

# **Magnitude of Postactivation Potentiation Response in Elite Rowers**

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## ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.



Ryan Turfrey

Date: 23.07.2014

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## **ETHICAL APPROVAL**

Ethical approval for the commencement of participant involvement for this research was granted by the Auckland University of Technology Ethics Committee (AUTEK). Ethics Application Number: 13/293. Date of approval: 29 October 2013.

## ABSTRACT

Postactivation Potentiation (PAP) has been proposed as a means by which to achieve greater physiological and mechanical power through the manipulation of previous contractile work. However, there is a lack of applied PAP studies conducted with elite, Olympic level athletes, particularly using endurance-trained populations. Whilst the proposed mechanisms responsible for PAP are increasingly complex, and further mediated according to the properties of the conditioning stimulus, it appears that PAP effects are greatest amongst highly-trained strength and power subjects. Highly endurance-trained elite rowers, a sport that necessitates superior levels of developed strength, power and muscular endurance, presented a unique opportunity to examine PAP in an applied setting within a specialised population. Therefore the primary aim of this thesis was to examine the magnitude of change in PAP in an elite endurance population.

A repeated measures crossover design (3-sets of 3-repetitions of back squat at 80% of 1RM, 5-minutes rest) was utilised in order to examine the PAP response, measured via countermovement jump (CMJ) performance, to the experimental condition. Nineteen elite level male rowing athletes from the Rowing New Zealand Summer squad volunteered to participate in the study.

The magnitude of observed changes in PAP ranged from unclear to small (positive). Specifically, small increases in mean power (W) (+5.7%, effect size (ES) = 0.36, 90%CI 0.13-0.59,  $p=0.01$ ) and mean velocity ( $\text{m}\cdot\text{s}^{-1}$ ) (+3.3%, ES=0.39, 90%CI 0.11-0.67,  $p=0.03$ ) were observed. Unclear responses were observed for peak power (W), peak velocity ( $\text{m}\cdot\text{s}^{-1}$ ), mean and peak force (N), rate of force development (RFD) ( $\text{N}\cdot\text{s}^{-1}$ ) and jump height (cm). Furthermore, and in keeping with findings of other

studies, responses exhibited a high level of individual variation. Test-retest reliability and measurement precision of the observed variables were strong ( $ICC \geq 0.78$ ,  $CV \leq 6.5\%$ ).

These results establish the ability of highly trained endurance athletes to engender small PAP responses to the given experimental condition. The study was unable to determine which physiological mechanisms were responsible for the observed PAP response. The magnitude of PAP response to differing conditioning stimuli, and the relevance of these findings to practical applications, requires further consideration. Whilst the results may have potential implications for the use of varying training methods and monitoring of fatigue, further research is required to greater understand the effect of variable manipulation in this specific population.

## CHAPTER 1 – INTRODUCTION

### 1.1 BACKGROUND TO THE PROBLEM

Postactivation Potentiation (PAP) is a physiological phenomenon characterised by an acute enhancement of muscular power production and, potentially performance, in response to a pre-load conditioning activity (Chiu, Fry, Weiss, Schilling, Brown & Smith, 2003). This acute enhancement is thought to result from a multitude of contributing factors including the traditionally proposed phosphorylation of myosin regulatory light chains and increased recruitment of high order motor units (Tillin & Bishop, 2009). However, the apparent complexity surrounding potential and often interrelated causative factors has led to an increasingly enhanced scope in proposed physiological mechanisms. Accordingly, increasing research interest has focused on identifying the methods involved in eliciting an optimal PAP response as a means of impacting positively on performance measures (Baker, 2003; Brandenburg, 2005; Chiu et al., 2003; Farup & Sorensen, 2010; Hrysomallis & Kidgell, 2001; Jensen & Ebben, 2003; Jo, Judelson, Brown, Coburn & Dabbs, 2010; Smith, Hannon, McGladrey, Shultz, Eisenman & Lyons, 2014; Tillin & Bishop, 2009; Weber, Brown, Coburn & Zinder, 2008; Yetter & Moir, 2008; Young, Jenner & Griffiths, 1998). Recent research suggests that the PAP response is both highly individual and specific to the population group examined (Wilson et al. 2013). Furthermore, consideration must be given by sports science and strength and conditioning practitioners as to the appropriate context within which any observed PAP response should be used (Nibali, Chapman, Robergs & Drinkwater, 2013).

