin and Delahunt (143) used forty plyometric contacts (20 ankle hops, 15 hurdle hops and five drop jumps) in order to potentiate CMJ performance. Countermovement jump height increased significantly by 4.8% one minute after the performance of the CA. Despite this finding, it must be noted that the warm-up prior to the CMJ pre-test involved no aerobic component and may have been inefficient in optimising pre-test performance.

Considering plyometric activities are so short in their duration (ground contacts generally < 0.25s compared to a heavy squat > 2s), potentially CAs that use plyometrics needs to increase the number of ground contacts similar to that of Tobin & Delahunt (143). Future research could focus on increasing the amount of plyometric activities performed and control the time under tension from these plyometric contacts, so that they match the time under tension of successful heavy dynamic CAs.

2.8.4 Optimal CA parameters

There is more literature to support both heavy dynamic activities (39,44,102,163) and isometric MVC's (21,52,62) as successful CA than plyometric exercise. Turki et al. (146) compared different CAs and their effect on CMJ performance. The different protocols were dynamic stretching (DS), three sets of 3 maximal tuck jumps (DS/PLYO), three sets of three deadlifts (concentric) and three repetitions of a 3-second isometric MVC squat (isometric). Only the dynamic stretching (2.2cm) and the concentric protocols (2.7cm) significantly increased jump height above control levels. Both the isometric and the plyometric activities did not increase improve CMJ height above the smallest worthwhile change. These results suggest that heavy dynamic activities are generally more effective in eliciting potentiation.

Wilson et al. (154) performed a meta-analysis on past PAP research and concluded that dynamic CAs were more effective than isometric, as the intensity of the CA can more accurately be controlled. Heavy dynamic activities make it easy to distinguish the intensity of the CA, whilst isometric activities are more difficult (unless you perform them at maximum effort). Future research should use heavy dynamic activities as a CA, as it has best been supported by the literature. Further investigation is needed into increasing the volume of plyometric activities to match the "time under tension" of heavy dynamic activities. The practical implications from a successful plyometric CA protocol are large, as they're easy to complete (no equipment) which allows them to be performed on-field in specific sporting scenarios.

2.8.5 Effect of CA load and repetitions

The intensity or load of CAs as well as the repetitions performed have also varied drastically throughout the potentiation research. For heavy dynamic CAs, studies have successfully used the following sets, repetition and load schemes to potentiate subsequent performance; three repetitions with a 3RM load (or approximate) (33,39,82,91,116), five repetitions at a 5RM load (19,31,103,163), four repetitions of a 5RM load (81,115,139,151), six repetitions at 65% of 1RM, (3), five sets of two repetitions with increasing loads (57) as well as 10 sets of one repetition at 90% of participants 1RM load (28). Furthermore, isometric CAs have also varied in the percentage of maximum effort as well as the time that that the conditioning contraction was maintained (54,62,76).

From the above inconsistencies, it is understandable that it is unclear as to what the best repetition and load protocol is in order to maximise performance via potentiation. Despite this, the meta-analysis by Wilson et al. (154) concluded that for heavy dynamic CAs, the optimum intensity should be between 60 and 85% of an individual's 1RM for recreationally trained participants.

2.8.6 Sets volume within a CA

Another question in relation to PAP research is whether a CA should be only a single set, or spread across multiple sets. Much of the past research has only used single sets in a CA (19,33,91,102,103), where other examples have produced positive change after a CA that involved multiple sets (31,39,44,57,118). Batista et al. (9) suggested that by using multiple sets within a CA that a "stair case effect" would occur, allowing for a greater PAP response. Batista et al. (9) used intermittent knee extensions as a CA to investigate the effect it would have on potentiation. Participants performed a total of 10 sets of one maximal isokinetic knee extensions 30s apart from one another. After the performance of the CA, knee extension torque significantly increased across all post-time tests when compared to the pre-tests ($p < 0.05$). Furthermore, Wilson et al. (154) concluded that for athletes with high strength and extensive weight training experience, a CA with multiple sets will be more beneficial. Wilson et al. (154) also recommended that for recreationally trained participants, that a CA should only involve one set of exercises. Further research should be conducted comparing the effects of multiple to single set CAs amongst different populations of participants.

2.8.7 Strength of participants

It has been suggested extensively throughout the research that participants with greater muscular strength and resistance training experience are more likely to obtain a potentiating effect from a CA (15,31,44,116,125,128,129,163). Furthermore, a higher proportion of fast twitch muscle fibres has also been suggested to improve an individual's likelihood of obtaining a potentiating effect (128). Young, Jenner and Griffiths (163) reported a significant and very large correlation between 5RM strength and the enhancement in jump performance following a squat CA. Furthermore, Duthie, Young and Aitken (44) initially found no significant difference in jump squat performance after a heavy dynamic CA when compared to the control condition. After this non-significant finding, researchers then split the participants into two groups; a high strength and a low strength group depending on their 1RM testing results. The high strength group expressed significant increases in peak power for the jump squat after the CA, whilst no significant differences in performance were evident for the low strength group.

Suggestions were originally made that in order to see a potentiating response in jumping activities, participants should have a relative 1RM back squat greater than 1.5 times their body weight (31,44,116). More current research from Seitz, Villarreal and Haff (129) suggested that relative strength should exceed two times body weight in order to maximise a potentiating response.

In terms of the amount of relative strength required in order to identify a positive potentiating response, the squatting depth used throughout 1RM testing in the PAP literature is inconsistent, which makes it difficult to distinguish a particular relative strength guideline for all CAs. Some research use the full back squat (103,116,118,153) as a CA (upper-leg parallel to the ground), whilst other research only uses half-squats within a CA (90º knee angle) (57,107,131,163), however, the maximum loads that participants can lift within each exercise would be vastly different (much lower with the full back squat compared to the half-squat). It is assumed that the previous relative strength guidelines within the literature are based around the full back squat; hence, future research may need to distinguish strength requirement guideline for the half-squat in order to see a positive potentiation response.

Past research has focussed upon strength training experience and its effect on potentiation, however, minimal research has focussed specifically upon highly "sports trained" athletes. You could have elite athletes in their sport with high technical training, but not well strength trained. Potentiation research has used highly sports trained individuals and displayed positive improvements in performance after a CA (25,33,141,153), however, it has generally been concluded that the potentiation effect was due to their high strength level. Future research could focus upon comparing highly strength trained and highly sports trained populations, and what affect each has upon potentiation.

2.8.8 Other mitigating factors of CA on potentiation

Despite the different types and intensities of the CA, the rest periods allowed and the physical attributes of the participants all being reasons that may have contributed to the inconsistencies within the PAP research, there are potentially other factors that may also contribute to the erratic findings of the previous literature that have not previously been considered. Examples may include the warm-ups used prior to the performance of the pre-test as well as the lifting strategy used throughout the heavy dynamic CAs.

2.8.9 The effect of the general warm-up prior to pre-test

Before the commencement of any physical activity, participants should perform a warm-up in order to minimise the risk of injury as well as to optimise performance. Previous literature has suggested that an effective warm-up should be comprised of a ten minute aerobic component (approximately 60% of VO_2 max) (17,18), a bout of dynamic stretching (12,13,41,105,146) as well as a specific skill rehearsal component (60,161) in order to maximise athletic performance.

There are many reasons as to why a warm-up will increase an athlete's performance other than potentiation. Bishop (18) suggests that a warm-up improves performance due to an increase in muscle temperature, increased baseline oxygen consumption as well as possible psychological reasons. An increase in muscle temperature leads to vasodilation of the blood vessels, hence increasing blood flow to the working muscles (104,105) preparing them for exercise. Dynamic stretching has also been suggested to increase performance, as it allows a greater uptake of O_2 at working muscles, increases the range of motion (ROM) of the individual and decreases the lactate and increases the blood pH levels, which improves the efficiency of thermoregulation (105). Finally, by performing practice efforts of the skill, participants are able to use the specific neural pathway of the activity, which improves the readiness of the individual's neuromuscular system (161). An optimum WU requires a brief rest interval to dissipate the negative effects of fatigue. It might be expected that the optimum load of the WU exercise and the recovery should be individualised, based in the individual's fitness (120,161).

If the volume or intensity of a warm-up is too high, research has shown that it can have a negative effect on sporting performance. Wittekind et al. (157) conducted a study which involved participants taking part in moderate, high or severely intense warm-ups. Researchers found that the mean power progressively decreased through 30 second Wingate tests as the intensity of the warm-up increased (moderate: 672 W, high: 666 W, intense: 655 W). Hence, there is an optimal duration and intensity for an ideal warm-up. Furthermore, it must be noted that the optimal warm-up will vary between people, as everyone has different fitness capabilities (161).

The concept of exploiting PAP assumes that the general warm-up prior to any pre-tests, is adequate. Therefore, the CA "adds value" to potentiate performance, rather than just making up for a poor warm-up. If the general warm-up used before a CA is insufficient, then improvements in performance may not be due to the mechanisms of PAP.

2.8.9.1 Warm-ups throughout the PAP Literature

The general warm-ups used before any pre-test measurements have varied significantly throughout the PAP literature. Some warm-ups have only involved five minutes of light aerobic exercise (88,102,111), whilst others have been thorough involving an aerobic component, dynamic stretches as well as performance of the specific skill (9,31,54). Some studies only used stretching that was of a dynamic nature (82,99), whilst particular PAP studies have used static stretching techniques within the warm-up (30,44,69), even though research has suggested that static stretching has a negative effect on speed-strength (25,50,105,161).

If a warm-up is not optimum, it could affect the pre-testing results of participants in a negative manner. A participant then performs a CA, which increases their post-test performance. But because the original warm-up prior to the pre-testing was inefficient, are these improvements from the CA due to potentiation, or are the simply enhancing performance due to the mechanisms of a general warm-up that were not optimised prior to the pre-test?

There are many examples of studies that have suggested a positive improvement in performance due to potentiation, however, these examples have used an insufficient warm-up prior to the pre-test (88,102,111,158). McBride, Nimphius & Erickson (102) required participants to perform five minutes of jogging as a warm-up before pre-testing 40-metre sprint performance. Researchers then concluded that the 0.9% significant decrease in post 40-metre sprint time was due to the CA (three repetitions of back squats at 90% of 1 RM). With the insufficient warm-up protocol, it is unclear whether the CA has improved performance due to PAP, or whether the CA along with the pre-test itself (practise sprint), have just added to the general mechanisms of an efficient warm-up.

Insufficient and inconsistent warm-ups are a weakness throughout the PAP literature. Therefore, it is important for future research to perform an optimal warm-up prior to pre-testing, hence, any positive change in performance can be attributed to a potentiating effect.

2.8.10 Effect of maximising intention to lift explosively during half-squat CAs

Heavy squats (full or partial) have been identified as successful CAs to potentiate performance throughout the literature (33,107,118,153,163), however, the instructions of these squats haven’t always been the same. Some of the past literature has instructed at a controlled speed (102), whilst other research has instructed participants to maximise intention to move the bar quickly in the upward phase of the squat (57). By changing the tempo of the squat, the kinetics and kinematics have been shown to change (121). Furthermore, by increasing the intention to lift the weight as fast as possible, the neural mechanics of the squat change. Efforts that require high force as well as high speed have been shown to create larger motor unit recruitment, as well as increased firing frequency and synchronisation (14). Increasing the intention to lift explosively has also been shown to have greater chronic changes in power development when compared to controlled squats (14,162).

Considering the change in kinetic, kinematic and the response of the neural system between controlled and explosive squats, the effect each squatting strategy has as a CA could be quite different. Despite this, no previous research has compared squatting with maximal intention to move explosively to controlled squats during CAs and the effect each technique has on potentiating future contractions.

2.8.11 Other potential fitness components

Despite a plethora of the previous literature suggesting the participant strength if vital in order to identify a positive potentiating response (31,44,116,125,128,129,163), the effect of other physical qualities on potentiation has not been assessed. Past research has suggested that participant with a better endurance capacity may produce a greater potentiating effect, as they will be more accustomed to recover from the fatigue created by the CA (20,65). Despite this fact, no previous literature has attempted to assess if other physical attributes (for example aerobic endurance, sprint speed, muscular endurance) of individuals influences whether they respond positively to a CA.

2.9 Examples of previous PAP studies

2.9.1 Examples of past potentiation research that has used an insufficient warm-up

After the previous discussion on warm-ups used throughout the potentiation literature (2.8.9.1), below are examples that have used insufficient warm-ups prior to any baseline measurements. For this particular table, an insufficient warm-up was considered to be any warm-up that did not have an aerobic component greater than five minutes, didn't consist of dynamic stretching or any maximal skill rehearsal of the performance measure. Furthermore, as static stretching has been shown to decrease performance, any warm-up that consisted of large amounts of static stretching was also considered to be insufficient.

Table 2.2. Examples of research using an inappropriate warm-up prior to the performance of a CA. Sig = significant; ↑ = increase; DJ = drop jump; CMJ = countermovement jump VJ = vertical jump; JS = jump squat; BS = back squat; RM = repetition maximum; min = minutes & sec = seconds.

Author	Participants	Warm-up used	CA	CA Volume & Intensity/ Load	Rest Period	Performance Measure	Outcome/s
Chen et al. (30)	10 division 1 collegiate volleyball players	5 minutes of cycling followed by 5 minutes of static stretching of the lower limbs	DJ	Either 1 or 2 sets of 5 reps of the DJ	2, 6 and 12 mins	CMJ	Sig ↑ in CMJ for both conditions after two minutes of rest
Duthie, Young & Aitken (44)	11 female hockey or softball athletes	4 mins of cycling followed by 5 mins of static stretching. Warm-up finished with several sets of sub-maximal squats.	BS	3 sets of 3 reps @ 3RM load	4 mins	JS	Originally no sig change Stronger participants sig ↑ JS peak force by 2% after contrast method
Harrison (69)	10 recreationally trained males	3 mins of jogging followed by upper body static stretching.	Repeated sled push	Repeatedly pushed the weighted sled until push height dropped below 90% of max push height	15, 45, 120 & 300 seconds	Sled push	Sled push height sig ↑ by 7.9% and reactive strength sig ↑ by 7.5% after 300 seconds of rest
Hilfiker (71)	13 male international athletes	Participants performed their own warm-up, that mainly consisted of static stretching	DJ	1 set of 5 DJs off 60cm box	1 min	CMJ	Sig 2.2% ↑ in CMJ PP
Linder et al. (88)	12 collegiate level female participants	5 minutes of cycling at 70 RPM with a resistance of 1 kg.	BS	4 reps at a 4 RM load	9 mins	100m sprint	Significantly ↓ 100m sprint time by 0.19 sec
McBride et al. (102)	15 male collegiate footballers	5 minutes of sub-maximal cycling and 4 minutes of walking	BS or loaded CMJ	BS 1 x 3 @ 90% 1RM Loaded CMJ 1 X 3 @ 30% 1RM	4mins	40m sprint with splits at 10 and 30m.	Sig 0.87% ↓ in 40m sprint time for the BS CA.

Okuno et al. (111)	12 male handball players	5 min jog without heart rate going above 140 BPM	BS	5 sets of 1 repetition @ 90% 1RM load	4 mins	Repeat sprint ability (RSA) test	RSA best sig ↑ by 1.4% (0.08s. $p < 0.05$)
Rahimi (115)	12 elite male soccer players	5 minute cycle followed by 4 minutes of walking	BS	2 sets of 4 reps @ either 60, 70 or 85% of participant 1RM load	4 mins	40m sprint	All CA intensities sig ↓ 40m sprint times (60% 1RM = 1.9%; 70% 1RM = 1.77%; 85% 1RM = 2.98%).
Terzis et al. (140)	8 male and 8 female recreationally trained	5 minutes of running followed by 5 minutes of stretching	DJ	5 maximal from 40cm box	No rest	Underhand squat throw	Throw distance sig ↑ by 4.6%.
Tobin & Delahunt (143)	20 professional rugby union players	*Consisted of:* 10 body weight squats 10 lunges 3 mins of dynamic stretching 5 sub-maximal CMJs	Ankle hops Hurdle hops Drop jumps	2 x 10 ankle hops 3 x 5 hurdle hops 1 x 5 drop jump (50cm box) Total: 40 jumps	1, 3 & 5 minutes	CMJ	CMJ height and PF ↑ significantly across all post times. JH 4.8% ↑ after 1 min rest being the greatest.
Yetter & Moir (158)	10 recreationally trained participants	5 minute cycle (light-moderate) and 4 minute walk	BS or Front squats (FS)	Performed 3 sets of CA at the following repetitions and loads: 5 x 30% 1 RM 4 x 50% 1 RM 3 X 70% 1 RM	4 mins	40m sprint	The BS CA produced significantly faster40m sprint times than the control (2.3%, p=0.02)

2.9.2 Examples of past potentiation research that has used plyometric CAs

Table 2.3 below provides examples from the literature that have used plyometric CAs in order to potentiate future performance. Both successful and unsuccessful outcomes are included within the table.

Table 2.3. Examples of research using plyometric CAs in order to elicit a potentiating response in post-performance. Sig = significant; ↑ = increase; DJ = drop jump; CMJ = countermovement jump VJ = vertical jump; JS = jump squat; BS = back squat; BW = body weight; RM = repetition maximum; min = minutes & sec = seconds.

Author	**Participants**	**CA**	**CA Volume & Intensity/ Load**	**Rest Period**	**Performance Measure**	**Outcome/s**
Bridgeman et al. (23)	12 strength trained males	DJs	5 reps of DJs at either BW, or BW + 10, 20 or 30%.	2, 6 and12 mins	CMJ	Sig ↑ in CMJ JH and PP after BW+20% DJ protocol. Also concluded two minutes best rest period
Burkett et al. (25)	29 collegiate track or football players	Weighted box jump	1 set of 5 reps @ 10% BW	2 mins	VJ on vertec	Sig 3.3% ↑ in VJ height
Chattagong et al. (27)	20 resistance trained males	Weighted box jumps	1 set of 5 reps @ either 5, 10, 15 or 20% of BW.	2 mins	VJ on vertec	Sig time effect ($p<0.05$) between pre and post-VJs
Deutsch & Lloyd (42)	8 male university rugby players	CMJ	3 sets of 1 CMJ	10 mins	20m sprint	Sig ↓ in sprint performance after CMJ CA
Esformes, Cameron & Bampouras (47)	13 recreationally trained males	Rebound jumps	3 sets of 24 rebound jumps	5, 10 and 15 mins	CMJ	No sig changes from pre to post-tests
Miarka, Del Vecchio & Francinni (106)	8 male judo athletes	Drop jumps	10 x 3 reps @ 20,40 and 60 cms	3 mins	Specific judo fitness test	After the plyometric CA sig 14.3% ↑ in throws performed.
Till & Cooke (141)	12 professional soccer players	Tuck jumps	5 tuck jumps	4, 5 or 6mins (sprint) 7, 8 or 9 mins (VJ)	Sprint and VJ	No significant change in either sprint or VJ performance at any rest period.
Turki et al. (146)	20 highly trained male athletes	Tuck jumps	3 sets of 3 reps	15 seconds, 4, 8, 12, 16 & 20 mins	CMJ	Plyometric CA did not create a high likelihood of exceeding the smallest worthwhile change
Turner, Bellhouse, Kilduff & Russell (147)	23 plyometrically trained males	Alternate leg bounding	3 sets of 10 bounds either at BW, or BW + 10%	15 seconds, 2, 4, 8, 12 and 16 minutes	20m sprint with 10m split	*Body weight bounds:* Sig 3.3% ↑ in 10m sprinting velocity compared to control condition at four minutes post ($p = 0.047$). *Weighted bounds:* Sig 3.1% ↑ in 10m sprinting velocity compared to control condition at 4 minutes (p =

						0.009) and a sig 3.6% ↑ at eight minutes ($p = 0.002$).
Villarreal et al. (151)	12 trained volleyball players	DJ	3 sets of 5 reps	5 mins	DJ, CMJ & loaded CMJ	No sig change in any jumping performance

2.9.3 Successful use of potentiation protocols identified throughout the literature

Below are examples from the literature that have successfully potentiated future performance by the use of a CA. To define successfully potentiate performance, the studies in the following tables either displayed a significant improvement in post-performance ($p < 0.05$), produced a change with an effect size that was at least small ($ES > 0.20$) or produced a change greater than the smallest worthwhile change. The type of participants, the type and intensity of the CA used, the rest period after the CA and the outcome are all mentioned within the tables.

2.9.4 Literature that has positively potentiated jumping performance

Table 2.4 below provides many examples throughout the literature that have used a particular CA (varying in type (not plyometric) and intensity) to increase all types of post-jumping performance after an allocated rest time.

Table 2.4. Examples of literature reporting significant increases ($p < 0.05$) in jumping performance following a lower-body CA. Sig = significant; ↑ = increase; DJ = drop jump; CMJ = countermovement jump VJ = vertical jump; JS = jump squat; BS = back squat; BW = body weight; RM = repetition maximum min = minutes & sec = seconds.

Author	**Participants**	**CA**	**CA Volume & Intensity/ Load**	**Rest Period**	**Performance Measure**	**Outcome/s**
Boullosa & Tuimil (20)	12 endurance trained athletes	Performance of the "university of Montreal track test"	Performed running test	2 & 7 mins	CMJ	Sig ↑ in CMJ height at both 2 and 7 minutes rest
Boullosa et al. (19)	12 recreationally trained	HS	1 set of 5 reps @ 5RM load. Either performed "traditionally" or in "cluster" (30 secs between reps)	1, 3, 6, 9 & 12 mins	CMJ	**Traditional** Sig ↑ in CMJ JH and PP after 9 mins rest **Cluster** Sig ↑ in CMJ JH and PP after 9 mins rest
Boyd, Donald & Balshaw (21)	10 strength trained males	Isometric squat or HS	1 sets of 3 reps @ 150% 1RM BS load (HS condition) or a single isometric effort	2 and 11 mins	CMJ	Sig ↑ in CMJ PF across both conditions (although sig ↓ in PP)
Chiu et al. (31)	12 male and 12 female Split into athletic (n=7) and recreational (n=17)	BS (parallel)	5 sets of 1 rep @ 90% 1RM load	5 & 18.5 mins	Rebound JS and concentric only JS (30, 50 & 70% of 1RM)	Average force, power and peak power all sig ↑ for the rebound JS (30% 1 RM load)
Clark, Bryant & Reaburn (32)	9 strength trained males	Loaded CMJ	40 kg load with the reps varied to match concentric work of control condition	4 mins	Sets of loaded CMJ (20 kg)	The 40kg loaded CMJ CA sig ↑ JH compared to the 20kg loaded CMJ condition.
Comyns et al. (33)	12 elite rugby players	BS	1 set of 3 reps @ 65, 80 & 93% of 1RM load	4 mins	DJ	Although flight time ↑, contact time improved sig by 7.8% after the 93% 1RM CA
Crewther et al. (39)	9 sub-elite male rugby players	BS	3 reps @ 3RM load	15 seconds, 4, 8, 12, 16 minutes.	CMJ	Sig ↑ in JH @ 4 mins (3.9%), 8 mins (3.5%) and 12 mins (3%).
French, Kraemer and	14 track and field	Isometric knee ext.	Either 3 sets of 3 or 5	10 mins	CMJ, DJ, 5 sec	**3 x3 sec CA**

Cooke (54)	athletes		seconds		Sprint cycle & isokinetic knee extension	Sig 5% ↑ in DJ height Sig 5 % ↑ in DJ max force
Garcia-Pinillos, Soto-Hermoso & Latore-Romàn (55)	30 endurance trained athletes	400m efforts	4 sets of 3 reps of 400m high intensity efforts	2 mins after each set	CMJ and 3 sec hand grip strength	For the PAP responders within the study (n = 17), sig ↑ in both CMJ and hand grip performance after the sets of sprints
Gourgoulis et al. (57)	20 physically active males	HS	5 sets of 2 reps @ 20, 40, 60, 80 & 90% of 1RM	Directly after final set	CMJ	Sig 2.4% ↑ in CMJ JH Stronger participants sig 4% ↑ in CMJ JH
Gullich & Schmidtbleicher (62)	36 strength trained participants	Isometric leg press	3 x 3 seconds Or 3 x 5 seconds	3 – 5.20 mins	CMJ & DJ	Sig 3.3% ↑ in CMJ height
Iglesias-soler et al. (76)	14 male sports science students	Isometric soleus contraction	Either 10 or 100% max effort for 7 or 10 seconds	5 secs, 4 and 10mins.	Plantar flexion power output	Sig ↑ in power output after 4 mins rest for the maximal 10 sec isometric CA
Kilduff et al. (16)	20 professional rugby players	BS	3 sets of 3 reps @ 87% of 1RM	15 seconds, 4, 8, 12, 16, 20 & 24 minutes	CMJ	PP & JH sig ↓ at 15 secs rest PP & JH sig ↑ at 8 minutes rest
Kilduff et al. (82)	23 professional rugby players	BS	1 set of 3 reps @ 3RM load	15 seconds, 4, 8, 12, 16 & 20 minutes	CMJ	CMJ height sig ↑ at both 8 and 12 mins rest

Lowery et al. (91)	13 recreationally trained males	BS	**3 conditions** 1 x 5 @ 56% 1RM 1 x 4 @70% 1RM 1 x 3 @ 93% 1RM	0, 2, 4, 8 & 12 mins	VJ height and PP	Sig ↑ in VJ height and PP for heavy CA @ 4 and 8 minutes. Sig ↑ in VJ height and PP @ 4 minutes
McCann & Flannigan (103)	16 volleyball athletes (women n=8 male n=8)	BS Hang clean (mid-thigh)	5 repetitions at a 5RM load	4 or 5 mins	VJ	Sig 5.7% ↑ in JH after each individuals best CA (either BS or hang clean).
Mitchell & Sale (107)	11 university rugby players	HS	5 repetitions at a 5RM load	4 mins	CMJ	Sig 2.9% ↑ in CMJ JH.
Rixon et al. (116)	30 recreationally trained male (n=15) & females (n=15)	BS	3 reps at a 3RM load	3 mins	CMJ	Males sig 2.9% ↑ in JH and sig 8.7% ↑ in PP.
Ruben et al. (118)	12 Male participants (1RM BS > 1.5 BW)	BS	Three ascending sets 5 @30% 1RM 3@ 70% 1RM 3@ 90% 1RM	5 mins	5 horizontal hurdle jumps.	Sig ↑ in average PP, max PP and max PF after the BS CA.

Smilios et al. (131)	10 recreationally trained males	HS or loaded JS	3 X 5 JS @ 30 or 60% 1RM 3 x 5 HS @ 30 or 60% 1RM	5 & 10 mins	CMJ	Sig ↑ across all CAs apart from HS @ 30% 1RM load
Turki et al. (146)	20 highly trained male athletes	Deadlift	3 sets of 3 reps @ 3RM load	15 seconds, 4, 8, 12, 16 & 20 mins	CMJ	Deadlift CA elicited a substantial likelihood to potentiate CMJ height, power, velocity and peak force (> 75% likelihood of exceeding cohen's *d*)
Villarreal et al. (151)	12 trained volleyball players	BS	Either: 2 sets of 4 reps @ 80% 1RM + 2 sets of 2 reps @ 85% 1RM load Or 2 sets of 4 reps @ 80% 1RM + 2 sets of 2 reps @ 90% 1RM load + 2 sets of 1 rep @ 95% 1RM load	5 mins	DJ, CMJ & loaded CMJ	Both CAs sig ↑ DJ height, CMJ height and loaded CMJ height. However, it must be noted that all of the above variables increased most after a specific volleyball WU that did not include a CA.
Weber et al. (153)	12 Div 1 collegiate track and field athletes	BS or JS	BS: 5 repetitions @ 85% 1RM load JS: 5 unweighted JSs	3 mins	JS	Sig ↑ in mean JH (5.8%), peak JH (4.7%) and PF (4.6%) after the BS CA. The JS CA decreased most jump variables.

Young, Jenner & Griffiths (163)	10 male participants	HS	1 set of 5 reps @ 5RM load	4 mins	Loaded CMJ (19kg load)	Sig 2.8% ↑ in loaded CMJ height

2.9.5 Literature that has positively potentiated sprinting performance

Table 2.5 below provides many examples throughout the literature that have used a particular CA (varying in type and intensity) to increase post-sprinting performance after an allocated rest time.

Table 2.5. Examples of literature reporting significant increases ($p < 0.05$) in sprinting performance following a lower-body CA. ↓ = decrease.

Author	**Participants**	**CA**	**CA Volume & Intensity/ Load**	**Rest Period**	**Performance Measure**	**Outcome/s**
Bevan et al. (15)	16 professional rugby players	BS	1 set of 3 reps @ 91% 1RM load.	4, 8, 12 & 16 mins	10m sprint with 5m split	When each individuals best rest period was considered, both 5 and 10m sprint times ↓ significantly by 0.04 secs.
Chatzopoulos et al. (28)	15 recreationally trained males	BS	10 sets of 1 rep @ 90% 1 RM load	3 & 5 mins	30 metre sprint with 10 metre split	Sig ↓ in sprint time for both 0-10 and 0–30 m sprint times after 5 minutes rest. Sprint times ↑ after only 3 mins rest.
Crewther et al. (39)	9 sub-elite male rugby players	BS	3 reps @ 3RM load	15 seconds, 4, 8, 12, 16 minutes.	10m sprint with a 5m split	Post-best 5m sprint time 2.6% faster than pre-tests.
Matthews, Matthews & Snook (99)	20 male rugby players	BS	5 reps @ a 5RM load	10 mins	20m sprint	Sig 3.3% ↓ in 20m sprint time
Seitz, Mina & Haff (125)	20 male rugby league players	Weighted sled push	Either 9m push at 120% BW or 15m push at 75% BW	15 seconds, 4, 8 and 12 mins.	20m sprint	Sig improvements in sprint performance at post-8 and 12 minutes for the lighter CA (75% BW)
Seitz, Trajano & Haff (128)	13 elite junior rugby league players	BS or power cleans	1 x 3 @ 90% of 1RM load	7 mins	20m sprint	Both the BS and power clean CA sig ↓ 20m sprint times (back squat: $p=0.001$, ES = -0.66; power cleans: $p=.001$, ES = -0.92),

2.9.6 Literature that has positively potentiated upper-body performance

Table 2.6 below provides many examples throughout the literature that have used a particular CA (varying in type and intensity) to increase post-upper-body performance after an allocated rest time.

Table 2.6. Examples of literature reporting significant increases ($p < 0.05$) in upper body performance following a CA. BP = bench press.

Author	Participants	CA	CA Volume & Intensity/ Load	Rest Period	Performance Measure	Outcome/s
Baker (3)	16 national or state level rugby league players	BP	6 reps @ 65% of 1RM	3 mins	BP throw	A sig 4.5% ↑ in BP throw height.
Baker (4)	7 professional rugby league players	BP with chains	Sets of 3 BP @ 65% 1RM load with 17.5kg chains	90 secs	BP throw (60kg)	In all sets, BP throw mean concentric power sig ↑ by 3.4 – 7.7%
Baker (6)	11 professional rugby league players	Concentric only narrow grip BP	2 sets of 3 reps	90-120 secs	Concentric only BP throw (60kg)	Sig 3.6% ↑ in BP throw PP
Bevan et al. (16)	26 professional rugby players	BP	3 sets of 3 reps @ 87% 1RM load	15 secs, 4, 8, 12, 16, 20 and 24 mins	BP throw	Both BP throw height and peak power sig ↑ after 8 minutes rest.
Esformes et al. (48)	10male rugby players	Isometric (ISO) Concentric BP (CON) Eccentric BP (ECC) BP (DYN)	*ISO* 7 sec isometric BP *CON, ECC and DYN* 1 set of 3 reps at 3RM load	12 mins	BP throw	ISO CA sig ↑ BP throw PP by 2.8%. CON CA ↑ BP throw PP by 3.3%, although this change was non-significant.
Judge, Bellar & Judge (80)	10 high school trained weight throwers	Weighted throws	**Control**: 5 throws with normal weight **Overweight 1**: 5 throws with implement 1.37kg heavier **Overweight 2**: 5 throws with implement 2.27kg heavier	Immediate, 3 and 6 mins	Weight throw	Both overweight 1 and 2 warm-ups produced significant better throwing distance than control warm-up.
Kilduff et al. (82)	23 professional rugby players	BP	1 set of 3 reps @ 3RM load	15 seconds, 4, 8, 12, 16 & 20 minutes	BP throw @ 40% 1RM	BP throw sig ↑ by 2.8% at 8 mins rest 5.3% at 12 mins.
Markovic, Simek & Bradic (97)	23 recreationally participants (control n=12, experimental n=11)	BP	3 sets of 3 reps @ 90% 1RM load	3 minutes	Medicine ball throw (0.5 and 4.0 kg)	Sig 8.3% ↑in max throwing velocity with 4kg ball

2.9.7 Literature that has positively potentiated performance in activities other than jumping, sprinting or upper-body throwing

Table 2.7 below provides many examples throughout the literature that have used a particular CA (varying in type and intensity) to other specific performance measures after an allocated rest time.

Table 2.7. Examples of literature reporting significant increases ($p < 0.05$) in other physical skills following a CA.

Author	Participants	CA	CA Volume & Intensity/ Load	Rest Period	Performance Measure	Outcome/s
Batista et al. (9)	10 active males (not strength trained)	Unilateral knee extension	10 repetitions at 60º.s^{-1}	4, 6, 8, 10 and 12 mins	Knee extension	Knee extension peak torque was significantly greater in all post-times compared to pre-test.
Etnyre & Kinugasa (49)	12 participants	Isometric knee extension	3 second maximal contraction	1, 2 and 3 seconds	Reaction (RT) and movement time (MT) of knee extension	RT and MT both significantly greater after CA.
Feros et al. (52)	10 national level rowers	Isometric rowing pull	5 x 5 secs (2 secs sub-max & 3 secs max).	4 mins	1000m rowing ergometer perf.	500m (1.9%) and 1000m time (0.8%) sig ↓ after potentiated WU. Peak power showed a 6.6% sig ↑ over first 500m.
Huguchi et al. (70)	24 collegiate baseballers	Isometric emulation of bat swing or weighted bat swings	4 sets of 5 sec maximal contraction	1 min	Bat swing velocity	Bat swing velocity ↑ sig by 0.38 m.s^{-1} after isometric CA. No change after weighted bat swings.
Matthews, Comfort & Crebin (100)	11 competitive ice hockey players	Resisted ice skate sprint	10 second resisted sprint	4 mins	25m Ice skate sprint	Sig 2.6 % ↓ in 25m ice sprint times for experimental condition ($p = 0.02$)
Smith et al. (133)	9 male cyclists	BS	10 x 1 rep @ 90% of 1RM load	5 & 20 mins (separate days)	10 sec sprint cycle	Average power sig ↑ by 4.8% after the 5 min rest period.

2.9.8 Literature that has failed to identify a positive effect on performance after the use of a CA

Table 2.8 below provides many examples throughout the literature that have used a particular CA (varying in type and intensity) and have found no change in performance measures after an allocated rest time.

Table 2.8. Examples of literature reporting no significant increases ($p > 0.05$) in other physical skills following a CA.

Author	**Participants**	**CA**	**CA Volume & Intensity/ Load**	**Rest Period**	**Performance Measure**	**Outcome/s**
Boyd, Donald & Balshaw (21)	10 strength trained males	Isometric squat or HS	1 sets of 3 reps @ 150% 1RM BS load (HS condition) or a single isometric effort	2 and 11 mins	CMJ	Sig ↓ in CMJ PP across both conditions (although improvements in peak force)
Brandenburg (22)	9 recreationally trained male university students	BP	Either 5 repetitions at 50, 75 or 100% of 5RM load	4 mins	Bench press throw	No significant changes for any testing protocol
Chaouachi et al. (26)	12 volleyball athletes	BS	Either: 10 reps @ 70% 1RM 5 reps @ 70% 1RM 5 reps @ 85% 1RM 3 reps @ 85% 1RM 3 reps @ 90% 1RM 1 rep @ 90% 1RM	1, 3, 5, 10 and 15 mins	CMJ	No significant change in any CMJ with it being concluded that it would be probable CMJ perf ↓ after 5 mins rest.
Comyns et al. (34)	18 anaerobically trained subjects (9 female, 9 male)	BS	5 reps @ 5RM load	30 seconds, 2, 4 or 6 mins	Sledge CMJ	Sig ↓ in flight time after 30 seconds and 6 minutes rest. No improvement at other rest intervals.
Deutsch & Lloyd (42)	8 male university rugby players	BS	3 sets of 1 Rep @ 3RM load	10 mins	20m sprint	No change in sprint performance after BS CA.
Ebben, Jensen & Blackard (45)	10 resistance trained division 1 college basketballers	BP	5 reps at a 5RM load	3 mins	Med ball power drop test (GRF as well as EMG)	No significant change in GRF or EMG after CA
Esformes, Cameron & Bampouras (47)	13 recreationally trained males	HS or control	3 set of 3 HS @ 3RM load	5, 10 and 15 mins	CMJ	No condition displayed sig changes from pre to post-tests, however, jump height sig ↑in squat post-1, when compared to control post-3

Farup & Sorensen (51)	8 strength trained males	BP	5 sets of 1 rep @ 1RM load	2, 10, 15 and 20 minutes	Isometric bench press and bench throw (30% of 1RM)	No change in post-bench throw performance. Significant decreases in post-isometric RFD at post-2 and 10 minutes.
Gossen & Sale (56)	10 moderately active participants	Isometric knee extension	10 second isometric knee extension @ 15, 30, 45 & 60% MVC	15 seconds	Maximal dynamic knee extension	No change in post-knee extension test, with control protocol producing greater post-results than PAP protocol.
Guggenheimer et al. (61)	9 division I college athletes	Power clean	1 set of 3 reps @ 90% 1RM	3 and 6 mins	40m sprint	No change in sprint performance after the power clean CA
Hanson et al. (67)	30 resistance trained subjects	BS	Either 1set of 8 reps @ 40% 1RM or 1 set of 4 reps @ 80% 1RM.	5 mins	CMJ	No significant change in any post-CMJ variable
Hrysomallis & Kidgell (75)	12 recreationally trained males	BP	Five reps @ 5RM load	3 minutes	Power push-ups	No significant increase in any power push up variable.
Jensen & Ebben (77)	21 Division I college athletes (11 females, 10 males)	BS	Five reps @ 5RM load	15 seconds, 1, 2,3 & 4 mins	CMJ	No significant improvement in JH or CMJ PF.
Jones & Lee (79)	10 strength trained males	BS	Multiple sets of 5 reps @ 85% of participants 1RM	3, 10 and 20 mins	CMJ & DJ	No sig change in either of the two types of jump.
Khamoui et al. (81)	16 recreationally trained males	BS	Either 2, 3, 4 or 5 repetitions of the BS with a load of 85% 1RM	5 minutes	VJ	No sig change for any VJ variable. In fact, sig time effect (↓) in PF and VJ impulse
Koch et al. (86)	32 trained and untrained male and female subjects	BS	Either: 3 sets of 3 heavy squats building up load (50, 75 & 87.5% 1 RM) OR 3 sets of 3 light power squats building up load (20, 30 &40% 1RM)	Immediately after 15mins rest	Standing broad jump	No significant change in broad jump performance

Parry et al. (112)	7 male rugby players	BS	5 sets of 1 rep @ 30% 1RM or 5 sets of 1 rep @ 90% 1 RM	20 minutes	30 second Wingate test	No significant change for any variable of the cycling test
Robbins and Docherty (117)	16 male university students	Isometric squat (100º knee angle)	7 seconds maximal contraction	4 minutes	CMJ	No significant change identified for any CMJ variable
Till & Cooke (141)	12 professional soccer players	Deadlift or isometric leg extension	5 reps at a 5 RM (deadlift) or 3 sets of 3 sec MVC (isometric)	4, 5 or 6mins (sprint) 7, 8 or 9 mins (VJ)	Sprint and VJ	No significant change in either sprint or VJ performance at any rest period.

2.10 Conclusion

Post-activation potentiation can be implemented by athletes and coaches to enhance future power performance; however, due to the contradicting results expressed throughout this literature review, the ideal methodology in order to produce a positive potentiating effect is unclear. A focus upon other cofounding variables mentioned within this review (warm-up prior to pre-test, effect of intent to maximise bar velocity during a CA) needs to be made in order to further help the future consistency of research within the area. Once the best methodology to elicit a potentiating response has been addressed, further research can focus upon creating effective CAs that are more practical for certain sporting examples (plyometric CAs). Furthermore, literature can address the individualistic nature of PAP and identify other potential factors other than muscular strength that may influence a potentiating effect.

Chapter 3: Study 1 - The Effect of Warm-up Volume on Potentiation.

3.1 Introduction

3.1.1 Background

Past potentiation research has used insufficient warm-ups prior to any pre-testing performance (30,44,69,88,102,115,143,158). On multiple occasions, participants have only completed an aerobic component of warm-up (88,102,111), whilst other research has used static stretching within their protocol (30,44,69), despite the fact that the inclusion of prolonged static stretching within a warm-up has been identified to decrease subsequent performance (25,50,105,161). From these examples it is suggested that the baseline performance will not be at an optimal level for each individual. If the warm-up before the pre-test does not optimise performance, then any positive change after the CA could be attributed to the general mechanisms of a warm-up, rather than potentiation. Therefore, there needs to be an emphasis that the warm-up used prior to any pre-tests within the PAP literature are effective and sufficient. From this, any increase in performance after the CA can more accurately be assumed due to a potentiating effect, rather than just a general warm-up effect.

3.1.2 Aim

The aim of this study was to identify a participant's optimum warm-up and then assess if a CA of four half-squats at a 5RM load can further enhance CMJ performance.

3.1.3 Research Questions

The main research questions for study 1 were:

1. What is the optimum warm-up (WU) volume for CMJ performance?
2. Did the addition of a CA of four half-squats at a 5RM load potentiate CMJ or drop jump (DJ) performance after an optimum and sub-optimum WU?

The following specific research questions were also addressed throughout study 1:

1. Is a particular WU volume optimal for all/most participants?

3.2 Methodology

3.2.1 Experimental Design

The following study used a within-subjects repeated measures design to establish which warm-up protocol was the most effective for each individual participant and secondly, assess the effectiveness of the CA on post-CMJ performance. All testing sessions were performed within an indoor venue with a temperature (between 18 and 22º C) as well as other environmental conditions could be controlled. The same conditions were used for all testing sessions used throughout this thesis. After the familiarisation sessions, participants completed six different experimental warm-up sessions in a random order 2-5 days apart. An ideal warm-up is individualised (95) depending on the participant's fitness level. The optimum WU for each individual was the procedure that produced the greatest relative peak power (RPP) within the CMJ test. After completing the 6 experimental warm-up sessions, participants performed their "optimum" warm-up and the warm-up that was the next lowest in total volume (explained later) on separate days, with the addition of the four half-squat CA to assess the potentiation effect on post-CMJ performance. These last two sessions were completed 2-5 days apart and performed in a random order.

With the six WU volumes, the very low volume (WU1) was considered likely to be insufficient, whereas the very high volume (WU6) was considered to be excessive. By doing this procedure, it is expected to identify the individual differences of the participants so that each individual's optimum warm-up can be specified.

Although each individual's optimum warm-up was identified, analysis was also conducted to decide which warm-up was best on average. If a particular warm-up seems better for most participants, then time constraints to calculate each individual's optimum warm-up may not be required for future research.

3.2.2 Participants

Sixteen recreationally trained male university students with a minimum of one year resistance training experience completed the following study (Mean ± SD age = 21.4 ± 1.9 years, height = 179.9 ± 6.1 centimetres, body mass = 81.7 ± 8.1 kg, predicted 1RM half-squat = 193.6 ± 42.6 kg). Participants were all over the age 18, free of injury or illness and were able to half-squat 1.5 times their body weight for one repetition. These requirements were established as previous research has positively attributed participant strength with potentiation (31,44,115). Recruitment of males was deemed more likely to yield adequate numbers based on participation rates in resistance training. Recruitment of one gender was undertaken as it is unclear in the research if males and females respond differently to potentiation. Before the commencement of the study, the procedure and potential risks were explained to all participants and informed consent was obtained. The study had ethical approval from the Human Research Ethics Committee (HREC) at Federation University Australia. After all participants had acquired their optimum warm-up, two participants dropped out of the study due to injuries that occurred outside of testing sessions.

3.2.3 Procedures

Overall participants completed nine separate sessions that were two to five days apart.

Session 1-2: Familiarisation session of procedures and 5RM half-squat testing.

Sessions 3-8: Different warm-up sessions ranging from low to very high volumes (random order).

Sessions 9-10: Optimum warm-up condition (best results from sessions 3-8) plus CA and warm-up volume directly below best plus CA.

3.2.3.1 Familiarisation and 5 RM Testing Sessions.

Each participant attended two familiarisation sessions. Within the first session, participants initially had their half-squat height (90º knee angle) determined with the use of a goniometer. Participants lowered approximately into a half-squat position within the Smith machine and were instructed to either move up or down by a research assistant to obtain a 90º knee angle. Once they were in the appropriate position, a marker was placed on the side of the Smith machine that had a tape measure showing how far the marker was from the ground. For the remainder of the study, the marker was placed at each participant's half-squat height and allowed for consistent half-squat depth from session to session.

Before the commencement of the 5RM half-squat test, participants performed three warm-up sets with submaximal loads of their self-predicted 5RM. These sets were two minutes apart and included eight repetitions with 50%, five repetitions at 70% and three repetitions at 90% of their predicted 5RM load. Participants then commenced a 5RM half-squat test, with participants selecting a load that they believed was close to their 5RM. If the participant successfully lifted the load for five repetitions, the load was increased and after a sufficient recovery (longer than four minutes), participants proceeded to attempt to lift the load again for five repetitions. Once a participant failed to complete five repetitions at a particular load, their last successful lift was considered their 5RM.