The efficacy of methods used to elicit any PAP response is determined by the product of the relationship between potentiation and fatigue (Tillin & Bishop, 2009). Several factors modulate the magnitude of a given PAP response to a pre-load;

training age or experience, the rest periods allowed as well as the volume and the relative intensity of the stimulus prescribed (Kilduff, Owen, Bevan, Bennett, Kingsley & Cunningham, 2008; Sale, 2002). For example, in a comparative study examining the percentage change in vertical and drop jump height following 5 sets of 1 repetition back squat at 90% of a given participants one repetition max (1RM), trained participants exhibited a 1-3% increase in jump performance whereas previously untrained participants showed a 1-4% decrement (Chiu et al., 2003). Similarly, the magnitude of PAP response appears to be linked to an individual's absolute force development capability (Tillin & Bishop, 2009).

A recent and extensive meta-analysis of the identified factors that modulate PAP responses attempted to identify broadly the magnitude effects of these influencing constraints on the phenomenon (Wilson et al., 2013). PAP effects were determined from 32 studies with respect to the influence of type of conditioning activity, relative intensity, volume, gender, rest periods and training status on power augmentation (Wilson et al., 2013). Overall, moderate performance gains in muscle power (ES=0.38) were observed using a conditioning stimulus (Wilson et al., 2013). With regards to relative intensity of pre-load activity, greater benefits were observed from moderate (60-84% 1RM, ES=1.06), than heavy pre-loads (>85% 1RM, ES=0.31) (Wilson et al., 2013). Additionally, multiple set pre-loads (ES=0.66) had a significant overall difference over a single set pre-load (ES=0.24), whilst rest periods of 7-10min (ES=0.71) produced a greater ES than both shorter (3-7min, ES=0.54) and lengthier (<10min, ES=0.02) rest periods (Wilson et al., 2013). Whilst training experience was seen to increase the ES of power augmentation, the magnitude was not significantly different between male and female populations (Wilson et al., 2013). Furthermore, the type of conditioning activity, as differentiated by dynamic and static

or isometric pre-load activities, showed no significant differences between the two (Wilson et al., 2013).

However, whilst such analysis helps to increase an overall appreciation of the magnitude of pre-load variable influence on PAP response, the current body of literature presents varying and often conflicting results. The magnitude of influence these factors had on PAP responses were mediated by training status, possibly accounting for the discrepancies in literature to date (Wilson et al., 2013). Through the meta-analysis, lesser experienced subjects demonstrated a lower ES increment in power augmentation compared to higher experienced participants irrespective of rest period allowed (Wilson et al., 2013). Furthermore, more experienced strength athletes were observed to attain peak power following performance of a conditioning stimulus more quickly than those lesser experienced.

Whilst these findings support the highly individualised responses to PAP, and the further need for individualisation of methods used to elicit them, little research has been conducted in this area using elite athletes and performance of functional tasks (Bevan, Cunningham, Tooley, Owen, Cook & Kilduff, 2010; Kilduff, Cunningham, Owen, West, Bracken & Cook, 2011). Furthermore, to the knowledge of this author only one study has examined the effects of a PAP protocol in an elite, endurance-trained population (Feros, Young, Rice & Talpey, 2012). Interestingly, this study showed average power over a 1000-m rowing time trial can be increased from PAP in endurance trained elite rowers (Feros et al., 2012). However, the lack of research studies with endurance-trained athletes mean that gaps still exist for practitioners who wish to use these findings within an applied context.

## 1.2 PURPOSE STATEMENT

The purpose of this thesis was to: 1) explore the magnitude of PAP response in elite rowers to a given stimulus; 2) explore how any evoked response may be used within an applied context.

## 1.3 SIGNIFICANCE OF THE RESEARCH

Overall, research utilising elite level athletes is rare. This study recruited a population of elite rowers who had represented New Zealand at various international regattas and achieved high levels of performance at pinnacle events (i.e. World Cup and World Rowing Championships, 2013).

This thesis examined an area of research concerned with the acute improvement of physiological performance (PAP) and, as such, holds considerable significance to this population as a means of potentially enhancing both training and competitive environments. However, the current body of literature is predominantly concerned with the improvement of populations more traditionally associated with power sports (i.e. sprinting, throwing, and jumping). Furthermore, due to the constraints of recruiting elite level athletes, the quality of participants utilised in studies are often untrained or sub-elite, recreation based or, at best, sub-elite populations.

Subsequently, this thesis presented a significant opportunity to examine the potential suitability of PAP protocols within an elite endurance sporting population. Such examination may allow the provision of practical applications that can be utilised to enhance the training and performance environments by which elite athletes perform.



#### 1.4 THESIS FORMAT

This thesis fulfils the AUT University Master of Sport and Exercise Guidelines by conducting an applied research investigation in a relevant area. This thesis critiques previous literature relevant to the topic and provides experimental application to the growing body of knowledge.

This thesis is presented as a singular piece of work, divided into appropriate chapters. The second chapter consists of a systematic review of the current academic literature regarding PAP incorporating: the currently accepted physiological responses to contractile work; the mechanisms for, and the characteristics of, PAP; their relevance to sports performance; and, the influence of conditioning stimulus upon PAP response. Following this, the remainder of the thesis is presented in the traditional format, inclusive of methodology, results, discussion and summary, practical applications and future recommendations.

## **CHAPTER 2 - LITERATURE REVIEW**

### **2.1 INTRODUCTION**

PAP refers to a phenomenon where muscular performance is acutely enhanced as a result of previous contractile events (Tillin & Bishop, 2009). PAP is analogous to post-tetanic potentiation (PTP), differing only in the type of preceding muscle contraction; PAP is induced after a voluntary muscle contraction whereas a post-tetanic potentiation is induced after an involuntary contraction (Tillin & Bishop, 2009). For simplicity, this review will refer to all potentiation as PAP. Initially, an examination of the physiological responses to contractile history will be discussed, followed by a review of the proposed mechanisms that underpin the potentiation phenomenon. Thereafter, the impact or magnitude of change associated with acute PAP responses will be examined with context to improving athletic performance. Throughout, examination of relevant studies involving the use of elite level athletes will be considered.

### **2.2 PHYSIOLOGICAL RESPONSE TO CONTRACTILE EVENTS**

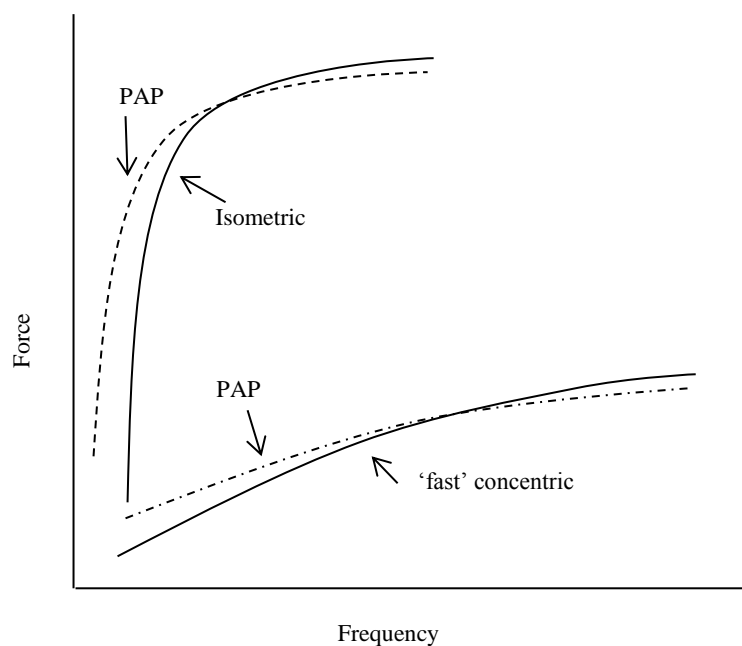
The resultant physiological state, and its expression, following any previous contractile performance are ultimately dependent upon the balance between muscle fatigue and potentiation (Tillin & Bishop, 2009). This balance remains in constant flux, influenced by a number of physiological responses such that to observe any improvement in performance, fatigue must dissipate more quickly than PAP decays (Nibali et al., 2013).