After distinguishing their 5RM half squat, participants practised CMJ's on the Ballistic Measurement System (BMS) with the linear position transducer to allow for familiarisation of the CMJ. Participants were instructed to perform the CMJ at a self-selected speed and depth before jumping upward for maximal height (138) with their hands placed on the bar evenly spread away from their shoulders. In the second familiarisation session, participants practised the dynamic stretches used within the warm-up and their warm-up running speed was also calculated. Participants were instructed to run around a 40-metre square track (10m x 10m) for 5 minutes at an intensity that would “produce a light sweat.” The number of laps were counted and an average time per lap was established for each individual to maintain for all warm-ups throughout the remainder of the data collection period. Participants then practised the drop jump test with a 30cm box and a contact mat. Participants were instructed to “keep their hands on their hips and step off (not jump) the box before jumping for maximum height with minimal contact time on the ground.” Participants had multiple trials at the drop jump test and were given feedback on both their contact time and jump height to maximise their reactive strength index (RSI: jump height/contact time) (161). The drop jump exercise was also included in the following investigation as RSI is a measure of reactive strength. Reactive strength is a different quality to measure used within the CMJ; hence both jump types were used. Once participants had become familiar with the drop jump exercise, they practised the CMJ on the BMS again.

All 5RM testing and practise CMJ’s were conducted under the supervision of a researcher to ensure participant safety and the use of appropriate technique.

3.2.3.2 Experimental Warm-up Conditions.

After the familiarisation sessions, participants took part in six experimental warm-up sessions that each differed in the total workload (ranging from “very low” to a “very high”). All sessions were performed in a random order to account for any order effect. Participants began each session by performing the specific warm-up allocated for the appropriate session. The warm-up sessions included an aerobic component (jogging), dynamic stretches and activities (Table 3.1) of the lower body as well as practise CMJ’s. Figure 3.1 displays the duration that each participant performed each component of the warm-up for all the different experimental sessions.

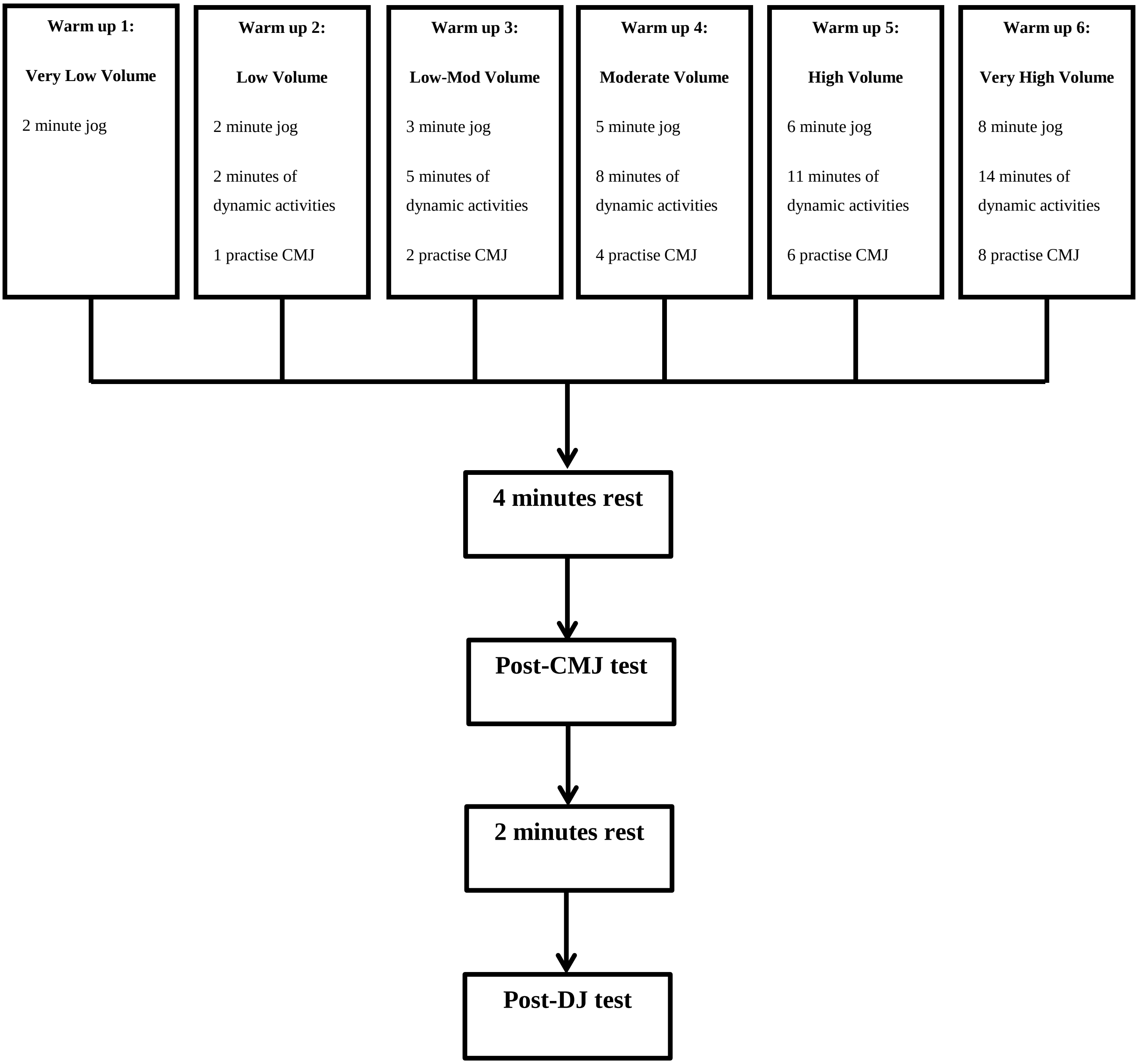

Figure 3.1. The different warm-up protocols, including the duration or the amount of repetitions that participants performed each component of the warm-up.

Table 3.1. The dynamic exercises performed for each warm-up protocol.

Dynamic Exercise	**Warm-up Volume Level**				
	Low	*Low-Mod*	*Moderate*	*High*	*Very High*
Gluteal Stretch Walk	2	6	10	14	18
Quadriceps Grab Walk	2	6	10	14	18
Bouncing on Spot (double leg)	4	16	28	40	52
Heel to Gluteal Run	2	8	14	20	26
Walking Lunges	1	3	6	9	12

Note: The number of exercises in the table are to be performed on each side of the body. The Very Low warm-up condition consisted of two minutes of jogging only.

After completing the appropriate warm-up procedure, participants rested passively for four minutes before performing three CMJ's on the BMS with the position transducer. The CMJ performance variables that were assessed included jump height, relative peak power (RPP) output and peak force.

3.2.3.3 Experimental Warm-up and Conditioning Activity Sessions.

After performing the six different warm-up volumes, participants then performed two of the warm-up protocols with an added CA of four half-squats at a 5RM load. These two warm-ups were the "optimum" warm-up as well as the warm-up volume that was just under the optimum (for example: if the "high" volume warm-up was optimum, then the sub-optimal warm-up performed was the "moderate" volume). Since it is possible that performing a CA after the optimum warm-up could cause excessive fatigue, the warm-up with slightly less volume to accommodate the CA was also be examined. Participants began each session by performing the previously prescribed warm-up (optimum or below optimum), before resting passively (seated) for four minutes. Once the rest period was over, participants then completed three CMJ's as the baseline-measure, rested for two minutes, and performed three DJ's. Participants then rested for a further two minutes before they performed three warm-up sets of half-squats to prepare for the CA (1st warm-up set: 8 repetitions at 50% 5RM, 2nd warm-up set: 5 at 70% 5RM, 3rd warm-up set: 3 repetitions at 90% 5RM) (Figure 3.2) . After the final warm-up set, participants rested for four minutes, before performing the CA of four half-squats at a 5RM load that has been successful in potentiating jump performance (163). At the completion of the CA, participants then rested before performing the post-CMJ's four and eight minutes and DJ's six and 10-min after the conclusion of the CA (Figure 3.2). The rest period of 8 and 10 minutes falls within the guidelines of the meta-analysis performed by Wilson et al. (154) who suggested that rest periods after a CA should be between seven and ten minutes for individuals with one year's training experience. Furthermore, Houston and Grange (74) concluded that myosin phosphorylation lasts for 10 minutes. Four and six minutes rest was also selected as it is half of the second post-rest periods and was used to assess if any individuals displayed a potentiating effect at a decreased rest interval.

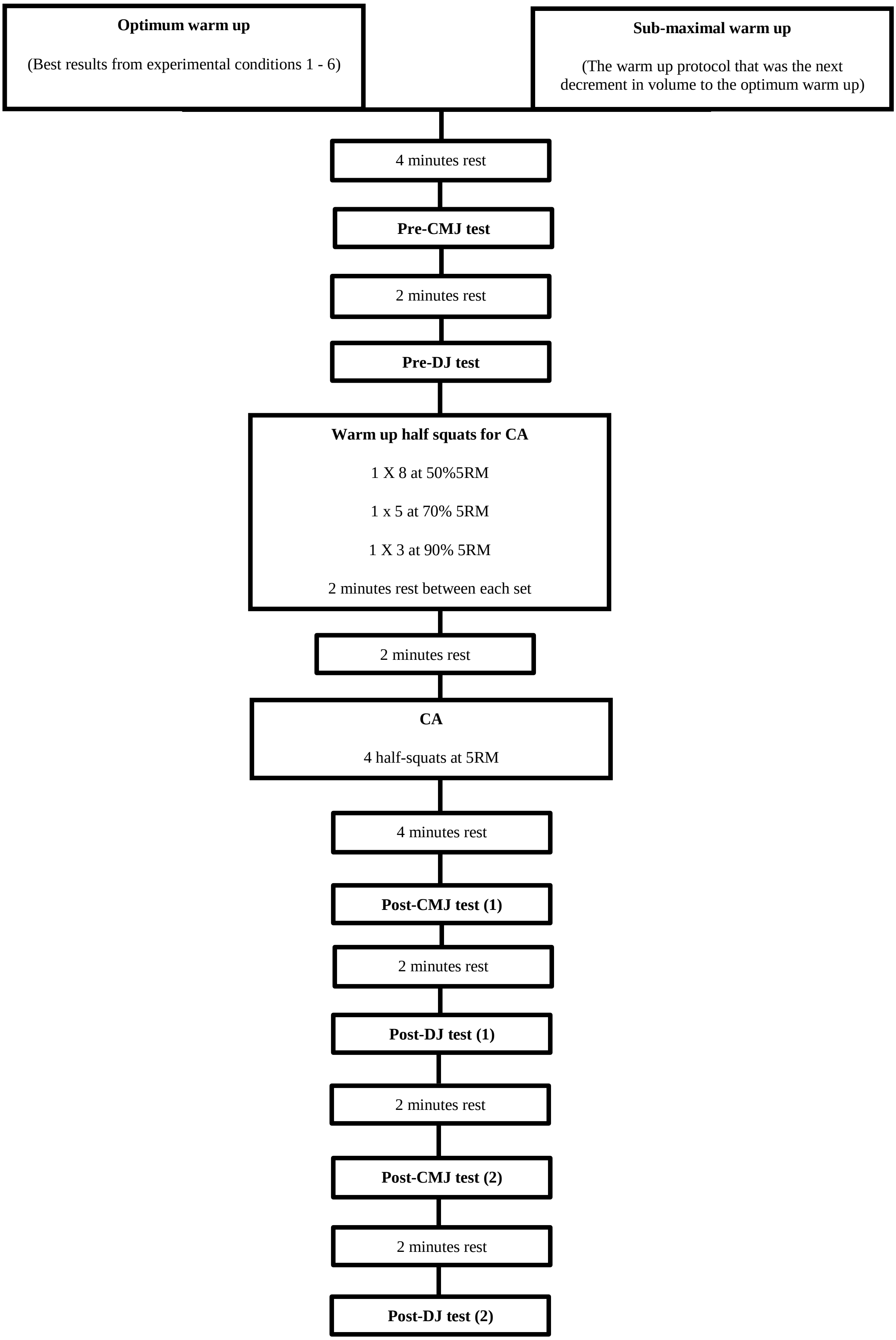

Figure 3.2. Protocol used with the “optimum” and “below optimum” warm-ups as well as the added conditioning activity of four half squats.

3.2.4 Data Collection

All CMJs were performed on a portable force plate (400 Series Force Plate-Fitness Technology, Adelaide, Australia) in conjunction with a linear position transducer (LPT) (PT5A-Fitness Technology, Adelaide, Australia). The LPT was attached to the end of an aluminium bar (0.4kgs in weight) that was held on the participant's trapezius. The sampling frequency for both the force plate and LPT was set at 500Hz, as this has been shown to be an acceptable sampling frequency in past research on CMJs (68). The BMS computer software (Fitness Technology, Adelaide, Australia) was used to calculate CMJ relative peak power, peak displacement and peak force. The force platform and LPT were calibrated prior to every testing session. A known weight of 20kg and 80kg were used to calibrate the force, whilst a known distance of a metre was used to calibrate the LPT. Prior to any data collection the force was zeroed in the BMS software with the participant off the force plate. The displacement was then zeroed with the participant standing evenly upon the force plate (heels on the force plate) with the aluminium bar evenly balanced upon their trapezius. The peak power, peak displacement (jump height) and peak force variables were exported from the BMS software into Microsoft excel. Relative peak power (RPP) was equated by dividing each participant's peak power by their body weight on the day of the testing session. For the RPP and jump height variables, the best result as well as the mean of all three jumps was collected. For peak force, only the best value was recorded due to the decrement within the three jumps.

The following CMJ variables had all previously been found to be reliable by Talpey (137) with the intra-class correlation (ICC) and coefficient of variation percentage (CV%) expressed below in Table 3.2. The following study uses the same protocol and equipment as Talpey (137) under the same laboratory conditions, hence all of the CMJ variables assessed are assumed to be reliable. After the CMJ participants rested a further two minutes before performing three DJ’s. The warm-up volume that provided the greatest CMJ RPP performance was classified as the individual’s optimum warm-up. After much deliberation, RPP was selected as the CMJ variable to determine the optimum WU. This was decided as changes in CMJ RPP could lead to practical applications for both acute and chronic responses to a CA.

Table 3.2. The reliability results expressed by Talpey (137) for all of the CMJ variables. CV% = coefficient of variation percentage & ICC = intra-class correlation.

	Reliability measure	
CMJ Variable	CV%	ICC
Jump height	6.1	0.908
Peak power	4.6	0.971
Peak velocity	3.3	0.914
Peak force	4.0	0.973

Figure 3.3. The set up and position of the BMS in conjunction with the LPT.

3.2.5 Statistical Analyses

All statistical analyses were completed using the software Statistical Package for the Social Sciences (SPSS for Windows, version 21.0; SPSS Inc., Chicago, ILL.). Descriptive statistics (mean and standard deviation (SD)) were calculated for RPP (W.kg^{-1}), jump height (m), peak force (N) and DJ reactive strength index (RSI) for all warm-up volumes as well as pre and post-CA conditions. All data was analysed for normality both numerically and graphically and was normally distributed. To determine which warm-up condition provided the best performance, a repeated measures Analysis of Variance (ANOVA) was performed to assess any significant differences in CMJ and DJ variables between the six different warm-up protocols ($p < 0.05$ being considered a significant change). To establish if the inclusion of the CA had an effect on potentiating CMJ or DJ performance, another repeated measure ANOVA was performed in order to assess any significant change between pre and post-CMJ and DJ performance (at either of the two post-tests). Two rest periods for each jump type were used as the optimal rest period for each individual may vary (26). Therefore, the post-time that produced the largest jump height for each individual was called the "post-best" rest interval. Jump height was selected as this was considered the CMJ variable most related to jumping performance. A paired t-test was conducted to analyse differences between pre to post-best for all CMJ and DJ variables. Effect sizes (Hopkins) were used to quantify the magnitude of differences between the pre to post-changes within the CA protocols. The effect sizes were classified as follows: trivial (ES = 0.00-0.19), small (ES = 0.20-0.59), moderate (ES = 0.60-1.19), large (ES = 1.2- 1.99) and very large (ES > 2.00).

3.3 Results

3.3.1 Different warm-up conditions

The mean and SD for CMJ and DJ variables across all warm-up volumes are displayed in Table 3.3. Warm-up condition 4 (WU4) (moderate) had the highest mean for CMJ RPP (59.07 ± 7.76) as well as jump height (0.507 ± 0.079). Warm-up condition 6 (very high) had the highest peak force values (2004.9 ± 365.3) whilst WU2 (low) produced the highest RSI score (163.9 ± 31.6).

Table 3.3. Comparison of the means and SD for post-performance variables across all warm-up volumes (n=16). WU = warm-up, RPP = relative peak power, JH = jump, PF = peak force and RS = reactive strength.

	Very Low WU (1)	**Low WU (2)**	**Low-mod WU (3)**	**Moderate WU (4)**	**High WU (5)**	**Very High WU (6)**
CMJ RPP (W . kg⁻¹)	55.49 ± 5.52	57.49 ± 6.15	57.20 ± 7.97	59.07 ± 7.76	58.27 ± 8.21	56.57 ± 7.41
CMJ JH (m)	0.491 ± 0.064	0.500 ± 0.061	0.485 ± 0.087	0.507 ± 0.079	0.493 ± 0.076	0.480 ± 0.068
CMJ PF (N)	1996.9 ± 271.6	1963.0 ± 306.1	1993.9 ± 294.3	1985.6 ± 304.3	1983.5 ± 308.3	2004.9 ± 365.3
DJ RSI (ft/ct)	159.0 ± 36.3	163.9 ± 31.6	157.96 ±41.1	162.2 ± 39.5	155.9 ± 34.8	155.5 ± 37.3

The results from the repeated measures ANOVA conducted on the different warm-up volumes are displayed in table 3.4.

Table 3.4. Results from the repeated measures ANOVA displaying p values between each warm-up volume for all post-CMJ and DJ variables (n=16). WU = warm up and statistical significance is represented by values in bold with * ($p < 0.05$).

CMJ Relative Peak Power

	WU.1	W.U 2	W.U 3	W.U 4	W.U 5	W.U 6
W.U 1		**0.043***	0.404	**0.004***	**0.011***	0.381
W.U 2			0.325	0.187	0.509	0.322
W.U 3				**0.010***	0.091	0.947
W.U 4					0.486	0.053
W.U 5						0.082
W.U 6						

CMJ Peak Force

	WU.1	W.U 2	W.U 3	W.U 4	W.U 5	W.U 6
W.U 1		0.115	0.662	0.733	0.882	0.772
W.U 2			0.380	0.575	0.183	0.247
W.U 3				0.960	0.760	0.604
W.U 4					0.749	0.429
W.U 5						0.692
W.U 6						

CMJ Jump Height

	WU.1	W.U 2	W.U 3	W.U 4	W.U 5	W.U 6
W.U 1		0.375	0.478	0.105	0.750	0.445
W.U 2			0.082	0.535	0.512	0.076
W.U 3				**0.022***	0.312	0.991
W.U 4					0.309	**0.013***
W.U 5						0.219
W.U 6						

DJ Reactive Strength Index

	WU.1	W.U 2	W.U 3	W.U 4	W.U 5	W.U 6
W.U 1		0.200	0.851	0.561	0.306	0.480
W.U 2			0.352	0.690	0.064	0.134
W.U 3				0.431	0.413	0.617
W.U 4					0.11	0.184
W.U 5						0.803
W.U 6						

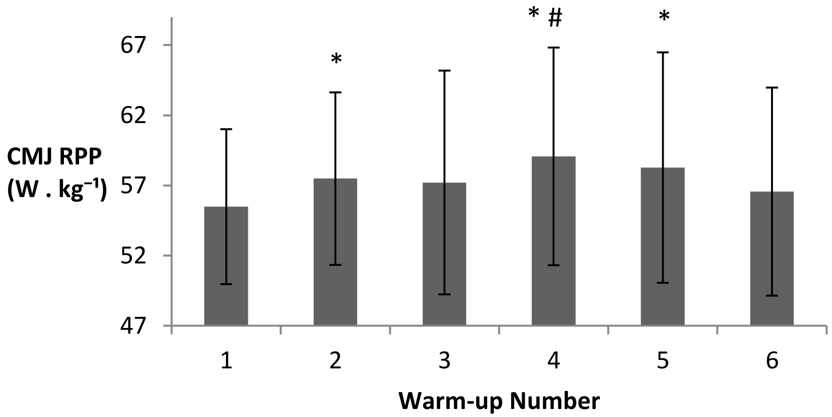

Figure 3.4. Graphical representation of the means for CMJ RPP across the six different warm-up volumes (n=16) with the error bars representing one standard deviation. RPP = relative peak power, * = significantly greater that warm-up 1 ($p < 0.05$), # = significantly greater than warm-up 3 ($p < 0.05$).

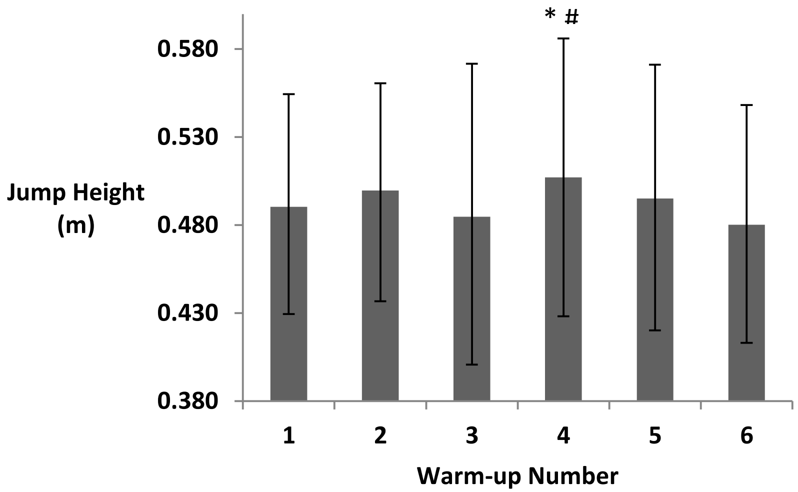

Figure 3.5. Graphical representation of the means for CMJ height across the six different warm-up volumes (n=16) with error bars representing one standard deviation from the mean. * = significantly greater than warm-up 3 ($p < 0.05$), # = significantly greater than warm-up 6 ($p < 0.05$)

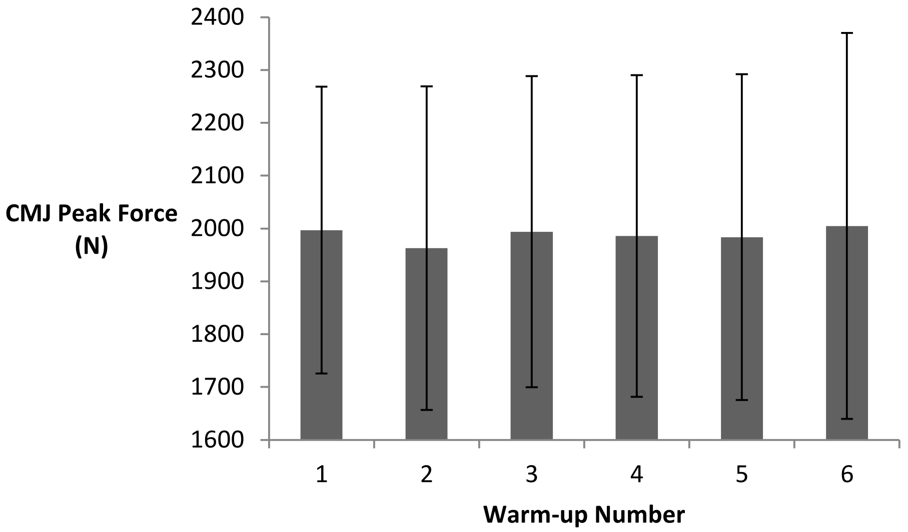

Figure 3.6. Graphical representation of mean peak force across the six different warm-up volumes (n=16) with the error bars representing one standard deviation.

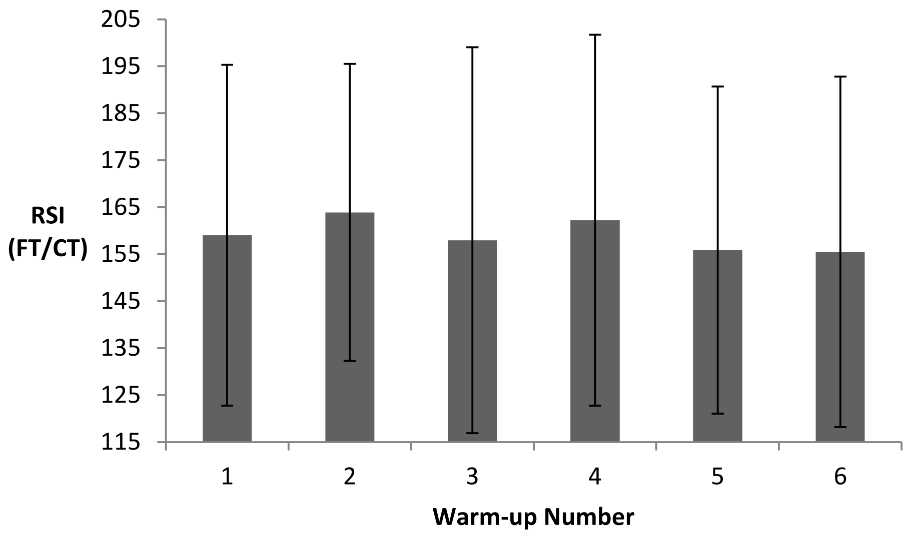

Figure 3.7. Graphical representation of mean DJ RSI across the six different warm-up volumes (n=16) with the error representing one standard deviation. RSI = reactive strength index, FT = flight time, CT = contact time.

3.3.2 Effect of squats on CMJ and DJ performance

3.3.2.1 Comparing pre to all post-CMJ and DJ tests

The mean and SD for all pre, post-1 and post-2 CMJ and DJ variables are displayed in Table (3.5) for both warm-up conditions. There was a significant time effect for DJ RSI scores ($p < 0.005$), with all post-DJ RSI scores being significantly less than the pre-tests for both conditions. No other significant changes were displayed for any other CMJ variables in either condition.

Table 3.5. Comparison of the pre and post-1 & 2 CMJ and DJ scores, for both the sub-optimum and optimum warm-up conditions (n = 14). WU = warm-up, RPP = relative peak power, JH = jump height, PF = peak force and RSI = reactive strength index, P1 = post-1, P2 = post-2, ES = effect size. Bold text and * are used to display statistical significance ($p < 0.05$)

Warm-up	**Jumping Variable**	**Pre mean ± SD**	**P1 mean ± SD**	**% diff pre-P1**	**P value**	**ES (desc)**	**P2 mean ± SD**	**% diff pre-P2**	**P value**	**ES(desc)**
Sub-optimum W.U Condition	CMJ RPP (W.kg^{-1})	59.96 ± 6.77	58.83 ± 5.67	-1.9	0.479	-0.18 (trivial)	58.98 ± 6.77	-1.6	0.869	-0.14 (trivial)
	CMJ JH (m)	0.510 ± 0.078	0.519 ± 0.071	1.7	0.610	0.12 (trivial)	0.510 ± 0.074	-0.1	1.000	-0.01 (trivial)
	CMJ PF (N)	2055.3 ± 219.1	2099.7 ± 272.6	2.2	0.708	0.18 (trivial)	2052.3 ± 252.1	-0.1	1.000	-0.01 (trivial)
	DJ RSI	154.7 ± 31.5	143.5 ± 31.4	-7.2	**0.011***	-0.36 (small)	142.1 ± 30.9	-8.2	**0.019***	-0.40 (moderate)
Optimum WU Condition	CMJ RPP (W.kg^{-1})	60.17 ± 7.16	59.56 ± 6.70	-1.0	1.000	-0.09 (trivial)	58.37 ± 7.36	-3.0	0.194	-0.25 (small)
	CMJ JH (m)	0.504 ± 0.089	0.519 ± 0.073	2.9	0.598	0.18 (trivial)	0.520 ± 0.079	3.1	0.216	0.19 (trivial)
	CMJ PF (N)	2027.5 ± 276.6	2003.0 ± 235.3	-1.2	1.000	-0.10 (trivial)	2024.9 ± 283.0	-0.1	1.000	-0.01 (trivial)
	DJ RSI	153.0 ± 38.4	141.9 ± 33.7	-7.3	**0.015***	-0.31 (small)	142.5 ± 34.6	-6.9	**0.020***	-0.29 (small)

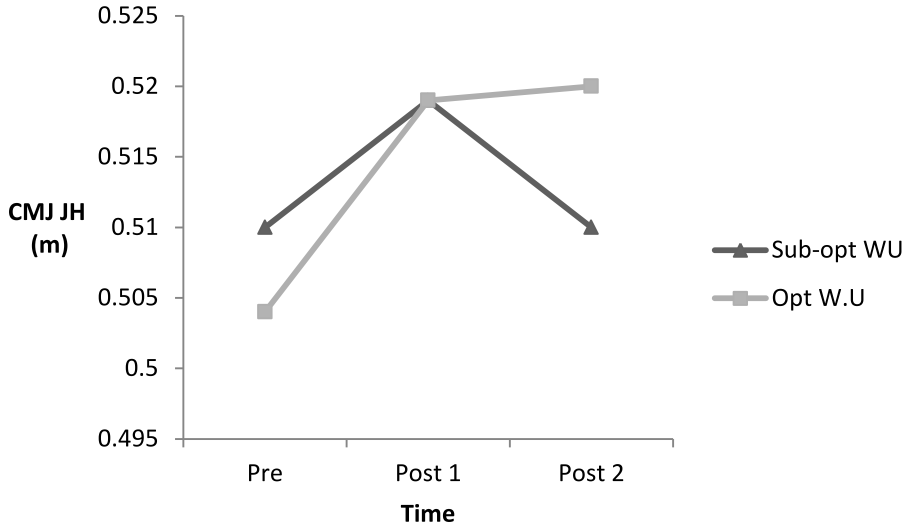

Figure 3.8. Graphical representation of the effect the CA had on jump height for both the optimum and sub-optimum warm-up conditions. JH = jump height and WU = warm-up.

3.3.2.2 Comparing pre to post-best CMJ and DJ tests

The mean and SD for all pre and post-best CMJ and DJ variables are displayed in Table (3.6) for both warm-up conditions. A significant time effect was evident for CMJ height b ($p = 0.011$), with post-jump height being significantly greater in the optimum warm-up condition when each individuals post-best recovery was considered. Drop jump RSI also displayed a significant time effect ($p = 0.005$), with post-best recovery DJ RSI significantly decreasing ($p = 0.018$) in the sub-optimum warm-up condition when compared to pre-testing. No other significant differences were identified for any other variables of the CMJ.

Table 3.6. Comparison of the pre and post-best CMJ and DJ scores, for both the sub-optimum and optimum warm-up conditions (n = 14). WU = warm-up, RPP = relative peak power, JH = jump height, PF = peak force and RSI = reactive strength index, PB = post-best, ES = effect size.

Warm-up	**Jumping Variable**	**Pre mean ± SD**	**PB mean ± SD**	**% diff pre-PB**	**P value**	**ES (desc)**
Sub-optimum W.U Condition	CMJ RPP (W.kg^{-1})	59.96 ± 6.77	59.75 ± 6.48	-0.4	0.792	-0.03 (trivial)
	CMJ JH (m)	0.510 ± 0.078	0.522 ± 0.071	2.2	0.100	0.16 (trivial)
	CMJ PF (N)	2055.3 ± 219.1	2095.8 ± 287.7	2.0	0.094	0.16 (trivial)
	DJ RSI	154.7 ± 31.5	141.4 ± 31.7	-8.6	0.018*	-0.42 (moderate)
Optimum WU Condition	CMJ RPP (W.kg^{-1})	60.17 ± 7.16	60.00 ± 6.80	-0.3	0.838	-0.02 (trivial)
	CMJ JH (m)	0.504 ± 0.089	0.530 ± 0.074	5.2	0.009*	0.32 (small)
	CMJ PF (N)	2027.5 ± 276.6	2055.1 ± 268.6	1.4	0.289	0.10 (trivial)
	DJ RSI	153.0 ± 38.4	144.3 ± 35.0	-5.7	0.019*	-0.24 (small)

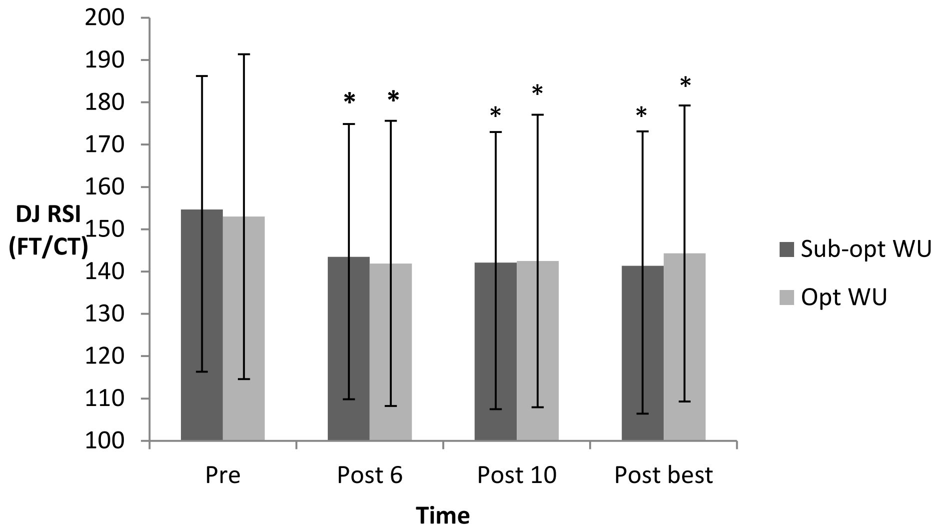

Figure 3.9. Graphical representation of the effect the CA had on DJ RSI for both the optimum and sub-optimum warm-up conditions with the error bars representing one standard deviation. WU = warm-up, RSI = reactive strength index, FT = flight time, CT = contact time, ***** = a significant change from pre test scores ($p < 0.05$).

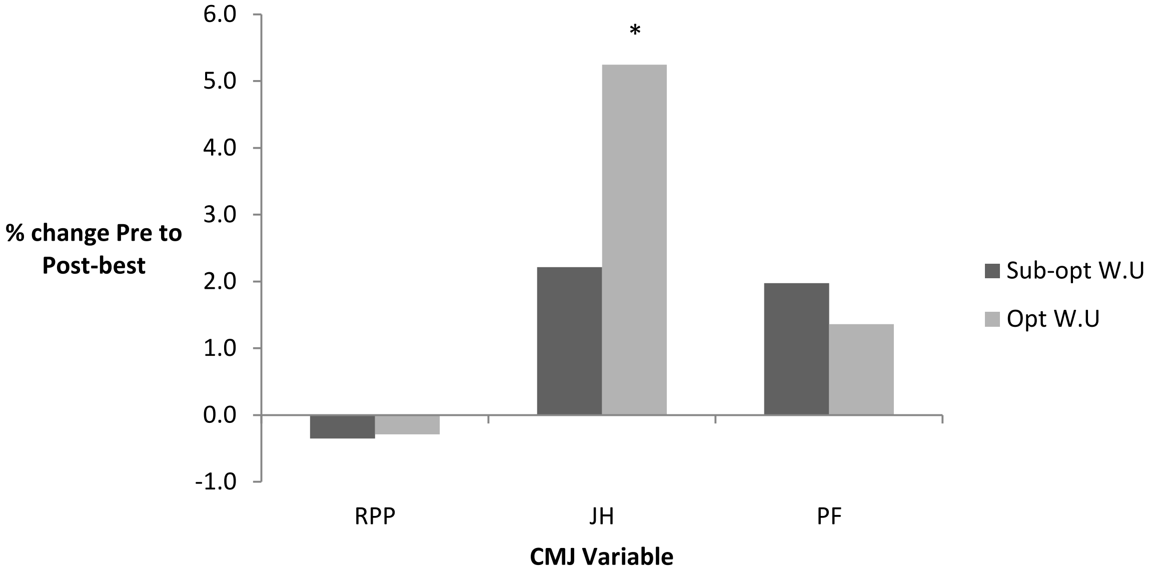

Figure 3.10. Graphical representation of the percentage change between pre and post-best CMJ variables for both warm-up conditions. WU = warm-up, RPP = relative peak power, JH = jump height, PF = peak force. The * represents statistical significance between the pre and post-best scores ($p < 0.05$).

3.4 Discussion

The first purpose of the following study was to identify which WU volume was the optimum to enhance CMJ and DJ performance for each individual. The further purpose was to investigate whether adding a CA, could potentiate CMJ and DJ after an optimum and sub-optimum WU. Considering the vast inconsistencies within the potentiation literature, it is imperative that a sufficient WU is performed before any pre-testing variables are assessed. By performing a sufficient WU, any significant increase in post-test variables after the CA, can more accurately be assumed due to potentiation, rather than the general mechanisms of a WU.

3.4.1 Different Warm-up volumes and their effect on CMJ and DJ performance

The one-way ANOVA showed that WU2, 4 and 5 lead to significantly greater CMJ RPP results than the WU1 volume ($p < 0.05$) (Figure 3.4). From these results, considering three of the five WU volumes compared to WU1 show a significant difference in at least one CMJ variable, it can be suggested that the "very low" WU volume is insufficient to prepare participants for optimal CMJ performance. The only difference between the very low and low volumed WUs was that the low WU volume included two minutes of dynamic activities as well as one practise CMJ.

Considering the low WU volume exhibited significantly heightened CMJ RPP than the very low volume, it supports the suggestions from Young and Behm (161) that a WU needs to consist of an aerobic, dynamic stretching and skill rehearsal component. From these findings, it further proposes that past PAP literature has not used adequate WUs and heightened pre-CMJ performance. McBride et al. (102) and Linder et al. (88) both only used four and five minutes of cycling at 70 Watts respectively to warm-up for sprinting. Even though both studies concluded that improvements in sprint performance were due to potentiation, questions must be raised about such an assumption as the CAs could have improved performance due to general mechanisms of a WU as opposed to potentiation. From these studies, the addition of the CA may have enhanced post-performance by increasing blood flow and vasodilation (104,105), increasing blood pH levels or even rehearsed the neural pathway (161), none of which are mechanisms of potentiation. Furthermore, Tobin &

Delahunt (143) concluded that a CA of 40 plyometric jumps potentiated CMJ jump height and peak force across all post-time tests. Despite this finding, questions must be asked about whether pre-CMJ performance was optimal, as no aerobic component was included within this warm-up.

In terms of CMJ jump height, WU 4 produced significantly greater scores than WU 3 and 6 ($p < 0.05$) (Figure 3.5). The decreases in CMJ jump height after the very high WU volume suggests that this volume may be too high to enhance CMJ performance. Despite the significant change, three of the sixteen participants had WU6 as their optimal warm-up to improve CMJ performance. Despite the moderate WU volume displaying the highest mean for most CMJ variables, there was considerable spread in terms of which volume of WU produced the greatest performance (Table 3.7). An explanation for the individuality in the optimum warm-ups could be the different fitness qualities amongst the population. Furthermore, an individual's optimum WU volume may vary from day to day depending on other confounding variables that could not be controlled within this study.

Table 3.7. The number of participants where their best performance occurred in a particular WU volume for all CMJ and DJ variables.

	RPP	JH	PF	RSI
WU1	0	1	3	3
WU2	2	4	2	4
WU3	1	1	3	4
WU4	6	6	3	3
WU5	4	3	3	1
WU6	3	1	2	1

CMJ = counter-movement jump, DJ = drop jump, RPP = relative peak power, JH = jump height, PF = peak force, RSI = reactive strength index, WU = warm-up.

Unlike many of the CMJ variables, no significant changes were identified for DJ RSI across any of the six WU volumes ($p > 0.05$). A probable reason for this is that the DJ test was performed after the CMJ test. It is possible that the CMJ test actually further added to the WU effect before the performance of the DJ test, potentially contributing to no WU volume being significantly better than any other. It must also be noted that the WU was more specific to enhance CMJ performance, as no practise DJ's were performed in any warm-up.

Although RPP was selected as the CMJ variable to assess which WU volume would be considered optimum, much deliberation occurred suggesting jump height could be the variable used. Considering jump height is actually the performance outcome from the CMJ, it could have greater practical applications for coaches who are looking to acutely enhance jumping performance.

3.4.2 The effect of a squatting CA on jumping performance

3.4.2.1 Comparing pre-CMJ performance to all post-tests

The repeated measures ANOVA showed no significant improvements in any CMJ variable across post-4 or post-8 tests ($p > 0.05$) for either the sub-optimum or optimum WU conditions. For the optimum warm-up condition, CMJ jump height displayed a 2.9% improvement after four minutes recovery, and a 3.1% increase at eight minutes (Figure 3.8), however, neither change was significant and was considered "trivial" (effect size post-4 = 0.19; post-8 = 0.18). The following results contradict the findings of much of the previous literature in terms of potentiating CMJ performance (19,91,103,107). Lowery et al. (91) had participants perform a similar CA to the present investigation (four half-squat at a load of 70% of the participants 1RM) and identified significant increases in both jump height and PP after four minutes rest. Furthermore, Bollousa et al. (19) used five repetitions of the half-squat at a 5RM load to significantly increase CMJ jump height and PP at nine minutes rest. Mitchell and Sale (107) identified a significant 2.9% increase in jump height after the performance of the above CA and four minutes recovery. Despite the insignificant change in jump height after the CA in the present study, the percentage increase in jump height after four minutes recovery was actually the same as the significant 2.9% increase identified in the investigation by Mitchell & Sale (107). The following result could suggest that the small sample size (n = 14) contributed to a type two error.

Another explanation as to why no significant improvements in CMJ performance were identified at post 4-min or 8-min, could be the intensity and number of repetitions performed during the CA. Much of the previous literature used either five repetitions at a 5RM load (103,107,163) or three repetitions at a 3RM load (39,83,116) as a CA. The present investigation used four repetitions at a 5RM load due to the recommendations from Wilson et al. (154), suggesting that recreationally trained participants should not perform CAs that are too fatiguing. It was decided that the four repetitions would be appropriate for the sample of the present study; however, potentially a CA with an extra repetition or a greater load (three at a 3RM) could have elicited greater improvements in post-CMJ performance.

An alternative contributing factor may have been that the strength of the population within the present study was not adequate enough to elicit a potentiating response. Previous research has identified the importance of participant relative strength and training experience to enhance a potentiating response (31,44,129). Chiu et al. (31) suggested that participants should be able to squat 1.5 times their body weight whilst Seitz, Villarreal & Haff (129) recommended relative squat strength should exceed twice that of body weight. The mean relative squat strength of the participants in the present study 2.4kg lifted per kg of body weight. Although this exceeds both the strength recommendations of the previously mentioned literature, it must be noted that the squats were only half-squats (90 degree knee angle) and were performed in a Smith machine. From the research conducted by Chiu et al. (31) and Seitz, Villarreal and Haff (129), participants performed parallel squats. This increase in squatting depth would have decreased the total amount lifted during their RM testing. Furthermore, no comment was made whether the squat testing was performed as a free squat or in a Smith machine. Previous research has suggested that individuals can lift more in a

Smith machine than compared to a free squat (38), hence, the mean relative strength levels (2.4 times body weight) provided in the present study, may have needed to be higher in order to identify an increase in the CMJ.

3.4.2.2 Comparing pre-CMJ performance to the best post-recovery interval after the CA.

Wilson et al. (154) suggested that both the optimal rest period and CA intensity would be different between individuals. From this following suggestion, a comparison between pre and post-best CMJ performance was also conducted. Significant time interactions were identified for the CMJ variables jump height and peak force, suggesting that the CA had an effect on post-best CMJ performance. Post-best jump height (5.2%) and jump height showed a"small" significant increases ($p < 0.05$) after the CA in the optimal WU condition. In the sub-optimum WU condition, jump height (2.1%, $p = 0.100$) improved, however, such an improvement was non-significant and trivial. Such improvements in jump height are now similar to that of Young, Jenner and Griffiths (163) and Mitchell & Sale (107), even though the following investigations found these increases in performance at specific recovery periods. Considering a significant acute enhancement in jump height performance occurred after the performance of the CA, and an optimal WU was executed prior to any pre-CMJ testing, the following increase in jump height may have been due to a potentiating effect.

Although improvements in jump height were observed, no other CMJ variable displayed significant changes from pre to post-best. Peak force did show an increase for both conditions (sub-opt WU: 2.0%, Opt WU; 1.4%), however both these improvements were "trivial" and non-significant. Again, possible reasons may have been due to the small sample size used, intensity of the CA, or the strength of the participants.

Due to the significant increases in jump height after the performance of the CA in the optimum WU condition, a similar WU and CA protocol could be used in specific sports settings to take advantage of the acute enhancement of jump height. Provided the sufficient equipment was available and the recovery interval could be controlled, athletes could perform a similar WU and CA of four half-squat at a 5RM load to potentiate jumping performance similar to that of the CMJ.

3.4.3 The effect of the CA on DJ performance

Significant decreases in DJ RSI for both conditions across all post-rest intervals (including post-best) were evident when compared to the pre-DJ test. The post 6-min and 10-min DJ tests showed performance decrements that varied from 6.9% to 8.2% between both testing conditions. Such findings oppose that of Comyns et al. (33) and French, Kraemer & Cooke (54) who both identified significant increases in DJ performance after a CA. Although rest periods were similar to the present study, the CAs used and their intensities were different. Comyns et al. (33) used a more intense back squat CA of three repetitions at 93% of a participants 1RM load. They found that such a CA significantly improved ground contact time in the DJ by 7.8%. French, Kraemer & Cooke (54) used a completely different type of CA to enhance the DJ. The following researchers used multiple sets of three second maximal isometric knee extension as a CA to potentiate DJ performance. Both DJ height and peak force significantly increased by 5%, suggesting that increases in reactive strength were due to potentiation.

It is important to discuss that both post-DJ tests were performed two minutes after a post-CMJ test in the present investigation. In the literature mentioned above, only DJ performance was measured as a dependent variable, meaning that no other post-test could have influenced the DJ performance. Like the current research, Gullich and Schmidtbleicher (62) assessed both CMJ and DJ performance in the one session. Although significant increases in CMJ jump height were observed, contact times within the DJs increased to display no improvements in DJ RSI performance. It can be suggested that in the case of Gullich and Schmidtbleicher (62) and the current study, that the fatigue from the CA as well as the post-CMJs may have potentially been too great, causing a decrease in DJ performance. Due to excessive fatigue, participants possibly could not overcome the extra eccentric force created within the drop jump, hence leading to a larger contact time and a decrease in RSI.