Fatigue can be broadly defined as any acute decrement in observed muscle force or power in response to muscular contractile work (Rassier & Macintosh, 2000). Research studies have identified multiple mechanisms of fatigue, both central and

peripheral. These include, but are not limited to: a reduction in  $\text{Ca}^{2+}$  release from the sarcoplasmic reticulum; a reduced sensitivity of the myofibrillar elements to  $\text{Ca}^{2+}$ , and a decrement in the neural drive to evoked motor units (Sale, 2002; Westerblad, Lee, Lannergren & Allen, 1991). It also appears that the mechanism of fatigue is specific to the stress applied and includes the type of contractions performed, and the relative magnitude of both duration and intensity of the stimulus (Chiu, Fry, Schilling, Johnson & Weiss, 2004; Enoka & Duchateau, 2008). An intriguing counterpoint to mechanisms causing fatigue, previous muscle contraction activity also appears to enhance the acute production of force (Sale, 2002). Similar to measures of fatigue, the magnitude of a PAP response is specific to the type, duration and intensity of stimulus (Wilson et al., 2013).

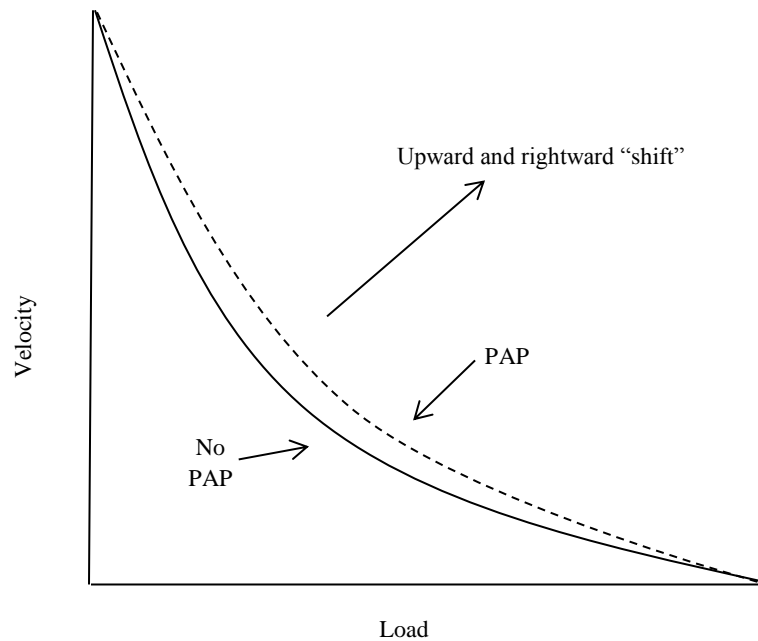
With respect to fatiguing muscular endurance performance, characterised by repeated submaximal contractions, recruited motor units discharge at relatively low rates. The force output of individual motor units may be increased through PAP, by delaying or attenuating the concomitant onset of fatigue caused by the impairment of the neural drive to motoneurons, peripheral neuromuscular nerve transmissions, neuromuscular endpoint action potentials or excitation-contraction myofibrillar couplings (Sale, 2002). Of greatest effect, the impairment of excitation-contraction coupling leads to low-frequency fatigue (LFF), where a disproportionate loss in low-frequency force production is observed. However this decreased level of force production can be compensated by PAP, where a conversely disproportionate increase in low-frequency force is observed, resulting in either an increase in force to contrast LFF or a decrement in motor unit firing rates, reducing the number of nerve impulses and action potentials required for myofibril contraction per unit time (Sale, 2002).

When considering explosive performance fatigue, characterised by a significantly greater systemic metabolic impact such as the loss of adenosine triphosphate-phosphocreatine (ATP-PC) reserves and a decline in muscle force at faster firing rates, PAP appears to play a negligible or even negative role, as shown in Figure 2.1 (Sale, 2002). Regardless of whether the contraction is isometric or concentric, it seems at maximal firing rates that PAP cannot positively impact upon peak force production.



*Figure 2.1.* Effect of contraction type on the force-frequency relation and range of frequency over which Postactivation Potentiation extends. Modified from Sale, 2002.

Furthermore, PAP does not appear to elicit an increase in the maximum resisted shortening velocity ( $V_{\max}$ ) (Gossen & Sale, 2000). Resultantly, in relation to the force-velocity relationship, it appears that PAP cannot impact positively at both extremes of the spectrum (Figure 2.2).



*Figure 2.2.* Effect of Postactivation Potentiation on the load (force)-velocity relationship. Modified from Sale, 2002.

However, PAP has been observed to elicit a positive effect on the RFD at contraction frequencies where peak force was not observed to have improved, and with a range of loads between that of peak isometric force and  $V_{\max}$  (Abbate, Sargeant, Verdijk & de Haan, 2000; Vandenboom, Grange & Houston, 1993). In turn, this creates an upward right shift of the force-velocity curve as seen in Figure 2.2, having potentially beneficial implications for movements such as throwing and jumping (Sale, 2002).

### 2.3 PHYSIOLOGICAL UNDERPINNINGS OF POTENTIATION

The physiological manifestation of both muscle fatigue and potentiation is present to varying degrees following contractile work and as noted earlier, is specific to the stressing stimulus. These mechanisms of fatigue occur both centrally, such as through the depression of central neural drive, and peripherally at the muscle fibre; the site of fatigue ultimately occurring at a cross-bridge level through disruption to the

interplay of free  $\text{Ca}^{2+}$  concentration and sensitivity (Sale, 2002; Westerblad et al., 1991). As the counterpoint to fatigue, potentiation can similarly occur in response to mechanistic changes achieved both centrally and peripherally (Tillin & Bishop, 2009). However, given numerous central and peripheral physiological systems both responsible for, and influenced by, previous contractile work, it is not surprising that the accepted mechanisms that contribute to PAP grow more complex with further investigation.

### 2.3.1 PHYSIOLOGICAL MECHANISMS

Traditionally, the prevailing theory on the mechanistic causes of potentiation has focussed upon the phosphorylation of myosin regulatory light chains (RLC) and increased recruitment of higher order motor units (Tillin & Bishop, 2009). Increasingly however, the accepted scope of what may influence the magnitude of potentiation is expanding, better reflecting the complex and multifactorial nature of physiological responses to a conditioning stimulus.