Chapter 4: Study 2 - The Effect of Intention to Squat Explosively on Acute Counter Movement Jump Performance: "Controlled vs. Explosive" Squats.

4.1 Introduction

4.1.1 Background

Considering the results of the previous study, the moderate warm-up (WU4) was used for all participants in the remaining studies. Due to time constraints, it was not feasible to identify every new participants' optimal warm-up intensity. Since the WU4 protocol allowed for good performance for all CMJ variables, it was deemed appropriate. Furthermore, since the CA of four half-squats with a 5RM load significantly improved CMJ height (in the optimum warm-up condition) after the best recovery period, the same load and repetitions were used as the CA for this study.

By increasing the intention to maximise squatting velocity, the kinematic and kinetic variables are drastically changed compared to if the squat is performed in a slower controlled manner (121). Since Newton's 2nd law of motion states that acceleration is proportional to the force applied, it can be expected that an attempt to maximally accelerate the bar during the ascent of the squat will produce greater forces. Much research has focussed on the effects the two lifting strategies have on chronic power development (14,162) throughout a training period, or even the effect on increasing muscle cross sectional area (122). If the squats with the maximal intent to increase bar velocity have greater force production, this could be a better stimulus for enhanced potentiation. The increase in peak force production as well as RFD during a squat with maximise intention to move the bar quickly, could increase motor unit recruitment (14) and hence increase the potentiating stimulus. However, the two lifting strategies have not been compared in terms of being CAs to elicit potentiation.

Within previous potentiation research, participants have been instructed squat at a controlled tempo (102), whilst other research has suggested explosively performing the concentric phase of the squat (57). As the two different squatting instructions change the nature of the exercise, there is a need to investigate the effect each lifting strategy has on potentiating future contractions.

4.1.2 Aim

The aim of the study was to investigate the difference between a CA that emphasises the intention to squat explosively in the concentric phase, as opposed to a CA that performs the squats in a controlled manner and their subsequent effect on potentiating CMJ and DJ performance.

4.1.3 Research Questions

The main research questions for study 2 are:

1. Does increasing the intention to maximise bar velocity during the concentric phase of a CA of four half-squats at a 5RM load have an effect on potentiating CMJ and DJ performance?

The following specific research question were also addressed throughout this study.

1. What kinematic differences are there between squatting to maximise bar velocity compared to squatting in a controlled manner.

4.2 Methodology

4.2.1 Participants

Fourteen recreationally resistance trained male university students with a minimum of one year resistance training experience completed the following study (Mean ± SD age = 22.1 ± 1.7 years, height = 179.9 ± 4.2 centimetres, body mass = 83.8 ± 6.6 kg, predicted 1RM half-squat = 201.0 ± 27.8 kg). The participants recruited for this study followed the same criteria discussed in study one (3.2.2). Before the commencement of the study, the procedure and potential risks were explained to all participants and informed consent was obtained. The study had ethical approval from the HREC at Federation University Australia.

4.2.2 Experimental Design

This study used a within-subjects repeated measure design to establish if altering half-squat tempo during a CA has an acute effect on CMJ or DJ performance (potentiation). After a familiarisation session, participants took part in two experimental procedures that were performed 2-5 days apart. These sessions were performed in a random order to prevent any order-effect influencing results. For one of the experimental sessions participants were instructed to perform half-squats with an emphasis on maximising bar velocity during the raising portion of the half-squat, whilst during the other experimental session participants were instructed to squat at a controlled speed. Pre and post-CMJ and DJ performance were analysed to assess whether a particular experimental condition had an effect on performance (negative or positive).

4.2.3 Procedures

4.2.3.1 Familiarisation and 5 RM Testing Session.

Each participant attended a familiarisation session, where their 5RM half-squat (90º knee angle) load was determined via the same testing protocol that was used in the first study (3.2.3.1). After the completion of their 5RM testing, participants then practised both the "controlled" and "explosive" half-squat techniques. For the normal half-squat CA, participants were instructed "to lower the bar in a controlled manner as you would normally do, and then raise the bar in the same controlled manner." For the explosive CA, participants were instructed to "lower the bar in a controlled manner, but then to drive up explosively to move the bar as fast as possible in the upward phase of the squat." Participants were also instructed in the explosive CA, to reduce their movement speed towards the end of the repetition to maintain contact with the force platform (i.e. a jump squat was not allowed). Participants were allowed to raise their heels off the ground, but no jump squat was performed so that the heavy squat technique was still safe to perform. After practising both lifting techniques, participants also practised CMJs on the force platform with the LPT and DJs on the contact mat to allow for familiarisation with each activity.

4.2.3.2 Experimental Conditions.

After the familiarisation sessions, participants performed two randomised testing conditions on separate days. In the controlled condition (HS-CON), participants performed a general warm-up to allow for optimum performance and decrease the risk of injury. The general warm-up was the WU4 protocol used in the previous chapter (Figure 3.1). Although the first study showed that particular individuals had different optimum warm-ups, the WU4 protocol produced the highest mean results for almost all of the CMJ and DJ variables (all except for DJ RSI and CMJ peak force). With multiple new participants, it was not logistically viable to use every participant's optimum warm-up, hence, the WU4 protocol was used for all participants in this study. At the completion of the warm-up, participants rested for a total of 4-mins before performing three pre CMJs . The variables RPP, jump height, peak velocity and peak force were all assessed within the CMJ. For this investigation, CMJ peak velocity was also included in the analysis. Considering no significant change was identified in terms of RPP in the first investigation, peak velocity could provide explanation as to why an individual did not change their RPP, as PP is the product of force and velocity. Participants then rested for a further two minutes and performed the pre DJ test. After the pre-jump testing, participants rested another two minutes, before completing the same half-squat warm-up protocol used in study 1 (3.2.3.3). After the final warm-up squat set, participants rested for four minutes before performing four half-squats at a 5RM load in a "controlled" manner (HS-CON) on the force platform with the LPT attached to the squat bar

(Figure 4.2). Once they completed the half-squats, the weight and the squat bar was removed from the Smith machine, allowing space for participants to perform their post-CMJs. For this study, participants performed the CMJ tests inside the frame of the Smith machine. This was done to save time and meant that the force platform did not have to be moved during a testing session (Figure 4.3). Post-CMJ's were performed at four and eight minutes after the completion the CA whilst the post-DJs were performed six and ten minutes after respectively. For the half-squat explosive condition (HS-EXP), the same protocol was followed; however, participants were given the instruction to maximise bar velocity in the concentric phase of the CA.

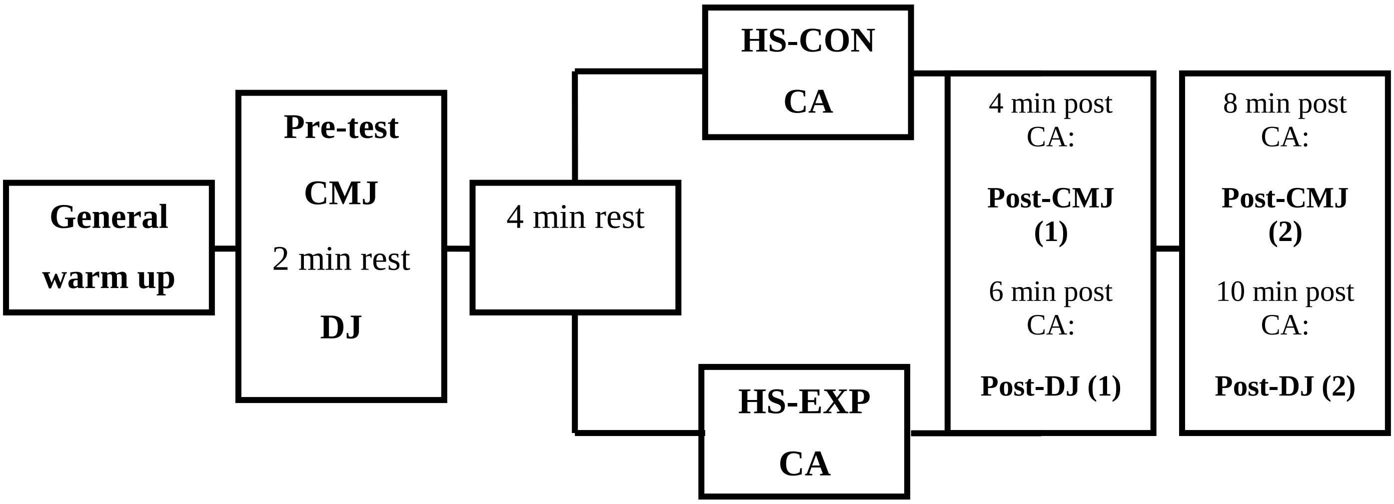

Figure 4.1. Diagram representation of the procedures used throughout the experimental conditions of study 2. HS-CON = half-squat controlled, HS-EXP = half-squat explosive.

Figure 4.2. Participant preparing to perform the half-squat protocol on the BMS with the LPT attached to the squat bar.

Figure 4.3. Participant performing a CMJ test on the BMS whilst inside the Smith machine rack.

4.2.4 Data Collection

The data collection protocol for the CMJs and DJs followed the same procedure as study 1 (3.2.4). For this study, peak velocity was also measured as a performance variable of the CMJ. Due to a change in the LPT used for this study, test-retest reliability was assessed for each CMJ variable. As the warm-up protocols for both conditions were the same and sessions were only 2-5 days apart, the pre-CMJ and DJ of each condition were used to assess reliability (73).

The peak force, mean force (MF), peak power (PP) and rate of force development (RFD) for each CA was also quantified for both the concentric and eccentric phases of the half-squats. To assess RFD, the force curve within the BMS software was used to determine the increase in force during a particular phase of the squat, and then dividing that by time to establish RFD. This particular methodology was used by Cormie et al. (35), when they compared the kinematic and kinetic variables of different loaded jump squats. The start and finish of the eccentric and concentric phases were determined by the displacement curve within the BMS software. The eccentric phase was considered being from the first onset of the bar displacement decreasing until the final point at which the bar displacement decreased. The concentric phase was considered from the first point that the bar displacement began to increase until the final point that bar displacement increased. By quantifying these values for each protocol (HS-CON and HS-EXP), differences between the two protocols can be identified and hence provide possible reasons as to why a particular CA caused a change in post-jumping performance. Furthermore, by analysing both the concentric and eccentric phases of the squat, the entire differences that the two different instructions had on the demands of the half-squat can be identified.

4.2.5 Statistical Analyses

All statistical analyses were completed using the software Statistical Package for the Social Sciences (SPSS for Windows, version 21.0; SPSS Inc., Chicago, ILL.). Descriptive statistics (mean and standard deviation (SD)) were calculated for peak force (N), MF (N), PP (W) and RFD($N \cdot s^{-1}$) in both half-squat CAs. Descriptive statistics were also used to assess CMJ RPP ($W.kg^{-1}$), jump height (M), peak velocity ($m.s^{-1}$), peak force (N) and DJ RSI for all pre and post-CMJs and DJs. For both CMJ and DJ variables, coefficient of variation percentage (CV%) and intra-class correlations (ICC) were conducted to assess the test-retest reliability of each variable.

Paired sample t-tests were used to assess if there were significant differences between the kinematic and kinetic variables of the two different squatting instructions. In order to assess if either squatting instruction was more effective to potentiate post-performance, a repeated measure ANOVA with a post-hoc Bonferroni correction was performed in order to assess any significant change between pre and post-CMJ and DJ performance for both the CA conditions ($p < 0.05$ being considered a significant change) over all post-times. A separate repeated measures 2 way ANOVA (2 conditions x 3 times) was used in order to assess any significant change occurred between pre and post-best CMJ and DJ performance. Effect sizes were used to quantify the magnitude of differences between the pre to post-changes within the CA protocols as well as the differences for all the variables for the HS-CON and HS-EXP squats. The effect sizes were classified as follows: trivial (ES = 0.00-0.19), small (ES = 0.20-0.59), moderate (ES = 0.60-1.19), large (ES = 1.2- 1.99) and very large (ES > 2.00).

4.3 Results

4.3.1 Comparisons between HS-CON to HS-EXP squats

For the HS-EXP condition, all of the concentric variables were significantly greater than the HS-CON condition ($p < 0.05$), with the effect sizes ranging from “moderate” to “very large.” No significant changes were identified between the two squatting conditions for any of the eccentric variables with all of the effect sizes being “trivial.”

Table 4.1. A comparison between the HS-CON and the HS-EXP squatting CA for both concentric and eccentric phases of the half-squat. "Best" or "lowest" refers to the maximum or minimum value that occurred during all four squats, whilst mean refers to the average peak of the four squats. RFD = rate of force development.

	HS-CON	HS-EXP	% diff to HS-CON	p-value	Effect size (description)
Concentric					
Best Peak Power (W)	1575.8 ± 225.3	2193.7 ± 187.2	39.2	< 0.001	2.73 (very large)
Mean Peak Power (W)	1420.7 ± 227.1	2040.7 ± 154.6	43.7	< 0.001	3.19 (very large)
Best Peak Force (N)	2958.4 ± 382.9	3198.1 ± 334.3	8.1	< 0.001	0.67 (moderate)
Mean Peak Force (N)	2864.2 ± 334.9	3120.9 ± 321.9	9.0	< 0.001	0.78 (moderate)
Best Peak Velocity ($m{\cdot}s^{-1}$)	0.559 ± 0.047	0.708 ± 0.041	26.7	< 0.001	3.38(very large)
Mean Peak Velocity ($m{\cdot}s^{-1}$)	0.513 ± 0.050	0.669 ± 038	30.4	< 0.001	3.51 (very large)
Best RFD ($N{\cdot}s^{-1}$)	764.0 ± 234.4	1382.2 ± 440.2	80.9	0.001	1.75 (large)
Mean RFD ($N{\cdot}s^{-1}$)	586.3 ± 161.5	1111.68 ± 254.1	89.6	< 0.001	2.47 (very large)
Eccentric					
Best Peak Force (N)	2759.3 ± 293.4	2786.0 ± 276.0	1.0	0.105	0.09 (trivial)
Mean Peak Force (N)	2726.4 ± 291.8	2737.52 ± 284.0	0.4	0.347	0.04 (trivial)
Lowest Min Force (N)	1912.78 ± 270.1	1925.7 ± 288.6	0.7	0.740	0.05 (trivial)
Mean Min Force(N)	2025.6 ± 253.1	2036.5 ± 254.6	0.5	0.720	0.04 (trivial)
Best RFD ($N{\cdot}s^{-1}$)	3257.1 ± 1328.9	3419.9 ± 1341.2	5.0	0.549	0.12 (trivial)
Mean RFD($N{\cdot}s^{-1}$)	2368.3 ± 1085.8	2442.6 ± 882.7	3.1	0.678	0.08 (trivial)

4.3.2 Test-retest reliability of the CMJ and DJ variables

The ICC and CV% for each CMJ and DJ variable are presented in table 4.2. All CMJ and DJ variables displayed sufficient test-retest reliability (73).

Table 4.2. The test-retest reliability results for all of the CMJ and DJ variables. ICC = intra-class correlation, CV% = coefficient of variation percentage.

	RPP	JH	PV	PF	DJ RSI
ICC	0.963	0.980	0.990	0.813	0.994
CV%	2.2	2.2	1.0	3.0	2.1

4.3.3 Differences between HS-CON and HS-EXP CAs on potentiating future contractions

Whilst comparing pre to post-1 and post-2 variables, CMJ RPP exhibited a significant time effect ($p = 0.003$), with RPP significantly decreasing after eight minutes post-CA in both conditions. Countermovement jump height revealed a significant CA effect ($p = 0.032$), although neither condition displayed a significant change in jump height at any recovery period. Drop jump RSI exhibited a significant time effect ($p = 0.006$), with DJ RSI significantly decreasing at all post-periods in the HS-EXP condition.

When comparing pre to post-best jumping variables, no significant interactions were identified, although DJ RSI was significantly lower after the post-best rest period for the HS-EXP condition. No other significant changes were identified for any other CMJ variable.

Table 4.3. Comparison between the pre and post-CMJ and DJ performance, for both the HS-CON and the HS-EXP CA (n = 14). RPP = relative peak power, JH = jump, PV = peak velocity, PF = peak force and RSI = reactive strength index, PB = post-best, ES = effect size. The * symbol in bold text represents a statistical significant difference.

CA	**Jumping Variable**	**Pre mean ± SD**	**P1 mean ± SD**	**% diff pre-P1**	**P value**	**ES (desc)**	**P2 mean ± SD**	**% diff pre-P2**	**P value**	**ES(desc)**	**PB mean ± SD**	**% diff pre-PB**	**P value**	**ES (desc)**
HS-EXP	CMJ RPP (W.kg^{-1})	56.55 ± 6.97	55.51 ± 7.16	-1.8	0.160	-0.15 (trivial)	54.19 ± 6.82	-4.2	**0.004***	-0.34 (small)	56.07 ± 7.20	-0.8	0.083	-0.07 (trivial)
	CMJ JH (m)	0.470 ± 0.082	0.470 ± 0.078	-0.2	1.000	< 0.01 (trivial)	0.468 ± 0.079	-0.4	1.000	-0.02 (trivial)	0.483 ± 0.076	2.6	0.231	0.16 (trivial)
	CMJ PV (m.s^{-1})	2.642 ± 0.262	2.634 ± 0.266	-0.3	1.000	-0.03 (trivial)	2.583 ± 0.235	-2.2	0.173	-0.24 (small)	2.649 ± 0.260	0.3	0.988	0.03 (trivial)
	CMJ PF (N)	1938.9 ± 245.8	1927.9 ± 238.6	-0.6	1.000	-0.05 (trivial)	1945.2 ± 235.2	0.3	1.000	0.03 (trivial)	1956.9 ± 242.3	0.9	0.462	0.07 (trivial)
	DJ RSI	149.8 ± 38.1	137.1 ± 38.6	-8.5	**0.005***	-0.33 (small)	136.5 ± 36.0	-8.9	**0.016***	-0.36 (small)	143.7 ± 39.3	-4.1	**0.050***	-0.16 (trivial)
HS-CON	CMJ RPP (W.kg^{-1})	56.18 ± 5.96	55.13 ± 6.77	-1.9	0.389	-0.16 (trivial)	54.32 ± 6.36	-3.3	**0.023***	-0.30 (small)	55.83 ± 6.58	-0.6	0.233	-0.06 (trivial)
	CMJ JH (m)	0.467 ± 0.065	0.463 ± 0.076	-1.0	1.000	-0.06 (trivial)	0.465 ± 0.079	-0.5	1.000	-0.03 (trivial)	0.471 ± 0.074	0.9	0.390	0.06 (trivial)
	CMJ PV (m . s^{-1})	2.649 ± 0.204	2.612 ± 0.266	-1.4	0.733	-0.16 (trivial)	2.603 ± 0.257	-1.7	0.335	-0.20 (small)	2.619 ± 0.260	-1.2	0.633	-0.13 (trivial)
	CMJ PF (N)	1901.1 ± 240.9	1892.9 ± 238.6	-0.4	1.000	-0.03 (trivial)	1913.9 ± 229.9	0.7	1.000	0.05 (trivial)	1943.7 ± 246.4	2.2	0.097	0.17 (trivial)
	DJ RSI	141.7 ± 33.2	133.2 ± 36.3	-6.0	0.137	-0.24 (small)	132.6 ± 34.8	-6.4	0.397	-0.27 (small)	136.9 ± 36.2	-3.4	0.283	-0.14 (trivial)

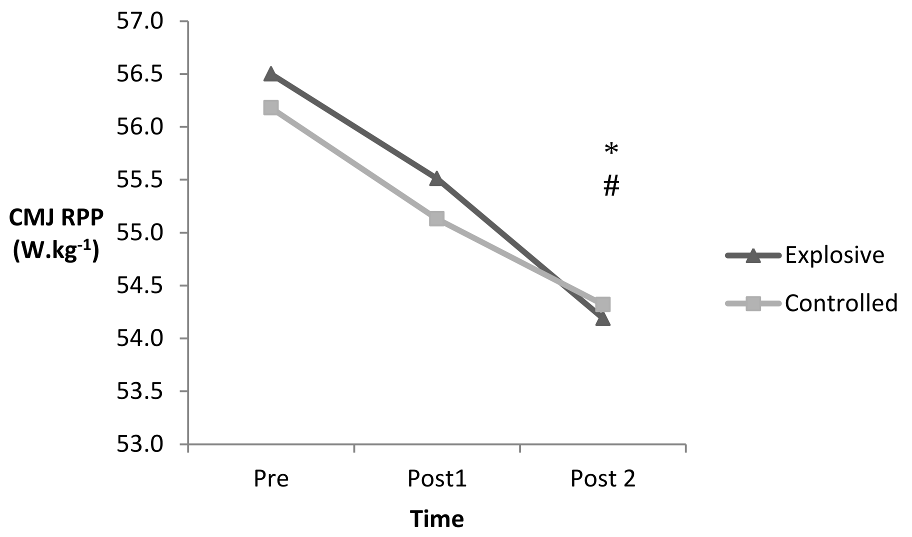

Figure 4.4. Graphical representation of the effect the HS-EXP and HS-CON CAs had on both RPP. RPP = relative peak power, * = statistical significant change from pre to post-test ($p < 0.05$) for HS-EXP condition and # = statistical significant change from pre to post-test ($p < 0.05$) for HS-CON condition. Note: error bars have been omitted to enhance appearance of the figure, the SD is included in table 4.3.

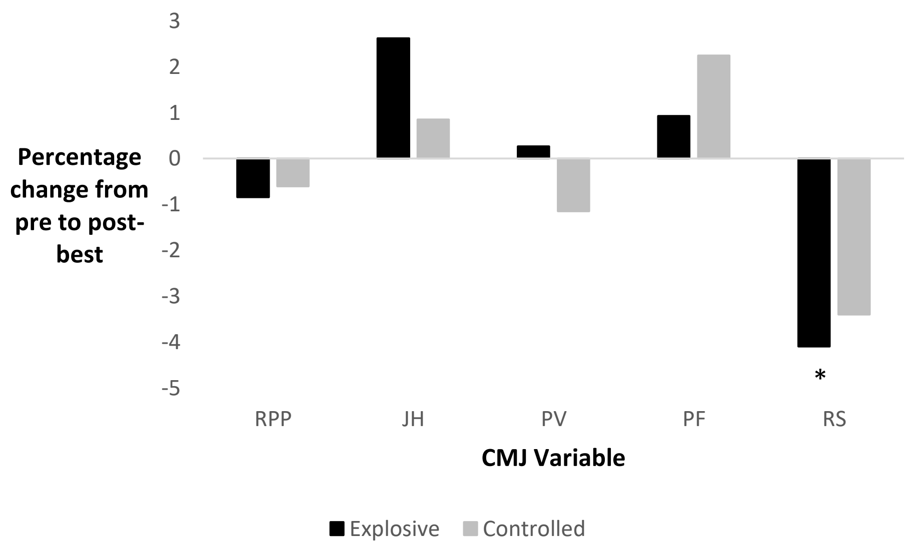

Figure 4.5. Graphical representation comparing the effect both CAs had on pre to post-best results for all CMJ and DJ variables. The * symbol represents a statistical significant change between pre- and post-best testing values.

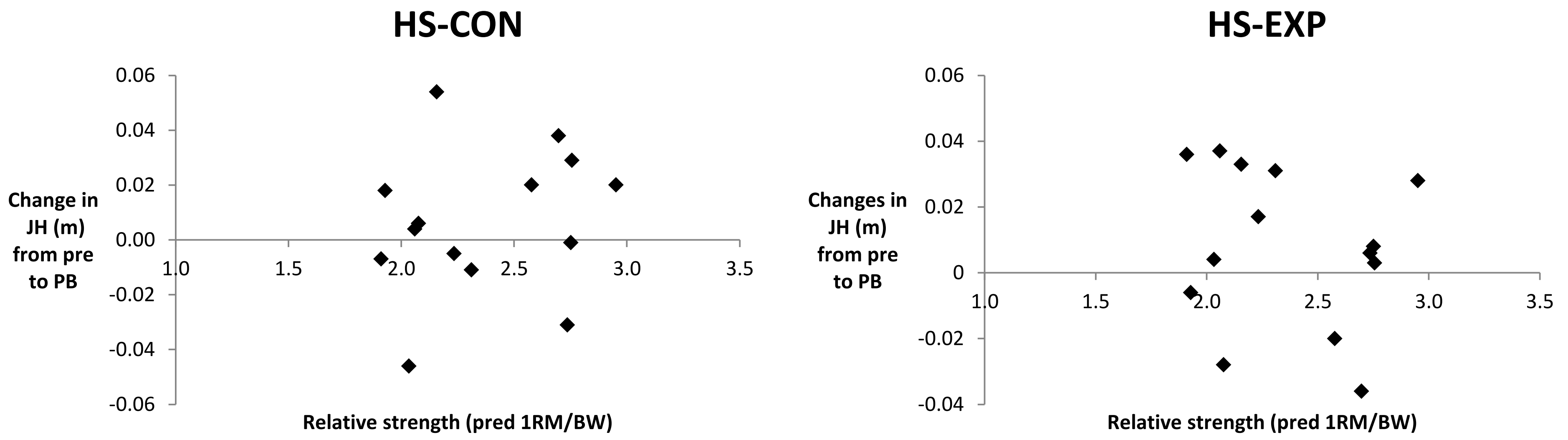

Figure 4.6. Scatterplot displaying the results for each individual participant in terms of relative strength (horizontal axis) and the change in their jump height from pre to post-best (vertical axis). The graph on the left shows the HS-CON CA, whilst the graph on the right depicts the HS-EXP CA. PB = post-best.

4.4 Discussion

The first purpose of the following study was to investigate the kinetic and kinematic differences between explosive and controlled half-squats. The further purpose was then to investigate if either of the two squatting instructions had a greater effect as a CA to potentiate CMJ and DJ performance. If the kinetic or kinematic variables from the two squatting instructions are different, then the effects that each of the methods have as a CA for jumping performance could also differ.

4.4.1 A kinematic and kinetic comparison of the explosive and controlled half-squats

Within the HS-EXP CA, participants displayed significantly greater results for all concentric squatting variables when compared to the HS-CON condition ($p \leq 0.001$). The greatest differences were observed in the concentric RFD, with the best RFD showing a very large 89.6% difference, whilst mean RFD presented a large 80.9% difference compared to the HS-CON condition. Very large changes were also observed for both PP measures whilst the increase in force during the HS-EXP condition was considered moderate. Bar velocity (both peak and mean) also showed a very large difference in the HS-EXP CA, which supports the idea that instructions can make a huge difference, even with the same load is used in the squat. For the eccentric variables of the squats, no significant changes were identified ($p > 0.05$) and all effect sizes were trivial ($ES < 0.2$) when comparing the HS-EXP and HS-CON conditions. The instructions for the eccentric phase for both conditions were the same, as participants were instructed to lower the weight in a controlled manner. Therefore, the change in the instructions for the concentric phase of the squat had no effect on the eccentric kinetic or kinematic variables. Table 4.4 below explains (by using Newton's second law of motion) why these concentric squatting variables changed between the HS-EXP and HS-CON CAs.

Table 4.4. Adaptation of the table presented by Schillings, Falvo and Chiu (121), simplistic look at Newton's second law and how it can be affected with different forms of lifting strategies.

	*F = m * a*	*a = ΔV/t*
Lift type	**Manipulation of F = m*a**	**Effect explanation**
Controlled Heavy squats (normal)	F = m * ΔV/t	
Heavy Squats with Maximal Intention to Increase Velocity	↑F = ↔m *↑ΔV/↓t	The ↑ intention, would lead to a ↑ Δ velocity and a ↓ time. Hence a ↑ force is produced
Purposely Slow Heavy Squats	↓F = ↔m *↓ΔV/↑t	↓ Δ velocity and ↑ time would lead to a ↓force produced

F = force, v = velocity, m = mass, t = time, ↑ = large, ↓ = small, ↔ = same

Considering all the concentric squat variables increased when they were performed explosively, lifting with maximum intention to move the bar explosively has to be considered when training with heavy loads for chronic adaptations in performance, however, this was not the purpose of the present investigation. The very large to large increases however, could be expected to change the potentiation stimulus of the CA. Considering concentric peak force, peak power, peak velocity and RFD are significantly greater in the HS-EXP condition, this type of CA would be hypothesized to produce greater phosphorylation of the RLC on the myosin head (135), as well as higher order motor unit recruitment (62) to create a greater potentiating effect. However, this potentiating effect did not occur in the present study for either condition.

4.4.2 The effect of the HS-EXP and HS-CON CAs on potentiating CMJ performance

4.4.2.1 Four and eight minutes recovery

No significant increases in performance for any CMJ variable ($p > 0.05$) across either of the two types of CA were identified. In fact, RPP significantly decreased for both CAs at eight minutes rest ($p < 0.05$). Any small increases in post-CA CMJ performance were trivial, with the HS-EXP CA causing a 0.3% increase in peak force at eight minutes. After the HS-CON CA, only peak force at eight minutes increased above pre-test values (0.7% improvement). For CMJ jump height, a significant main effect was evident for the CA type (p=0.032), suggesting that the HS-EXP was better than the HS-CON to maximise CMJ jump height. This is most likely due to the decreases in jump height after the HS-EXP CA being smaller than the decreases in the HS-CON condition, however, at no post-test time for either CA did the CMJ jump height increase above pre-test values. Similar to the first investigation, the finding from the current investigation oppose that of the previous potentiation literature that has identified improvements in CMJ performance by using a similar CA (19,91,103,107). Furthermore, the changes in jump height in the current study are less than the first investigation of this thesis.

In the first study, in the optimum WU condition, jump height improved by 2.9% four minutes and 3.1% eight minutes after the CA. Yet in the present investigation, the only small improvement in jump height was in the HS-EXP condition at four minutes post-CA (0.4% improvement). Reasons to suggest such a difference between the two studies are unclear. Participants actually displayed a greater predicted 1RM in the second study compared to the 1st (2nd study: 201.0kg vs. 1st study: 193.6kg), suggesting that the strength of the participants was not the cause for the differences between the studies. One interesting point is that the pre-RPP and jump height values are far greater within the first study, compared to pre-scores in either of the conditions of the second. The mean pre-jump height in the first study was 0.504 m, yet pre-jump height for the second study only reached 0.470 and 0.467 m respectively for each condition. Comparably, RPP was 60.17 W/kg in the first study, however, was only 56.55 and 56.18 W/kg in the second. Reason to explain this could be that the cohort used in the second study was not as well trained in higher velocity movements as the first. Another possible explanation is that CMJs were performed inside the frame of the

Smith for the second study, where they were not in the first. By being inside the frame, participants could have felt restricted and this could have had an unexpected effect upon their CMJ performance.

4.4.2.2 Each individual's best-post recovery interval.

As the optimal recovery period for a potentiating response varies between individuals (26), each individual's optimum rest period was also considered to provide a greater opportunity for a potentiating effect to be revealed. No significant time or CA interactions were observed when comparing pre to post-best CMJ variables. Furthermore, no significant increases in CMJ performance were identified from pre to post-best testing and all effect sizes were trivial. For the HS-EXP CA, a non-significant improvement in jump height (1.3cm; 2.6%) was observed in the post-best recovery, however, this increase was still considered to be trivial. As discussed in the previous chapter (3.4.2,1), participants strength and prior training may have also diminished any potentiating effect, even though the strength of the participants were slightly higher in this study.

Although all the changes in post-best are minimal, for the HS-EXP CA, all of the CMJ variables improved apart from RPP (three out of four). For the HS-CON CA, CMJ jump height and peak force displayed minor enhancements. Although most changes are trivial and statistically non-significant, it is plausible to suggest that the CA is causing some effect on subsequent CMJ performance, at least for certain individuals. For both the HS-EXP and HS-CON CAs, three participants increased their jump height by over 2.5cms in the post-best CMJ compared to the pre. However, three participants decreased their post-best CMJ jump height by more than two centimetres after the HS-EXP CA and two participants after the HS-CON CA (figure 4.6). From the above results, it seems individualistic as to whether a person responds positively or negatively to a CA. The amount of potentiation or fatigue that is created from a CA will vary from person to person (26). Additionally, the amount of potentiation or fatigue will vary depending on the type or intensity of the CA being used. Even a relatively low intensity activity such as dynamic stretching can lead to potentiation (146). Relative strength has been posed as pivotal in whether an individual displays a potentiating effect (44,129), however, further research is required to investigate other possible reasons as to why an individual does or does not exhibit a positive potentiating response to a CA.

Although no significant CA interactions were identified, when comparing the post-best changes between the two CAs, the HS-EXP CA produced better results in both jump height and peak velocity (pre to post-best % change) compared to the HS-CON CA. Furthermore, considering the increased kinetic and kinematic squatting variables in the HS-EXP CA, it is suggested to perform squatting CAs with this instruction. It must be noted that the evidence for such a suggestion is minimal, and further research is required to clearly understand the effect of maximising the intention to lift explosively as a CA.

4.4.3 The effect of the HS-EXP and HS-CON CAs on potentiating DJ performance

The repeated measures ANOVA showed significant decreases in DJ RSI for all post-times (post-6, 10 & post-best) after the HS-EXP CA. Drop jump RSI decreased at all post-times for the HS-CON CA as well, however, none of the following reductions were deemed to be statistically significant. It would seem neither CA is effective at potentiating DJ performance, again contradicting the findings of Comyns et al. (33) and French, Kraemer & Cooke (54). Such decreases in DJ performance after the CA could be attributed to similar reasons suggested in the previous chapter (3.4.3), in that the CA was counterbalanced by fatigue and hence participants were unable to overcome the larger eccentric force from the DJ leading to longer contact times and a decrease in RSI scores. Considering the HS-EXP CA decreased DJ performance more than the HS-CON, possibly a high fatiguing CA is not the optimal protocol to potentiate DJ performance. Further research should investigate whether a CA with a lower intensity or smaller duration potentiates future DJ performance.

Chapter 5: Study 3 - Can an Increased Volume of Rebound Jumps be as Effective as Heavy Half-squats as a Conditioning Activity for Potentiating Jump and Sprint Performance?

5.1 Introduction

5.1.1 Background

Considering DJ RSI significantly decreased for most conditions in the previous studies (study 1 and 2), it seems that a heavy half-squat CA has a negative effect on DJ performance. Hence, the DJ test was replaced with sprint performance for the present study. Furthermore, although the results displayed trivial changes, participants were instructed to perform the CA to the same instructions as the HS-EXP condition in study two. Considering the HS-EXP improved CMJ jump height by 2.6% (HS-CON only 0.9%), it seemed that it was the better CA for recreationally resistance trained males. The CA load and repetitions also remained the same, as the CA was improving performance for certain participants and would allow for comparison between heavy dynamic CAs and the plyometric CAs also investigated within this study.

Much research, including studies 1 and 2 in this project, have used a back squat exercise as a CA in an attempt to induce potentiation. While this exercise can easily be adopted in a weight room environment for training with complex or contrast methods, it is less practical as a CA in the warm-up prior to sports competition, as the equipment is not accessible just prior to the competition starting. An alternative exercise modality that can be performed with no special equipment is plyometrics, and various jump exercises have been used in the potentiation research (23,30,143,151). Due to these facts, there is a lot of merit in trying to establish an effective plyometric CA, so that the positive effects of PAP can be used to acutely enhance competition performance for many other sporting examples.

There is little evidence to suggest that plyometric CAs can have a positive effect of subsequent performance (23,25). Similarly, research has also found no significant change in post-test performance after a plyometric-based CA (42,47,141,146,151). Generally, in the literature, investigations have used a low number of plyometric repetitions within a CA (27,141,146); however, the contraction times of plyometrics are so short, that possibly more repetitions need to be performed in order to identify a positive potentiating response. Both Turki et al.(146) and Till & Cooke (141) failed to identify any significant improvements in jumping or sprinting performance when they used a CA that consisted of nine and five tuck jumps respectively. However, Tobin & Delahunt (143) did report a significant improvement in jump height (4.8%) when they used a CA that consisted of 40 plyometric contacts, hence providing potential rationale to increase the number of plyometric contacts used within a CA.

More specifically, the time under tension throughout these plyometric contacts could match that of other heavy dynamic CAs that have been shown to be successful within the literature. A heavy half-squat repetition may take approximately 2 seconds to complete (from the results of study 2), whereas a plyometric jump ground contact is typically less than 0.3 s (8). Therefore, the time the activated muscles are under tension can be expected to be considerable less with a jump CA, and this may make it more challenging to induce potentiation. If plyometric activities could be used effectively as a CA, it would allow many more sporting scenarios the opportunity to exploit potentiation to enhance performance.

5.1.2 Aim

The aim of the this study was to investigate whether repetitions of plyometric rebound jumps or four half-squats at a 5RM load has an effect on potentiating CMJ and 20 metre sprinting performance.

5.1.3 Research Questions

The main research questions for study 3 were:

1. Can an increased volume of rebound jumps be an effective CA to elicit potentiation in either CMJ or sprinting performance?

2. Does a CA of four half-squats at a 5RM load potentiate CMJ or sprinting performance?

The following specific research questions were also addressed throughout study 3:

1. Did a particular duration of rebound jumps have a greater effect on any post-CMJ and sprinting variables?

2. Which type of CA (plyometric vs. heavy squat) had the greater effect on potentiating CMJ and sprinting performance?

5.2 Methodology

5.2.1 Experimental Design

The following study used a within subject repeated measures design in order to compare particular volumes of rebound jumps (plyometric exercise) to heavy half-squats and the effects each have on potentiating jump and sprint performance. Participants took part in two familiarisation sessions and four experimental conditions. Each session was 2-5 days apart and was performed in a random order to minimise the possibility of an order-effect. One experimental condition involved heavy loaded half-squats, whilst the remaining three included different volumes of rebound jumps as the CA. Pre and post-CMJ and sprint performance was assessed to identify any significant differences between pre- and post-test values for any particular experimental CA.

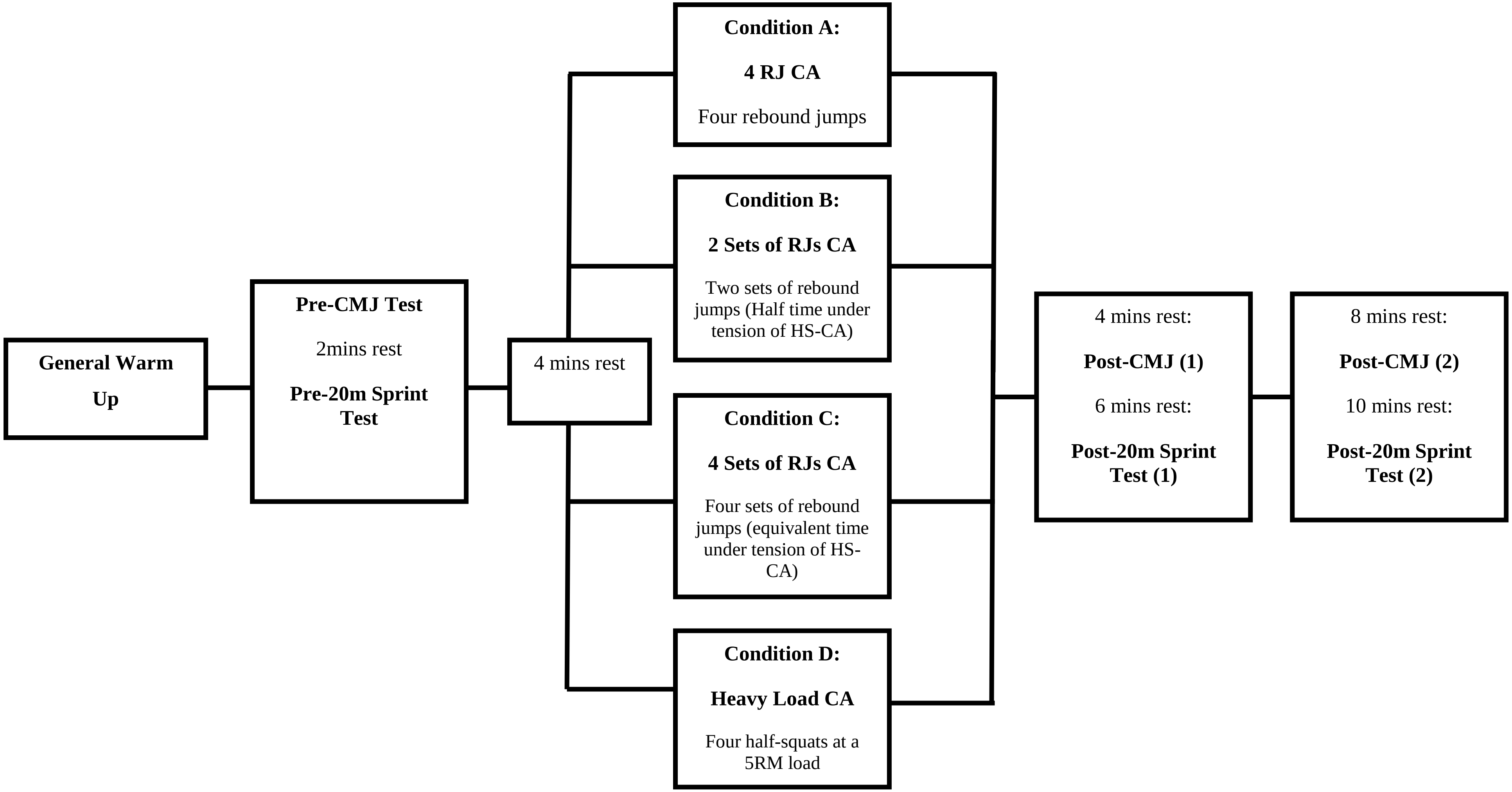

Figure 5.1. Diagram representation of the procedures used throughout the experimental conditions of study 3. RJ = rebound jump, CMJ = countermovement jump, CA = conditioning activity.

5.2.2 Participants

Fourteen recreationally resistance trained male university students with a minimum of one year resistance training experience completed the following study (Mean ± SD age = 21.4 ± 1.7 years, height = 178.6 ± 4.1 cm, weight = 83.0 ± 7.4 kg, predicted 1RM half-squat = 204.7 ± 29.0 kg). The participants recruited for this study followed the same criteria discussed in study one (3.2.2). Before the commencement of the study, the procedure and potential risks were explained to all participants and informed consent was obtained. The study had ethical approval from the HREC at Federation University Australia.

5.2.3 Procedures

5.2.3.1 Familiarisation, 5RM Testing and rebound jump timing sessions

Each participant attended two familiarisation sessions that both commenced with a general warm-up. For the first session, participants performed the 5RM half-squat (90º knee angle) test in the Smith machine, following the same protocol mentioned in the first study (3.2.3.1). Each participant’s half-squat test was filmed, so that the time it took to complete each squat could be equated. The camera was set up on a tripod three metres in front of the Smith machine and 1.2 metres off the ground, so that the full body of the participant was visible in the cameras view. The time each participant took between each squat repetition (not lowering or raising the bar) was not included in the total squatting time. From the above data, the total time under tension during the four half-squats was determined for each individual. After the completion of their 5RM testing and timing, participants then practised continuous rebound jumps with the instruction “try to jump continuously for maximum height with minimum contact time on the ground.” Whilst performing the jumps, hands were akimbo as the participants continuously jumped vertically trying to land in the same position before quickly absorbing the landing and jumping back up into the air. The rebound jump plyometric exercise was selected for this study as it had been used in previous potentiation literature (47) and was convenient to teach to the research participants in a small period of time.

In the second familiarisation session, participants firstly had their rebound jumps timed. Participants performed 10 continuous rebound jumps on the timing mat, with the same instruction to jump for maximum height whilst spending minimal time on the ground between each jump. Whilst the participant was mid-flight between rebound jumps, a research assistant reset the DJ software, so that the time spent on the ground was calculated for all ten rebound jumps individually. The mean rebound jump ground contact time was then equated for each individual. If a participant missed the jump mat on any of the 10 trials, they rested for two minutes before performing the ten rebound jumps again. The mean contact time in the rebound jumps was used to equate how many repetitions a participant would perform in their plyometric testing conditions. In one condition, participants would perform an amount of rebound jumps so that the time under tension matched that of the 4 half-squat CA, whilst in another condition, participants performed a number of rebound jumps to equal half the time under tension of the squats. This condition was included as the rebound jump CA will provide different demands than the half-squat CA, so potentially if the rebound jumps match the time under tension of the half-squat CA, potentially this may be too fatiguing and decrease post-performance. Once participants completed their rebound jumps, they were then familiarised with the CMJ and 20m sprint testing protocol.

The 20m sprint test was included for this as study as it is an actual sports performance test that is commonly used to assess speed in both team and court sports (89). Furthermore, a 10m split time was included to also assess the effect of the CA on early running acceleration. In the 20m sprint test, timing gates (Speedlight, Swift Performance, QLD, Australia) were set out at the starting line and then at 10 and 20 metres respectively.

Participants completed the 20-metre sprint as fast as they could and were instructed to not slow down until they had passed the final timing gates at 20 metres. A synthetic grass mat was placed and secured at the start of the 20m test, so that participants had better traction whilst taking off. A research assistant watched each trial and made sure participants were as close to the first timing gate as possible without setting it off. Participants were also instructed to "make their first movement forward" and if the research assistant noticed any swaying back before the start of the trial, the trial was void.

5.2.3.2 Heavy Load CA (loaded half squats)

After the familiarisation sessions, participants performed four randomised testing conditions on separate days; one of which involved a CA of four half-squats with a 5RM load. The session followed the same warm-up, pre-testing and CA protocol as HS-EXP condition from study 2 (4.2.3.2), except the pre DJ test was replaced with a pre 20m sprint test. Participants were instructed the perform the half-squats explosively, as the changes from pre to post-best jump height in the HS-EXP were greater than the changes displayed in the HS-CON condition (study 2). At the completion of the four half-squat with a 5RM load CA, participants performed post-CMJ tests at four and eight minutes rest, whilst post-20m sprint tests were performed at six and 10 minutes rest respectively. Similar recovery periods to four (107,163) and six (62,128) minutes rest have been used to successfully potentiate performance in the past, whilst both the eight and 10 minute rest period fall within the guidelines of Wilson et al. (154) for recreationally resistance trained participants.