The phosphorylation of myosin RLC via the enzyme myosin light chain kinase (MLCK) has long been proposed as one of the primary mechanisms of PAP, theoretically resulting in the action-myosin interaction being increasingly sensitive to  $\text{Ca}^{2+}$  released via the sarcoplasmic reticulum (Sweeney, Bowman & Stull, 1993). Specifically, a myosin molecule is composed of two heavy chains (a hexamer). The two terminal myosin heads each contain two RLC, in turn each possessing a specific binding site for a phosphate molecule (Szczesna, Zhao, Jones, Zhi, Stull & Potter, 2002; Vandenoorn et al., 1993). Early mammalian studies first established the process whereby, during muscular contraction,  $\text{Ca}^{2+}$  molecules released via the sarcoplasmic reticulum bind with the calcium regulatory protein (calmodulin), in turn

activating MLCK (Manning & Stull, 1982; Moore & Stull, 1984). The resultant phosphorylation of the RLC is believed to modulate subsequent force production by movement of the myosin head nearer to its hinge position with the opposing actin binding site (Manning & Stull, 1982). This ensures more ATP is available, increasing the potential rate at which cross-bridges can move to a force producing state (Vandenboom et al., 1993; Sweeney et al., 1993).

The process of RLC phosphorylation increases the sensitivity of actin-myosin regulated ATPase to myoplasmic levels of  $\text{Ca}^{2+}$ , as opposed to non-phosphorylated RLC (Szczesna et al., 2002). In that study, rabbit myosin filaments depleted of their endogenous RLC stores, when reconstituted with MLCK phosphorylated exogenous RLC, increased the sensitivity of the actin-myosin activity to  $\text{Ca}^{2+}$ . This resulted in a greater level of activation being observed when compared to that of non-phosphorylated RLC (Szczesna et al., 2002).

Of relevance to PAP, an increased sensitivity to  $\text{Ca}^{2+}$  appears to have greatest influence upon force production when myoplasmic  $\text{Ca}^{2+}$  levels are already relatively low, such as during singular twitch contractions evoked via electromyography (Vandenboom et al., 1993, Szczesna et al., 2002). This is noteworthy as, in conditions of high  $\text{Ca}^{2+}$  saturation, such that occur during high frequency tetanic contractions, there appears to be no change in observed force output as supported through the nature of the force-frequency relationship (Manning & Stull 1982; Moore & Stull, 1984; Sale, 2002; Szczesna et al., 2002; Vandenboom et al., 1993).

The relevance of RLC phosphorylation in human skeletal muscle to potentiation remains ambiguous. Methodological and fibre type distribution

differences between mammalian and human muscles are attributed to these conflicting or inconsistent findings on the significance of RLC phosphorylation (Tillin & Bishop, 2009). A study by Stuart, Lingley, Grange and Houston (1988) reported that an elevated level of vastus lateralis RLC phosphate content and potentiation of knee extensor potentiation were present following a single 10-second isometric MVC in human participants. A positive but non-significant relationship between these two findings was observed, as was a relationship between the level of potentiation and fast twitch muscle fibre content (Stuart et al., 1988). A more recent study failed to show any significant change in potentiation and RLC phosphorylation following a similar 10-second isometric MVC (Smith & Fry, 2007).

For any single neural fibre, numerous synapses link onto each  $\alpha$ -motoneuron (Tillin & Bishop, 2009). Muscular activation occurs via an 'all-or-none' principle whereby any pre-synaptic transmitter release must be met with reciprocal post-synaptic receptor acceptance (Tillin & Bishop, 2009). In response to the body's autonomously protected activation reserve, failure of transmissions at these junctions for either normal reflex or voluntary response is not an uncommon occurrence (Luscher, Ruenzel & Henneman, 1983; Hirst, Redman & Wong, 1981). Importantly, it appears that the degree to which this failure prevails can be reduced through the utilisation of a conditioning stimulus (Luscher et al., 1983).