5.2.3.3 Rebound jump CAs

Each rebound jump CA session followed the same procedure as the heavy half-squat CA condition, except participants performed different volumes of rebound jumps as the CA instead of half-squats. One condition consisted of four rebound jumps total, as this matched the total repetitions of half-squats used in the squatting CA and has been used as a CA in previous potentiation research (23,141). The second condition involved two sets of rebound jumps, however, the number of repetitions was individualised for each participant, so that the total contact time in the rebound jumps matched half the time under tension from the participants four half-squats (Table 5.1). Participants had two minutes rest between each set of rebound jumps to minimise any effect of fatigue. For the final condition, participants performed four sets of rebound jumps as the CA. The total number of rebound jumps was individualised for each participant so that the total contact time throughout the four sets of rebound jumps matched the total time under tension from the participant's four half-squats. Participants had two minutes rest between each set of rebound jumps to avoid excessive fatigue. For the four sets of rebound jump CA, the first and fourth sets of rebound jumps were performed on the BMS using a LPT on a light stick (0.4kg) held on the shoulders. By completing the rebound jumps with the BMS, variables from the rebound jump CA were quantified and differences between the rebound jump and half-squat CAs were identified.

Table 5.1. The total time each individual took to complete their four half-squats, the mean contact time spent on the ground for each rebound jump, and the total repetitions of rebound jumps performed in both multiple sets of RJs conditions. HS = half-squat, RJ = rebound jump and CA = conditioning activity.

Participant no.	**4 HS time (s)**	**RJ time (s)**	**RJs to match 4 HS**	**RJs per set in 2 sets of RJ CA**	**RJs per set in 4 sets of RJ CA**
1	9.32	0.29	32	8 & 8	8, 8 , 8 & 8
2	9.08	0.22	41	10 & 10	11, 10, 10 &10
3	6.52	0.20	34	9 & 8	9, 8, 8 & 9
4	7.96	0.21	38	10 & 9	10, 9, 9 &10
5	8.32	0.28	29	8 & 7	8, 7, 7 & 7
6	7.92	0.20	40	10 & 10	10, 10, 10 & 10
7	9.24	0.36	26	7 & 6	8, 7, 7 & 8
8	7.84	0.39	20	5 & 5	5, 5, 5 & 5
9	7.60	0.34	22	6 & 5	6, 5, 5& 6
10	8.16	0.17	48	12 & 12	12, 12, 12 & 12
11	9.52	0.24	39	10 & 9	10, 10, 9 & 10
12	8.02	0.18	46	12 & 11	12, 11, 11 & 12
13	10.00	0.16	62	16 & 15	16, 15, 15 &16
14	8.52	0.26	33	8 & 8	9, 8, 8 & 8
Mean	**8.43**	**0.25**	**36.4**	**n/a**	**n/a**

5.2.4 Data Collection

Videos of half-squats were analysed using the computer software Kinovea (Kinovea, version 0.8.11, France). Each half-squat time was equated between the first frame where downward movement of the squat bar was noticeable and the final frame where the squat bar was moving upwards. The data collection protocol for the pre and post-CMJs were the same as study 2 (4.2.4). Pre and post-10 and 20 metre sprint times were recorded from the Speedlight application (Speedlight, Swift Performance, Australia) into an excel spreadsheet where all means and standard deviations were calculated.

5.2.5 Statistical Analyses

All statistical analyses were completed using the software Statistical Package for the Social Sciences (SPSS for Windows, version 21.0; SPSS Inc., Chicago, ILL.). Descriptive statistics (mean and SD) were calculated for RPP ($W.kg^{-1}$), jump height (m), peak velocity ($m.s^{-1}$), and peak force (N) for all pre and post-CMJs. Only the best result across the three CMJs was considered for analysis. Descriptive statistics were also calculated for pre and post-10 and 20m sprint times. In order to determine whether a particular load of plyometric jumps, or heavy dynamic squats were effective in potentiating CMJ or sprint performance, a 2 way Repeated Measure ANOVA (4 conditions x 3 times) with a post-hoc Bonferroni correction was performed in order to assess any significant change between pre and post-CMJ and sprint performance for all of the CA conditions ($p < 0.05$). A separate Repeated Measures ANOVA (4 conditions x 2 times) was used in order to assess any significant change between pre and post-best recovery CMJ and sprint performance. Effect sizes were used to quantify the magnitude of differences between the pre to post changes within the CA protocols. Effect sizes were classified as follows: trivial (ES = 0.00-0.19), small (ES = 0.20-0.59), moderate (ES = 0.60-1.19), large (ES = 1.2- 1.99) and very large (ES > 2.00).

5.3 Results

5.3.1 Quantifying the Rebound Jump CA.

The mean and SD for the first set and fourth set of rebound jumps is displayed in table 5.2. When comparing the first to the fourth set, no significant differences were identified for any eccentric, in-flight or concentric rebound jump variables.

Table 5.2. A Comparison of the first set of rebound jumps in the plyometric CA to the fourth set.

		1st set	4th set	% Diff	p-value
Eccentric Phase	Best PF	4672.7 ± 1012.9	4773.6 ± 977.7	2.2	0.569
	Mean PF	3821.3 ± 765.5	3846.8 ± 843.1	0.7	0.863
	Best RFD	59774.4 ± 15076.3	59877.8 ± 17804.6	0.2	0.983
	mean RFD	46350.0 ± 14003.8	49562.8 ± 15822.6	6.9	0.296
In Flight Phase	Best JH	0.339 ± 0.053	0.338 ± 0.064	-0.3	0.926
	Mean JH	0.301 ± 0.063	0.313 ± 0.063	3.9	0.241
Concentric Phase	RPP best	40.5 ± 8.6	40.5 ± 9.2	-0.1	0.974
	RPP mean	34.6 ± 9.0	36.1 ± 9.7	4.5	0.341
	Best PV	1.648 ± 0.369	1.671 ± 0.360	1.4	0.698
	Mean PV	1.400 ± 0.359	1.446 ±0.364	3.3	0.376
	Best PF	4445.2 ± 993.5	4390.5 ± 1007.4	-1.2	0.772
	Mean PF	3716.0 ± 783.6	3707.7 ± 838.1	-0.2	0.959

5.3.2 Comparing different volumes of rebound jumps and half-squats as a CA for CMJ performance.

5.3.2.1 Comparing pre to all post-CMJ tests.

Participant RPP showed a significant time by CA interaction (p = 0.028), as well as a significant time effect (p = 0.006) with RPP significantly decreasing after four minutes recovery in the 4 rebound jump condition and significantly decreasing after eight minutes recovery in the two sets of rebound jumps condition. Peak velocity (p = 0.004) demonstrated a significant time effect with a significant small decrease at four minutes recovery in the 4 rebound jump condition. No significant changes were displayed in the squat CA for any CMJ variable across any recovery period. The results for CMJ height (Figure 5.2) and peak velocity (Figure 5.3) across all time periods are displayed below for all four CAs.

Table 5.3. A comparison between pre and post-4 and 8 CMJ variables across the four different CAs. RJ = rebound jump, CMJ = countermovement jump and ES = effect size, RPP = relative peak power, JH = jump height, PV= peak velocity, PF = peak force and * with bold text representing statistical significance.

CA	CMJ Variable	Pre mean ± SD	Post 4 mean ± SD	% pre to post 4	P value	ES(descriptor)	Post 8 mean ± SD	% pre to post 8	P value	ES(descriptor)
4 repetitions of RJs	RPP (W . kg^{-1})	58.08 ± 5.13	56.23 ± 5.42	-3.2	**0.042***	-0.35 (small)	56.74 ± 6.22	-2.3	0.252	-0.24 (small)
	JH (m)	0.486 ± 0.073	0.475 ± 0.068	-2.2	0.075	-0.16 (trivial)	0.471 ± 0.068	-3.0	0.065	-0.21 (small)
	PV (m.s^{-1})	2.756 ± 0.187	2.681 ± 0.222	-2.7	**0.004***	-0.37 (small)	2.715 ± 0.216	-1.5	0.175	-0.20 (small)
	PF (N)	1996.4 ± 262.7	1971.3 ± 293.9	-1.3	0.891	-0.09 (trivial)	1969.1 ± 264.0	-1.4	0.909	-0.10 (trivial)
2 Sets of RJs *(time under tension equals ½ of squat CA)*	RPP (W . kg^{-1})	58.70 ± 6.45	57.70 ± 7.02	-1.7	0.361	-0.15 (trivial)	56.79 ± 6.62	-3.3	**0.011***	-0.29 (small)
	JH (m)	0.485 ± 0.070	0.476 ± 0.067	-1.9	0.303	-0.13 (trivial)	0.479 ± 0.074	-1.4	0.800	-0.08 (trivial)
	PV (m . s^{-1})	2.764 ± 0.230	2.693 ± 0.255	-2.6	0.181	-0.29 (small)	2.700 ± 0.237	-2.3	0.234	-0.27 (small)
	PF (N)	1985.5 ± 248.2	1955.0 ± 249.0	-1.5	0.232	-0.12 (trivial)	1964.0 ± 273.0	-1.1	1.000	-0.08 (trivial)
4 Sets of RJs *(time under tension equals squat CA)*	RPP (W . kg^{-1})	58.35 ± 4.94	56.76 ± 5.52	-2.7	0.132	-0.30 (small)	57.31 ± 5.90	-1.8	0.449	-0.19 (trivial)
	JH (m)	0.481 ± 0.066	0.474 ± 0.066	-1.4	1.000	-0.11 (trivial)	0.482 ± 0.066	0.1	1.000	0.02 (trivial)
	PV (m.s^{-1})	2.745 ± 0.196	2.666 ± 0.202	-2.9	0.066	-0.40 (small)	2.738 ± 0.240	-0.2	1.000	-0.03 (trivial)
	PF (N)	1979.3 ± 233.0	1951.9 ± 267.4	-1.4	0.365	-0.11 (trivial)	1961.8 ± 255.2	-0.9	1.000	-0.07 (trivial)
Squats	RPP(W . kg^{-1})	58.11 ± 4.76	57.95 ± 5.64	-0.3	1.000	-0.03 (trivial)	57.52 ± 6.55	-1.0	1.000	-0.10 (trivial)
	JH (m)	0.491 ± 0.054	0.487 ± 0.069	-0.8	1.000	-0.06 (trivial)	0.489 ± 0.059	-0.4	1.000	-0.04 (trivial)
	PV (m . s^{-1})	2.723 ± 0.145	2.711 ± 0.233	-0.4	1.000	-0.06 (trivial)	2.716 ± 0.201	-0.3	1.000	-0.04 (trivial)
	PF (N)	1976.5 ± 290.2	1983.2 ± 290.9	0.3	1.000	0.02 (trivial)	1966.5 ± 257.1	-0.5	1.000	-0.04 (trivial)

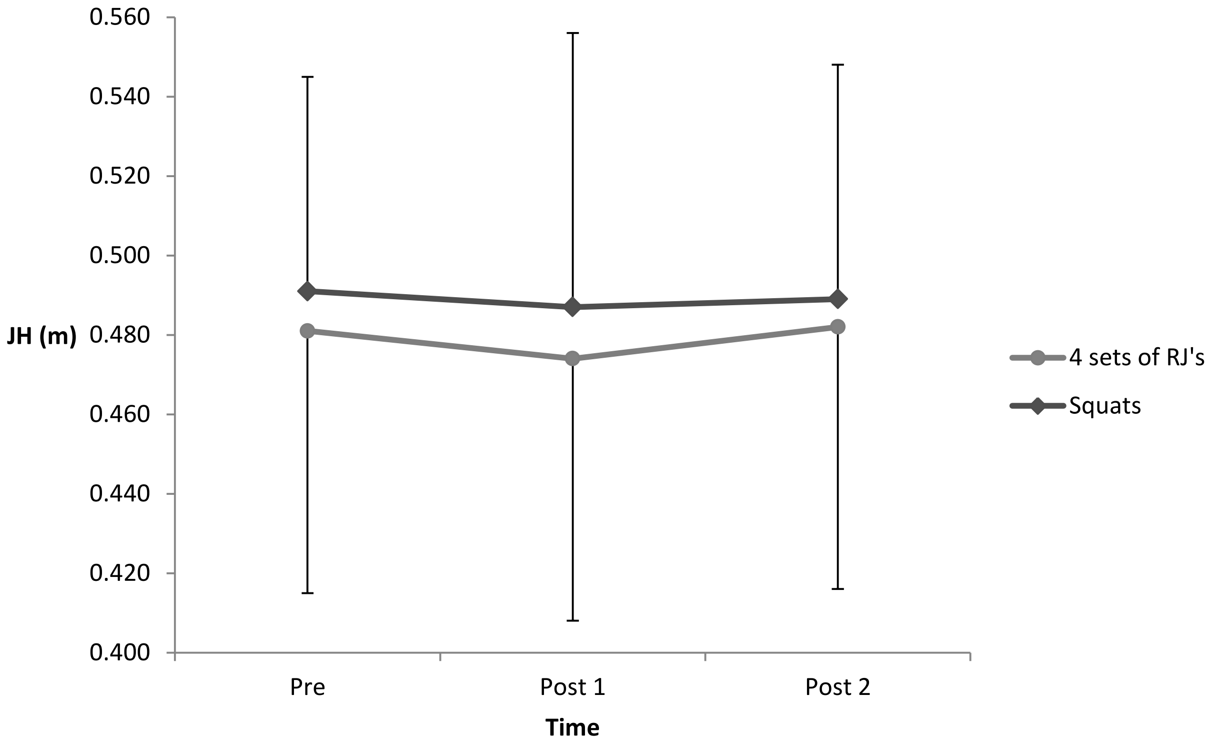

Figure 5.2. Pre, post-4 and post-8 jump height scores after both the four sets of RJ and half-squat CA. Error bars represent one standard deviation from the mean.

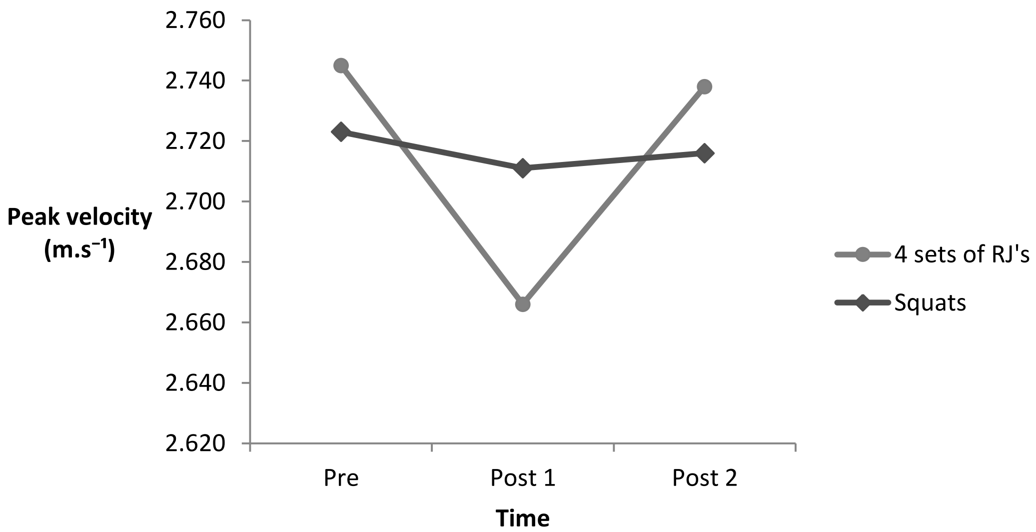

Figure 5.3. Pre, post-4 and post-8 peak velocity scores after both the four sets of RJ and half-squat CA. Error bars not included due to the cross-over of variables. Standard deviation presented in table 5.3.

5.3.2.2 Comparing pre to post-best CMJ tests

The mean and SD for all the pre and post-best CMJ variables are displayed in Table 5.4) across all four CAs. Each individuals post-best time was considered as past research has expressed that the optimal rest period following a CA can differ between individuals

(124,129). No significant interactions or effects were identified for any CMJ variable. The percentage changes from pre to post-best for all CMJ variables across all CAs are displayed in Figure 5.4.

Table 5.4. A comparison between pre and post-best CMJ variables across the four different CAs. RJ = rebound jump, CMJ = countermovement jump and ES = effect size.

CA	CMJ Variable	Pre mean ± SD	Post best mean ± SD	% pre to post best	P value	ES(descriptor)
4 RJs	RPP (W . kg^{-1})	58.08 ± 5.13	57.40 ± 5.87	-1.2	0.290	-0.12 (trivial)
	JH (m)	0.486 ± 0.073	0.481 ± 0.068	-1.0	0.314	-0.07 (trivial)
	PV (m.s^{-1})	2.756 ± 0.187	2.728 ± 0.209	-1.0	0.159	-0.14 (trivial)
	PF (N)	1996.4 ± 262.7	2006.7 ± 278.4	0.5	0.700	0.04 (trivial)
2 Sets of RJs	RPP (W . kg^{-1})	58.70 ± 6.45	58.02 ± 6.85	-1.2	0.239	-0.10 (trivial)
(time under tension equals ½ of squat CA)	JH (m)	0.485 ± 0.070	0.486 ± 0.070	0.1	0.956	0.01 (trivial)
	PV (m . s^{-1})	2.764 ± 0.230	2.737 ± 0.262	-1.0	0.425	-0.11 (trivial)
	PF (N)	1985.5 ± 248.2	1995.0 ± 263.7	0.5	0.569	0.04 (trivial)
4 Sets of RJs	RPP (W . kg^{-1})	58.35 ± 4.94	57.67 ± 5.69	-1.2	0.341	-0.13 (trivial)
(time under tension equals squat CA)	JH (m)	0.481 ± 0.066	0.486 ± 0.063	1.1	0.385	0.08 (trivial)
	PV (m.s^{-1})	2.745 ± 0.196	2.753 ± 0.236	0.3	0.799	0.04 (trivial)
	PF (N)	1979.3 ± 233.0	1990.1 ± 273.5	0.6	0.578	0.04 (trivial)
Squats	RPP (W . kg^{-1})	58.11 ± 4.76	58.76 ± 6.29	1.1	0.342	0.12 (trivial)
	JH (m)	0.491 ± 0.054	0.498 ± 0.063	1.5	0.168	0.12 (trivial)
	PV (m . s^{-1})	2.723 ± 0.145	2.748 ± 0.218	0.9	0.511	0.14 (trivial)
	PF (N)	1976.5 ± 290.2	2010.6 ± 284.8	1.7	0.062	0.12 (trivial)

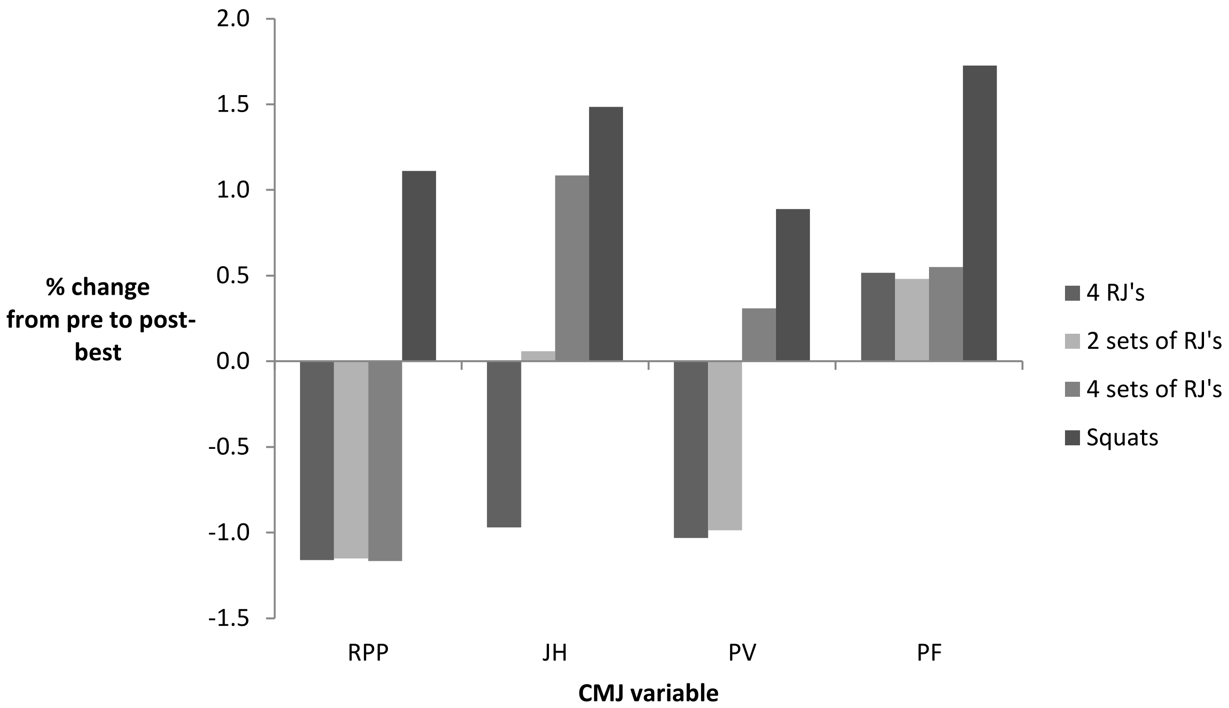

Figure 5.4. The percentage changes shown from pre to post-best for all CMJ variables across four different CAs.

5.3.3 Comparing different volumes of rebound jumps and half-squats as a CA for sprint performance.

The mean and SD for all pre, post-6, post-10 and post-best sprint times are displayed in Table 5.5 across all four CAs. When comparing pre to post-six and 10 minute sprints, significant time effects were evident for all sprint variables (0- 10m: $p = 0.018$, 10-20m: $p = 0.004$, 0-20m: $p = 0.002$). Whilst comparing pre to post-best sprint variables, a significant time effect occurred for the 0-20m sprint ($p = 0.028$). For all of the plyometric CAs, generally the results displayed a trivial to small increase in sprint times across all distances, suggesting a decrease in sprint performance. For the half-squat CA, no significant changes were identified for any sprint distance from pre to post-tests ($p > 0.05$); however, the effect sizes displayed trivial to small increases in sprint times for most distances.

Table 5.5. A comparison between pre and post-6 and 10 sprint variables across the four different CAs. RJ = rebound jump, ES = effect size and * with bold text representing statistical significance.

CA	Sprint Time	Pre mean ± SD	Post 6 mean ± SD	% pre to post 6	P value	ES(descriptor)	Post 10 mean ± SD	% pre to post 10	P value	ES(descriptor)	Post best mean ± SD	% pre to post best	P value	ES(descriptor)
4 RJs	0-10 metres (s)	2.00 ± 0.07	2.01 ± 0.08	0.2	1.000	0.13 (trivial)	2.01 ± 0.07	0.0	1.000	0.14 (trivial)	1.99 ± 0.07	-0.6	0.343	-0.14 (trivial)
	10-20 metres (s)	1.31 ± 0.06	1.32 ± 0.07	1.1	**0.011***	0.15 (trivial)	1.33 ± 0.08	1.5	**0.008***	0.28 (small)	[redacted]			
	0-20 metres (s)	3.31 ± 0.12	3.33 ± 0.14	0.6	0.558	0.15 (trivial)	3.33 ± 0.14	0.6	0.327	0.15 (trivial)	3.32 ± 0.13	0.1	0.747	0.08 (trivial)
2 Sets of RJs	0-10 metres (s)	1.99 ± 0.08	2.01 ± 0.09	1.4	**0.034***	0.23 (small)	2.00 ± 0.07	0.8	0.249	0.13 (trivial)	2.00 ± 0.08	0.4	0.346	0.13 (trivial)
	10-20 metres (s)	1.32 ± 0.06	1.33 ± 0.06	0.9	0.088	0.17 (trivial)	1.33 ± 0.06	0.9	0.051	0.17 (trivial)	[redacted]			
	0-20 metres (s)	3.31 ± 0.13	3.35 ± 0.14	1.2	**0.015***	0.30 (small)	3.33 ± 0.13	0.8	**0.036***	0.15 (trivial)	3.32 ± 0.13	0.5	0.063	0.08 (trivial)
4 Sets of RJs	0-10 metres (s)	1.99 ± 0.07	2.01 ± 0.07	1.2	**0.001***	0.29 (small)	2.01 ± 0.09	1.3	**0.025***	0.25 (small)	2.00 ± 0.08	0.6	**0.030***	0.13 (trivial)
	10-20 metres (s)	1.32 ± 0.05	1.32 ± 0.05	0.3	0.761	<0.01 (trivial)	1.33 ± 0.05	0.6	0.178	0.20 (small)	[redacted]			
	0-20 metres (s)	3.30 ± 0.11	3.33 ± 0.12	0.8	**0.001***	0.26 (small)	3.34 ± 0.13	1.0	**0.011***	0.33 (small)	3.32 ± 0.13	0.6	**0.014***	0.17 (trivial)
Squats	0-10 metres (s)	2.00 ± 0.07	2.01 ± 0.07	0.8	0.315	0.14 (trivial)	2.02 ± 0.08	1.3	0.515	0.27 (small)	2.01 ± 0.07	0.5	0.311	0.14 (trivial)
	10-20 metres (s)	1.32 ± 0.05	1.33 ± 0.06	0.8	0.247	0.18 (trivial)	1.32 ± 0.06	0.3	0.687	<0.01 (trivial)	[redacted]			
	0-20 metres (s)	3.31 ± 0.11	3.34 ± 0.13	0.8	0.216	0.25 (small)	3.35 ± 0.12	0.9	0.088	0.35 (small)	3.33 ± 0.12	0.5	0.233	0.17 (trivial)

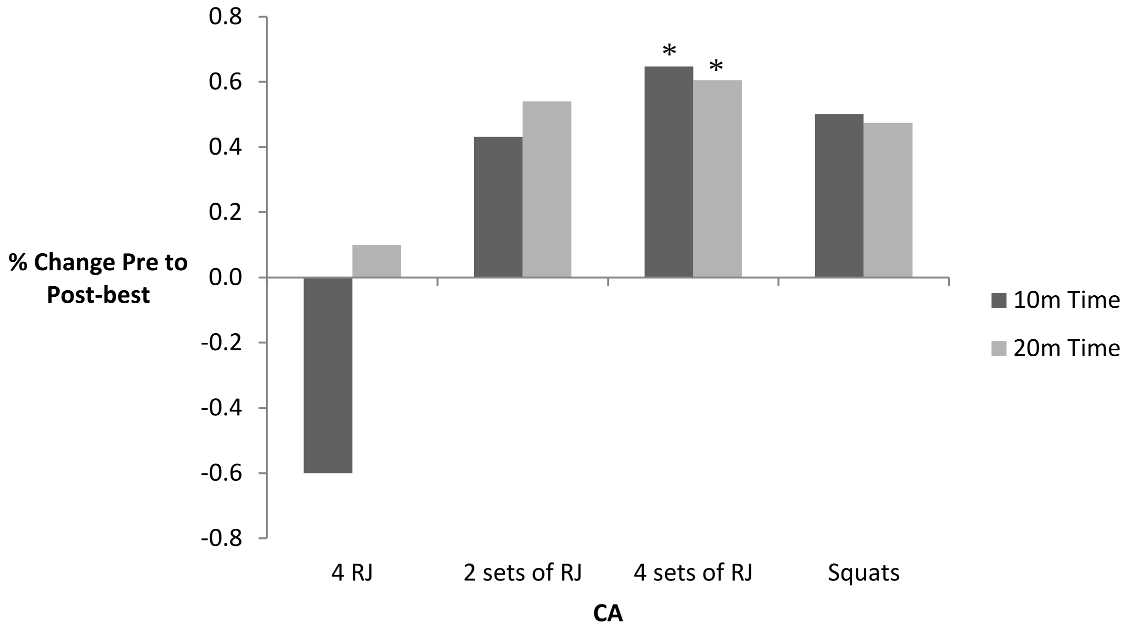

Figure 5.5. The percentage changes shown from pre to post-best for 10 and 20 metre sprint times across all four different CAs. Statistical significance is represented by * ($p < 0.05$).

5.4 Discussion

The initial purpose of the study was to quantify the kinetic and kinematic variables of the rebound jump CA. The main purpose was to investigate whether a particular volume of rebound jumps could be an efficient CA to elicit potentiation in either CMJ or sprinting performance; and whether it would be more effective than a heavy-loaded CA. This was the first study that attempted to match the time under tension of a plyometric CA to a heavy dynamic CA.

5.4.1 Quantifying the kinematic and kinetic variables of the rebound jump CA.

The first and fourth sets of the rebound jump CA were performed on the force platform to firstly provide an understanding of the kinematic and kinetic variables of the exercise. Secondly, the first and fourth sets were both performed to see if there were any significant changes between these sets due to fatigue. Considering no significant change was identified for any variable between set one and four ($p > 0.05$), the two minutes rest between each set of rebound jumps seems sufficient to recover from the fatigue caused by each set.

When comparing the kinematic and kinetic characteristics of the rebound jumps to the explosive squats performed in the last investigation, the differences are vast (Table 5.6). During the concentric phase of each CA, the rebound jumps produced higher values than the explosive half-squats across all variables measured. The rebound jumps produced 39.0 % more peak force than the explosive half-squats (best peak force) whilst the peak velocity was also more than doubled (1.648 $m.s^{-1}$ vs. 0.708 $m.s^{-1}$). The peak power was 53% greater in the rebound jumps compared to the half-squats. Concentric RFD could not be equated in the concentric phase for the rebound jump, as in almost every rebound jump trial, peak force occurred either during the eccentric or isometric phase of the jump. Therefore, peak force was always decreasing in the concentric phase of the rebound jump and hence a positive RFD did not occur.

Table 5.6. A comparison of the concentric kinetic and kinematic variables of the rebound jump CA from study 3 and the HS-EXP CA from study 2.

	HS-EXP CA	**RJ CA**	**% Difference**
Best Peak Power (W)	2193.7 ± 187.2	3356.1 ± 751.8	53.0
Mean Peak Power (W)	2040.7 ± 154.6	2859.1 ± 744.5	40.1
Best Peak Force (N)	3198.1 ± 334.3	4445.2 ± 993.5	39.0
Mean Peak Force (N)	3120.9 ± 321.9	3716.0 ± 783.6	19.1
Best Peak Velocity ($m\cdot s^{-1}$)	0.708± 0.041	1.648 ± 0.369	132.8
Mean Peak Velocity ($m\cdot s^{-1}$)	0.669 ± 0.038	1.400 ± 0.359	109.3

Considering the plyometric rebound jump CA is so different to the explosive half-squat CA, the effect that each could have on creating a potentiating response could also be dissimilar. Not only in the amount of potentiation that each CA creates, but also the amount of fatigue. Therefore, the repetitions that need to be performed as well as the rest period required after the CA could be completely different between the two types of CA.

5.4.2 The effect of different repetitions of rebound jumps as a CA for enhancing CMJ performance

The repeated measures ANOVA displayed no significant increases in the CMJ for any variable at post-four or eight minutes ($p > 0.05$) after the performance of a plyometric CA. For the CA that only consisted of four repetitions of the rebound jumps, CMJ RPP and peak velocity both significantly decreased four minutes after the CA compared to the pre-testing. This finding opposes that of Terzis et al (140), who saw a significant 4.6% increase in underhand throw distance after a CA of five drop jumps (off a 40cm box). Although the DJ is slightly different to the rebound jump used in this study, they are similar, as the instruction is to maximise jump height whilst minimising contact time for both activities. Burkett et al. (25) and Chattong et al. (27) also significantly improved vertical jump performance after a CA of five plyometric box jumps, however, both CAs are slightly different as they increased the load with the use of a weight vest. A possible explanation as to why Terzis et al. (140) identified a significant increase in performance may be due to the fact the warm-up did not consist of any practice or sub-maximal trials of the underarm squat throw. Therefore, pre-testing performance could have been decreased and the increase in performance after the DJ CA may not be due to potentiation. It should also be noted that the performance measure used by Terzis et al. (140) was different to the CMJ used in this investigation.

For the plyometric CAs that consisted of two and four sets of rebound jumps, no significant improvements occurred for any CMJ variable at four or eight minutes rest. Again this opposes certain findings of the literature where increases in performance after a plyometric CA that consisted of multiple contacts. Tobin and Delahunt (143) found significant improvements in CMJ peak force across all post-times as well as a significant 4.6% improvement in jump height after just one minute rest. They used a CA that consisted of 40 plyometric contacts (emphasising minimal ground contact time), which is similar to the amount that many of the participants used in the 4 sets of rebound jumps CA in this investigation. One difference between these two studies is that Tobin and Delahunt used a mixture of plyometric activities (Table 2.2), whereas this investigation only used rebound jumps. Although plyometric activities are similar in nature, each activity is unique, therefore, the different type of plyometric (or greater variation of exercises) used by Tobin & Delahunt (143) may have contributed to the significant improvement in jump performance that was not evident in this investigation. Potentially, if more types (or just a different type) of plyometrics were used in this investigation, the effect on future CMJ performance may have been different. Although Tobin & Delahunt found significant improvements in post-performance after a plyometric CA, it must be noted that the warm-up prior to pre-testing could be deemed insufficient, meaning the CA could have improved performance due to other mechanisms not associated with potentiation.

Another difference between the present study and the literature is how the plyometric activities are distributed over sets in the CAs. In this investigation, participants performed a mean of 36 rebound jumps over four sets. Conversely, Tobin and Delahunt (143) had participants perform their 40 plyometric contacts over six sets. Miarka, Del Vecchio & Francinni (106) also performed more sets in the CA, performing 10 sets of three DJs to significantly improve performance in a judo specific test by 14.3%. Considering the large eccentric force and RFD exhibited in this rebound jump CA, potentially fatigue after the four sets was too much and outweighed any underlying potentiating response, despite no significant change in rebound jump performance between the first and fourth sets. By performing the rebound jumps over more sets with fewer repetitions, it is possible that this would have created less fatigue and potentially lead to improvements in post-CMJs.

For the four sets of rebound jumps CA, CMJ variables were all better at post-eight minutes rest when compared to post-four. Peak velocity was lowest after the 4 sets of rebound jump CA at four minute rest; however, it produced the highest peak velocity at post-eight minutes compared to the other conditions (Figure 5.3). Jump height was similar, as the four sets of rebound jump CA produced the lowest jump height at four minutes rest, however, after eight minutes rest, this CA produced the second highest jump height (Figure 5.2). The following result suggest that the fatigue that was caused by this particular CA was too large at four minutes rest, however, with the additional four minutes rest, it seemed that fatigue began to dissipate and CMJ performance began to increase similar to that during the pre-testing. It is plausible to suggest that if a longer rest period was provided, the potentiation caused by the CA could have outweighed the fatigue. As discussed in the last paragraph, by performing the rebound jumps over more sets, it could have also decreased the amount of fatigue created by the CA, and lead to a heightened performance in the CMJ at eight minutes recovery.

When each participants best recovery period was compared to the pre-tests, the repeated measures ANOVA showed no significant improvements in CMJ performance for any condition. Considering no significant improvements were identified after any of the following plyometric CAs, other methods of how to utilise plyometric activities may have to be considered. This could mean changing the type of plyometric exercise or even using a number of different types like Tobin and Delahunt (143). Another alteration that could be considered would be to add small percentages of body weight whilst performing the plyometric jumps like Burkett et al. (25) and Chattong et al. (27). A final consideration would be to allow longer rest periods. This could be done by either increasing the rest period allowed after the performance of the CA, or even allowing greater rest between the sets of plyometric jumps.

By using plyometrics as a CA rather than heavy dynamic exercises, it would mean that more sporting examples would be able to utilize the acute potentiating response within competition, as the need for equipment is minimal. However, if using a plyometric CA means that longer rest periods are required before an increase in performance occurs, then this may make it more difficult to control for many sporting situations. Further investigation is required to establish better methods to acutely potentiate performance after a plyometric CA.

5.4.3 The effect of different repetitions of rebound jumps as a CA for enhancing sprint performance

The trends in sprint performance were similar to the trends exhibited in jumping performance, in that all plyometric CAs caused small to trivial increases in sprint times (i.e. slower sprints), indicating an impairment to sprinting performance. Furthermore, all the plyometric CAs significantly increased sprinting times at a particular rest period ($p < 0.05$). These results cannot accurately be compared to others, as no past investigations have successfully used a plyometric CA to improve sprinting performance. McBride et al. (102) found small non-significant ($p > 0.05$) improvements in 40m sprint time after a CA of three loaded CMJs, however, the load was far greater (30% of 1RM back squat) and the repetitions performed were much less than this present investigation. Furthermore, Seitz Trajano and Haff (127) used power cleans in a CA to successfully potentiate sprinting performance. Although power cleans require a greater velocity of movement than heavy squats (127), this type of CA will still be very different to the plyometric rebound jumps used within this investigation.

Seitz, Mina & Haff (125) significantly improved sprint performance after a CA that involved a heavy weighted sled push. Participants in separate sessions performed either a CA that involved a 9m sled push with a load of 120% BW or a 15m sled push that had 70% BW as its load. For the 70%BW condition, sprint times significantly decreased after eight (0.06 seconds, $p = 0.001$) and 12 minutes rest (0.05 seconds, $p = 0.003$). For the heavier sled push condition, no significant improvements were identified at any post-rest period. Similarly, Winwood et al. (156) reported significant improvements in 15 metre sprint times after a sled push CA with a load of 75% body weight and twelve minutes recovery. From these results and considering sprinting involves anterior-posterior forces (not just vertical force production like jumping), possibly the CA also needs to focus upon this movement plane. Considering past research has suggested that the CA should be biomechanically similar to the performance measure (72), possibly a plyometric activity that focussed on translational movement as well as vertical (for example a broad jump or bounding) would be more beneficial as a CA for sprinting performance (147). Future research should investigate if such a plyometric CA can be used to further improve sprinting performance.

5.4.4 The effect of heavy-loaded squats as a CA for enhancing CMJ performance

When assessing the effect of the heavy-loaded half-squat CA on CMJ performance, the repeated measures ANOVA displayed no significant changes for any jump variable across any post-rest period ($p > 0.05$). Even after each participants optimum rest period was taken into consideration, no significant improvements were identified. A near significant improvement was evident for post-best CMJ peak force ($p = 0.062$, 1.6% increase), however, the change was still considered to be trivial (ES = 0.12). Similarly, jump height also showed improvements from pre to post-best (1.5%), but once again was only a trivial change (ES = 0.12). Similar to the previous study, this contradicts previous literature that showed significant improvements in CMJ jump height (19,20,39,91,153,163) and PP (23,31,71,76) after heavy dynamic CA. Potential reasons to explain this finding may be the load or amount of repetitions used during the CA. Four repetitions of half-squats at a 5RM load was used as the participants of this particular study were only recreationally trained (154), however, maybe a heavier load (3RM) or an extra repetition of half-squats may have a greater effect on potentiating future contractions. Much of the literature has used a CA of three repetitions at a

3RM load to successfully potentiate jump performance (33,39,116) whilst there is also a plethora of evidence to suggest five repetitions at a 5RM load can also be effective (19,103,107,163). Possibly this increase in load or amount of repetitions either creates greater potentiation or less fatigue, allowing after an appropriate rest period, an improvement in future performance.

Another explanation for no significant improvement may be that the rest period allowed after the CA was insufficient. Wilson et al. (154) suggested that the rest period after a CA should fall between seven and 12 minutes. However, the current investigation only assesses the first part of that time window with the post-eight minute CMJ test. Other research has also found significant increases in performance when the post-testing is performed more than 12 minutes after the CA (39,82,125). Considering this, potentially the present research could have identified a significant improvement after the CA if another post-CMJ was performed at twelve minutes rest.

Similar to the previous studies, whether a participant responds positively to the CA or negatively seems individualistic. Although strength has been shown to be an important prerequisite as to whether somebody can take advantage of the PAP phenomenon, further research is required to focus upon other physical attributes that may lead to whether an individual produces a positive potentiation response or not.

5.4.5 The effect of heavy-loaded squats as a CA for enhancing sprint performance

For the heavy half-squat CA, the repeated measures ANOVA discovered no significant changes between pre and post-sprint tests for any distance across any rest interval ($p > 0.05$). In fact, all sprint splits (0-10m, 10-20m and 0-20m) were slower at all of the post-times (post-six, 10 and post-best) after the heavy half-squat CA. This opposes past literature that has successfully potentiated sprinting performance after heavy dynamic CAs (15,28,99).

One difference between the methodology of this study and the previous literature is the load of the CA. For much of the potentiation research on sprinting performance, a heavier CA has been used. Bevan et al. (15) used a CA of three back squats with a load of 91% of each participants 1RM (approximately 3RM). After this CA, they reported that sprint times significantly decreased by 0.04 seconds for both 5 and 10 metres when each participants best post-rest interval was considered. The same CA was also used by Crewther et al. (39) as they significantly increased 5m sprint performance by 2.6%. These findings are matched by the research of Seitz, Trajano and Haff (127), who significantly decreased 20m sprint times by 0.07 seconds after a CA of three back squats with a 3RM load (seven minutes rest). Furthermore, participants were significantly faster by 0.10 seconds after performing three power cleans with the same load. Considering the current investigation was attempting to elicit potentiation for both CMJ and sprint performance, four repetitions at a 5RM was considered to be the best approach to produce a positive response in both performance measures. However, if the only aim of the investigation was to acutely enhance sprint performance, then possibly a heavier shorter CA would have been more appropriate.

It must also be discussed that all the post-sprint tests were performed after a CMJ test. It is possible that the post-CMJ tests at four and eight minutes rest may have negatively affected any post-sprint test due to fatigue. It was not feasible to assess each individual rest period in a separate session, as the amount of sessions would have been too large in number. Previous research had used two minutes as a rest period between different post-tests to minimise the onset of fatigue, however, it is possible that after multiple tests this is not sufficient time to fully recover. It is a limitation that is common throughout the PAP literature, in that researchers test many different rest periods within the one testing session (15,16,39,82,91). The effect that multiple post-tests has on subsequent post-tests has never been investigated. This could be an area for future research, or, needs to be considered as a limitation in potentiation research.

5.4.6 Comparing CAs: heavy-loaded squats vs. rebound jumps.

For CMJ RPP, a significant time by condition interaction was identified ($p = 0.028$). Considering RPP showed a small significant decrease at a post-interval for both the four rebound jump and two sets of rebound jumps CAs, yet the squats CA only showed trivial changes, this is the reason for such an interaction. It must be noted however, that even though the squats CA may have been better for post-CMJ RPP performance, this particular variable still decreased at both post-time points for this CA. When comparing pre to post-best results, even though it produced no significant increases in CMJ performance, the half-squat CA produced smaller decrements in all CMJ variables when compared to any plyometric CA. From these results, it would suggest that heavy dynamic CAs are a more effective to improve CMJ performance. Despite this fact, plyometric CAs would be far more practical for many sporting examples; hence further research should continue ways to investigate how a plyometric CA could be used to enhance subsequent jump performance.

In terms of sprinting performance, the half-squat CA was the only condition that did not display at least one significant increase in sprint times for a particular sprint in the post-tests. Despite this fact, it is unclear as to which type of CA is better to enhance future sprinting efforts.

Chapter 6: Study 4 - The effect of physical qualities on mediating the potentiation of countermovement jump performance.

6.1 Introduction

6.1.1 Background

Considering no CA from study three displayed any significant improvement in sprinting performance, the present study focused on CMJ performance. Furthermore, since none of the different volume of plyometric activities displayed any sign of potentiation, only heavy dynamic CAs were assessed in study four. As the CA of four half-squats at a 5RM load failed to significantly potentiate any CMJ variable in study 2 or 3 (and only a small significant increase in CMJ height in study 1), two other CAs were included in this investigation with different volume of repetitions and loads. Furthermore, to address the common trend of the first three studies that some individuals respond positively to the CA, whilst others respond negatively, participants performed many different fitness tests in study four to provide further explanation as to why certain people respond to a heavy dynamic CA.

Although much of the research displays the positive effects of potentiation on jump performance (44,82,102,127,163), many other studies have failed to show a positive change (26,42,56,81,141), suggesting that the effects of a CA on potentiating subsequent jumps are individualised. Previous research has suggested that participants require good relative strength in order to elicit PAP, showing that stronger individuals display larger improvement in power performance after the completion of a CA (128). Although past research has shown that stronger individuals create greater amounts of potentiation, no other research has assessed the effect other fitness components have on potentiating future contractions. For an individual to have a positive enhancement in performance after a CA, the potentiation created must outweigh the fatigue that is also created by the CA. All the past suggestions of the importance of participant strength (44,129) refer to participants creating larger amounts of potentiation; however, it is possible that individuals with greater fatigue-resistance may benefit more as they not experience as much fatigue from a CA(20,66).

Previously research has suggested that more aerobically trained athlete may recover better from the fatigue caused by a CA, leading to a potentiating response. Furthermore, Hamada, Sale & McDougal (66) did report greater PAP twitch performance in endurance trained athletes compared to those who were considered sedentary, however, no direct investigation between other fitness capabilities and whether an individual responds to PAP has been investigated. Individuals who possess greater strength-endurance or aerobic capacity may recover faster from a CA, hence allowing them to recover from the fatigue caused by a CA quicker and potentially improve their performance.

6.1.2 Aim

The first aim of the following study was to investigate whether a CA of either three half-squats at a 3RM load (3RM), four half-squats at a 5RM load (4@5RM) or five half-squats at a 5 RM load (5 @ 5RM) would affect post-CMJ performance at either four, eight or twelve minutes rest.

The second aim of the following study was to investigate whether certain fitness components influenced the effect of the CAs on potentiating CMJ performance.

6.1.3 Research Questions

The main research questions for study 4 were:

1. Did any of the three CAs have an effect on CMJ performance?

2. Does any particular fitness component have an influence on whether a CA potentiates CMJ performance?

6.2 Methodology

6.2.1 Experimental Design

The following study used a repeated measures design in order to compare the effect of three different CAs on CMJ performance and whether certain fitness components influence this effect. Participants took part in two familiarisation sessions, two fitness testing session and three experimental conditions. Each session was 2-5 days apart, and the experimental conditions were performed in a random order to prevent the possibility of an order-effect. Each experimental condition involved a particular load and repetitions of half-squats as a CA. Pre and post-CMJs were assessed to identify any significant change caused by any particular experimental CA (Figure 6.1).

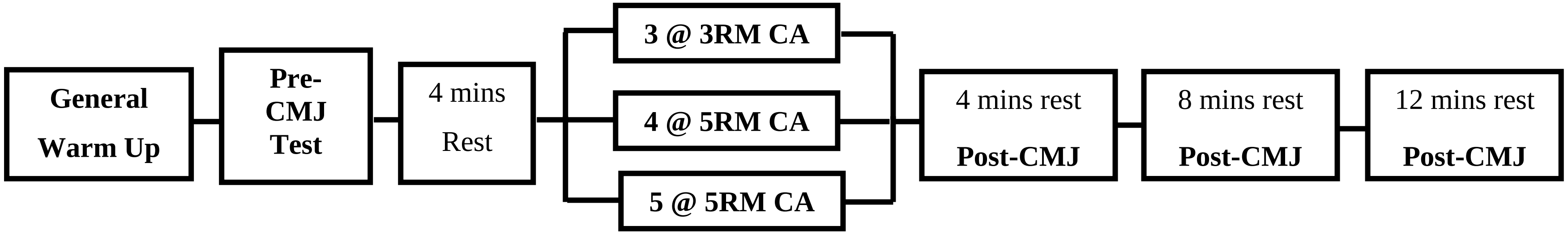

Figure 6.1. Diagram representation of the procedures used throughout the experimental conditions of study 4. RM = repetition maximum, CMJ = countermovement jump, CA = conditioning activity.

6.2.2 Participants

Sixteen recreationally resistance trained male university students with a minimum of one year resistance training experience completed the following study (Mean ± SD age = 21.4 ± 2.2 years, height = 180.0 ± 5.5 centimetres, body mass = 79.9 ± 8.9 kg, predicted 1RM half-squat = 172.8 ± 38.3 kg). The participants recruited for this study followed the same criteria discussed in study one (3.2.2), however, the minimum strength requirement was not required for this study, as the study aimed to investigate the effect of strength on potentiation (as well as other fitness components). Therefore, it was considered desirable to have a spread of strength capacities among the participants. It should also be noted that strength testing for this investigation was completed as a free half-squat, rather than in the Smith machine like previous studies. Before the commencement of the study, the procedure and potential risks were explained to all participants and informed consent was obtained. The study had ethical approval from the HREC at Federation University Australia.

6.2.3 Procedures

6.2.3.1 Familiarisation and 5RM testing sessions

Each participant attended two familiarisation sessions that both commenced with a general warm-up. For the first session, participants performed the 5RM half-squat (90º knee angle) test, following the same protocol mentioned in the first study (3.2.3.1), however, the half-squats were performed as free squats, rather than in a Smith machine. Since most research has used free squats rather than machine squats for the CA, the strength of the participants can be more easily compared to that of the current literature. After each participant's half-squat height was determined, a band (approximately 1 metre in length) was attached to the squat rack and stretched out parallel to the ground at the participant's half-squat height (Figure 6.2). Each time the participant slightly touched the band, they were told that their squatting depth had been reached by a research assistant. After the completion of their 5RM testing, participants then practised performing CMJs on the BMS following the same protocol as study 1 (3.2.3.1).

Figure 6.2. Participant performing half-squat CA, with their half-squat depth controlled by an outstretched band held by a research assistant.

For the second familiarisation session, participants practised all of the fitness tests that were conducted in the following two sessions. These included the multi-stage shuttle run (MSSR) test, DJ test, 20m sprint test and the strength-endurance test. Whilst practising the MSSR test, participants were explained the specific rules of the test, before completing the first stage with instruction from a research assistant. Once they were familiar with how the test was conducted, they practised their turns for the test at a higher speed. After familiarisation of the MSSR test, participants then practised the DJ test and the 20-metre sprint test. For the DJ test, the same protocol and instructions as study 1 (3.2.3.1) were used, whilst for the 20-metre sprint test, the same familiarisation protocol was used that was described in study 3 (5.2.3.1). For the strength-endurance test, participants had to half-squat 60% of their predicted 1RM half-squat for as many repetitions as possible.

6.2.3.2 Fitness testing sessions.

The fitness testing session commenced with a general warm-up that consisted of submaximal running, dynamic stretching and sub maximal practise jumps (same warm-up protocol as study 2). On the first day of fitness testing, participants completed the DJ test and MSSR test. The DJ test was performed first as it produced the least fatigue. Participants performed five DJs, with the jump resulting in the highest RSI score being selected as the participant's best jump. After completion of the DJ test, participants rested for eight minutes to minimise fatigue before the next test. For the MSSR test, 22 metres of synthetic turf was laid out and secured to the ground so that it covered the entire area of the test and participants would have sufficient grip. The floor surface was slightly slippery, therefore, to improve performance and decrease the risk of a fall, the synthetic turf was used. Cones were set out 20 metres apart and a taped line was marked out at each end so participants and research assistants could clearly see where the shuttles commenced and ended.

The second fitness testing session commenced with the same general warm-up, except participants practised five submaximal sprints (building up from 50 to 90% max effort) rather than practise jumps. Participants completed the 20-metre sprint test first and followed the same testing protocol that was followed in study 3 (5.2.3.1). Each participant performed three sprints, with the effort that resulted in the fastest 20m time considered to be their result. After the sprint testing, participants rested for eight minutes before completing the repeated half-squat test (strength-endurance). This testing order was not randomised as the strength-endurance test would negatively impact the sprint test, whereas the eight minutes rest after the sprint test should have provided sufficient recovery. Once participants commenced the test, participants half-squatted 60% of their predicted 1 RM load as many times as possible, with no pause allowed between squats. The test ceased once participants could no longer complete another repetition, could not reach their half-squat depth or squat technique had diminished to an unsafe level. The total amount of repetitions completed was considered the participants strength-endurance score. This particular test is novel to this particular study and has not been used previously. Pilot testing was performed prior to the testing sessions to distinguish the load that would be used to measure half-squat strength-endurance. Five participants were used for the pilot testing sessions and performed the test with 40, 50, 60 or 70% of their predicted 1RM load. It is suggested, that to train for strength-endurance, 20 – 40 repetitions need to be performed per set (108), and therefore the load that best fitted that repetition range during the pilot testing was selected as the load for the strength-endurance test. For the 60% of 1RM load, all participants performed between this repetition range, and hence this was used for the study to measure strength-endurance. Throughout the duration of all fitness tests, participants were provided with verbal encouragement in order to optimise performance.

Both CMJ height and RPP were considered as fitness variables, however, rather than the CMJ test being performed in the fitness testing sessions, the pre CMJ test in all participants first experimental session was used as their fitness testing measure. Therefore, participants would not be performing CMJs whist fatigued and after an appropriate warm-up.

Table 6.1. The different fitness tests used throughout study four, the rationale as to why each was included and whether each test had been tested for in terms of validity and re-test reliability.

Fitness test	**Fitness component**	**Rationale**	**Validity/Reliability assessed?**
5RM HS and 5RM HS / BW	Absolute and relative lower body strength	Previous research has suggested that participant's strength has a positive relationship with a potentiating response.	Validity: yes (150) Reliability: yes (130)
Repeated HS test	Lower body muscular endurance	If an individual has greater muscular endurance in the lower limbs, potentially they may have a greater capacity to resist fatigue after a CA, hence producing a greater potentiating response.	Validity and Reliability: No

CMJ RPP ($W.kg^{-1}$)	Lower body relative peak power	Previous literature has concluded maximal strength has a positive relationship with a potentiating response, suggesting that the higher proportion of fast twitch muscle fibres are a contributing factor. Other fitness components that are also attributed to fast twitch muscle fibres have not been considered.	Validity and reliability: Yes (137)
DJ test (RSI)	Lower body reactive strength (leg stiffness)	Considering reactive strength is a separate fitness component to peak power, potentially individuals with greater leg stiffness may also produce greater amounts of potentiation after a CA.	Validity and reliability: Yes (90)
20m Sprint (s)	Acceleration	Previous literature has concluded maximal strength has a positive relationship with a potentiating response, suggesting that the higher proportion of fast twitch muscle fibres are a contributing factor. Other fitness components that are also attributed to fast twitch muscle fibres have not been considered.	Validity and reliability: Yes (152)
MSSR test (m)	Aerobic capacity	As the improvement in performance after a CA is dependent upon the balance of the potentiation created as well as fatigue, individuals with greater aerobic capacity may recover faster after the CA. Hence possibly allowing for a positive improvement in performance.	Validity and reliability: Yes (113)

6.2.3.3 Conditioning activity sessions

After the familiarisation sessions, participants performed three randomised testing conditions on separate days. One session consisted of a CA of three half-squats at a 3RM load; one involved a CA of four half-squats at a 5RM load, whilst the final condition consisted of a CA of five half-squats at a 5RM load. The session followed the same warm-up and pre-CMJ testing protocol as study 2 (4.2.3.2). After completing the pre-CMJ test, participants performed the same half-squat warm-up routine as the previous studies (except the squats were not performed in the Smith machine). Once the final warm-up squat set was complete, participants rested for four minutes, before completing the particular CA prescribed for the session. After the completion of the CA, participants passively rested until they performed post-CMJ test 4 (post-4), eight (post-8) and twelve minutes (post-12) after the CA.

6.2.4 Data Collection

All fitness testing data was put into an excel spreadsheet where means and standard deviation were calculated. The data collection protocol for the pre and post-CMJs was the same as in study 2 (4.2.4). The change score between pre and post-best were equated for all CMJ variables across the three different CAs. These were later used to identify whether particular fitness test scores correlated with potentiation.

6.2.5 Statistical Analyses

All statistical analyses were completed using the software Statistical Package for the Social Sciences (SPSS for Windows, version 21.0; SPSS Inc., Chicago, ILL.). Descriptive statistics (mean and SD) were calculated for RPP ($W.kg^{-1}$), jump height (m), peak velocity ($m.s^{-1}$) and peak force (N) for all pre and post-CMJs. Descriptive statistics were also calculated for all fitness testing data. To determine whether any CA potentiated CMJ performance, a 2 way Repeated Measure ANOVA (3 conditions x 4 times) with a post-hoc Bonferroni correction was performed in order to assess any significant change between pre and post-CMJ performance for all of the CA conditions ($p < 0.05$ being considered a significant change). A separate Repeated Measures ANOVA (3 conditions x 2 times) was used in order to assess any significant change between pre and post-best CMJ performance. Effect sizes were used to quantify the magnitude of differences between the pre to post changes within the CA protocols. Effect sizes were classified as follows: trivial (ES = 0.00-0.19), small (ES = 0.20-0.59), moderate (ES = 0.60-1.19), large (ES = 1.2- 1.99) and very large (ES > 2.00). To determine the relationship between fitness components and the effect of potentiation, correlation tests were made between all the fitness testing data and the CMJ variable change scores across all CAs. If both the fitness test variable and the CMJ change variable were normally distributed, a Pearson's correlation test was used, however, if one of the variables was not normally distributed, a Spearman's correlation test was used. The correlation r scores were classified as follows; trivial ($r = 0 – 0.10$), small ($r = 0.11 – 0.30$); moderate ($r = 0.31 – 0.50$) and large ($r > 0.50$). To further investigate the effect of particular fitness components on potentiating CMJ performance, if a fitness testing variable displayed two or more significant correlations to the CMJ variable change scores (RPP, jump height, peak velocity or peak force), a median split was performed for that particular fitness component, breaking the sample into two halves of eight participants (for example, absolute strength displayed a significant correlation for two or more CMJ change scores, the population was then be split into the eight strongest participants and the eight weakest participants). A further repeated measure ANOVA with a post-hoc Bonferroni correction was performed in order to assess any significant change between pre and all post-CMJ performance for both the split samples across all of the CA conditions ($p < 0.05$ being considered a significant change). A separate repeated measures ANOVA was used in order to assess any significant change between pre and post-best CMJ performance in the split populations.

It should be noted that a regression of the data could not take place, as many of the change score variables were not normally distributed and many of the fitness test scores correlated with one another. Therefore, populations were median split (explained above) so further comparisons could be made into the effect certain fitness components have on potentiation.

6.3 Results

6.3.1 Fitness testing results

The mean and SD for the whole sample across all fitness tests are displayed in table (Table 6.2) (n=16). The means and SD are also displayed for the "higher" performing group of each fitness component (n=8) as well as the "lower" performing group for each fitness component (n=8).

Table 6.2. Descriptive statistics of the fitness testing results for the entire sample, as well as a comparison between the “higher” and “lower” performing population.

	Whole sample (n = 16)	High Performing (n = 8)	Low Performing (n = 8)	% Diff High to Low
5RM (kg)	150.3 ± 33.3	172.8 ±14.1	127.8 ± 31.9	26.0
Relative Strength (pred 1RM/BW)	2.17 ± 0.47	2.51 ± 0.10	1.83 ± 0.5	27.1
Strength Endurance (repetitions)	30.4 ± 8.8	36.3 ± 8.0	24.6 ± 5.0	32.2
DJ (RSI)	183.5 ± 50.9	216.8 ± 31.2	150.3 ± 45.4	30.7
CMJ Height (cm)	50.0 ± 7.5	56.4 ± 2.8	43.7 ± 4.5	22.5
CMJ RPP ($W . kg^{-1}$)	60.5 ± 8.8	67.4 ± 2.3	53.5 ± 7.0	20.6
20m Sprint (s)	3.21 ± 0.18	3.09 ± 0.06	3.23 ± 0.19	-4.5
MSSR test distance (m)	1520 ± 467.5	1872.5 ± 293.5	1167.5 ± 313.3	37.7

6.3.2 Whole population results

6.3.2.1 Comparing pre to all post-CMJ variables

The mean and SD for all pre, post-4, post-8 and post-12 CMJ variables are displayed in Table (6.3) across all three CAs. A significant time effect was identified for CMJ RPP ($p < 0.001$), with RPP significantly decreasing after 12 minutes post-CA in both the 3@3RM and 4@5RM conditions. Furthermore, the 3@3RM CA significantly decrease RPP at eight minute recovery as well.

At four and eight minutes post-CA, generally trivial decreases in CMJ performance occurred for most variables across each different CA. Furthermore, the decrease seemed greater 12 minutes post-CA, with CMJ variables decreasing by a trivial or small degree for all CA. For the 5 @ 5RM CA, although most CMJ variables displayed trivial decreases, both

CMJ jump height as well as peak force displayed trivial improvements eight minutes post-CA.

Table 6.3. A comparison of CMJ variables from pre to post-4, 8 and 12 minutes rest across the three different CAs. ES = effect size, RPP = relative peak power, JH = jump height, PV= peak velocity, PF = peak force and * with bold text representing statistical significance.

CA	CMJ Variable	Pre mean ± SD	Post 4 mean ± SD	% pre to P4	P value	ES (desc)	Post 8 mean ± SD	% pre to P8	P value	ES(desc)	Post 12 mean ± SD	% pre to P12	P value	ES(desc)
3 @ 3 RM	RPP (W . kg⁻¹)	59.18 ± 9.03	58.60 ± 8.74	-1.0	1.000	-0.07 (trivial)	57.43 ± 9.68	-3.0	**0.010***	-0.19 (trivial)	56.32 ± 8.53	-4.8	**< 0.001 ***	-0.33 (small)
	JH (m)	0.483 ± 0.078	0.475 ± 0.076	-1.5	0.657	-0.10 (trivial)	0.478 ± 0.078	-0.9	1.000	-0.06 (trivial)	0.466 ± 0.071	-3.5	0.196	-0.23 (small)
	PV (m.s⁻¹)	2.76 ± 0.27	2.78 ± 0.31	0.9	1.000	0.07 (trivial)	2.75 ± 0.32	-0.4	1.000	0.03 (trivial)	2.74 ± 0.29	-0.8	1.000	-0.07 (trivial)
	PF (N)	1872.2 ± 347.3	1886.0 ± 356.0	0.7	1.000	0.04 (trivial)	1855.8 ± 380.7	-0.9	1.000	-0.05 (trivial)	1847.0 ± 359.6	-1.3	1.000	-0.07 (trivial)
4 @ 5 RM	RPP (W . kg⁻¹)	58.03 ± 8.23	56.55 ± 9.19	-2.6	0.147	-0.17 (trivial)	56.58 ± 8.16	-2.5	0.098	-0.18 (trivial)	55.42 ± 7.40	-4.5	**0.001 ***	-0.33 (small)
	JH (m)	0.488 ± 0.070	0.488 ± 0.073	-0.1	1.000	0.01 (trivial)	0.478 ± 0.074	-2.0	0.236	-0.14 (trivial)	0.471 ± 0.061	-3.4	0.133	-0.26 (small)
	PV (m . s⁻¹)	2.76 ± 0.23	2.72 ± 0.27	-1.3	1.000	-0.16 (trivial)	2.74 ± 0.23	-0.7	1.000	-0.09 (trivial)	2.73 ± 0.24	-1.0	1.000	-0.13 (trivial)
	PF (N)	1840.5 ± 357.0	1850.9 ± 353.8	0.6	1.000	0.03 (trivial)	1842.7 ± 335.6	0.1	1.000	0.01 (trivial)	1830.7 ± 314.6	-0.5	1.000	-0.03 (trivial)
5 @ 5 RM	RPP (W . kg⁻¹)	58.04 ± 8.11	57.55 ± 8.61	-0.8	1.000	-0.06 (trivial)	57.85 ± 9.25	-0.3	1.000	-0.02 (trivial)	56.38 ± 9.12	-2.9	0.180	-0.19 (trivial)
	JH (m)	0.481 ± 0.07	0.477 ± 0.07	-0.9	1.000	-0.06 (trivial)	0.487 ± 0.08	1.3	1.000	0.08 (trivial)	0.472 ± 0.07	-1.9	0.781	-0.13 (trivial)
	PV (m . s⁻¹)	2.78 ± 0.25	2.74 ± 0.27	-1.5	1.000	-0.15 (trivial)	2.77 ± 0.31	-0.5	1.000	-0.04 (trivial)	2.74 ± 0.32	-1.4	1.000	-0.14 (trivial)
	PF (N)	1835.5 ± 317.1	1867.1 ± 343.2	1.7	0.803	0.10 (trivial)	1881.7 ± 344.1	2.5	0.436	0.14 (trivial)	1850.2 ± 339.3	0.8	1.000	0.04 (trivial)

6.3.2.2 Comparing pre to post-best CMJ variables

A significant time effect was observed for CMJ height (p = 0.020), with post-best jump height being significantly greater after the 5@5RM CA than the pre-test values (p=0.048). A significant time effect was also evident for peak velocity (p = 0.039), with participants significantly improving after the performance of the 3 @ 3RM CA. Peak force also displayed a significant time effect (p = 0.001) with CMJ peak force significantly improving after both the 4 @ 5RM and 5 @ 5RM CAs. Although some significant improvements occurred from pre to post-best CMJs, most of the changes were only considered to be of a trivial magnitude.

Table 6.4. A comparison between pre and post-best CMJ variables across the three different CAs. ES = effect size, RPP = relative peak power, JH = jump height, PV= peak velocity, PF = peak force and * with bold text representing statistical significance.

CA	CMJ Variable	Pre mean ± SD	Post best mean ± SD	% diff pre to post best	P value	Effect Size (descriptor)
3 @ 3 RM	RPP (W . kg^{-1})	59.18 ± 9.03	59.19 ± 8.89	0.0	0.989	< 0.01 (trivial)
	JH (m)	0.483 ± 0.078	0.486 ± 0.078	0.7	0.545	0.04 (trivial)
	PV (m.s^{-1})	2.76 ± 0.27	2.81 ± 0.31	1.9	**0.039 ***	0.17 (trivial)
	PF (N)	1872.2 ± 347.3	1915.2 ± 374.6	2.3	0.053	0.12 (trivial)
4 @ 5 RM	RPP (W . kg^{-1})	58.03 ± 8.23	57.53 ± 8.46	-0.9	0.394	-0.04 (trivial)
	JH (m)	0.488 ± 0.070	0.494 ± 0.070	1.1	0.129	0.09 (trivial)
	PV (m . s^{-1})	2.76 ± 0.23	2.79 ± 0.26	1.4	0.112	0.12 (trivial)
	PF (N)	1840.5 ± 357.0	1886.1 ± 360.9	2.5	**0.007 ***	0.13 (trivial)
5 @ 5 RM	RPP (W . kg^{-1})	58.04 ± 8.11	58.94 ± 9.44	1.6	0.134	0.10 (trivial)
	JH (m)	0.481 ± 0.070	0.493 ± 0.080	2.4	**0.048 ***	0.16 (trivial)
	PV (m . s^{-1})	2.78 ± 0.25	2.82 ± 0.32	1.4	0.305	0.14 (trivial)
	PF (N)	1835.5 ± 317.1	1914.6 ± 340.9	4.3	**0.002 ***	0.24 (small)

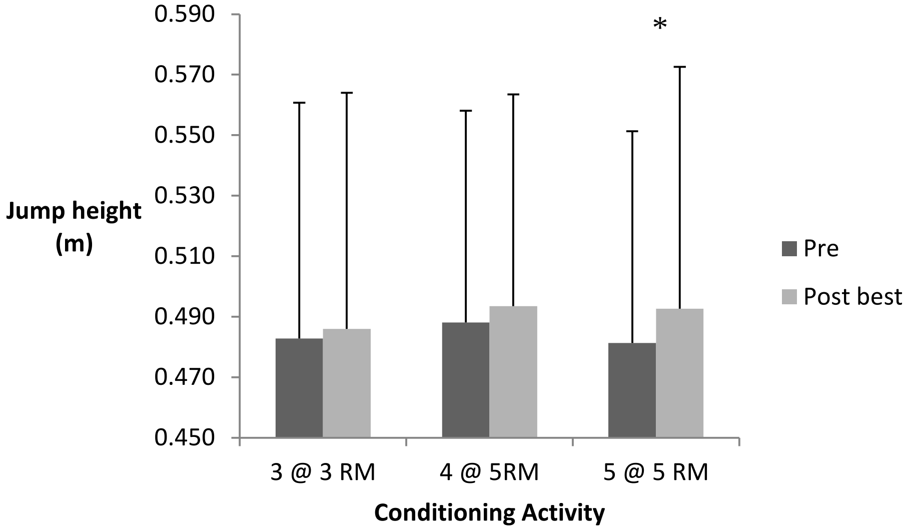

Figure 6.3. A comparison of pre to post-best jump height across all three different CAs.

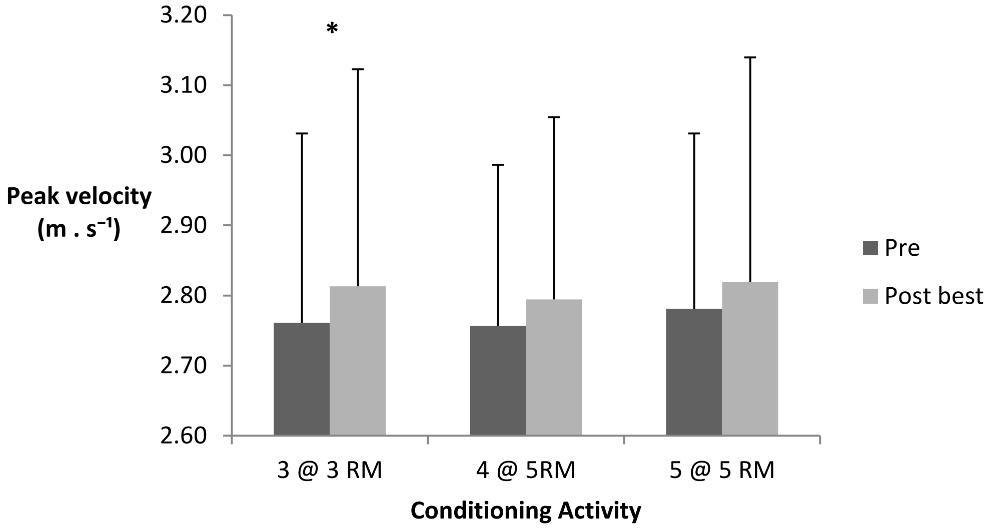

Figure 6.4. A graphical comparison of pre to post-best peak velocity displayed in the CMJ across all three different CAs.

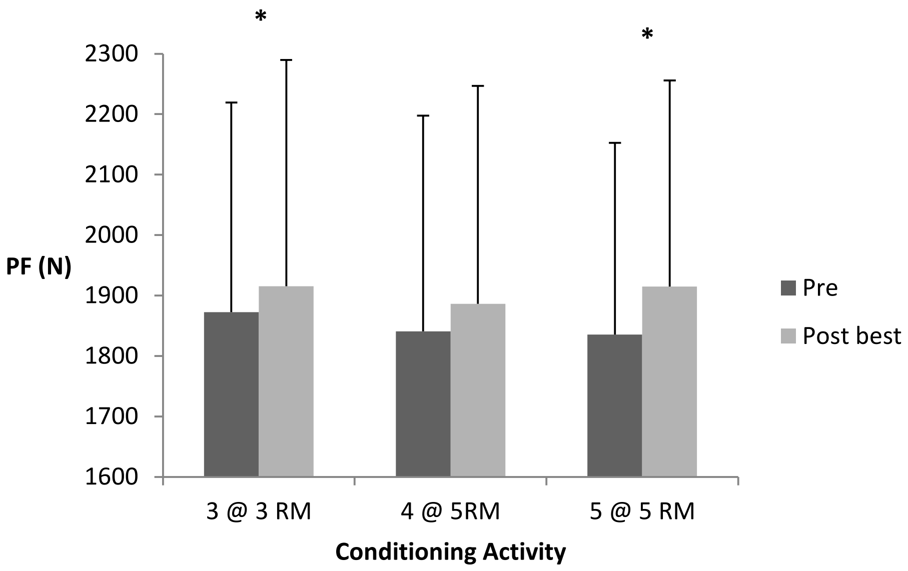

Figure 6.5. A graphical comparison of pre to post-best peak force displayed in the CMJ across all three different CAs.

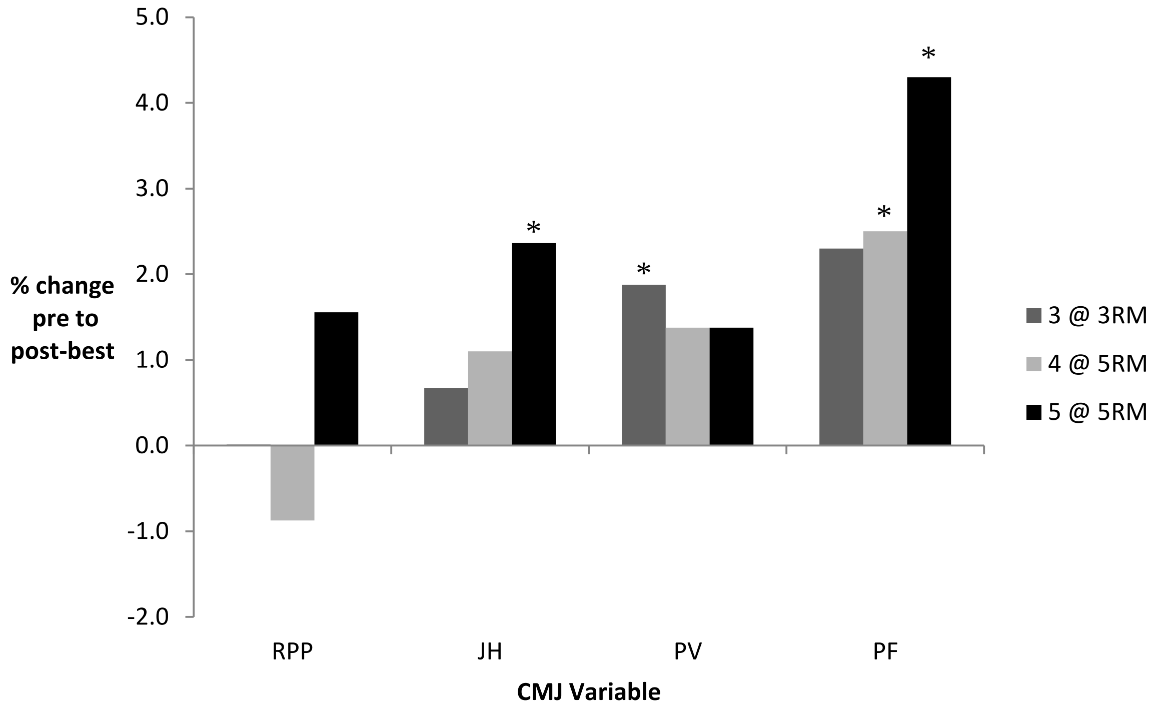

Figure 6.6. A graphical representation of the percentage change from pre-CMJ variables to post-best across all three CAs.

6.3.3 Correlations between fitness components and a potentiating effect.

Table (6.5) displays the results from the Pearsons and Spearmans correlations between the fitness testing and the pre to post-best CMJ change scores, reporting both the r and p-values. On most occasions, the fitness testing results did not show significant correlations to the change scores in CMJ variables after the CAs. Despite this, 5RM half-squat, CMJ RPP and MSSR test performance all displayed two or more significant positive correlations with the CMJ change scores after certain CAs. Participant 5RM half-squat scores displayed a large significant positive correlation with the change scores in both RPP (r = 0.582, p = 0.018) and jump height (r = 0.673, p = 0.004) after the 5 @ 5RM CA, whilst relative strength only displayed one positive significant correlation. Four significant positive correlations were evident between fitness testing CMJ RPP and the change scores after the CAs, as the changes in RPP and peak velocity after both the 4 @ 5RM and 5 @ 5RM CAs all displayed high positive correlations with the fitness testing measure. Participants MSSR distance also displayed multiple significant positive correlations, with the change scores in both CMJ RPP (r = 0.646, p = 0.007) and peak velocity (r = 0.530, p = 0.035) for the 4 @ 5RM CA, as well as the change scores in CMJ peak velocity(r = 0.517, p = 0.040) after the 5 @ 5RM CA all displaying significant correlations.

Considering participant absolute strength, CMJ RPP and MSSR distance all displayed two or more positive significant correlations to the change scores after certain CAs, the population was median split in terms of each fitness variable to further investigate the effect each one has on potentiating CMJ performance with a heavy dynamic CA.

Table 6.5. The correlation between fitness components and changes in pre to post-best CMJ variables. Both r and p values are presented with * and bold text representing a significant correlation ($p < 0.05$).

		3 @ 3RM				4 @ 5RM				5 @ 5RM			
Fitness Performance Test		**RPP**	**JH**	**PV**	**PF**	**RPP**	**JH**	**PV**	**PF**	**RPP**	**JH**	**PV**	**PF**
5RM Half-Squat	*r*	0.356	0.016	0.460	0.197	0.284	0.356	0.399	0.188	**0.582***	**0.673***	0.473	0.183
	p value	0.176	0.954	0.073	0.466	0.287	0.176	0.126	0.486	**0.018**	**0.004**	0.064	0.497
Relative Strength	*r*	0.121	0.090	0.412	-0.103	0.212	0.179	0.485	0.185	0.282	**0.624***	0.300	0.126
	p value	0.656	0.741	0.113	0.704	0.431	0.506	0.057	0.492	0.289	**0.010**	0.259	0.641
Strength Endurance	*r*	-0.229	0.025	-0.038	-0.009	0.328	-0.162	**0.549***	0.223	0.256	0.135	0.397	0.346
	p value	0.393	0.928	0.888	0.974	0.215	0.549	**0.028**	0.407	0.338	0.618	0.128	0.189
Reactive Strength	*r*	-0.129	-0.204	0.499	-0.045	0.060	0.006	0.074	-0.046	0.193	0.213	0.366	-0.032
	p value	0.635	0.447	0.051	0.868	0.825	0.983	0.787	0.867	0.474	0.427	0.163	0.906
CMJ RPP	*r*	0.040	-0.045	0.124	-0.113	**0.557***	0.087	**0.585***	0.069	**0.636***	0.460	**0.676***	0.270
	p value	0.884	0.869	0.649	0.677	**0.025**	0.748	**0.017**	0.800	**0.008**	0.073	**0.004**	0.311
20m Sprint Time	*r*	-0.100	-0.089	-0.410	-0.099	-0.296	0.108	0.430	-0.184	-0.463	-0.414	-0.435	-0.424
	p value	0.712	0.742	0.115	0.716	0.265	0.692	0.053	0.495	0.071	0.111	0.092	0.101
MSSR test (distance)	*r*	-0.301	-0.425	-0.193	0.025	**0.646***	0.414	**0.530***	-0.115	0.288	0.014	**0.517***	0.392
	p value	0.257	0.1	0.474	0.927	**0.007**	0.111	**0.035**	0.672	0.28	0.96	**0.04**	0.133

6.3.4 Splitting the population in terms of 5RM half-squat load (lower body absolute strength).

6.3.4.1 Comparing pre to all post-CMJ variables

The mean and SD for all pre, post-4, post-8 and post-12 CMJ variables for the top half of the population in terms of absolute strength (stronger) are displayed in Table 6.6, whilst all the data for the bottom half of participants in terms of absolute strength (less strength) are displayed in table 6.7. Within the stronger population, a significant time effect was observed for CMJ RPP ($p = 0.005$), as RPP commonly decreased across most post-times and CAs, including a significant decrease at 12 minutes post-CA in the 3@3RM condition. At 12 minutes post-CA, most CMJ variables displayed small or trivial decreases when compared to the pre-test values. Eight minutes after the performance of the 5@5RM CA, CMJ height (3.7%) showed a small non-significant improvement. For the population with less strength, CMJ variables commonly displayed trivial or small decreases after all CAs for all rest periods.

Table 6.6. A comparison of the CMJ variables from pre to post-4, 8 and 12 minutes rest across the three different CAs for the higher performing population in terms of absolute strength (n = 8). ES = effect size, RPP = relative peak power, JH = jump height, PV= peak velocity, PF = peak force and * with bold text representing statistical significance.

CA	Jumping Variable	Pre mean ± SD	Post 4 mean ± SD	% diff pre to post 4	P value	Effect Size (descriptor)	Post 8 mean ± SD	% diff pre to post 8	P value	Effect Size (descriptor)	Post 12 mean ± SD	% diff pre to post 12	P value	Effect Size (descriptor)
3 @ 3 RM	RPP (W . kg^{-1})	63.32 ± 6.41	63.27 ± 5.44	-0.1	1.000	-0.01 (trivial)	61.91 ± 7.27	-2.2	0.791	-0.21 (small)	59.84 ± 6.09	-5.5	**0.011***	-0.56 (small)
	JH (m)	0.520 ± 0.069	0.514 ± 0.064	-1.1	1.000	-0.09 (trivial)	0.517 ± 0.071	-0.5	1.000	-0.04 (trivial)	0.504 ± 0.052	-3.0	1.000	-0.26 (small)
	PV (m.s^{-1})	2.859 ± 0.15	2.917 ± 0.22	2.1	0.996	0.32 (small)	2.88 ± 0.24	0.7	1.000	0.1(trivial)	2.87 ± 0.18	0.5	1.000	0.06 (trivial)
	PF (N)	2082.9 ± 300.0	2111.3 ± 304.1	1.4	1.000	0.09 (trivial)	2095.5 ± 335.0	0.6	1.000	0.04 (trivial)	2064.7 ± 274.2	-0.9	1.000	-0.06 (trivial)
4 @ 5 RM	RPP (W . kg^{-1})	61.71 ± 5.92	60.61 ± 6.58	-1.8	1.000	-0.11 (trivial)	60.57 ± 5.81	-1.8	0.355	-0.19 (trivial)	58.87 ± 5.04	-4.6	0.451	-0.52 (small)
	JH (m)	0.518 ± 0.057	0.524 ± 0.063	1.2	1.000	0.10 (trivial)	0.509 ± 0.067	-1.8	1.000	-0.14 (trivial)	0.497 ± 0.058	-4.0	0.529	-0.37 (small)
	PV (m . s^{-1})	2.84 ± 0.16	2.83 ± 0.22	-0.5	1.000	-0.05 (trivial)	2.82 ± 0.15	-0.7	1.000	-0.13 (trivial)	2.82 ± 0.17	-0.7	1.000	-0.12 (trivial)
	PF (N)	2094.8 ± 304.2	2101.0 ± 301.6	0.3	1.000	0.02 (trivial)	2083.6 ± 267.3	-0.5	1.000	-0.04 (trivial)	2059.7 ± 229.4	-1.7	1.000	-0.13 (trivial)
5 @ 5 RM	RPP (W . kg^{-1})	61.16 ± 6.28	61.00 ± 4.88	-0.3	1.000	-0.03 (trivial)	61.96 ± 6.27	1.3	1.000	0.13 (trivial)	59.73 ± 5.86	-2.3	0.802	-0.24 (small)
	JH (m)	0.504 ± 0.055	0.510 ± 0.052	1.0	1.000	0.11 (trivial)	0.523 ± 0.062	3.7	0.247	0.32 (small)	0.510 ± 0.045	1.1	1.000	0.12 (trivial)
	PV (m . s^{-1})	2.86 ± 0.20	2.81 ± 0.13	-1.5	1.000	-0.30 (small)	2.85 ± 0.22	-0.2	1.000	-0.05 (trivial)	2.83 ± 0.21	-0.9	1.000	-0.15 (trivial)
	PF (N)	2059.3 ± 258.3	2079.2 ± 289.6	1.0	1.000	0.07 (trivial)	2106.1 ± 267.6	2.3	0.342	0.18 (trivial)	2057.0 ± 287.3	-0.1	1.000	-0.01 (trivial)

Table 6.7. A comparison of the CMJ variables from pre to post-4, 8 and 12 minutes rest across the three different CAs for the lower performing population in terms of absolute strength (n = 8). ES = effect size, RPP = relative peak power, JH = jump height, PV= peak velocity, PF = peak force and * with bold text representing statistical significance.

CA	Jumping Variable	Pre mean ± SD	Post 4 mean ± SD	% diff pre to post 4	P value	Effect Size (descriptor)	Post 8 mean ± SD	% diff pre to post 8	P value	Effect Size (descriptor)	Post 12 mean ± SD	% diff pre to post 12	P value	Effect Size (descriptor)
3 @ 3 RM	RPP (W . kg⁻¹)	55.05 ± 9.72	53.92 ± 9.17	-2.0	1.000	-0.12 (trivial)	52.96 ± 10.10	-3.8	**0.011 ***	-0.21 (small)	52.80 ± 9.52	-4.1	**0.008***	-0.23 (small)
	JH (m)	0.446 ± 0.073	0.437 ± 0.070	-2.0	1.000	-0.13 (trivial)	0.440 ± 0.069	-1.3	1.000	-0.08 (trivial)	0.428 ± 0.069	-4.1	0.526	-0.25 (small)
	PV (m.s⁻¹)	2.66 ± 0.34	2.652 ± 0.35	-0.4	1.000	-0.03 (trivial)	2.62 ± 0.35	-1.5	0.848	-0.12 (trivial)	2.61 ± 0.32	-2.1	0.361	-0.15 (trivial)
	PF (N)	1661.5 ± 258.7	1660.6 ± 251.1	-0.1	1.000	< 0.01 (trivial)	1616.0 ± 258.9	-2.7	0.360	-0.18 (trivial)	1629.2 ± 305.9	-1.9	1.000	-0.11 (trivial)
4 @ 5 RM	RPP (W . kg⁻¹)	54.35 ± 8.91	52.49 ± 10.01	-3.4	0.740	-0.20 (small)	52.59 ± 8.51	-3.2	0.451	-0.20 (small)	51.97 ± 8.04	-4.4	0.641	-0.28 (small)
	JH (m)	0.459 ± 0.072	0.452 ± 0.068	-1.5	0.864	-0.10 (trivial)	0.448 ± 0.072	-2.4	0.837	-0.15 (trivial)	0.446 ± 0.055	-2.8	1.000	-0.20 (small)
	PV (m . s⁻¹)	2.67 ± 0.26	2.61 ± 0.29	-2.2	1.000	-0.22 (small)	2.66 ± 0.28	-0.7	1.000	-0.04 (trivial)	2.64 ± 0.27	-1.4	1.000	-0.11 (trivial)
	PF (N)	1586.2 ± 181.1	1600.8 ± 185.3	0.9	1.000	0.08 (trivial)	1601.8 ± 193.2	1.0	1.000	0.08 (trivial)	1601.7 ± 199.0	1.0	1.000	0.08 (trivial)
5 @ 5 RM	RPP (W . kg⁻¹)	54.92 ± 8.91	54.11 ± 10.39	-1.5	1.000	-0.08 (trivial)	53.75 ± 10.27	-2.1	1.000	-0.12 (trivial)	53.03 ± 10.87	-3.4	0.873	-0.19 (trivial)
	JH (m)	0.458 ± 0.075	0.444 ± 0.082	-3.0	0.518	-0.18 (trivial)	0.452 ± 0.075	-1.4	1.000	-0.08 (trivial)	0.434 ± 0.072	-5.2	**0.011***	-0.33 (small)
	PV (m . s⁻¹)	2.71 ± 0.29	2.66 ± 0.36	-1.6	1.000	-0.15 (trivial)	2.69 ± 0.37	-0.7	1.000	-0.06 (trivial)	2.65 ± 0.40	-1.9	1.000	-0.17 (trivial)
	PF (N)	1611.8 ± 185.4	1655.0 ± 256.2	2.7	1.000	0.19 (trivial)	1657.3 ± 258.8	2.8	1.000	0.20 (small)	1643.5 ± 257.7	2.0	1.000	0.14 (trivial)

6.3.4.2 Comparing pre to post-best CMJ variables

The mean and SD for all the pre and post-best CMJ variables for the stronger participants are displayed in Table 6.8 across all three CAs, whilst the results for the participants with less strength are displayed in table 6.9. For the stronger participants, RPP displayed a significant time effect ($p = 0.034$) as well as a significant CA effect ($p = 0.033$), with CMJ RPP displaying a small statistically significant increase after the performance of the 5@ 5RM CA ($p = 0.021$), however, no significant change for either of the other two CAs. Significant time effects were also identified for the CMJ height ($p = 0.006$), as jump height also significantly improved after the 5 @ 5RM CA ($p = 0.010$). Both CMJ peak velocity ($p = 0.017$), and peak force ($p = 0.010$) also showed significant time effects, as peak velocity displayed significant improvements after both the 3 @ 3RM and 4 @ 5RM CAs, whilst CMJ peak force significantly improved after the 5 @ 5RM CA. The 5 @ 5RM CA significantly improved three out of the four CMJ variables when each individuals best recovery period was considered, whilst both the 3@ 3RM and 4 @ 5RM CAs significantly improved one CMJ variable.

For the participants with less strength, significant time effects were identified for CMJ peak force ($p = 0.045$), with CMJ peak force significantly increasing after 4 @ 5RM CA ($p = 0.039$). Most other CMJ variables only displayed trivial changes for this particular population.

Table 6.8. A comparison of the CMJ variables from pre to post-best across the three different CAs for the higher performing population in terms of absolute strength (n = 8). ES = effect size, RPP = relative peak power, JH = jump height, PV= peak velocity, PF = peak force and * with bold text representing statistical significance.

CA	Jumping Variable	Pre mean ± SD	Post best mean ± SD	% diff pre to post best	P value	Effect Size (descriptor)
3 @ 3 RM	RPP (W . kg^{-1})	63.32 ± 6.41	63.83 ± 5.98	0.8	0.582	0.08 (trivial)
	JH (m)	0.520 ± 0.069	0.527 ± 0.065	1.4	0.434	0.1(trivial)
	PV (m.s^{-1})	2.859 ± 0.15	2.95 ± 0.21	3.3	**0.026***	0.49 (small)
	PF (N)	2082.9 ± 300.0	2145.1 ± 310.1	3.0	0.13	0.2 (small)
4 @ 5 RM	RPP (W . kg^{-1})	61.71 ± 5.92	61.35 ± 6.00	-0.6	0.521	-0.06 (trivial)
	JH (m)	0.518 ± 0.057	0.526 ± 0.062	1.7	0.113	0.13 (trivial)
	PV (m . s^{-1})	2.84 ± 0.16	2.90 ± 0.18	2.1	**0.044***	0.35 (small)
	PF (N)	2094.8 ± 304.2	2149.1 ± 286.7	2.6	0.076	0.18 (trivial)
5 @ 5 RM	RPP (W . kg^{-1})	61.16 ± 6.28	63.02 ± 6.34	3.0	**0.021***	0.29 (small)
	JH (m)	0.504 ± 0.055	0.529 ± 0.056	4.9	**0.010 ***	0.45 (small)
	PV (m . s^{-1})	2.86 ± 0.20	2.92 ± 0.20	2.4	0.207	0.30 (small)
	PF (N)	2059.3 ± 258.3	2132.2 ± 270.5	3.5	**0.012***	0.28 (small)

Table 6.9. A comparison of the CMJ variables from pre to post-best across the three different CAs for the lower performing population in terms of absolute strength (n = 8). ES = effect size, RPP = relative peak power, JH = jump height, PV= peak velocity, PF = peak force and * with bold text representing statistical significance.

CA	Jumping Variable	Pre mean ± SD	Post best mean ± SD	% diff pre to post best	P value	Effect Size (descriptor)
3 Reps @ 3 RM	RPP (W . kg^{-1})	55.05 ± 9.72	54.55 ± 9.18	-0.9	0.446	-0.05 (trivial)
	JH (m)	0.446 ± 0.073	0.445 ± 0.071	-0.1	0.924	-0.01 (trivial)
	PV (m.s^{-1})	2.66 ± 0.34	2.67 ± 0.35	0.4	0.692	0.03 (trivial)
	PF (N)	1661.5 ± 258.7	1685.3 ± 289.5	1.4	0.256	0.09 (trivial)
4 Reps @ 5 RM	RPP (W . kg^{-1})	54.35 ± 8.91	53.70 ± 9.15	-1.2	0.559	-0.07 (trivial)
	JH (m)	0.459 ± 0.072	0.461 ± 0.065	0.5	0.626	0.03 (trivial)
	PV (m . s^{-1})	2.67 ± 0.26	2.69 ± 0.29	0.6	0.697	0.07 (trivial)
	PF (N)	1586.2 ± 181.1	1623.0 ± 196.7	2.3	**0.039***	0.19 (trivial)
5 Reps @ 5 RM	RPP (W . kg^{-1})	54.92 ± 8.91	54.86 ± 10.61	-0.1	0.949	-0.01 (trivial)
	JH (m)	0.458 ± 0.075	0.456 ± 0.079	-0.4	0.688	-0.03 (trivial)
	PV (m . s^{-1})	2.71 ± 0.29	2.72 ± 0.39	0.3	0.870	0.03 (trivial)
	PF (N)	1611.8 ± 185.4	1697.1 ± 260.2	5.3	0.063	0.38 (small)

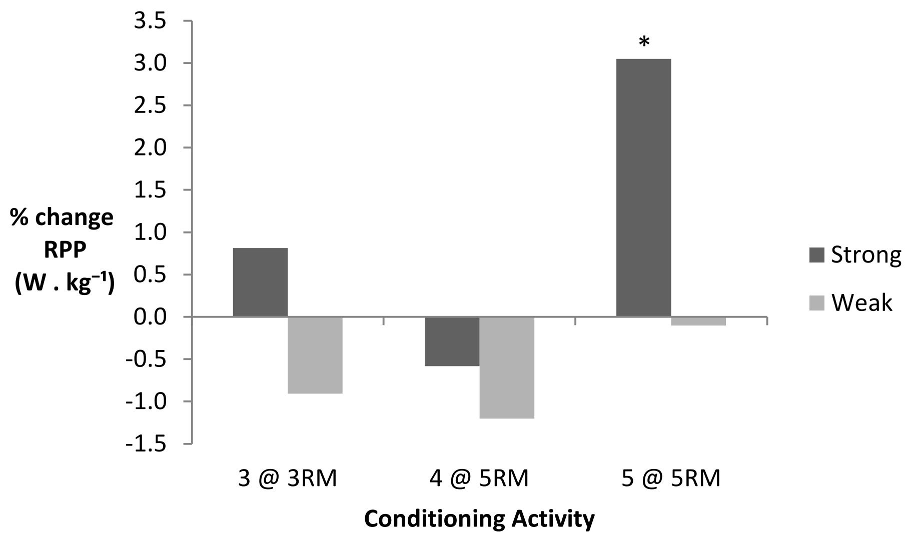

Figure 6.7. A comparison of higher vs. lower performing participants (in terms of absolute strength) and the change from pre to post-best RPP across all three CAs.

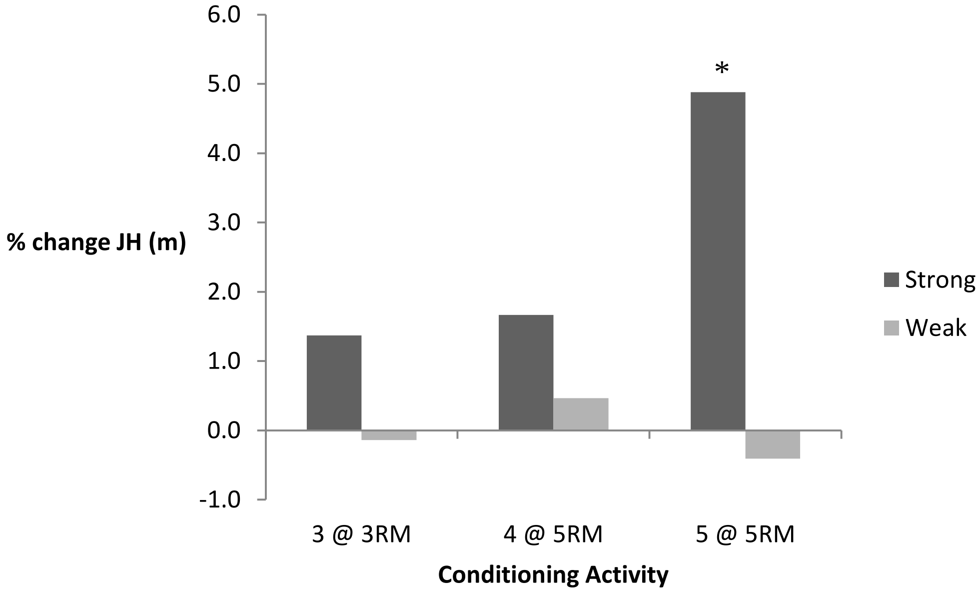

Figure 6.8. A comparison of the higher vs. lower performing participants (in terms of absolute strength) and the change from pre to post-best jump height across all three CAs.

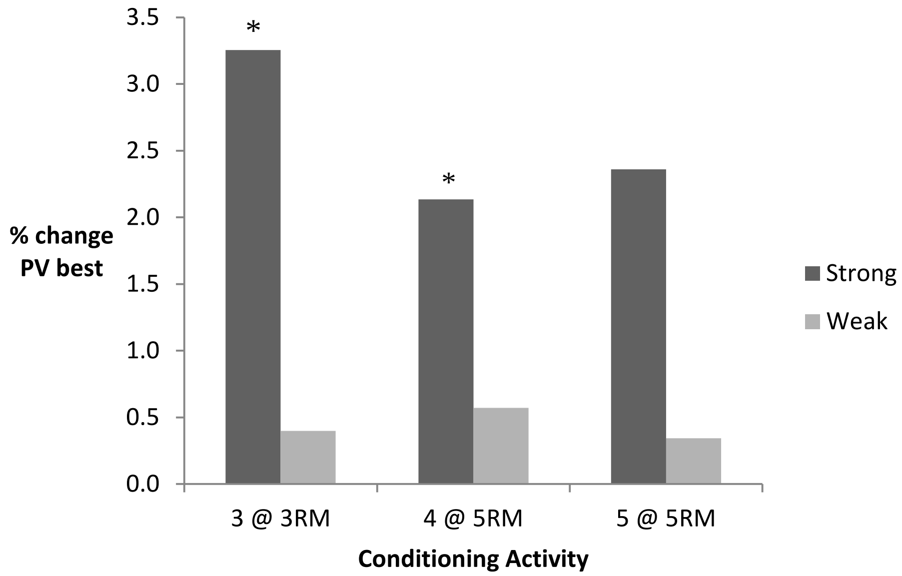

Figure 6.9. A comparison of the higher vs. lower performing participants (in terms of absolute strength) and the change from pre to post-best peak velocity across all three CAs.

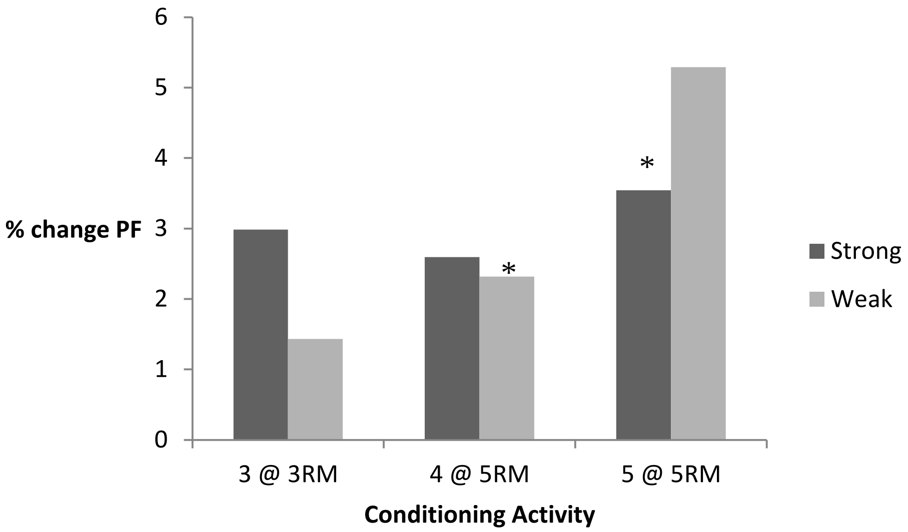

Figure 6.10. A comparison of the higher vs. lower performing participants (in terms of absolute strength) and the change from pre to post-best peak force across all three CAs.

6.3.5 Splitting the population in terms of CMJ RPP (lower body power)

6.3.5.1 Comparing pre to all post-CMJ tests

The mean and SD for all pre, post-4, post-8 and post-12 CMJ variables for the higher population in terms of CMJ RPP (powerful) are displayed in Table 6.10, whilst all the pre and post-data for the lower performing participants in terms of CMJ RPP (less-powerful) are displayed in table 6.11.

For the higher performing population, after the 3 @ 3RM CA, CMJ RPP ($p = 0.023$) significantly decreased 12 minutes after the CA, compared to the pre testing scores. No other significant changes were identified across any CMJ variable or rest period with most changes only being of a trivial magnitude. For the lower performing population, significant time effects were evident for CMJ RPP ($p < 0.001$), peak velocity ($p = 0.011$) and peak force ($p = 0.028$), as each CMJ variable consistently displayed trivial to small decreases in performance throughout the post-tests.

Table 6.10. A comparison of the CMJ variables from pre to post-4, 8 and 12 minutes rest across the three different CAs for the higher performing population in terms of CMJ RPP (n = 8).

CA	Jumping Variable	Pre mean ± SD	Post 4 mean ± SD	% diff pre to post 4	P value	Effect Size (descriptor)	Post 8 mean ± SD	% diff pre to post 8	P value	Effect Size (descriptor)	Post 12 mean ± SD	% diff pre to post 12	P value	Effect Size (descriptor)
3 Reps @ 3 RM	RPP (W . kg⁻¹)	66.02 ± 3.41	65.70 ± 2.48	-0.5	1.000	-0.11 (trivial)	65.23 ± 3.60	-1.2	1.000	-0.23 (small)	63.14 ± 1.99	-4.4	**0.023***	-1.03 (moderate)
	JH (m)	0.536 ± 0.044	0.528 ± 0.044	-1.5	1.000	-0.18 (trivial)	0.539 ± 0.043	0.5	1.000	0.07 (trivial)	0.517 ± 0.032	-3.6	0.714	-0.49 (small)
	PV (m.s⁻¹)	2.959 ± 0.168	3.045 ± 0.161	2.9	0.083	0.52 (small)	3.008 ± 0.154	1.6	1.000	0.30 (small)	2.959 ± 0.137	0.0	1.000	< 0.01 (trivial)
	PF (N)	2091.6 ± 319.9	2092.4 ± 344.5	0.0	1.000	< 0.01 (trivial)	2072.7 ± 367.0	-0.9	1.000	-0.05 (trivial)	2062.6 ± 332.3	-1.4	1.000	-0.09 (trivial)
4 Reps @ 5 RM	RPP (W . kg⁻¹)	64.60 ± 2.98	63.83 ± 3.01	-1.2	1.000	-0.26 (small)	62.94 ± 3.03	-2.6	0.261	-0.55 (small)	61.33 ± 1.94	-5.1	0.163	-1.30 (large)
	JH (m)	0.539 ± 0.036	0.543 ± 0.043	0.7	1.000	0.10 (trivial)	0.530 ± 0.053	-1.6	1.000	-0.2 (small)	0.517 ± 0.027	-4.1	0.490	-0.69 (moderate)
	PV (m . s⁻¹)	2.920 ± 0.114	2.944 ± 0.116	0.8	1.000	0.21 (small)	2.918 ± 0.073	-0.1	1.000	-0.02 (trivial)	2.920 ± 0.123	0.0	1.000	< 0.01 (trivial)
	PF (N)	2013.2 ± 362.1	2011.1 ± 350.2	-0.1	1.000	-0.01 (trivial)	2011.9 ± 325.2	-0.1	1.000	<0.01 (trivial)	1997.2 ± 276.2	-0.8	1.000	-0.05 (trivial)
5 Reps @ 5 RM	RPP (W . kg⁻¹)	64.54 ± 2.22	64.49 ± 2.14	-0.1	1.000	-0.02 (trivial)	64.72 ± 3.54	0.3	1.000	0.06 (trivial)	63.63 ± 2.67	-1.4	1.000	-0.37 (small)
	JH (m)	0.528 ± 0.049	0.525 ± 0.053	-0.6	1.000	-0.06 (trivial)	0.538 ± 0.054	1.8	1.000	0.19 (trivial)	0.520 ± 0.045	-1.6	1.000	-0.17 (trivial)
	PV (m . s⁻¹)	2.961 ± 0.125	2.940 ± 0.164	-0.7	1.000	-0.14 (trivial)	2.999 ± 0.189	1.3	1.000	0.24 (small)	2.996 ± 0.201	1.2	1.000	0.21 (small)
	PF (N)	2013.0 ± 298.0	2079.3 ± 302.4	3.2	0.620	0.22 (small)	2088.6 ± 306.3	3.7	0.533	0.25 (small)	2056.2 ± 313.5	2.1	1.000	0.14 (trivial)

Table 6.11. A comparison of the CMJ variables from pre to post-4, 8 and 12 minutes rest across the three different CAs for the lower performing population in terms of CMJ RPP (n = 8).

CA	**Jumping Variable**	**Pre mean ± SD**	**Post 4 mean ± SD**	**% diff pre to post 4**	**P value**	**Effect Size (descriptor)**	**Post 8 mean ± SD**	**% diff pre to post 8**	**P value**	**Effect Size (descriptor)**	**Post 12 mean ± SD**	**% diff pre to post 12**	**P value**	**Effect Size (descriptor)**
3 Reps @ 3 RM	RPP (W . kg⁻¹)	52.34 ± 7.49	51.50 ± 6.50	-1.6	1.000	-0.12 (trivial)	49.63 ± 6.97	-5.2	**0.001***	-0.37 (small)	49.50 ± 6.76	-5.4	**0.012***	-0.40 (small)
	JH (m)	0.429 ± 0.069	0.423 ± 0.063	-1.6	1.000	-0.09 (trivial)	0.418 ± 0.053	-2.7	0.739	-0.18 (trivial	0.415 ± 0.061	-3.4	1.000	-0.21 (small)
	PV (m.s⁻¹)	2.563 ± 0.194	2.524 ± 0.166	-1.5	1.000	-0.22 (small)	2.494 ± 0.200	-2.7	0.136	-0.35 (small)	2.521 ± 0.222	-1.6	0.597	-0.2 (small)
	PF (N)	1652.8 ± 214.5	1679.6 ± 236.1	1.6	1.000	0.12 (trivial)	1638.8 ± 261.4	-0.9	1.000	-0.06 (trivial	1631.3 ± 245.8	-1.3	1.000	-0.09 (trivial
4 Reps @ 5 RM	RPP (W . kg⁻¹)	51.47 ± 6.15	49.26 ± 7.13	-4.3	0.098	-0.33 (small)	50.22 ± 6.39	-2.4	1.000	-0.20 (small)	49.51 ± 5.80	-3.8	0.205	-0.33 (small)
	JH (m)	0.437 ± 0.057	0.432 ± 0.051	-1.1	0.978	-0.09 (trivial)	0.426 ± 0.052	-2.5	0.223	-0.20 (small)	0.426 ± 0.049	-2.6	1.000	-0.21 (small)
	PV (m . s⁻¹)	2.593 ± 0.186	2.496 ± 0.175	-3.7	0.096	-0.54 (small)	2.558 ± 0.196	-1.3	1.000	-0.18 (trivial	2.538 ± 0.154	-2.1	0.606	-0.30 (small)
	PF (N)	1667.8 ± 271.6	1690.7 ± 294.9	1.4	0.852	0.08 (trivial)	1673.5 ± 264.9	0.3	1.000	0.02 (trivial	1664.2 ± 269.1	-0.2	1.000	-0.01 (trivial
5 Reps @ 5 RM	RPP (W . kg⁻¹)	51.54 ± 6.29	50.61 ± 6.64	-1.8	1.000	-0.14 (trivial)	50.98 ± 7.92	-1.1	1.000	-0.08 (trivial	49.14 ± 7.15	-4.7	0.120	-0.36 (small)
	JH (m)	0.434 ± 0.049	0.429 ± 0.062	-1.2	1.000	-0.09 (trivial)	0.437 ± 0.062	0.6	1.000	0.05 (trivial	0.425 ± 0.057	-2.2	1.000	-0.17 (trivial
	PV (m . s⁻¹)	2.601 ± 0.216	2.537 ± 0.195	-2.5	1.000	-0.31 (small)	2.538 ± 0.211	-2.4	1.000	-0.30 (small)	2.491 ± 0.183	-4.3	0.208	-0.55 (small)
	PF (N)	1657.1 ± 232.2	1655.0 ± 240.8	-0.1	1.000	-0.01 (trivial)	1674.7 ± 249.0	1.1	1.000	0.07 (trivial	1644.3 ± 226.7	-0.8	1.000	-0.06 (trivial

6.3.5.2 Comparing pre to post-best CMJ tests

The mean and SD for all pre, post-best CMJ variables for the higher performing population in terms of CMJ RPP (powerful) are displayed in Table 6.12, whilst all the pre and post-best data for the lower performing participants in terms of CMJ RPP (less powerful) are displayed in Table 6.13. For the more powerful population, CMJ peak velocity displayed a significant time effect ($p = 0.003$) as post-best peak velocity displayed small improvements after all CAs, with significant improvements after both the 3 @ 3RM ($p = 0.011$) and 4 @ 5RM ($p = 0.020$) CAs. Counter-movement jump peak force also displayed a significant time effect ($p = 0.008$) as CMJ peak force displayed significant improvements after the 5 @ 5RM ca ($p = 0.010$). For the less powerful population, only trivial changes were evident for all CMJ variables across the three different CAs.

Table 6.12. A comparison of the CMJ variables from pre to post-best, across the three different CAs for the higher performing population in terms of CMJ RPP (n = 8).

CA	Jumping Variable	Pre mean ± SD	Post best mean ± SD	% diff pre to PB	P value	Effect Size (descriptor)
3 Reps @ 3 RM	RPP (W . kg^{-1})	66.02 ± 3.41	66.33 ± 2.96	0.5	0.705	0.10 (trivial)
	JH (m)	0.536 ± 0.044	0.543 ± 0.044	1.2	0.475	0.16 (trivial)
	PV (m.s^{-1})	2.959 ± 0.168	3.062 ± 0.157	3.5	**0.011***	0.63 (moderate)
	PF (N)	2091.6 ± 319.9	2138.4 ± 353.0	2.2	0.152	0.14 (trivial)
4 Reps @ 5 RM	RPP (W . kg^{-1})	64.60 ± 2.98	64.41 ± 2.62	-0.3	0.834	-0.07 (trivial)
	JH (m)	0.539 ± 0.036	0.547 ± 0.042	1.4	0.228	0.20 (small)
	PV (m . s^{-1})	2.920 ± 0.114	3.000 ± 0.095	2.7	**0.020***	0.76 (moderate)
	PF (N)	2013.2 ± 362.1	2060.5 ± 348.0	2.3	0.093	0.13 (trivial)
5 Reps @ 5 RM	RPP (W . kg^{-1})	64.54 ± 2.22	66.37 ± 3.22	2.8	0.051	0.66 (moderate)
	JH (m)	0.528 ± 0.049	0.543 ± 0.053	2.9	0.093	0.29 (small)
	PV (m . s^{-1})	2.961 ± 0.125	3.065 ± 0.193	3.5	0.064	0.64 (moderate)
	PF (N)	2013.0 ± 298.0	2131.0 ± 289.9	5.8	**0.010***	0.40 (small)

Table 6.13. A comparison of the CMJ variables from pre to post-best, across the three different CAs for the lower performing population in terms of CMJ RPP (n = 8).

CA	Jumping Variable	Pre mean ± SD	Post best mean ± SD	% diff pre to PB	P value	Effect Size (descriptor)
3 Reps @ 3 RM	RPP (W . kg^{-1})	52.34 ± 7.49	52.05 ± 6.64	-0.6	0.721	-0.04 (trivial
	JH (m)	0.429 ± 0.069	0.429 ± 0.062	0.0	0.984	< 0.01 (trivial)
	PV (m.s^{-1})	2.563 ± 0.194	2.564 ± 0.203	0.0	0.992	0.01 (trivial
	PF (N)	1652.8 ± 214.5	1692.0 ± 249.5	2.4	0.241	0.17 (trivial
4 Reps @ 5 RM	RPP(W . kg^{-1})	51.47 ± 6.15	50.64 ± 6.17	-1.6	0.334	-0.13 (trivial
	JH (m)	0.437 ± 0.057	0.440 ± 0.048	0.7	0.421	0.06 (trivial
	PV (m . s^{-1})	2.593 ± 0.186	2.589 ± 0.187	-0.2	0.890	-0.02 (trivial
	PF (N)	1667.8 ± 271.6	1711.6 ± 297.4	2.6	**0.044***	0.15 (trivial
5 Reps @ 5 RM	RPP (W . kg^{-1})	51.54 ± 6.29	51.52 ± 7.39	0.0	0.98	< 0.01 (trivial)
	JH (m)	0.434 ± 0.049	0.442 ± 0.061	1.7	0.342	0.14 (trivial
	PV (m . s^{-1})	2.601 ± 0.216	2.574 ± 0.199	-1.1	0.563	-0.13 (trivial
	PF (N)	1657.1 ± 232.2	1698.3 ± 240.8	2.5	0.088	0.17 (trivial

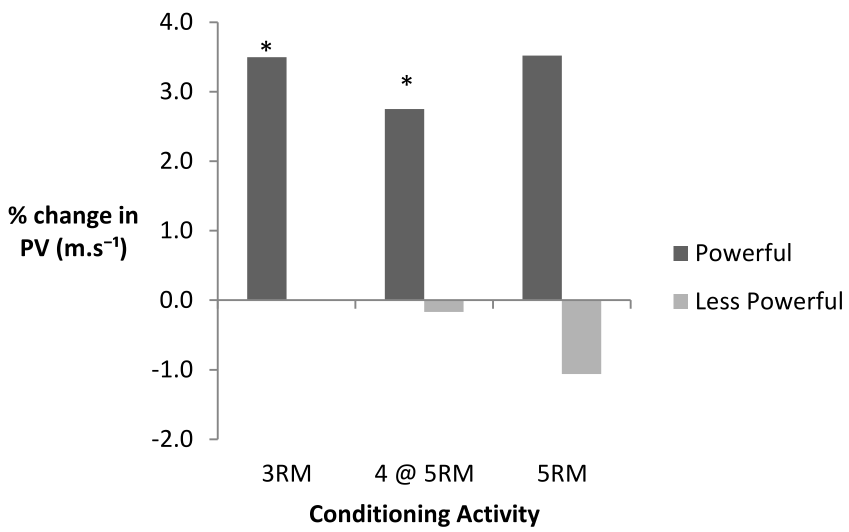

Figure 6.11. A comparison of the powerful and less powerful participants and the percentage change from pre to post-best peak velocity across all three CAs.

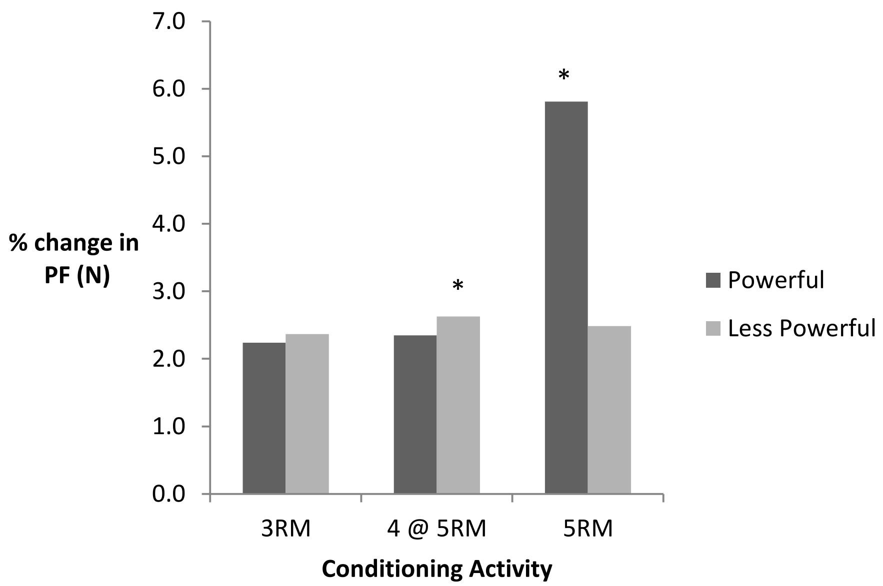

Figure 6.12. A comparison of the powerful and less powerful participants and the percentage change from pre to post-best peak force across all three CAs.

6.3.6 Splitting the sample in terms of multi-stage shuttle run performance (aerobic power).

6.3.6.1 Comparing pre to all post-CMJ tests

The mean and SD for all pre, post-4, post-8 and post-12 CMJ variables for the higher population in terms of MSSR metres (more aerobic capacity) are displayed in Table 6.14, whilst all the pre and post-data for the lower performing participants in terms of MSSR test metres (less aerobic capacity) are displayed in Table 6.15.

For the population with better aerobic capacity, CMJ peak velocity displayed a significant time by CA interaction ($p = 0.041$), although no significant changes were identified for any CA across any post-test. For the population with a lower aerobic capacity, significant time by CA interactions were evident for CMJ height ($p = 0.034$), as jump height significantly decreased after eight minutes recovery in the 4 @ 5RM condition ($p = 0.045$), whilst no other significant decreases were evident for the other two conditions. Significant time by CA interactions were also evident for CMJ peak velocity ($p = 0.042$), as peak velocity displayed non-significant small changes after both the 4@ 5RM and 5 @ 5RM CAs, however, only trivial changes after the 3 2 3RM CA. Significant time effects were also evident for both CMJ RPP ($p < 0.001$), as RPP significantly decrease after 12 minutes recovery or both the 3 @ 3RM ($p = 0.016$) and 4 @ 5RM CAs ($p = 0.020$).

Table 6.14. A comparison of the CMJ variables from pre to post-4, 8 and 12 minutes rest across the three different CAs for the higher performing population in terms of aerobic capacity (n = 8).

CA	Jumping Variable	Pre mean ± SD	Post 4 mean ± SD	% diff pre to post 4	P value	Effect Size (descriptor)	Post 8 mean ± SD	% diff pre to post 8	P value	Effect Size (descriptor)	Post 12 mean ± SD	% diff pre to post 12	P value	Effect Size (descriptor)
3 Reps @ 3RM	RPP (W . kg^{-1})	62.36 ± 8.42	60.78 ± 9.01	-2.5	0.209	-0.18 (trivial)	60.48 ± 9.35	-3.0	0.181	-0.21 (small)	59.38 ± 7.91	-4.8	**0.017***	-0.36 (small)
	JH (m)	0.510 ± 0.060	0.495 ± 0.065	-2.8	0.496	-0.24 (small)	0.501 ±0.062	-1.7	1.000	-0.15 (trivial)	0.485 ± 0.059	-4.8	0.422	-0.42 (small)
	PV (m.s^{-1})	2.851 ± 0.287	2.877 ± 0.330	0.9	1.000	0.08 (trivial)	2.863 ± 0.325	0.4	1.000	0.04 (trivial)	2.830 ± 0.290	-0.7	1.000	-0.07 (trivial)
	PF (N)	1878.1 ± 384.4	1879.7 ± 406.9	0.1	1.000	> 0.01 (trivial)	1857.9 ± 438.8	-1.1	1.000	-0.05 (trivial)	1879.5 ± 442.8	0.1	1.000	> 0.01 (trivial)
4 Reps @ 5RM	RPP (W . kg^{-1})	60.63 ± 8.62	59.91 ± 8.92	-1.2	1.000	-0.08 (trivial)	59.20 ± 7.75	-2.4	0.189	-0.17 (trivial)	57.81 ± 6.86	-4.7	0.419	-0.36 (small)
	JH (m)	0.512 ± 0.066	0.510 ± 0.071	-0.3	1.000	-0.03 (trivial)	0.508 ± 0.075	-0.7	1.000	-0.06 (trivial)	0.490 ± 0.043	-4.4	0.455	-0.39 (small)
	PV (m . s^{-1})	2.824 ± 0.260	2.846 ± 0.281	0.8	1.000	0.08 (trivial)	2.840 ± 0.230	0.6	1.000	0.07 (trivial)	2.816 ± 0.243	-0.3	1.000	-0.03 (trivial)
	PF (N)	1841.8 ± 440.1	1830.2 ± 417.0	-0.6	1.000	-0.03 (trivial)	1830.5 ± 371.0	-0.6	1.000	-0.03 (trivial)	1806.4 ± 331.2	-1.9	1.000	-0.09 (trivial)
5 Reps @ 5RM	RPP (W . kg^{-1})	60.97 ± 7.40	59.86 ± 8.20	-1.8	1.000	-0.14 (trivial)	61.08 ± 8.59	0.2	1.000	0.01 (trivial)	59.77 ± 8.63	-2.0	1.000	-0.15 (trivial)
	JH (m)	0.505 ± 0.059	0.493 ± 0.070	-2.5	0.678	-0.19 (trivial)	0.512 ± 0.072	1.4	1.000	0.11 (trivial)	0.491 ± 0.065	-2.9	0.807	-0.23 (small)
	PV (m . s^{-1})	2.860 ± 0.255	2.815 ± 0.288	-1.6	1.000	-0.17 (trivial)	2.913 ± 0.306	1.8	1.000	0.19 (trivial)	2.878 ± 0.342	0.6	1.000	0.06 (trivial)
	PF (N)	1835.0 ± 336.9	1867.4 ± 360.2	1.8	1.000	0.09 (trivial)	1906.1 ± 358.1	3.9	1.000	0.20 (small)	1877.7 ± 367.1	2.3	0.786	0.12 (trivial)

Table 6.15. A comparison of the CMJ variables from pre to post 4, 8 and 12 minutes rest across the three different CAs for the lower performing population in terms of aerobic capacity (n = 8).

CA	Jumping Variable	Pre mean ± SD	Post 4 mean ± SD	% diff pre to post 4	P value	Effect Size (descriptor)	Post 8 mean ± SD	% diff pre to post 8	P value	Effect Size (descriptor)	Post 12 mean ± SD	% diff pre to post 12	P value	Effect Size (descriptor)
3 Reps @ 3RM	RPP (W . kg⁻¹)	56.01 ± 8.98	56.42 ± 8.46	0.7	1.000	0.05 (trivial)	54.39 ± 9.59	-2.9	0.244	-0.17 (trivial)	53.26 ± 8.49	-4.9	**0.016***	-0.31 (small)
	JH (m)	0.456 ± 0.089	0.455 ± 0.085	-0.1	1.000	-0.01 (trivial)	0.456 ± 0.090	0.0	1.000	> 0.01 (trivial)	0.446 ± 0.080	-2.1	1.000	-0.12 (trivial)
	PV (m.s⁻¹)	2.672 ± 0.233	2.692 ± 0.282	0.8	1.000	0.08 (trivial)	2.639 ± 0.282	-1.2	1.000	-0.13 (trivial)	2.651 ± 0.274	-0.8	1.000	-0.08 (trivial)
	PF (N)	1866.4 ± 332.5	1892.3 ± 325.6	1.4	1.000	0.08 (trivial)	1853.6 ± 343.6	-0.7	1.000	-0.04 (trivial)	1814.4 ± 280.4	-2.8	1.000	-0.17 (trivial)
4 Reps @ 5RM	RPP (W . kg⁻¹)	55.43 ± 7.45	53.18 ± 8.71	-4.1	0.125	-0.28 (small)	53.96 ± 8.17	-2.7	1.000	-0.19 (trivial)	53.03 ± 7.56	-4.3	**0.020***	-0.32 (small)
	JH (m)	0.464 ± 0.069	0.465 ± 0.073	0.2	1.000	0.01 (trivial)	0.448 ± 0.064	-3.5	**0.045***	-0.24 (small)	0.453 ± 0.072	-2.4	1.000	-0.16 (trivial)
	PV (m . s⁻¹)	2.689 ± 0.174	2.593 ± 0.207	-3.6	0.146	-0.50 (small)	2.635 ± 0.202	-2.0	0.666	-0.29 (small)	2.642 ± 0.215	-1.7	1.000	-0.24 (small)
	PF (N)	1839.2 ± 281.9	1871.6 ± 305.7	1.8	0.242	0.11 (trivial)	1854.9 ± 321.6	0.9	1.000	0.05 (trivial)	1855.0 ± 317.9	0.9	1.000	0.05 (trivial)
5 Reps @ 5RM	RPP (W . kg⁻¹)	55.10 ± 8.16	55.25 ± 8.92	0.3	1.000	0.02 (trivial)	54.62 ± 9.26	-0.9	1.000	-0.05 (trivial)	52.99 ± 8.81	-3.8	0.169	-0.25 (small)
	JH (m)	0.457 ± 0.070	0.461 ± 0.079	0.8	1.000	0.05 (trivial)	0.463 ± 0.076	1.1	1.000	0.08 (trivial)	0.454 ± 0.074	-0.8	1.000	-0.04 (trivial)
	PV (m . s⁻¹)	2.702 ± 0.239	2.663 ± 0.248	-1.4	1.000	-0.16 (trivial)	2.624 ± 0.246	-2.9	0.616	-0.32 (small)	2.608 ± 0.247	-3.5	0.423	-0.39 (small)
	PF (N)	1836.1 ± 319.4	1866.9 ± 350.2	1.7	1.000	0.09 (trivial)	1857.3 ± 352.3	1.2	1.000	0.06 (trivial)	1822.8 ± 331.9	-0.7	1.000	-0.04 (trivial)

6.3.6.2 Comparing pre to post-best CMJ tests

The mean and SD for all pre, post-best CMJ variables for the higher performing population in terms of aerobic capacity are displayed in Table 6.16, whilst all the pre and post-best data for the lower performing participants are displayed in Table 6.17. For the population with better aerobic capacity, CMJ peak velocity displayed a significant time effect ($p = 0.014$), as peak velocity significantly increased after the 4 @ 5RM CA ($p = 0.009$) and displayed a small non-significant improvement after the 5 @ 5RM condition. Counter-movement jump peak force also displayed a significant time effect ($p = 0.026$), as peak force significantly improved after the 5 @ 5RM CA ($p = 0.026$). Most other CMJ variables only displayed trivial changes when comparing post-best results with the pre-tests. For the population with less aerobic capacity, a significant time effect was evident for CMJ peak force ($p = 0.017$), as peak force was significantly higher at the post-best rest interval for both the 4 @ 5RM ($p = 0.028$) and 5 @ 5RM CAs ($p = 0.032$). All other changes for CMJ variables were only considered to be of a trivial magnitude.

Table 6.16. A comparison of the CMJ variables from pre to post-best, across the three different CAs for the higher performing population in terms of MSSR test distance (n = 8).

CA	**Jumping Variable**	**Pre mean ± SD**	**Post best mean ± SD**	**% diff pre to post best**	**P value**	**Effect Size (descriptor)**
3 Reps @ 3 RM	RPP (W . kg^{-1})	62.36 ± 8.42	61.51 ±8.85	-1.4	0.186	-0.10 (trivial)
	JH (m)	0.510 ± 0.060	0.507 ± 0.062	-0.5	0.734	-0.05 (trivial)
	PV (m.s^{-1})	2.851 ± 0.287	2.908 ± 0.326	2.0	0.124	0.19 (trivial)
	PF (N)	1878.1 ± 384.4	1925.3 ± 435.6	2.5	0.152	0.11 (trivial)
4 Reps @ 5 RM	RPP (W . kg^{-1})	60.63 ± 8.62	60.69 ± 7.97	0.1	0.947	0.01 (trivial)
	JH (m)	0.512 ± 0.066	0.517 ± 0.065	1.1	0.321	0.08 (trivial)
	PV (m . s^{-1})	2.824 ± 0.260	2.913 ± 0.252	3.1	**0.009***	0.35 (small)
	PF (N)	1841.8 ± 440.1	1870.1 ± 410.6	1.5	0.152	0.07 (trivial)
5 Reps @ 5 RM	RPP (W . kg^{-1})	60.97 ± 7.40	62.08 ± 9.06	1.8	0.265	0.13 (trivial)
	JH (m)	0.505 ± 0.059	0.517 ± 0.073	2.3	0.216	0.18 (trivial)
	PV (m . s^{-1})	2.860 ± 0.255	2.955 ± 0.335	3.3	0.112	0.32 (small)
	PF (N)	1835.0 ± 336.9	1939.1 ± 358.2	5.7	**0.026***	0.30 (small)

Table 6.17. A comparison of the CMJ variables from pre to post-best, across the three different CAs for the lower performing population in terms of MSSR test distance (n = 8).

CA	Jumping Variable	Pre mean ± SD	Post best mean ± SD	% diff pre to post best	P value	Effect Size (descriptor)
3 Reps @ 3RM	RPP (W . kg⁻¹)	56.01 ± 8.98	56.87 ± 8.87	1.5	0.341	0.10 (trivial)
	JH (m)	0.456 ± 0.089	0.465 ±0.091	2.0	0.22	0.10 (trivial)
	PV (m.s⁻¹)	2.672 ± 0.233	2.718 ± 0.285	1.7	0.215	0.18 (trivial)
	PF (N)	1866.4 ± 332.5	1905.1 ±332.9	2.1	0.242	0.12 (trivial)
4 Reps @ 5RM	RPP (W . kg⁻¹)	55.43 ± 7.45	54.36 ± 8.17	-1.9	0.219	-0.14 (trivial)
	JH (m)	0.464 ± 0.069	0.470 ± 0.070	1.1	0.295	0.09 (trivial)
	PV (m . s⁻¹)	2.689 ± 0.174	2.676 ± 0.212	-0.5	0.669	-0.07 (trivial)
	PF (N)	1839.2 ± 281.9	1902.0 ± 331.5	3.4	**0.028***	0.20 (small)
5 Reps @ 5RM	RPP (W . kg⁻¹)	55.10 ± 8.16	55.80 ± 9.30	1.3	0.376	0.08 (trivial)
	JH (m)	0.457 ± 0.070	0.469 ± 0.076	2.5	0.151	0.16 (trivial)
	PV (m . s⁻¹)	2.702 ± 0.239	2.684 ± 0.248	-0.7	0.705	-0.07 (trivial)
	PF (N)	1836.1 ± 319.4	1890.2 ± 345.5	2.9	**0.032***	0.16 (trivial)

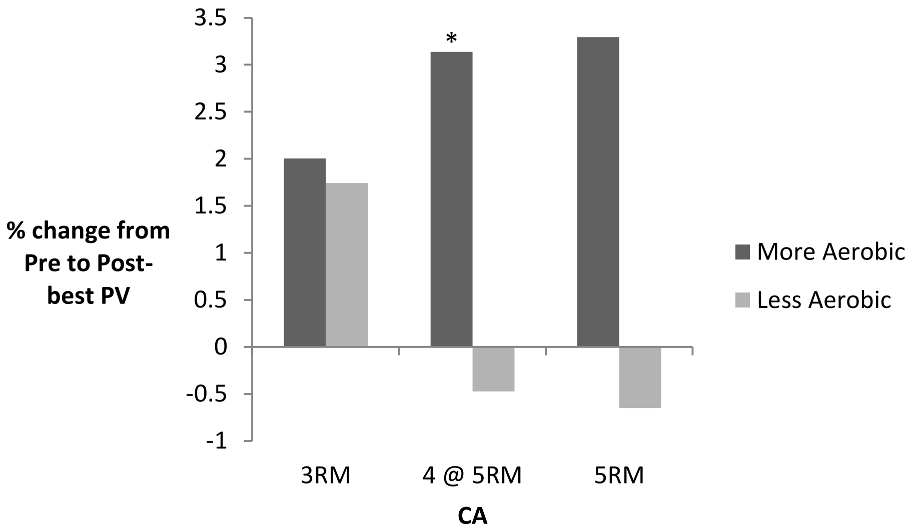

Figure 6.13. A comparison of the “more aerobic” vs. “less aerobic” populations and the percentage change from pre to post-best peak velocity across all three CAs.

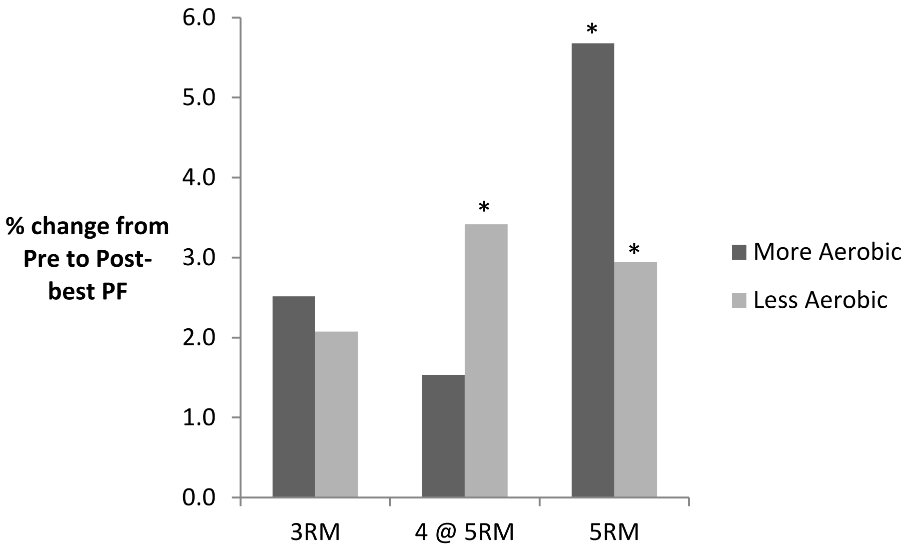

Figure 6.14. A comparison of the “more aerobic” vs. “less aerobic” populations and the percentage change from pre to post-best peak force across all three CAs.

6.4 Discussion

Considering the small findings of the previous studies, the first purpose of this study was to investigate three CAs with different loads and repetitions to identify which specific protocol was best to elicit an enhancement in CMJ performance. The next purpose of the study was to review the physical attributes of the participants used in order to identify any common links as to why an individual would show a potentiating response for a particular CMJ variable.

6.4.1 The effect of a heavy half-squat CA on potentiating CMJ

6.4.1.1 CMJ performance at four, eight and twelve minutes recovery

For all three conditions, no significant improvements in CMJ performance were identified at any particular recovery period. In fact, CMJ RPP significantly decreased at both eight and 12 minutes recovery in the 3 @ 3RM condition, and also significantly decreased after 12 minutes recovery for the 4 @ 5RM condition.

The results from the 3 @ 3RM condition contradict much of the literature that used a similar CA. Crewther et al. (39) used a CA of three repetitions at a 3RM load to potentiate CMJ performance. Although they reported no significant changes after 15 seconds recovery, jump height significantly increased after four (3.9%), eight (3.5%) and 12 minutes post-CA (3%). Kilduff et al. (82) also used the same CA to potentiate CMJ in elite rugby players. Researchers not only reported significant increases in jump height at eight minutes, but also significant increases in participant PP at the same rest interval.

A similar trend was exhibited in the 5 @ 5RM condition, in that no CMJ variable significantly improved at any particular recovery time, which again contradicts the literature. Mitchell and Sale (107) reported a 2.9% increase in CMJ jump height at four minutes recovery with the same CA as the current investigation. Furthermore, McCann and Flannigan (103) discovered even greater increases in jump height, as participants increased by 5.7% at either four or five minutes post-CA. It must be noted that the CA used could have been different in this instance, as participants either performed a 5RM back squat or hang clean, with the CA that created the greatest improvement in jump height being used in the analysis. A CA of five repetitions at a 5RM load was also used successfully by Young, Jenner and

Griffiths (163), who potentiated loaded CMJ height (19kg load) by 2.8% at four minutes recovery.

It must be remembered for the current investigation, a minimal level of strength was no longer a pre-requisite for participants. Considering much of the literature has stressed the importance of participant strength on eliciting a potentiation response (44,129), a population with greater lower limb strength may have evoked a significant increase in CMJ variables. In the investigation by Kilduff et al. (82), participants had a predicted 1RM back squat of 153kg (parallel squat), whereas the estimated 1RM half-squat mean for the current study was 172.8 kg. Despite the predicted 1RM being greater in this investigation, it must be noted that the squatting depths were different. Considering the findings by Bryanton et al. (24) suggesting that an increase in squatting depth required greater relative muscular effort, it is plausible to suggest that the participants within the Kilduff et al. (82) study were stronger than the present investigation. Similarly, the mean 5RM half-squat for the rugby players that were used by Mitchell and Sale (107) displayed a parallel squat 5RM of 144.5kg, whilst the participants in this investigation had a 5RM half-squat 150.3 kg. Again suggesting that the lower limb strength of the participants used in this investigation was less.

The findings of Duthie, Young and Aitken (44) also reiterated the importance of strength levels in potentiation. At first, the researchers reported no significant change in post-CMJ when investigating the effects of contrast training. However, after performing a median split of the population in terms of strength, the stronger population displayed a significant 2% increase in CMJ jump height after the heavy squats. Comparing the strength levels of this particular investigation to the present study are difficult as the participants for Duthie, Young and Aitken were female, where the present research used male participants. The effect of performing a median split in terms of strength for this study will be discussed later in the thesis. One issue with the research by Duthie, Young and Aitken was the amount of participants used, as once the median split of the population occurred, the analysis was only performed on five participants. It is possible that such a small sample size would limit statistical power.

6.4.1.2. Comparing pre-CMJ performance to post-best

Considering that research has demonstrated that the extent and timing of potentiation is specific to the individual (26), a subsequent analysis examined changes independent of recovery time. When each participants' best recovery period was considered, CMJ peak velocity significantly increased (1.9%) after the 3 @ 3RM CA (Figure 6.4), whilst a trend was identified for an increase in CMJ peak force as well (2.3%, $p = 0.053$). No previous research has identified a significant increase in CMJ peak velocity after a heavy dynamic CA. Despite the significant increases in CMJ peak velocity and improvements of peak force, RPP (increased by < 0.1%, $p = 0.989$) failed to show any change from pre to post-best testing. Considering PP is a product of both force and velocity (85), this finding is interesting as both peak velocity and peak force increased, yet RPP either decreased or had no change. This suggests that PP, peak velocity and peak force during a CMJ occur at different times; otherwise, RPP would also increase as participants increase their peak velocity and peak force. From this finding, examining the CMJ variables peak velocity and peak force in order to see which variable is affecting RPP, is not a suggested method.

For the 4 @ 5RM condition, CMJ peak force significantly increased by 2.6% when the best recovery period was considered. Although other CMJ displayed improvements, these were all statistically non-significant and only of a trivial magnitude. This significant improve in CMJ peak force is similar to that of Duthie, Young and Aitken (44), who identified a significant 2% increase in CMJ peak force from their stronger participants. Furthermore, Chiu et al. (31) also concluded significant increases in rebound jump peak force, whilst Ruben et al. (118) reported significant increases in peak force during the performance of horizontal hurdle hops. Considering the other CMJ variables failed to display any significant improvements within this condition, it is unclear to what extent potentiation has occurred. However, by having a greater peak force during the concentric phase of the CMJ, the acceleration of the body will also be increased and could lead to improvements in jump height.

For the 5 @ 5RM condition, CMJ jump height (2.4%, $p = 0.048$), and peak force (4.3%, $p = 0.002$) significantly increased once each participants best recovery period was considered. Although significant increases in the jump height were identified, the ES considered the magnitude trivial. Since significant improvements are only being identified after each participants best-recovery period is considered; the results support the theory that the optimal recovery period after a CA varies from person to person. A similar relationship was identified by Bevan et al. (15), as they found no change in sprint performance at specific rest intervals, but then found a significant decrease in sprint times after each participants post-best times were analysed.

Considering two of the four CMJ variables have displayed a significant improvement when comparing the post-best rest interval to the pre-testing, it is suggested that the present CA has created an increase in CMJ performance, which may be attributed to potentiation. The 2.4% increase in jump height matched the change shown by Young, Jenner and Griffiths (163) as well as Mitchell and Sale (107). The 4.3% increase peak force was greater than the change exhibited in the study by Duthie, Young and Aitken (44), but it must be noted that they only considered a single post-test interval (four minutes). Considering this finding, the time each participant takes to overcome the fatigue from the 5RM effort must be different, meaning that the window of opportunity for a potentiating response will also differ.

Although the change was non-significant, for the first time in any of the present investigations, CMJ RPP increased above pre-testing levels. The fact that no change in RPP has previously been identified in these investigations has been surprising, as a plethora of previous literature has found a significant increase in CMJ PP (19,31,76,82,91,116) Relative peak power increased by 1.6% after each individuals best recovery time was compared to the pre-test, although this was considered to be a trivial change (ES= 0.10). The magnitude of the change is far less than that exhibited in the research by Rixon et al. (116) who increased CMJ PP by 8.7% after a CA of three squats at a 3RM load.

6.4.2 The effect of the recovery period on potentiating CMJ performance

It seems that after a heavy dynamic CA, four and eight minutes a more appropriate to increase CMJ performance than 12 minutes. Across all three CAs, there was only one instance that a CMJ improved at 12 minutes-post compared to the pre-values (peak force in the 5 @ 5RM CA). Furthermore, across the three CAs, on four occasions a CMJ variable either significantly or displayed a small decrease at 12 minutes, where only RPP displayed significant drops at eight minutes in the 3 @ 3RM condition (Table 6.3). Table 6.18 below identifies at what rest interval each individuals best post-CMJ occurred for each CA. It would seem that 12 minutes is too long in order to take advantage of a potentiating effect, as only on three occasions (across all three CAs) was 12 minutes the optimal recovery period for an individual's CMJ performance. This could be because any potentiation that is created by the CA has dissipated over this longer rest, as the phosphorylation of the RLC has been reported to last no longer than 10 minutes (132), leading to a decrease in performance. Such a finding opposes that of Kilduff et al. (82) and Crewther et al. (39), who still found significant increases in CMJ performance after a rest period equal to or greater than 12 minutes. Although it is suggested that the phosphorylation of the RLC last 10 minutes (132), research also concluded that the higher order motor-unit recruitment after a CA may last longer than

10 minutes, allowing for some improvements to still be achievable after this time (26). Again the strength levels of these participants may have played a contributing factor in this response lasting longer (elite rugby players), as they may have created larger amounts of initial potentiation from this specific mechanisms of potentiation.

For the 3 @ 3RM and 4 @ 5RM CAs, 4-8 minutes seems appropriate rest for most participants. However, the 5 @ 5RM CA seems to produce greater fatigue, and hence many more participants required eight minutes rest to produce their post-best results (12 out of the 16 participants) as opposed to four minutes (only three participants out of the 16). From these results, it also explains that as the intensity of the CA changes, so does the optimal rest period after the CA.

Table 6.18. The amount of participants whose best post-CMJ performance occurred in each recovery period.

Number of participants optimum recovery period			
	Rest interval		
HS CA	**4 mins**	**8 mins**	**12 mins**
3 @ 3RM	8	8	0
4 @ 5RM	8	6	2
5 @ 5RM	3	12	1

6.4.3 The effect of CA repetitions and load on potentiating CMJ performance

Considering no time by CA interaction was identified, it is hard to definitively conclude than any particular CA condition was greater than the others. However, there is evidence that suggests that the 5 @ 5RM CA is more effective at creating an acute increase in CMJ performance than the other two CAs. The 5 @ 5RM CA produced the greatest percentage change from pre to post-best across all CMJ variables. The significant 4.3% increase in CMJ peak force in the 5 @ 5RM outweighed the 2.5% significant increase identified in the 4 @ 5RM condition, whilst RPP increased by 1.6% after the 5 @ 5RM CA, however, it decreased after the 4 @ 5RM CA and showed no change after the 3 @ 3RM CA. It must be noted that the sample size in this case is small and further research is required to reiterate the above findings. Furthermore, there is a degree of individuality amongst the population and certain CAs and rest periods are more valuable for particular persons. The above findings do suggest however, that a CA that involves five repetitions at a 5RM load is more beneficial to potentiate an acute response in CMJ performance for recreationally trained males, when compared to CAs of less repetitions (4 @ 5RM) and a greater load (3 @ 3RM).

6.4.4 Correlations between fitness attributes and creating an acute enhancement of CMJ performance

There is strong evidence in the literature suggesting that individuals need to be strong in order to elicit a potentiating effect (15,31,44,116,124,129,163). Originally guidelines were created to suggest participants need to be able to squat 1.5 times their body weight (31,44,116), however, more recent research has even suggested that participants must be able to complete a squat with over double their body weight (128,129). From the correlation results (Table 6.5), it is possible that other fitness attributes may contribute to whether an individual responds positively to a CA. Absolute strength displayed a significant large correlation to the change in CMJ RPP and jump height after the 5 @ 5RM CA. Fitness testing RPP correlated significantly to changes in CMJ RPP in both the 4 @ 5RM and the 5 @ 5RM CA. Furthermore, a large significant correlation was also evident between participant RPP and changes in CMJ peak velocity for both the 4 @ 5RM and 5 @ 5RM CA. Despite most of the literature suggesting that strength is important for an individual to be able to elicit a heightened potentiating response (44,116,129), the changes in CMJ RPP was more highly correlated to participant RPP rather than absolute strength. Participant aerobic capacity also displayed large significant correlations to changes in CMJ RPP and peak velocity for the 4 @ 5RM CA, and also CMJ peak velocity after the 5 @ 5RM CA. Considering these findings, each of the following fitness components were analysed to investigate the effect they have on creating a potentiating response.

6.4.4.1 The effect of a heavy dynamic CA on potentiating CMJ performance in a population with greater absolute strength (5RM half-squat).

For the higher performing group in terms of absolute strength, no significant increases in CMJ performance were identified for any specific rest period, with RPP significantly decreasing post-12 minutes for the 3@3RM CA. Despite the fact no significant improvements were identified; effect sizes identified small improvements in CMJ peak velocity at four minutes recovery after the 3 @ 3RM CA (2.1%), as well as small improvements in jump height at eight minutes recovery after the 5 @ 5RM CA (3.7%).

The small increases in stronger participant jump height at eight minutes recovery are similar to the significant findings of Mitchell and Sale (107) (2.9%) and also Young, Jenner and Grifffiths (163) (2.8%), however, the finding of this present investigation were non-significant. This non-significant finding could be attributed to the small sample size, as only eight participants were left when the group was split in half in terms of absolute strength. Although these participant numbers were similar to that of Seitz, Villarreal and Haff (129) when they split their population in terms of relative strength, it is plausible to suggest that the low number of participants could have attributed to the non-significant finding. Further research may be required before suggesting that the strong population increased CMJ height due to a potentiating effect, however, participant strength seems beneficial in producing an acute enhancement in CMJ performance after a heavy CA.

For the lower strength population, a small non-significant 2.1% increase in CMJ peak force occurred at eight minute rest (ES = 0.21) for the 5 @ 5RM CA. All other CMJ variables decreased after all the CAs, with significant decreases occurring in RPP for the 3 @ 3RM CA (eight and 12 minutes recovery) and jump height (12 minutes recovery) in the 5 @ 5RM condition. It seems that from the results that a heavy dynamic CA has a negative effect on CMJ performance for populations with lower strength levels.

When considering each individuals optimum rest period, the stronger population significantly increased many CMJ variables after particular CAs. For both the 3 @ 3RM (3.3% increase) and 4 @ 5RM CA (2.1%), CMJ peak velocity significantly improved after each individuals best recovery period, however, these were the only variables to display significant improvements for these CAs. The CA with the most significant improvements was the 5 @ 5RM CA. Relative peak power (3%) jump height (4.9%) and peak force (3.5%) all significantly improved. Considering three of the four CMJ variables have significantly increased after the 5 @ 5RM CA, it is fair to assume that an acute enhancement in CMJ performance has occurred for this stronger population.

In terms of CMJ RPP, seven out of the eight stronger participants showed improvements in post-best performance, however, only two out of the eight weaker individuals displayed positive effects after the 5 @ 5RM CA (Figure 6.15). Furthermore, in terms of CMJ jump height, seven of the stronger individuals improved, whilst only three of the eight weaker individuals displayed improvements in jump height for the same CA (Figure 6.16). These results not only identify the significant role participant strength has in creating a positive potentiating response, but also highlights the individualistic nature of whether an individual will respond positively to a particular CA.

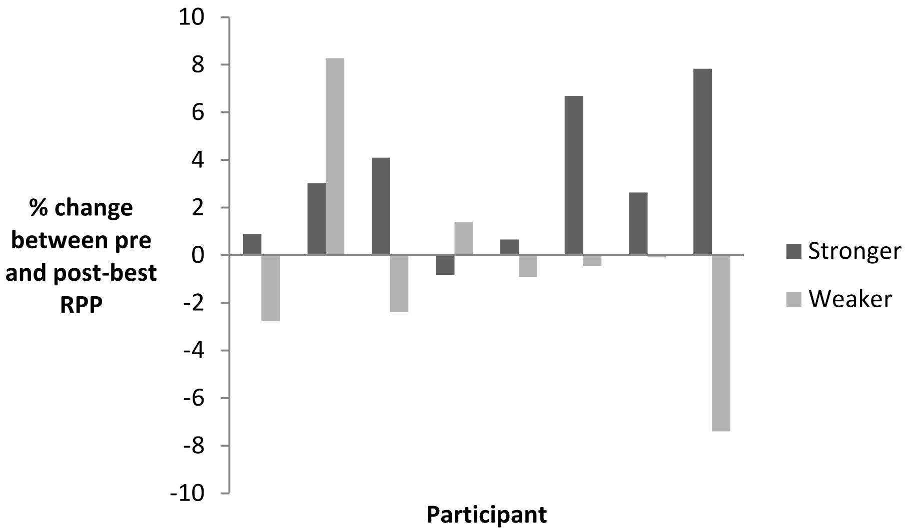

Figure 6.15. Representation of the percentage change in CMJ RPP that each individual participant displayed at their best rest period after the 5 @ 5RM CA.

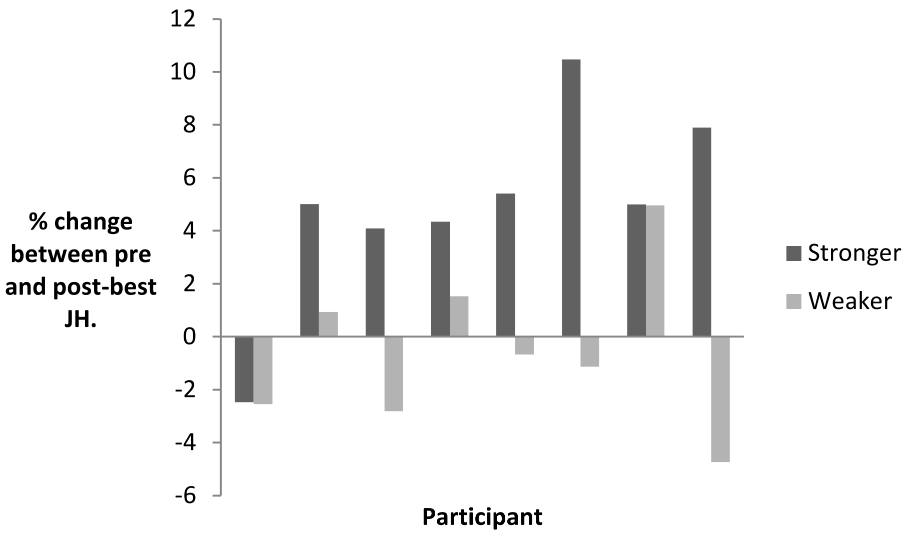

Figure 6.16. Representation of the percentage change in CMJ jump height that each individual participant displayed at their best rest period after the 5 @ 5RM CA.

Although no time by CA interaction was identified, the following results suggest that for this particular population, the 5 @ 5RM CA was more beneficial to enhance CMJ performance than the 4 @ 5RM or 3 @ 3RM CAs. This particular CA activity allowed the stronger population to jump 2.5cms higher than the pre-test. Such an increase in performance would be considered quite large for many jumping sports and could be the difference between winning or not. Furthermore, a three percent improvement in CMJ RPP may also transfer to improvements for other athletic activities. The significant increases in RPP after the heavy half squat CA could mean that contrast or complex training could be beneficial for these particular participants. If the heavy half-squat CA leads to a heightened speed-strength performance in subsequent sets, heavy sets could be used to increase power production in lighter activities throughout a training session and potentially lead to larger chronic adaptations to a person's muscular speed-strength. Further research is required in order to investigate the chronic effect of complex and contrast training when using an effective complex pair.

For the 5 @ 5RM CA, three of the four CMJ variables significantly improved after the CA, however, not one variable displayed a significant change for the lower strength population. This result supports the findings of the literature that concluded that participant strength is imperative in order to elicit a potentiating response (44,116,126,129,163). Furthermore, Seitz et al. (128) discovered that participant strength correlated to a potentiating response, however, the correlation between the potentiation response and the percentage of type II muscle fibres was greater. Stronger participants will generally have a higher amount of type II muscle fibres (2), which could contribute to a larger phosphorylation of the myosin RLC (128) after a CA, one of the major mechanisms of a PAP response (142). By increasing the phosphorylation of the myosin RLC, the actin and myosin become more sensitive to CA^{2+}, which would increase the amount of actin-myosin cross bridges and lead to a more forceful muscle contraction. Furthermore, stronger individuals will have an increased ability to recruit a higher amount of type II muscle fibres, which is one of the other main mechanisms of PAP (62).

6.4.4.2 The effect of a heavy dynamic CA on potentiating CMJ in a population with greater CMJ RPP

For the higher performing group in terms of CMJ RPP, no significant improvements in CMJ performance across any CA or post-test period were identified, with RPP displaying a significant decrease at 12 minutes recovery in the 3 @ 3RM condition. For the lower performing population, multiple significant decrements in CMJ performance were identified across all CAs and recovery periods.

When using each participants best recovery period, the more powerful population significantly improved CMJ peak force (5.8%) after the 5 @ 5RM CA, as well significant improvements in CMJ peak velocity after both the 3 @ 3RM (3.5%) and 4 @ 4RM CAs (2.7%). Counter-movement jump RPP also displayed a moderate non-significant improvement after the 5 @ 5RM CA (ES = 0.66, p = 0.051). For the less powerful population, the only significant improvement in performance was evident in the change in CMJ peak force after the 4 @ 5RM CA.

Since the more powerful group displayed improvements in more post-CMJ variables, there is some evidence to suggest that an individual's CMJ RPP may also contribute to whether they produce a potentiating response. It must be noted that muscular power is a hybrid as muscular strength, as muscular power is the product of both muscular force and velocity (85). Considering this, the finding that participant muscular power also correlates to an individual potentiating CMJ performance is not major; however, it may back up the theory of Seitz et al. (128) that muscle fibre type plays a larger role in potentiation than just participant strength alone. Participants who are more speed-strength, will generally have a larger proportion of type II muscle fibres like that of those with great muscular strength. Therefore, this particular population may benefit more from a CA to the reasons explained in previous section (6.4.4.1) in regards to a higher percentage of type II muscle fibres.

6.4.4.3 The effect of a heavy dynamic CA on potentiating CMJ in a population with greater aerobic capacity

Post-activation potentiation is the balance between the potentiation caused by a CA, and the fatigue created, as multiple studies have identified significant drops in post-performance directly after a CA (16,82,83,125). The previous sections have discussed how participants with a higher percentage of type II muscle fibres (assumed due to greater strength and speed-strength) may lead to greater amounts of potentiation created. However, participants who are more aerobically dominant (potentially from having a larger proportion of type I muscle fibres) potentially could recover faster from the fatigue caused by the CA, leading to an acute enhancement in post-test performance.

No significant improvements in CMJ performance were identified for either of the populations (in terms of MSSR distance) across any specific recovery period for any particular CA. When each individual's optimum rest-period was considered, significant improvements were identified for the more aerobic population, as CMJ peak velocity (3.1%) increased after the 4 @ 5RM condition, whilst CMJ peak force (5.7%) increased after the 5 @ 5RM condition. An interesting finding was that the population with the less aerobic capacity, significantly improved CMJ peak force at their best rest interval after both the 4 @ 5RM CA (3.4%, $p = 0.028$) and the 5 @ 5RM CA (2.9%, $p = 0.032$).

From the following results, it is unclear what effect an individual's aerobic capacity has on whether they produce a positive potentiating response in the CMJ. It seems that the population with greater aerobic capacity improve CMJ peak velocity after certain CAs when compared to the participants with a lower aerobic capacity (Figure 6.13). Despite this indifference, other changes in CMJ variables do not seem to differ too much when comparing the better aerobic to the less aerobic group. These findings may be attributed to the small sample size used, as only eight participants were compared for each group once the median split occurred.

Although the more aerobic group performed better on the MSSR test than the lower aerobic group, this particular population (better aerobic capacity) would still not be considered to be aerobically trained. For these studies, it was a pre-requisite that participants needed resistance training experience; however, there was no aerobic training experience necessary. Hence, although this population is above the median for this study, it does not mean they are necessarily well trained in this fitness component. Potentially further research needs to focus on more aerobically trained populations to investigate whether aerobic capacity influences potentiation. The practical application to acutely enhance performance of an aerobic dominant athlete would not be as high as a speed-strength based athlete, as the demands of their sport are much longer in their duration, hence any potentiating response may be negligible.

Chapter 7: Summary & Conclusions

7.1 Summary

This thesis sought out to determine the best methodological approach that would enable a CA to potentiate subsequent jumping and sprinting performance. Due to much of the previous PAP literature using poor warm-ups prior to pre-testing (30,44,71,88,102,111,115,140,143), the first study identified each individuals optimum warm-up for jumping performance, before adding a CA of four half-squats at a 5RM load in order to further potentiate jumping performance.

Once the half-squat CA was added to each individual's optimum warm-up, CMJ height significantly increased above pre-testing when the best rest period was considered. No other significant changes were identified in any other variable of the CMJ. Drop jump RSI significantly decreased across all post-times after the addition of the heavy dynamic CA.

The second investigation compared the effect of maximising the intention to lift explosively during a half-squat CA. Previous research had investigated the effect of maximising intention during the squat exercise (14), however, no research had previously investigated the effectiveness of the lifting strategy as a CA. The research was also conducted as the squatting instruction throughout the literature was not consistent, with some literature telling participants to squat in a controlled manner (102), whilst other investigations were emphasising the need to maximise bar velocity on the way up (57).

The results did not distinguish any significant increases in CMJ for either CA across any particular rest interval. Furthermore, the HS-EXP CA significantly decreased DJ RSI at all post-times (post-6, 10 and post-best). Despite there being no significant changes in CMJ performance, generally the HS-EXP CA was better at increasing post-best CMJ height (2.6 vs. 0.9% improvement) than the HS-CON condition. Due to the low strength levels of the participants, further research is required in order to assess the effect each CA has on potentiating jump performance.

It was unclear within the previous literature whether plyometric activities could be used as an effective CA to potentiate subsequent performance. If plyometric activities could be used successfully as a CA, the implications for many sporting situation are large, as coaches and athletes would not need heavy pieces of equipment to be available prior to competition. Some of the literature had supported the use of plyometric CAs (23,30,143), whilst others had failed to identify their positive effect (42,47,141,146). It was hypothesised that by increasing the repetitions of the plyometric activities to match the time under tension of successful heavy dynamic CAs, it may lead to a positive potentiating effect. Despite this hypothesis, no volume of plyometric activities or the heavy dynamic half-squats were a successful CA to potentiate CMJ or sprinting performance. Although no significant improvements were identified, generally the half-squat CA was more effective at potentiating CMJ and sprinting performance than the plyometric CA.

Considering the previous two studies displayed no significant improvements after the heavy dynamic CA, the final study investigated different volumes of half-squats to see if CMJ performance could be potentiated. The study also attempted to identify if any other fitness qualities other than relative strength had an effect on whether an individual responds positively to a CA. Therefore, prior to any potentiation sessions, participants performed multiple fitness tests over two sessions.

Whilst investigating the population as a whole, the 5@5RM CA had the greatest effect on potentiating post-CMJ performance, as CMJ jump height and peak force increased significantly when the best rest period of each individual was considered.

Participant absolute strength, RPP and aerobic endurance all displayed multiple significant correlations with the change score between pre and post-best CMJ variables. From splitting the population in terms of absolute strength, the effect that individual strength has on PAP is clear. Three of the four CMJ variable significantly increased after the 5@5RM CA when the post-best interval was considered. Furthermore, significant improvements were identified in post-best CMJ variables for both of the other CAs (3@3RM and 4@5RM). When the population was split in terms of RPP and aerobic endurance, the effect these qualities had on PAP was not as clear as absolute strength.

7.2 Conclusions

From the previous studies, the following conclusions are made:

Study 1

1. The optimum warm-up for CMJ performance varied between individuals within the following study. Despite there being variety within which warm-up was optimum, WU 1 was not sufficient enough in terms of duration, whilst the duration of WU6 seemed too much and decreased CMJ performance.
2. The addition of the four half-squats with a 5RM load CA to the optimum warm-up significantly increased CMJ height in recreationally trained males once their best rest period was considered (between four and eight minutes). Despite the significant improvement in jump height, no other CMJ variable significantly improved.
3. The addition of the four half-squats with a 5RM load CA to the optimum warm-up and sub-optimum WU significantly decreased DJ performance at all post-intervals. It must be noted that DJ performance was always after the CMJ; hence, a possible order effect may have occurred due to fatigue or loss of potentiation.

Study 2

1. When performing the concentric phase of the half-squat explosively, squat concentric PP, peak force, peak velocity and RFD were all significantly greater compared to the half-squats that were performed in a controlled manner.
2. No eccentric squatting variable was significantly different between the HS-EXP and HS-CON conditions.
3. Neither CA significantly increased any CMJ variable after any particular rest period. Both CAs also significantly decreased RPP after eight minutes rest, potentially due to the low relative strength levels of participants.
4. Despite no significant improvement in CMJ height being identified, mean results suggested that the HS-EXP CA was better to potentiate jump height (2.6% improvement after best recovery period) compared to the HS-CON CA (0.9%).
5. Both CA decreased post-DJ performance across all rest intervals.

Study 3

1. No volume of plyometric CA had any significant positive effect on CMJ variables or sprinting performance at any of the allocated rest periods. A new methodological approach on how to use a plyometric CA needs to be considered. Potentially using additional load during the plyometric CA (similar to the research by Chen et al. (30)) may increase the time under tension as well as the force required for the CA, possibly leading to a potentiating effect.
2. The half-squat CA provided no significant improvement upon CMJ variables or sprinting performance at any of the allocated rest periods.

Study 4

1. Twelve minutes recovery after a heavy dynamic CA appears to be too long in order to see a positive effect of potentiation on CMJ performance.
2. When each individuals best recovery was considered, both the 3@3RM (peak velocity) and 4@5RM (peak force) CAs significantly improved one CMJ variable, whilst the 5@5RM CA significantly improved two (jump height and peak force).
3. Participant absolute strength, CMJ RPP and MSSR test metres all displayed multiple significant positive correlations with the change scores between pre and post-best CMJ variables.
4. An increase in participant absolute strength enhances the likelihood of a positive potentiating response in the CMJ, with the stronger participants significantly improving three out of the four CMJ variables after the 5@5RM CA when their best recovery period was considered. Furthermore, statistically significant improvements in CMJ peak velocity were identified after both the 3@3RM and 4@5RM CAs (best rest period).
5. For the higher performing population in terms of RPP and aerobic endurance, some significant CMJ improvements were identified, however, more research is required to understand the effect each fitness quality has on potentiation.
6. As it created the greatest number of positive significant changes in post-CMJ variables, it would seem that the 5 @ 5RM half-squat CA is more effective at potentiating CMJ performance than a CA that involves four repetitions at a 5RM or three repetitions at a 3RM.

7.3 Practical Applications

The results from the following investigations provide many practical applications in how to best use a CA to elicit a positive potentiating response in jumping or sprinting performance. The following considerations include:

Study 1:

The results from the first study support the fact that a warm-up should consist of an aerobic component, dynamic stretching and skill rehearsal. Although the moderate warm-up intensity produced the highest mean for most CMJ variables, the optimum WU intensity still varied among participants. This identifies that athletes and coaches need to spend time identifying what warm-up intensity, duration and exercises, optimises their match or training performance. Furthermore, future research based around potentiation, must use a sufficient warm-up prior to any pre-testing variables so that post-test improvements can be attributed to a potentiating effect. It is suggested that if the appropriate time to evaluate an individuals optimum warm-up is not available, then a warm-up volume similar to the moderate warm-up used in the first study, should be sufficient enough to enhance jumping performance.

The inclusion of four half-squats at a 5RM load could acutely enhance jump height for particular individuals. Such an acute enhancement could further improve an athlete's performance in competition. In saying this, the appropriate equipment would need to be available and the sport or event that the athlete competes in, would need to have rest periods that can be controlled, as too little or too much rest could affect the acute enhancement in jumping performance. This makes it difficult to use in many team sports, however, it could be applicable to many individual sports that are short in duration and high in intensity. Coaches should trial the protocol on athletes first, as the CA may not enhance performance for all individuals' and the best recovery period may also differ between individuals.

Young, Cormack and Crichton (159) concluded that the variables within the CMJ are independent to each other. Considering this, coaches need to identify which CMJ variable is most beneficial for their athlete and focus upon enhancing that. Since CMJ RPP and peak force showed no significant differences after the CA, further research is required to identify what effect such a CA has on these particular CMJ variables. If CMJ RPP is decreasing after the performance of a CA, the use of contrast or complex sets may not be the best way to produce a chronic adaptation to speed-strength over a training period for certain athletes. Coaches should continuously measure athletes PP whilst using contrast or complex training methods, to reiterate that the heavier sets are actually improving PP performance in the subsequent lighter sets.

A CA of four half-squats at a 5RM load significantly decreased DJ RSI, suggesting that such a CA was not effective in potentiating DJ performance. Future research could potentially identify other CA types or intensities that could potentiate DJ performance or other exercises that look to enhance the stretch-shortening cycle.

Study 2:

The half-squats performed in the HS-EXP condition significantly increased all concentric squatting variables compared to the HS-CON condition. Considering this, researchers and coaches need to understand that by changing the squatting instruction, they also change the kinetics and kinematics of the squat. In terms of potentiation, this means that the effect each squatting instruction has on subsequent contractions could also be different. From this investigation, by lifting with maximal acceleration in in the concentric phase of a CA, this technique improved more aspects of the CMJ compared to a controlled lift. However, the evidence to support this was minimal and was not consistent for all participants throughout the research. Therefore, if a coach wants to potentiate subsequent jumping performance by using a squatting CA, they need to trial both squatting instructions with all individuals to identify whether either CA provides an increase in performance. If an acute enhancement in jump height is evident, then such a protocol could be used to enhance competition performance, provided the necessary equipment was available and the appropriate rest period could be controlled. Coaches also need to identify what is the best rest interval for their athlete.

Study 3:

No plyometric CA displayed any sign of creating potentiation to enhance subsequent CMJ or sprinting performance. It seemed from the results that after the four sets of rebound jump CA, post-eight CMJ results began to improve towards pre-testing levels. Potentially a longer rest period may be required for participants to take advantage of a plyometric based CA for jumping performance. In terms of sprinting performance, there was no evidence to suggest that any of the rebound jump CAs would improve post-performance. Reasons to explain this may be that the CA only focusses upon vertical movement, rather than movement in both the vertical and horizontal plane. Future research should investigate the effect of using plyometric activities that involve both horizontal and vertical movement (broad jump or bounding), as this is more biomechanically similar to sprinting performance. Furthermore, potentially a weighted sled push could be used to potentiate sprinting performance (125), however, this would require the availability of certain equipment before competition performance (not as practical).

Although no significant improvements were identified in the CMJ after the half-squat CA, some individuals increased their jump height after the heavy dynamic CA. Similar to the conclusions from the previous studies, these minimal jump height enhancements could improve competition performance, however, coaches need to trial the CA protocol on athletes to identify whether they produce a potentiating response and also evaluate their optimum rest period.

Once again no increases in CMJ RPP were identified after the performance of the half-squat CA. Considering this finding has been relatively consistent throughout the present studies, further investigation is required into the load and repetition schemes of the CA. Furthermore, more thorough examination into the participants is required to try to identify more explanations as to why some individuals respond positively to a CA, whilst others show no change or performance decrements.

It is suggested from these findings that a heavy dynamic CA (heavy squats) is more effective in potentiating CMJ performance than a plyometric CA for recreationally resistance trained males. Despite this, the positive effects of potentiation from the heavy dynamic CA were still not clear in this investigation. Hence, coaches need to trial whether athletes actually improve jumping performance after a heavy squat CA. In terms of sprinting performance, it is unclear whether either CA is an effective strategy in order to enhance future performance. Due to the possibility that a plyometric CA will be more practical to acutely enhance sporting performance, more research is required to identify certain strategies that may be able to create a positive potentiating response.

Study 4:

The 5 @ 5RM CA was the most beneficial condition to potentiate CMJ performance in recreationally trained men. The 5 @ 5RM CA significantly increased post-best CMJ jump height, whilst both the 4 @ 5RM and 3 @ 3RM failed to potentiate any change in jump height when the whole study population was considered. This may explain why significant changes in CMJ performance were not identified in previous studies, as the CA used was four repetitions at a 5RM load.

By performing a CA of five half-squat with a 5RM load, jump height can be acutely increased for competition performance, provided the appropriate equipment is available and the rest period can be controlled. Considering these significant changes in CMJ performance were identified after each individuals optimum rest period, coaches need to trial what specific rest period is best for each individual athlete.

The results do suggest that twelve minutes recovery is too long to identify a positive potentiating response in CMJ performance for most participants. Although such a rest period may be optimum for a small number of individuals, coaches should focus on identifying effective rest periods that are less than eight minutes in length for each individual athlete.

In terms of participant absolute lower body strength, the stronger population significantly improved in three of the four post-best CMJ variables, whilst the group with lower absolute strength displayed no significant changes. Considering the stronger population had a mean 5RM half-squat of 172.8kg, it is suggested that in order to elicit a positive potentiating response in CMJ performance, individuals need to have similar or better 5RM half-squat testing results than 170kg. Coaches must also note the depth of squat used during the RM testing, as values for parallel squats would be lower than that of half-squats.

Much of the previous literature states a relative strength figure that is suggested for an individual using a complex pair (44,116,129); however, the present investigation discovered that the correlation between a potentiating response and absolute strength was greater than that exhibited by relative strength (Table 6.5). Potentially, future research should suggest minimal strength requirements to elicit a potentiating response in absolute terms as opposed to relative.

The stronger population also significantly improved CMJ RPP (3%) and peak force (3.5%) after the 5 @ 5RM CA. Considering these results, for this particular stronger population, coaches could use a heavy half-squat and CMJ (or similar activity) as a complex pair to improve the PP production throughout a training session. It must be noted that the present study only looked at performing a single set of the CA. Therefore, the effect of performing multiple sets of the CA (whether this be by complex or contrast training methods) throughout a session have not been investigated. Considering this, it is suggested that coaches closely measure variables throughout a training session, to ensure the CA sets are still having a positive effect and performance is not diminishing due to fatigue.

Coaches should also understand that if an athlete exhibits greater speed-strength qualities, this may also improve the likelihood of eliciting a positive potentiating response. Considering speed-strength is related to strength, and the sample size of the present study is small once the population is split in half, further research may be required to investigate the effect of participant lower limb speed-strength in potentiating jumping activities.

From the present investigation, it is unclear whether having greater aerobic capacity effects whether an individual responds effectively to a CA. Considering the current population was not recruited on their endurance ability, future research could investigate whether aerobic dominant athletes are able to elicit a potentiating response.

7.4 Recommendations for future research

The purpose of the following thesis was to investigate and provide rational for the best methodology to perform a CA in order to acutely enhance jumping and sprinting performance via potentiation. After the completion of the research, the following suggestions for future research have been made.

Considering the final investigation suggested that the 5 @ 5RM was the most effective at potentiating CMJ performance, perhaps this repetition and load could be used to compare the difference between explosive and controlled half-squats CAs. Study two failed to identify any significant differences between the two methods, however, only four repetitions of the half squat was performed during the CA, possibly affecting the results.

Future research could also focus upon a different plyometric exercise as a CA to potentiate performance. Considering the results of the present study, it seems that continuous rebound jumps are not the best CA to potentiate CMJ and sprinting performance. However, it is possibly that a different type of plyometric exercise, once the repetitions are adapted to match the time under tension of an effective heavy dynamic CA, could potentially improve future contractions. The practicality of plyometric based CAs is too high, therefore, future research needs to focus upon the ideal methodology to elicit a potentiating response from these types of CAs.

Although the influence on participant strength is clear throughout the PAP literature (15,31,44,116,128,163), the effect of a participants aerobic endurance is not. This present thesis began to investigate the effects of aerobic endurance on potentiation, however, because the participants for these studies were selected on their resistance training history, there aerobic training background (even for the more aerobically trained population) was minimal. It is plausible to suggest that although an endurance athlete may not produce as much potentiation from a CA, their ability to recover from it should be heightened (66,119). Therefor future research should compare aerobic endurance athletes to strength dominant athletes and see if there are any differences in how each population responds to a CA.

Finally, future research could investigate the effect of PAP on more complex skills that involve a timing aspect. So much of the PAP literature looked at basic movements like jumping (39,44,82,107,116,118,131,163), sprinting (15,39,99,125) or bench press throws (3,4,80,97), however, a dearth of literature has explored the effect a CA has on more complex skills that may have an accuracy component. For example, can a CA potentiate overhand throwing performance? Firstly the velocity of the actual projectile thrown, but secondly, is the accuracy of the throw diminished after a CA? Considering so much literature has expressed the best methods to potentiate basic jumping skills, the effect that a CA would have on a more complex skill would add volume to the current literature.

References

1. Adams K, O'Shea JP, O'Shea KL, and Climstein M. The Effect of Six Weeks of Squat, Plyometric and Squat-Plyometric Training on Power Production. *J Strength Cond Res* 6, 1992.

2. Andersen JL and Aagaard P. Myosin heavy chain IIX overshoot in human skeletal muscle. *Muscle Nerve* 23: 1095–1104, 2000.

3. Baker D. Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. *J Strength Cond Res* 17: 493–497, 2003.

4. Baker D. Increases in Bench Throw Power Output When Combined With Heavier Bench Press Plus Accommodating Chains Resistance During Complex Training. *J Aust Strength Cond* 17: 3–11, 2009.

5. Baker D and Nance S. The Relation Between Running Speed and Measures of Strength and Power in Professional Rugby League Players. *J Strength Cond Res* 13, 1999.

6. Baker DG. Changes in upper body concentric mean power output resulting from complex training emphasizing concentric muscle actions. *J Aust Strength Cond* 20: 15–20, 2012.

7. Baker DG and Newton RU. Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. *J strength Cond Res* 22: 153–158, 2008.

8. Ball NB, Stock CG, and Scurr JC. Bilateral contact ground reaction forces and contact times during plyometric drop jumping. *J strength Cond Res* 24: 2762–2769, 2010.

9. Batista MAB, Ugrinowitsch C, Roschel H, Lotufo R, Ricard MD, and Tricoli VAA. Intermittent exercise as a conditioning activity to induce postactivation potentiation. *J strength Cond Res* 21: 837–840, 2007.

10. Behm DG. Neuromuscular Implications and Applications of Resistance Training. *J Strength Cond Res* 9, 1995.

11. Behm DG. Force maintenance with submaximal fatiguing contractions. *Can J Appl Physiol* 29: 274–290, 2004.

12. Behm DG, Blazevich AJ, Kay AD, and McHugh M. Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Appl Physiol Nutr Metab = Physiol Appl Nutr Metab* 41: 1–11, 2016.

13. Behm DG and Chaouachi A. A review of the acute effects of static and dynamic stretching on performance. *Eur J Appl Physiol* 111: 2633–2651, 2011.

14. Behm DG and Sale DG. Intended rather than actual movement velocity determines velocity-specific training response. *J Appl Physiol* 74: 359–368, 1993.

15. Bevan HR, Cunningham DJ, Tooley EP, Owen NJ, Cook CJ, and Kilduff LP. Influence of postactivation potentiation on sprinting performance in professional rugby players. *J strength Cond Res* 24: 701–705, 2010.

16. Bevan HR, Owen NJ, Cunningham DJ, Kingsley MIC, and Kilduff LP. Complex training in professional rugby players: influence of recovery time on upper-body power output. *J strength Cond Res* 23: 1780–1785, 2009.

17. Bishop D. Warm-up II: Performance changes following active warm-up and how to structure the warm-up. *Sport Med* 33: 483–498, 2003.

18. Bishop D. Warm up I: potential mechanisms and the effects of passive warm up on exercise performance. *Sports Med* 33: 439–454, 2003.

19. Boullosa DA, Abreu L, Beltrame LGN, and Behm DG. The acute effect of different half squat set configurations on jump potentiation. *J strength Cond Res* 27: 2059–2066, 2013.

20. Boullosa DA and Tuimil JL. Postactivation potentiation in distance runners after two different field running protocols. *J strength Cond Res* 23: 1560–1565, 2009.

21. Boyd DA, Donald N, and Balshaw TG. Comparison of acute countermovement jump responses after functional isometric and dynamic half squats. *J strength Cond Res* 28: 3363–3374, 2014.

22. Brandenburg JP. The acute effects of prior dynamic resistance exercise using different loads on subsequent upper-body explosive performance in resistance-trained men. *J strength Cond Res* 19: 427–432, 2005.

23. Bridgeman LA, McGuigan MR, Gill ND, and Dulson DK. The Effects of Accentuated Eccentric Loading on the Drop Jump Exercise and the Subsequent Postactivation Potentiation Response. *J strength Cond Res* 31: 1620–1626, 2017.

24. Bryanton MA, Kennedy MD, Carey JP, and Chiu LZF. Effect of squat depth and barbell load on relative muscular effort in squatting. *J strength Cond Res* 26: 2820–2828, 2012.

25. Burkett LN, Phillips WT, and Ziuraitis J. The best warm-up for the vertical jump in college-age athletic men. *J strength Cond Res* 19: 673–676, 2005.

26. Chaouachi A, Poulos N, Abed F, Turki O, Brughelli M, Chamari K, Drinkwater EJ, and Behm DG. Volume, intensity, and timing of muscle power potentiation are variable. *Appl Physiol Nutr Metab* 36: 736–747, 2011.

27. Chattong C, Brown LE, Coburn JW, and Noffal GJ. Effect of a dynamic loaded warm-up on vertical jump performance. *J strength Cond Res* 24: 1751–1754, 2010.

28. Chatzopoulos DE, Michailidis CJ, Giannakos AK, Alexiou KC, Patikas DA, Antonopoulos CB, and Kotzamanidis CM. Postactivation potentiation effects after heavy resistance exercise on running speed. *J strength Cond Res* 21: 1278–1281, 2007.

29. Chelly MS, Ghenem MA, Abid K, Hermassi S, Tabka Z, and Shephard RJ. Effects of in-Season Short-Term Plyometric Training Program on Leg Power, Jump- and Sprint Performance of Soccer Players. *J Strength Cond Res* 24, 2010.

30. Chen Z-R, Wang Y-H, Peng H-T, Yu C-F, and Wang M-H. The acute effect of drop jump protocols with different volumes and recovery time on countermovement jump performance. *J strength Cond Res* 27: 154–158, 2013.

31. Chiu LZF, Fry AC, Weiss LW, Schilling BK, Brown LE, and Smith SL. Postactivation potentiation response in athletic and recreationally trained individuals. *J strength Cond Res* 17: 671–677, 2003.

32. Clark RA, Bryant AL, and Reaburn P. The acute effects of a single set of contrast preloading on a loaded countermovement jump training session. *J strength Cond Res* 20: 162–166, 2006.

33. Comyns TM, Harrison AJ, Hennessy L, and Jensen RL. Identifying the optimal resistive load for complex training in male rugby players. *Sport Biomech* 6: 59–70, 2007.

34. Comyns TM, Harrison AJ, Hennessy LK, and Jensen RL. The optimal complex training rest interval for athletes from anaerobic sports. *J strength Cond Res* 20: 471–476, 2006.

35. Cormie P, McBride JM, and McCaulley GO. Power-time, force-time, and velocity-time curve analysis during the jump squat: impact of load. *J Appl Biomech* 24: 112–120, 2008.

36. Cormie P, McGuigan MR, and Newton RU. Developing maximal neuromuscular power: Part 1--biological basis of maximal power production. *Sports Med* 41: 17–38, 2011.

37. Cormie P, McGuigan MR, and Newton RU. Developing maximal neuromuscular power: part 2 - training considerations for improving maximal power production. *Sports Med* 41: 125–146, 2011.

38. Cotterman ML, Darby LA, and Skelly WA. Comparison of muscle force production using the Smith machine and free weights for bench press and squat exercises. *J strength Cond Res* 19: 169–176, 2005.

39. Crewther BT, Kilduff LP, Cook CJ, Middleton MK, Bunce PJ, and Yang G-Z. The Acute Potentiating Effects of Back Squats on Athlete Performance. *J Strength Cond Res* 25: 3319–3325, 2011.

40. Cronin J and Sleivert G. Challenges in understanding the influence of maximal power training on improving athletic performance. *Sport Med* 35: 213–234, 2005.

41. Daneshjoo A, Mokhtar AH, Rahnama N, and Yusof A. The Effects of Comprehensive Warm-Up Programs on Proprioception, Static and Dynamic Balance on Male Soccer Players. *PLoS One* 7: 1–10, 2012.

42. Deutsch M and Lloyd R. Effect of order of exercise on performance during a complex training session in rugby players. *J Sports Sci* 26: 803–809, 2008.

43. Docherty D, Robbins D, and Hodgson M. Complex Training Revisited: A Review of its Current Status as a Viable Training Approach. *Strength Cond J* 26: 52, 2004.

44. Duthie GM, Young WB, and Aitken DA. The acute effects of heavy loads on jump squat performance: an evaluation of the complex and contrast methods of power development. *J Strength Cond Res* 16: 530–538, 2002.

45. Ebben WP, Jensen RL, and Blackard DO. Electromyographic and Kinetic Analysis of Complex Training Variables. *J Strength Cond Res* 14: 451–456, 2000.

46. Enoka RM, Hutton RS, and Eldred E. Changes in excitability of tendon tap and Hoffmann reflexes following voluntary contractions. *Electroencephalogr Clin Neurophysiol* 48: 664–672, 1980.

47. Esformes JI, Cameron N, and Bampouras TM. Postactivation potentiation following different modes of exercise. *J strength Cond Res* 24: 1911–1916, 2010.

48. Esformes JI, Keenan M, Moody J, and Bampouras TM. Effect of Different Types of Conditioning Contraction on Upper Body Postactivation Potentiation. *J Strength Cond Res* 25, 2011.

49. Etnyre B and Kinugasa T. Postcontraction influences on reaction time. *Res Q Exerc Sport* 73: 271–281, 2002.

50. Faigenbaum AD, McFarland JE, Schwerdtman JA, Ratamess NA, Kang J, and Hoffman JR. Dynamic warm-up protocols, with and without a weighted vest, and fitness performance in high school female athletes. *J Athl Train* 41: 357–363, 2006.

51. Farup J and Sorensen H. Postactivation potentiation: upper body force development changes after maximal force intervention. *J strength Cond Res* 24: 1874–1879, 2010.

52. Feros SA, Young WB, Rice AJ, and Talpey SW. The effect of including a series of isometric conditioning contractions to the rowing warm-up on 1,000-m rowing ergometer time trial performance. *J Strength Cond Res* 26: 3326–34, 2012.

53. Flanagan EP and Comyns TM. The Use of Contact Time and the Reactive Strength Index to Optimize Fast Stretch-Shortening Cycle Training. *Strength Cond J* 30, 2008.

54. French DN, Kraemer WJ, and Cooke CB. Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *J Strength Cond Res* 17: 678–685, 2003.

55. Garcia-Pinillos F, Soto-Hermoso VM, and Latorre-Roman PA. Acute effects of extended interval training on countermovement jump and handgrip strength performance in endurance athletes: postactivation potentiation. *J strength Cond Res* 29: 11–21, 2015.

56. Gossen ER and Sale DG. Effect of postactivation potentiation on dynamic knee extension performance. *Eur J Appl Physiol* 83: 524–530, 2000.

57. Gourgoulis V, Aggeloussis N, Kasimatis P, Mavromatis G, and Garas A. Effect of a Submaximal Half-Squats Warm-up Program on Vertical Jumping Ability. 2003.

58. Gouvêa AL, Fernandes IA, César EP, Silva WAB, and Gomes PSC. The effects of rest intervals on jumping performance: A meta-analysis on post-activation potentiation studies. *J Sports Sci* 31: 459–467, 2013.

59. Grange RW, Vandenboom R, and Houston ME. Physiological Significance of Myosin Phosphorylation in Skeletal Muscle. *Can J Appl Physiol* 18: 229–242, 1993.

60. Grodjinovsky A and Magel JR. Effect of Warm-Up on Running Performance. *Res Quarterly Am Assoc Heal Phys Educ Recreat* 41: 116–119, 1970.

61. Guggenheimer JD, Dickin DC, Reyes GF, and Dolny DG. The effects of specific preconditioning activities on acute sprint performance. *J strength Cond Res* 23: 1135–1139, 2009.

62. Gullich A and Schmidtbleicher D. Short-term potentiation of power performance induced by maximal voluntary contractions. *XVth Congr Int Soc Biomech* 348–349, 1996.

63. Gullich BA and Schmidtbleicher D. Short-Term Increase of Explosive Strength Through Maximal Arbitrary Contractions the Relation of Neurolan Involution. , 1997.

64. Haff GG and Nimphius S. Training Principles for Power. *Strength Cond J* 34: 2–12, 2012.

65. Hamada T, Sale DG, and Macdougall JD. Postactivation potentiation in endurance-trained male athletes. *Med Sci Sports Exerc* 32: 403–411, 2000.

66. Hamada T, Sale DG, and Macdougall JD. Postactivation potentiation in endurance-trained male athletes. *Med Sci Sports Exerc* 32: 403—411, 2000.

67. Hanson ED, Leigh S, and Mynark RG. Acute effects of heavy- and light-load squat exercise on the kinetic measures of vertical jumping. *J strength Cond Res* 21: 1012–1017, 2007.

68. Harris NK, Cronin J, Taylor K-L, Boris J, and Sheppard J. Understanding Position Transducer Technology for Strength and Conditioning Practitioners. *Strength Cond J* 32: 66–79, 2010.

69. Harrison AJ. Throwing and catching movements exhibit post-activation potentiation effects following fatigue. *Sport Biomech* 10: 185–196, 2011.

70. Higuchi T, Nagami T, Mizuguchi N, and Anderson T. The Acute and Chronic Effects of Isometric Contraction Conditioning on Baseball Bat Velocity. *J Strength Cond Res* 27, 2013.

71. Hilfiker R, Hübner K, Lorenz T, and Marti B. Effects of drop jumps added to a warm-up of elite sport athletes with a high capacity for explosive force development. *J Strength Cond Res* 21: 550–555, 2007.

72. Hodgson M, Docherty D, and Robbins D. Post-activation potentiation. *Sport Med* 585–596, 2005.

73. Hopkins W. Reliability from consecutive pairs of trials. Available from: http://www.sportsci.org/resource/stats/

74. Houston ME and Grange RW. Myosin phosphorylation, twitch potentiation, and fatigue in human skeletal muscle. *Can J Physiol Pharmacol* 68: 908–913, 1990.

75. Hrysomallis C and Kidgell D. Effect of heavy dynamic resistive exercise on acute upper-body power. *J Strength Cond Res* 15: 426–430, 2001.

76. Iglesias-Soler E, Paredes X, Carballeira E, Márquez G, and Fernández-Del-Olmo M. Effect of intensity and duration of conditioning protocol on post-activation potentiation and changes in H-reflex. *Eur J Sport Sci* 11: 33–38, 2011.

77. Jensen RL and Ebben WP. Kinetic analysis of complex training rest interval effect on vertical jump performance. *J Strength Cond Res* 17: 345–349, 2003.

78. Jo E, Judelson DA, Brown LE, Coburn JW, and Dabbs NC. Influence of recovery duration after a potentiating stimulus on muscular power in recreationally trained individuals. *J strength Cond Res* 24: 343–347, 2010.

79. Jones P and Lees A. A biomechanical analysis of the acute effects of complex training using lower limb exercises. *J Strength Cond Res* 17: 694–700, 2003.

80. Judge LW, Bellar D, and Judge M. Efficacy of Potentiation of Performance Through Overweight Implement Throws on Male and Female High-School Weight Throwers. *J Strength Cond Res* 24, 2010.

81. Khamoui A V, Brown LE, Coburn JW, Judelson DA, Uribe BP, Nguyen D, Tran T, Eurich AD, and Noffal GJ. Effect of potentiating exercise volume on vertical jump parameters in recreationally trained men. *J strength Cond Res* 23: 1465–1469, 2009.

82. Kilduff LP, Bevan HR, Kingsley MIC, Owen NJ, Bennett MA, Bunce PJ, Hore AM, Maw JR, and Cunningham DJ. Postactivation potentiation in professional rugby players: optimal recovery. *J strength Cond Res* 21: 1134–1138, 2007.

83. Kilduff LP, Owen N, Bevan H, Bennett M, Kingsley MIC, and Cunningham D. Influence of recovery time on post-activation potentiation in professional rugby players. *J Sports Sci* 26: 795–802, 2008.

84. Klug GA, Botterman BR, and Stull JT. The effect of low frequency stimulation on myosin light chain phosphorylation in skeletal muscle. *J Biol Chem* 257: 4688–4690, 1982.

85. Knuttgen HG and Kraemer WJ. Terminology and Measurement in Exercise Performance. *J Strength Cond Res* 1, 1987.

86. Koch AJ, O'Bryant HS, Stone ME, Sanborn K, Proulx C, Hruby J, Shannonhouse E, Boros R, and Stone MH. Effect of warm-up on the standing broad jump in trained and untrained men and women. *J strength Cond Res* 17: 710–714, 2003.

87. Komi P V. Physiological and biomechanical correlates of muscle function: effects of muscle structure and stretch-shortening cycle on force and speed. *Exerc Sport Sci Rev* 12: 81–121, 1984.

88. Linder EE, Prins JH, Murata NM, Derenne C, Morgan CF, and Solomon JR. Effects of Preload 4 Repetition Maximum on 100-m Sprint Times in Collegiate Women. *J Strength Cond Res* 24: 1184–1190, 2010.

89. Little T and Williams AG. Specificity of acceleration, maximum speed, and agility in prefessional soccers players. *J Strength Cond Res* 19, 2005.

90. Lloyd RS, Oliver JL, Hughes MG, and Williams CA. Reliability and validity of field-based measures of leg stiffness and reactive strength index in youths. *J Sports Sci* 27: 1565–1573, 2009.

91. Lowery RP, Duncan NM, Loenneke JP, Sikorski EM, Naimo MA, Brown LE, Wilson FG, and Wilson JM. The Effects of Potentiating Stimuli Intensity Under Varying Rest Periods on Vertical Jump Performance and Power. *J Strength Cond Res* 26: 3320–3325, 2012.

92. Lyttle A, J. Wilson G, and J. Ostrowski K. Enhancing Performance: Maximal Power Versus Combined Weights and Plyometrics Training. 1996.

93. Maffiuletti NA and Martin A. Progressive versus rapid rate of contraction during 7 wk of isometric resistance training. *Med Sci Sports Exerc* 33: 1220–1227, 2000.

94. Mahlfeld K, Franke J, and Awiszus F. Postcontraction changes of muscle architecture in human quadriceps muscle. *Muscle and Nerve* 29: 597–600, 2004.

95. Mandengue SH, Seck D, Bishop D, Cisse F, Tsala-Mbala P, and Ahmaidi S. Are athletes able to self-select their optimal warm up? *J Sci Med Sport* 8: 26–34, 2005.

96. Manning DR and Stull JT. Myosin light chain phosphorylation-dephosphorylation in mammalian skeletal muscle. *Am J Physiol* 242: C234-41, 1982.

97. Markovic G, Simek S, and Bradic A. Are acute effects of maximal dynamic contractions on upper-body ballistic performance load specific? *J strength Cond Res* 22: 1811–1815, 2008.

98. Matthews M and Comfort P. Applying Complex Training Principles to Boxing: A Practical Approach. *Strength Cond J* 30: 12–15, 2008.

99. Matthews M, Matthews H, and Snook B. The Acute Effects of a Resistance Training Warmup on Sprint Performance. *Res Sport Med* 12: 151–159, 2004.

100. Matthews MJ, Comfort P, and Crebin R. Complex training in ice hockey: the effects of a heavy resisted sprint on subsequent ice-hockey sprint performance. *J strength Cond Res* 24: 2883–2887, 2010.

101. May CA, Cipriani D, and Lorenz KA. Power Development Through Complex Training for The Division I Collegiate Athlete. *Strength Cond J* 32: 30–43, 2010.

102. McBride JM, Nimphius S, and Erickson TM. The acute effects of heavy-load squats and loaded countermovement jumps on sprint performance. *J strength Cond Res* 19: 893–897, 2005.

103. McCann MR and Flanagan SP. The effects of exercise selection and rest interval on postactivation potentiation of vertical jump performance. *J strength Cond Res* 24: 1285–1291, 2010.

104. McCutcheon LJ, Geor RJ, and Hinchcliff KW. Effects of prior exercise on muscle metabolism during sprint exercise in horses. *J Appl Physiol* 87: 1914–1922, 1999.

105. McMillian DJ, Moore JH, Hatler BS, and Taylor DC. Dynamic vs. static-stretching warm up: the effect on power and agility performance. *J strength Cond Res* 20: 492–499, 2006.

106. Miarka B, Del Vecchio FB, and Franchini E. Acute effects and postactivation potentiation in the Special Judo Fitness Test. *J strength Cond Res* 25: 427–431, 2011.

107. Mitchell CJ and Sale DG. Enhancement of jump performance after a 5-RM squat is associated with postactivation potentiation. *Eur J Appl Physiol* 111: 1957–1963, 2011.

108. Nelson AG, Kokkonen J, and Arnall DA. Acute muscle stretching inhibits muscle strength endurance performance. *J strength Cond Res* 19: 338–343, 2005.

109. Newton RU, Kraemer WJ, and Hakkinen K. Effects of ballistic training on preseason preparation of elite volleyball players. *Med Sci Sports Exerc* 31: 323–330, 1999.

110. Newton RU and McEvoy KI. Baseball Throwing Velocity: A Comparison of Medicine Ball Training and Weight Training. *J Strength Cond Res* 8, 1994.

111. Okuno NM, Tricoli V, Silva SBC, Bertuzzi R, Moreira A, and Kiss MAPDM. Postactivation Potentiation on Repeated-Sprint Ability in Elite Handball Players. *J Strength Cond Res* 27: 662–668, 2013.

112. Parry S, Hancock S, Shiells M, Passfield L, Davies B, and Baker J. Physiological Effects of Two Different Postactivation Potentiation Training Loads on Power Profiles Generated During High Intensity Cycle Ergometer Exercise. *Res Sport Med* 16: 56–67, 2008.

113. Penry J. Validity and reliability analysis of Coopers 12-minute run and Multistage shuttle run in healthy adults. 2008.

114. Potteiger JA, Lockwood RH, Haub Ma, Dolezal BA, Almuzaini KS, Schroeder JM, and Zebas CJ. Muscle Power and Fiber Characteristics Following 8 Weeks of Plyometric Training. *J Strength Cond Res* 13, 1999.

115. Rahimi R. the Acute Effects of Heavy Versus Light-Load Squats on Sprint Performance. *Phys Educ Sport* 5: 163–169, 2007.

116. Rixon KP, Lamont HS, and Bemben MG. Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. *J strength Cond Res* 21: 500–505, 2007.

117. Robbins DW and Docherty D. Effect of loading on enhancement of power performance over three consecutive trials. *J strength Cond Res* 19: 898–902, 2005.

118. Ruben RM, Molinari MA, Bibbee CA, Childress MA, Harman MS, Reed KP, and Haff GG. The acute effects of an ascending squat protocol on performance during horizontal plyometric jumps. *J strength Cond Res* 24: 358–369, 2010.

119. Sale DG. Postactivation potentiation: role in human performance. *Exerc Sport Sci Rev* 30: 138–43, 2002.

120. Samson M, Button DC, Chaouachi A, and Behm DG. Effects of dynamic and static stretching within general and activity specific warm-up protocols. *J Sports Sci Med* 11: 279–285, 2012.

121. Schilling BK, Falvo MJ, and Chiu LZF. Force-velocity, impulse-momentum relationships: Implications for efficacy of purposefully slow resistance training. *J Sport Sci Med* 7: 299–304, 2008.

122. Schuenke MD, Herman JR, Gliders RM, Hagerman FC, Hikida RS, Rana SR, Ragg KE, and Staron RS. Early-phase muscular adaptations in response to slow-speed versus traditional resistance-training regimens. *Eur J Appl Physiol* 112: 3585–3595, 2012.

123. Scott SL and Docherty D. Acute effects of heavy preloading on vertical and horizontal jump performance. *J strength Cond Res* 18: 201–205, 2004.

124. Seitz LB and Haff GG. Application of Methods of Inducing Postactivation Potentiation During the Preparation of Rugby Players. *Strength Cond J* 37: 40–49, 2015.

125. Seitz LB, Mina MA, and Haff GG. A sled push stimulus potentiates subsequent 20-m sprint performance. *J Sci Med Sport* , 2016.

126. Seitz LB, Trajano GS, Dal Maso F, Haff GG, and Blazevich AJ. Postactivation potentiation during voluntary contractions after continued knee extensor task-specific practice. *Appl Physiol Nutr Metab* 40: 230–237, 2015.

127. Seitz LB, Trajano GS, and Haff GG. The back squat and the power clean: elicitation of different degrees of potentiation. *Int J Sports Physiol Perform* 9: 643–649, 2014.

128. Seitz LB, Trajano GS, Haff GG, Dumke CCLS, Tufano JJ, and Blazevich AJ. Relationships between maximal strength, muscle size, and myosin heavy chain isoform composition and postactivation potentiation. *Appl Physiol Nutr Metab* 41: 491–497, 2016.

129. Seitz LB, de Villarreal ES, and Haff GG. The Temporal Profile of Postactivation Potentiation Is Related to Strength Level. *J Strength Cond Res* 28: 706–715, 2014.

130. Seo D-I, Kim E, Fahs CA, Rossow L, Young K, Ferguson SL, Thiebaud R, Sherk VD, Loenneke JP, Kim D, Lee M-K, Choi K-H, Bemben DA, Bemben MG, and So W-Y. Reliability of the one-repetition maximum test based on muscle group and gender. *J Sports Sci Med* 11: 221–225, 2012.

131. Smilios I, Pilianidis T, Sotiropoulos K, Antonakis M, and Tokmakidis SP. Short-term effects of selected exercise and load in contrast training on vertical jump performance. *J Strength Cond Res* 19, 2005.

132. Smith JC and Fry AC. Effects of a ten-second maximum voluntary contraction on regulatory myosin light-chain phosphorylation and dynamic performance measures. *J strength Cond*

Res 21: 73–76, 2007.

133. Smith JC, Fry AC, Weiss LW, Li Y, and Kinzey SJ. The effects of high-intensity exercise on a 10-second sprint cycle test. *J strength Cond Res* 15: 344–348, 2001.

134. Steben RE and Steben AH. The validity of the stretch shortening cycle in selected jumping events. *J Sports Med Phys Fitness* 21: 28–37, 1981.

135. Stuart DS, Lingley MD, Grange RW, and Houston ME. Myosin light chain phosphorylation and contractile performance of human skeletal muscle. *Can J Physiol Pharmacol* 66: 49–54, 1988.

136. Sweeney HL, Bowman BF, and Stull JT. Myosin light chain phosphorylation in vertebrate striated muscle: regulation and function. *Am J Physiol* 264: C1085-95, 1993.

137. Talpey SW. Efficacy of various complex and contrast set protocols for acute responses and chronic muscle power development. 2014.

138. Talpey SW, Young WB, and Beseler B. Effect of Instructions on Selected Jump Squat Variables. *J Strength Cond Res* 30, 2016.

139. Talpey SW, Young WB, and Saunders N. The Acute Effects of Conventional, Complex, and Contrast Protocols on Lower-Body Power. *J Strength Cond Res* 28, 2014.

140. Terzis G, Spengos K, Karampatsos G, Manta P, and Georgiadis G. Acute effect of drop jumping on throwing performance. *J strength Cond Res* 23: 2592–2597, 2009.

141. Till KA and Cooke C. The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *J strength Cond Res* 23: 1960–1967, 2009.

142. Tillin NA and Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Med* 39: 147–166, 2009.

143. Tobin DP and Delahunt E. The acute effect of a plyometric stimulus on jump performance in professional rugby players. *J strength Cond Res* 28: 367–372, 2014.

144. Toji H and Kaneko M. Effect of multiple-load training on the force-velocity relationship. *J strength Cond Res* 18: 792–795, 2004.

145. Tricoli V, Lamas L, Carnevale R, and Ugrinowitsch C. Short-term effects on lower-body functional power development: weightlifting vs. vertical jump training programs. *J strength Cond Res* 19: 433–437, 2005.

146. Turki O, Chaouachi A, Drinkwater EJ, Chtara M, Chamari K, Amri M, and Behm DG. Ten minutes of dynamic stretching is sufficient to potentiate vertical jump performance characteristics. *J strength Cond Res* 25: 2453–2463, 2011.

147. Turner AP, Bellhouse S, Kilduff LP, and Russell M. Postactivation Potentiation of Sprint Acceleration Performance Using Plyometric Exercise. *J Strength Cond Res* 29, 2015.

148. Vandenboom R, Grange RW, and Houston ME. Threshold for force potentiation associated with skeletal myosin phosphorylation. *Am J Physiol* 265: C1456-62, 1993.

149. Vandervoort AA, Quinlan J, and McComas AJ. Twitch potentiation after voluntary contraction. *Exp Neurol* 81: 141–152, 1983.

150. Verdijk LB, van Loon L, Meijer K, and Savelberg HHCM. One-repetition maximum strength test represents a valid means to assess leg strength in vivo in humans. *J Sports Sci* 27: 59–68, 2009.

151. Villarreal ES, González-Badillo JJ, and Izquierdo M. Optimal warm-up stimuli of muscle activation to enhance short and long-term acute jumping performance. *Eur J Appl Physiol* 100: 393–401, 2007.

152. Waldron M, Worsfold P, Twist C, and Lamb K. Concurrent validity and test-retest reliability

of a global positioning system (GPS) and timing gates to assess sprint performance variables. *J Sports Sci* 29: 1613–1619, 2011.

153. Weber KR, Brown LE, Coburn JW, and Zinder SM. Acute effects of heavy-load squats on consecutive squat jump performance. *J strength Cond Res* 22: 726–730, 2008.

154. Wilson JM, Duncan NM, Marin PJ, Brown LE, Loenneke JP, Wilson SMC, Jo E, Lowery RP, and Ugrinowitsch C. Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *J strength Cond Res* 27: 854–859, 2013.

155. Winter EM, Abt G, Brookes FBC, Challis JH, Fowler NE, Knudson D V, Knuttgen HG, Kraemer WJ, Lane AM, van Mechelen W, Morton RH, Newton RU, Williams C, and Yeadon MR. Misuse of "Power" and Other Mechanical Terms in Sport and Exercise Science Research. *J strength Cond Res* 30: 292–300, 2016.

156. Winwood PW, Posthumus LR, Cronin JB, and Keogh JWL. The Acute Potentiating Effects of Heavy Sled Pulls on Sprint Performance. *J strength Cond Res* 30: 1248–1254, 2016.

157. Wittekind A, Cooper CE, Elwell CE, Leung TS, and Beneke R. Warm-up effects on muscle oxygenation, metabolism and sprint cycling performance. *Eur J Appl Physiol* 112: 3129–3139, 2012.

158. Yetter M and Moir GL. The acute effects of heavy back and front squats on speed during forty-meter sprint trials. *J strength Cond Res* 22: 159–165, 2008.

159. Young W, Cormack S, and Crichton M. Which jump variables should be used to assess explosive leg muscle function? *Int J Sports Physiol Perform* 6: 51–57, 2011.

160. Young W, Wilson G, and Byrne C. Relationship between strength qualties and performance in standing and run-up vertical jumps. *J Sports Med Phys Fitness* 39: 285–293, 1999.

161. Young WB and Behm DG. Effects of running, static stretching and practice jumps on explosive force production and jumping performance. *J Sports Med Phys Fitness* 43: 21–27, 2003.

162. Young WB and Bilby GE. The Effect of Voluntary Effort to Influence Speed of Contraction on Strength, Muscular Power, and Hypertrophy Development. *J Strength Cond Res* 7, 1993.

163. Young WB, Jenner A, and Griffiths K. Acute Enhancement of Power Performance From Heavy Load Squats. J. Strength Cond. Res. 12: 82–84, 1998.

Appendix A: Ethics Approval

Study 1 & 2

Principal Researcher:	Warren Young
Other/Student Researcher/s:	Mathew O'Grady David Behm
School/Section:	SHS
Project Number:	A13-151
Project Title:	Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance.
For the period:	19/12/2013 **to** 27/11/2015

Please quote the Project No. in all correspondence regarding this application.

<u>REPORTS TO HREC:</u>

<u>An annual report</u> for this project must be submitted to the Ethics Officer on:

19 December 2014

<u>A final report</u> for this project must be submitted to the Ethics Officer on:

27 December 2015

Please note: Any correspondence sent out as of 1 January 2014 needs to have the Federation University logo (see below) and not the University of Ballarat.

Federation UNIVERSITY • AUSTRALIA

<u>Ethics Officer</u>

19 December 2013

CONDITIONS OF APPROVAL

1. The project must be conducted in accordance with the approved application, including any conditions and amendments that have been approved. You must comply with all of the conditions imposed by the HREC, and any subsequent conditions that the HREC may require.

2. You must report immediately anything which might affect ethical acceptance of your project, including:

    - Adverse effects on participants;
    - Significant unforeseen events;
    - Other matters that might affect continued ethical acceptability of the project.

3. Where approval has been given subject to the submission of copies of documents such as letters of support or approvals from third parties, these must be provided to the Ethics Office before the research may commence at each relevant location.

4. Proposed changes or amendments to the research must be applied for, using a 'Request for Amendments' form, and approved by the HREC before these may be implemented.

5. If an extension is required beyond the approved end date of the project, a 'Request for Extension' should be submitted, allowing sufficient time for its consideration by the committee. Extensions cannot be granted retrospectively.

6. If changes are to be made to the project's personnel, a 'Changes to Personnel' form should be submitted for approval.

7. An 'Annual Report' must be provided by the due date specified each year for the project to have continuing approval.

8. A 'Final Report' must be provided at the conclusion of the project.

9. If, for any reason, the project does not proceed or is discontinued, you must advise the committee in writing, using a 'Final Report' form.

10. You must advise the HREC immediately, in writing, if any complaint is made about the conduct of the project.

11. You must notify the Ethics Office of any changes in contact details including address, phone number and email address.

12. The HREC may conduct random audits and / or require additional reports concerning the research project.

Failure to comply with the *National Statement on Ethical Conduct in Human Research* (2007) and with the conditions of approval will result in suspension or withdrawal of approval.

SCHOOL OF HEALTH SCIENCES

PROJECT TITLE:	**Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance**
PRINCIPAL RESEARCHER:	**Associate Professor Warren Young**
OTHER/STUDENT RESEARCHERS:	**Dr David Behm** (dbehm@mun.ca) Mr Mathew O'Grady (m.ogrady@ballarat.edu.au)

I would like to invite you to take part in new research conducted by Mathew O'Grady that is looking at assessing the instant effect that heavy strength activities may have on power activities like jumping, sprinting and throwing, under the supervision of Associate Professor Warren Young and Dr David Behm. The following research has been cleared by the University of Ballarat's Human Research Ethics Committee.

What is Post-activation Potentiation (PAP)?

Post-activation potentiation is a phenomenon where by performing a heavy strength based activity almost instantly improves an individual's performance in power activities. For example, a person may be able to perform heavy squats and with the appropriate rest period be able to jump higher due to the effect of PAP.

What is the purpose of the research?

The purpose of this research is to alter and change how a heavy strength based activity is performed and assess how these changes affect power performance.

What will you need to do in the research project?

You will be asked to attend the Federation University biomechanics lab for a number of sessions that could vary in number from four to ten sessions. These sessions will approximately last for 30 minutes, which means your time commitment may be between 120-300 minutes. For this research project you will need to perform varying warm-ups that include different intensities and durations. You will also be asked to perform five heavy half-squats. You may be instructed to perform these half-squats in different ways. You may be asked to perform them at a controlled speed, or as fast as you possibly can. You may have to perform one set of the half-squats or you may be required to perform up to four sets. After completing these half-squats you will need to complete either a series of jump tests on a force platform, sprint tests over 20 metres or throwing tests at a target sheet where your performance will be assessed. You will perform these sessions in small groups; however, each testing element of the session will be performed away from other participants to maintain confidentiality of your results. Your participation in this research project is completely voluntary and you are free to withdraw from the research at any time that you feel without any explanation or any prejudice from the researchers.

What are the risks involved?

Like with any physical activity, there is the chance that injury could occur. However, the risks involved will be no greater than your regular weight training session that you complete. While performing heavy squats or jumps you may experience mild discomfort associated with the exercise, however, you will take part in appropriate warm-ups to minimise the injury risk. At each testing session a first aid trained person will be available if an injury was to occur. A sports trainer will also be available to assist with any soreness you may have after each session. A qualified strength and conditioning coach will also be at each session to ensure correct and safe technique is used at all times. You will also have the option to wear a weight belt during heavy efforts to decrease the chance of lower back injury. There could be minimal psychological risk associated with the study if your performance is poor during testing. University counsellors will be made available to any participants that feel that they need help and can be contacted on (03) 5327 9470. Participants may also contact Lifeline on 13 11 14.

What happens with the information and data that is obtained in this research project?

All information that you provide or that is collected will be treated with the strictest confidence, subject to legal limitations. Upon beginning this study you will be given a code so that all your data and information will remain anonymous. All data that is collected in hard copy will be kept in a locked cabinet whilst all data that is collected on a computed will be protected by a password. Only the three researchers mentioned in this document will have access to this data. Five years after the completion of the all hard copy documents will be shredded and all computer files will be deleted in order to maintain confidentiality. No identifying information will be used in any publication.

An unequal relationship may be present between the researchers of this study and yourself due to researchers being lecturers or tutors at the University of Ballarat. If an unequal relationship is present other research assistants will be used for your data collection and participation in this study will not affect your university coursework in any way.

At the completion of the study you will have the opportunity to obtain a report with your individual results and group means from the research. A researcher will talk you through these results and explain what they mean.

What happens with the results from the research?

The results of this study will be displayed at conference presentations, published journal articles as well as a PhD thesis. However, all data will be de-identified so that it remains confidential.

What are your rights as a participant?

Participation in this research is completely voluntary and you are free to withdraw at any time throughout the study with no questions asked. It should be noted that it will not be possible to withdraw your data from this study once it has been completed and published.

Any Questions?

If you have any questions regarding the current research or what you will be required to do please feel free to contact Associate Professor Warren Young on (03) 5327 9685 or via email at w.young@ballarat.edu.au. We appreciate your commitment to take part in the following research project and your time will be rewarded.

If you have any questions, or you would like further information regarding the project titled "Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance", please contact the Principal Researcher, Warren Young of the School of Health Sciences:

PH: (03) 5327 9685

EMAIL: w.young@ballarat.edu.au

Should you (i.e. the participant) have any concerns about the ethical conduct of this research project, please contact the University of Ballarat Ethics Officer, Research Services, University of Ballarat, PO Box 663, Mt Helen VIC 3353. Telephone: (03) 5327 9765, Email: ub.ethics@ballarat.edu.au

CRICOS Provider Number 00103D

PROJECT TITLE:	Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance.
RESEARCHERS:	**Dr. Warren Young** **Dr. David Behm** **Mr Mathew O'Grady**

Code number allocate to the participant:	

Consent – Please complete the following information:

I, ... of . . . .
. . . .
hereby consent to participate as a subject in the above research study.

The research program in which I am being asked to participate has been explained fully to me, verbally and in writing, and any matters on which I have sought information have been answered to my satisfaction. I understand that that the testing sessions will require physical activity to some extent and there is a low risk of injury associated with the study.

I understand that: all information I provide will be treated with the strictest confidence, subject to legal limitations, and data will be stored separately from any listing that includes my name and address.

- aggregated results will be used for research purposes and may be reported in scientific and academic journals
- ***I am free to withdraw my consent at any time during the study in which event my participation in the research study will immediately cease and any information obtained from it will not be used.***
- ***once information has been aggregated it is unable to be identified, and from this point it is not possible to withdraw consent to participate***

SIGNATURE: . . . . **DATE**: . . . . . . …….. . . .. …………

Please indicate the type of report	☐ Annual Report **(Omit 3b & 5b)** ☒ Final Report
Project No:	A13-151
Project Name:	Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance.
Principal Researcher:	Associate professor Warren Young
Other Researchers:	Dr. David Behm Mathew O'Grady
Date of Original Approval:	19/12/2013
School / Section:	Faculty of Health
Phone:	0432 544 514
Email:	m.ogrady@federation.edu.au

Please note: For HDR candidates, it is a requirement of candidature to submit Candidature reports annually to research.degrees@federation.edu.au in addition to Ethics Annual/Final reports.

1) Please indicate the current status of the project:				
1a) Yet to start **1b) Continuing** **1c) Data collection completed** **1d) Abandoned / Withdrawn:**				☐ ☐ ☒ ☐
1e) If the approval was subject to certain conditions, have these conditions been met? (If not, please give details in the comments box below)			☒ Yes	☐ No
Comments:				
1f) Data Analysis	☐ Not yet commenced	☐ Proceeding	☒ Complete	☐ None
1g) Have ethical problems been encountered in any of the following areas: **Study Design**				

Recruitment of Subjects **Finance** **Facilities, Equipment** **(If yes, please give details in the comments box below)**	☐ Yes ☐ Yes ☐ Yes ☐ Yes	☒ No ☒ No ☒ No ☒ No
Comments:		

2a) Have amendments been made to the originally approved project?	
☒ No	☐ Yes
2b) If yes, was HREC approval granted for these changes?	
☐ Yes	**Provide detail:** ☐ Yes **Application for Amendment to an Existing Project** ☐ Yes **Change of Personnel** ☐ Yes **Extension Request**
☐ No	**If you have made changes, but not had HREC approval, provide detail as to why this has not yet occurred:**
2c) Do you need to submit any amendments now?	
☒ No	☐ Yes **Application for Amendment to an Existing Project** ☐ Yes **Change of Personnel** ☐ Yes **Extension Request** *** NB: If 'Yes', download & submit the appropriate request to the HREC for approval:** **Please note: Extensions will not be granted retrospectively. Apply well prior to the project end date, to ensure continuity of HRE approval.**

3a) Please indicate where you are storing the data collected during the course of this project: (Australian code for the Responsible conduct of Research Ch 2.2.2, 2.5 – 2.7)
All paper data is stored in a locked cabinet and computer data is protected via password.
3b) Final Reports: Advise when & how stored data will be destroyed (Australian code for the Responsible conduct of Research Ch 2.1.1)
All data documents will be shredded and computer data deleted as of December 1st 2020.

4) Have there been any events that might have had an adverse effect on the research

participants OR unforeseen events that might affect continued ethical acceptability of the project?

☒ No	☐ Yes *** NB: If 'yes', please provide details in the comments box below:**
Comments:	

5a) Please provide a short summary of results of the project so far (no attachments please):
Each individuals optimum warm-up was identified during the study. By adding the half-squat CA to an optimum warm-up, CMJ height significantly increased above pre-jumping levels. Despite this change in jump height, no other variable of the CMJ displayed any significant improvement. In terms of maximising the squatting speed during the CA, no particular CA produced any change in post-CMJ performance.
5b) Final Reports: Provide details about how the aims of the project, as stated in the application for approval, were achieved (or not achieved). (Australian code for the Responsible conduct of Research 4.4.1)
Study 1: Identified a warm-up volumes was best for most participants. Identified that a heavy squatting CA could potentiate post-CMJ height. **Study 2:** Explained the major differences between the fast and controlled squatting techniques. Neither CA method potentiated post-CMJ performance.

6) Publications: Provide details of research dissemination outcomes for the previous year resulting from this project: eg: Community seminars; Conference attendance; Government reports and/or research publications
Presented a poster titled "A biomechanical comparison of controlled and explosive back squats" at the ASCA conference, Melbourne, 2014.

7) The HREC welcomes any feedback on: • **Difficulties experienced with carrying out the research project; or** • **Appropriate suggestions which might lead to improvements in ethical clearance and monitoring of research.**

8) Signatures			
Principal Researcher:	………………………………….. Print name:	**Date:**	
Other/Student Researchers:	………………………………….. Print name:	**Date:**	
	………………………………….. Print name:	**Date:**	

Submit to the Ethics Officer, Gippsland or Mt Helen campus, by the due date:
research.ethics@federation.edu.au

Appendix B: Ethics Approval

Study 3 and 4

Principal Researcher:	Warren Young
Other/Student Researcher/s:	Mathew O'Grady David Behn
School/Section:	**FHS**
Project Number:	**A14-103**
Project Title:	**Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance.**
For the period:	22/08/2014 **to** 27/11/2015

Please quote the Project No A14-103 in all correspondence regarding this application.

Amendment Detail: Two separate fitness testing sessions added to the project.

Extension Date: N/A

REPORTS TO HREC:

An annual report for this project must be submitted to the Ethics Officer on:

22 August 2015

A final report for this project must be submitted to the Ethics Officer on:

27 December 2015

These report forms can be found at:

http://federation.edu.au/research-and-innovation/research-support/ethics/human-ethics/human-ethics3

Fiona Koop

Ethics Officer

23 April 2015

CONDITIONS OF APPROVAL

1. The project must be conducted in accordance with the approved application, including any conditions and amendments that have been approved. You must comply with all of the conditions imposed by the HREC, and any subsequent conditions that the HREC may require.

2. You must report immediately anything which might affect ethical acceptance of your project, including:

    - Adverse effects on participants;
    - Significant unforeseen events;
    - Other matters that might affect continued ethical acceptability of the project.

3. Where approval has been given subject to the submission of copies of documents such as letters of support or approvals from third parties, these must be provided to the Ethics Office before the research may commence at each relevant location.

4. Proposed changes or amendments to the research must be applied for, using a 'Request for Amendments' form, and approved by the HREC before these may be implemented.

5. If an extension is required beyond the approved end date of the project, a 'Request for Extension' should be submitted, allowing sufficient time for its consideration by the committee. Extensions cannot be granted retrospectively.

6. If changes are to be made to the project's personnel, a 'Changes to Personnel' form should be submitted for approval.

7. An 'Annual Report' must be provided by the due date specified each year for the project to have continuing approval.

8. A 'Final Report' must be provided at the conclusion of the project.

9. If, for any reason, the project does not proceed or is discontinued, you must advise the committee in writing, using a 'Final Report' form.

10. You must advise the HREC immediately, in writing, if any complaint is made about the conduct of the project.

11. You must notify the Ethics Office of any changes in contact details including address, phone number and email address.

12. The HREC may conduct random audits and / or require additional reports concerning the research project.

Failure to comply with the *National Statement on Ethical Conduct in Human Research* (2007) and with the conditions of approval will result in suspension or withdrawal of approval.

Faculty of Health

PROJECT TITLE:	**Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance**
PRINCIPAL RESEARCHER:	**Associate Professor Warren Young** Office: P905 Phone: (03) 5327 9685
OTHER/STUDENT RESEARCHERS:	**Dr David Behm** (dbehm@mun.ca) Mr Mathew O'Grady **(m.ogrady@federation.edu.au)**

I would like to invite you to take part in new research conducted by Mathew O'Grady that is looking at assessing the instant effect that heavy strength activities may have on power activities like jumping, sprinting and throwing, under the supervision of Associate Professor Warren Young and Dr David Behm. The following research has been cleared by the Federation University Human Research Ethics Committee.

What is Post-activation Potentiation (PAP)?

Post-activation potentiation is a phenomenon where by performing a heavy strength based activity almost instantly improves an individual's performance in power activities. For example, a person may be able to perform heavy squats and with the appropriate rest period be able to jump higher due to the effect of PAP.

What is the purpose of the research?

The purpose of this research is to alter and change how a heavy strength based or plyometric activities are performed to assess how these changes affect power performance.

What will you need to do in the research project?

You will be asked to attend the Federation University biomechanics lab for approximately eight sessions. These sessions will approximately last for 30 minutes, which means your time commitment may be 240 minutes. For this research project you will firstly perform two days of fitness testing, which involve aerobic endurance, strength, strength-endurance and power tests. After completing the fitness testing sessions, you will be asked to perform varying warm-ups that include different intensities and durations of jogging, stretching and jumping. You will also be asked to perform five heavy half-squats. You may be instructed to perform these half-squats in different ways. You may be asked to perform them at a controlled speed, or as fast as you possibly can. You may have to perform one set of the half-squats or you may be asked to perform up to four sets of 10 continuous jumps instead. After completing these half-squats or jumps, you will be asked to complete a series of jump tests on a force platform as well as a 20 metre sprint test. You will perform testing sessions in an allocated timeslot by yourself to maintain confidentiality of your results. Your participation in this research project is completely voluntary and you are free to withdraw from the research at any time that you feel without any explanation or any prejudice from the researchers.

What are the risks involved?

Like with any physical activity, there is the chance that injury could occur. However, the risks involved will be no greater than your regular weight training session that you complete. While performing heavy squats or jumps you may experience mild discomfort associated with the exercise, however, you will take part in appropriate warm-ups to minimise the injury risk. At each testing session a first aid trained person will be available if an injury was to occur. A sports trainer will also be available to assist with any soreness you may have after each session. A qualified strength and conditioning coach will also be at each session to ensure correct and safe technique is used at all times. You will also have the option to wear a weight belt during heavy efforts to decrease the chance of lower back injury. There could be minimal psychological risk associated with the study if your performance is poor during testing. University counsellors will be made available to any participants that feel that they need help and can be contacted on (03) 5327 9470. Participants may also contact Lifeline on 13 11 14.

What happens with the information and data that is obtained in this research project?

All information that you provide or that is collected will be treated with the strictest confidence, subject to legal limitations. Upon beginning this study you will be given a code so that all your data and information will remain anonymous. All data that is collected in hard copy will be kept in a locked cabinet whilst all data that is collected on a computed will be protected by a password. Only the three researchers mentioned in this document will have access to this data. Five years after the completion of the all hard copy documents will be shredded and all computer files will be deleted in order to maintain confidentiality. No identifying information will be used in any publication.

An unequal relationship may be present between the researchers of this study and yourself due to researchers being lecturers or tutors at the University of Ballarat. If an unequal relationship is present other research assistants will be used for your data collection and participation in this study will not affect your university coursework in any way.

At the completion of the study you will have the opportunity to obtain a report with your individual results and group means from the research. A researcher will talk you through these results and explain what they mean.

What happens with the results from the research?

The results of this study will be displayed at conference presentations, published journal articles as well as a PhD thesis. However, all data will be de-identified so that it remains confidential.

What are your rights as a participant?

Participation in this research is completely voluntary and you are free to withdraw at any time throughout the study with no questions asked. It should be noted that it will not be possible to withdraw your data from this study once it has been completed and published.

Any Questions?

If you have any questions regarding the current research or what you will be required to do please feel free to contact Associate Professor Warren Young on (03) 5327 9685 or via email at w.young@federation.edu.au. We appreciate your commitment to take part in the following research project and your time will be rewarded.

If you have any questions, or you would like further information regarding the project titled, Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance please contact the Principal Researcher, Warren Young of the Faculty of Health.

PH: (03) 5327 9685

EMAIL: w.young@federation.edu.au

Should you (i.e. the participant) have any concerns about the ethical conduct of this research project, please contact the Federation University Ethics Officer, Research Services, Federation University Australia, PO Box 663, Mt Helen VIC 3353. Telephone: (03) 5327 9765, Email: research.ethics@federation.edu.au

CRICOS Provider number 00103D

PROJECT TITLE:	Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance.
RESEARCHERS:	**Dr. Warren Young** **Dr. David Behm** **Mr Mathew O'Grady**

Code number allocated to the participant:	

Consent – Please complete the following information:

I, ... of . . . .

. . . .

hereby consent to participate as a subject in the above research study.

The research program in which I am being asked to participate has been explained fully to me, verbally and in writing, and any matters on which I have sought information have been answered to my satisfaction. I understand that that the testing sessions will require physical activity and testing; including a 20-metre shuttle run test, strength-endurance tests, weighted squats, jumping and sprinting that may be associated to a low injury risk. I understand that safety precautions will be put in place to minimise this risk and an individual trained in first aid will be at all sessions.

I understand that: all information I provide will be treated with the strictest confidence,

subject to legal limitations, and data will be stored separately from any listing that includes my

name and address.

- aggregated results will be used for research purposes and may be reported in scientific and academic journals
- I am free to withdraw my consent at any time during the study in which event my participation in the research study will immediately cease and any information obtained from it will not be used.
- once information has been aggregated it is unable to be identified, and from this point it is not possible to withdraw consent to participate

SIGNATURE: . . . . **DATE**: . . . . . . …….. . . ..

Please indicate the type of report	☐ Annual Report **(Omit 3b & 5b)** ☒ Final Report
Project No:	A14-103
Project Name:	Manipulating the conditioning stimulus to enhance potentiation and its application to jumping, sprinting and throwing performance.
Principal Researcher:	Associate professor Warren Young
Other Researchers:	Dr. David Behm Mathew O'Grady
Date of Original Approval:	22/08/14
School / Section:	Faculty of Health
Phone:	0432 544 514
Email:	m.ogrady@federation.edu.au

Please note: For HDR candidates, it is a requirement of candidature to submit Candidature reports annually to research.degrees@federation.edu.au in addition to Ethics Annual/Final reports.

1) Please indicate the current status of the project:				
1a) Yet to start **1b) Continuing** **1c) Data collection completed** **1d) Abandoned / Withdrawn:**				☐ ☐ ☒ ☐
1e) If the approval was subject to certain conditions, have these conditions been met? (If not, please give details in the comments box below)			☒ Yes	☐ No
Comments:				
1f) Data Analysis	☐ Not yet commenced	☐ Proceeding	☒ Complete	☐ None
1g) Have ethical problems been encountered in any of the following areas: **Study Design**				

Recruitment of Subjects **Finance** **Facilities, Equipment** **(If yes, please give details in the comments box below)**	☐ Yes ☐ Yes ☐ Yes ☐ Yes	☒ No ☒ No ☒ No ☒ No
Comments:		

2a) Have amendments been made to the originally approved project?	
☐ No	☒ Yes
2b) If yes, was HREC approval granted for these changes?	
☒ Yes	**Provide detail:** ☒ Yes **Application for Amendment to an Existing Project** ☐ Yes **Change of Personnel** ☐ Yes **Extension Request**
☐ No	**If you have made changes, but not had HREC approval, provide detail as to why this has not yet occurred:**
2c) Do you need to submit any amendments now?	
☒ No	☐ Yes **Application for Amendment to an Existing Project** ☐ Yes **Change of Personnel** ☐ Yes **Extension Request** *** NB: If 'Yes', download & submit the appropriate request to the HREC for approval:** **Please note: Extensions will not be granted retrospectively. Apply well prior to the project end date, to ensure continuity of HRE approval.**

3a) Please indicate where you are storing the data collected during the course of this project: (Australian code for the Responsible conduct of Research Ch 2.2.2, 2.5 – 2.7)
All paper data is stored in a locked cabinet and computer data is protected via password.
3b) Final Reports: Advise when & how stored data will be destroyed (Australian code for the Responsible conduct of Research Ch 2.1.1)
All data documents will be shredded and computer data deleted as of December 1st 2020.

4) Have there been any events that might have had an adverse effect on the research

participants OR unforeseen events that might affect continued ethical acceptability of the project?

☒ No	☐ Yes *** NB: If 'yes', please provide details in the comments box below:**
Comments:	

5a) Please provide a short summary of results of the project so far (no attachments please):
Originally, no significant improvements in CMJ or sprinting performance were identified after any particular CA. However, once participant strength was considered, the stronger participants significantly improved post-CMJ performance (significantly improved jump height, relative peak power and peak force)after the performance of the heavy dynamic CAs.
5b) Final Reports: Provide details about how the aims of the project, as stated in the application for approval, were achieved (or not achieved). **(Australian code for the Responsible conduct of Research 4.4.1)**
No specific amount of rebound jumps were identified as the best method to elicit a potentiating response. After all conditions, no plyometric CAs significantly improved either CMJ or sprinting performance. Participant absolute strength correlated positively with the change in post-CMJ scores, suggesting this fitness component improves an individual's likelihood to produce a potentiating response.

6) Publications: Provide details of research dissemination outcomes for the previous year resulting from this project: eg: Community seminars; Conference attendance; Government reports and/or research publications
Poster presentation title "A comparison of Smith machine & barbell half-squats to elicit potentiation in countermovement jump performance " at the 2015 ASCA conference, Gold Coast.

7) The HREC welcomes any feedback on: • **Difficulties experienced with carrying out the research project; or** • **Appropriate suggestions which might lead to improvements in ethical clearance and monitoring of research.**

8) Signatures			
Principal Researcher:	…………………………………….. Print name:	**Date:**	
Other/Student Researchers:	…………………………………….. Print name:	**Date:**	
	…………………………………….. Print name:	**Date:**	

Submit to the Ethics Officer, Gippsland or Mt Helen campus, by the due date:
research.ethics@federation.edu.au