Early animal studies have shown that transmittance of action potentials across the synapse may be improved by electrical stimulation, providing evidence of a neurogenic contribution to PAP. For example, following the stimulation of feline afferent neural fibres, an observed 54% increase in excitatory post-synaptic potentials (EPSPs) for the same pre-synaptic stimulus was recorded (Hirst et al., 1981). This



increased post-synaptic potential represents a greater depolarisation at the  $\alpha$ -motoneuron membrane, increasing the likelihood of a motor unit reaching the required threshold to instigate muscle contraction (Hirst et al., 1981). Luscher et al. (1983) also examined post-synaptic potential response in cats, reporting a strong correlation ( $r=0.77$ ) between the prevalence of transmitter failure and the size of the motoneuron, with those responsible for the activation of higher order fast twitch motor units more greatly affected. In addition, a very strong negative correlation ( $r=-0.92$ ) between the magnitude of post-synaptic potential potentiation and input resistance was observed. These authors suggested that the greater the stimulus, the greater the depolarisation of the  $\alpha$ -motoneuron membrane, leading to lower thresholds required to initiate muscular contraction (Luscher et al., 1983). If through the use of a pre-load conditioning activity one could elicit an increase in higher order unit recruitment, then the concomitant increase in fast twitch fibre contribution to muscular work may be able to enhance functional physical performance (Gullich & Schmidtbleicher, 1996).

An electrically evoked conditioning stimulus has been shown to increase the level of post-synaptic potentials in human subjects. In response to stimulation of the tibial nerve (5x5-second isometric MVCs), an increased level (20%) of synaptic excitation was observed between 5- and 13-minutes following MVC (Gullich & Schmidtbleicher, 1996). As a result, for the same pre-synaptic potential during subsequent activity, an increase in post-synaptic potentials was observed, suggesting at a decreased number of action potentials failing to cross the synapse (Gullich & Schmidtbleicher, 1996). Studies have examined the potential mechanisms behind this elevated transmittance of action potentials across synaptic junctions at the spinal cord. It has been proposed that these may include both the quantity and efficiency of

neurotransmitters released, and a reduction in the axonal branch-point failure (Luscher et al., 1983; Hirst et al., 1981; Tillin & Bishop, 2009).

Greater synchronisation of activated motor units may also reflect an improved neurogenic state. Through use of a preload stimulus for a specific movement pathway, improved coordination between contracting muscle fibres could in turn allow an increased subsequent level of performance (Docherty, Robbins & Hodgson, 2004). Inhibition of protective golgi-tendon organ (GTO) activation may similarly improve performance, attenuating GTO effect on maximal motor unit activation (Baker & Newton, 2005). This premise has been one of the underlying effect mechanisms associated with whole body vibration and superimposed vibratory stimulation studies and their effect on motor function (Cochrane & Stannard, 2005; Issurin, 2005; McBride, Nuzzo, Dayne, Israel, Nieman & Triplett, 2010). The phenomenon of reciprocal inhibition, whereby antagonist musculature undergoes a contractile function prior to agonist activation, has also been shown to improve power production. A study by Baker and Newton (2005) examining the effects of a heavy pre-load bench pull on subsequent bench press throw performance, reported a 4.7% increment in power output following the conditioning stimulus. Such findings are of significant interest to practitioners when considering the functional application of PAP effects within athletic populations.

Whilst both the phosphorylation of RLC and increased neurogenic drive are attributed the greatest mechanistic foundations for PAP, it is important not to disregard any potentially beneficial physiological responses occurring in other systems that may influence subsequent performance. It has been proposed that acute architectural changes to pennation angle, the angle formed by the fascicles and the

inner aponeurosis, may positively contribute to any observable PAP response (Tillin & Bishop, 2009). The pennation angle impacts upon transmission of force from the musculature to the series elastic components (SEC) and bone (Folland & Williams, 2007; Fukunaga, Ichinose, Ito, Kawakami, & Fukashiro, 1997). For the purpose of force transmission from muscle fibre to tendon, smaller angles of pennation are considered to be mechanically advantageous (Folland & Williams, 2007; Fukunaga et al., 1997). Mahlfeld, Franke & Awiszus (2004) examined the effects of 3x3-second MVCs on vastus lateralis pennation angle and its time course. Immediate changes in pre-MVC pennation angle was not observed; however, between 3-6-minutes post MVC the pennation angle reduced to an angle equivalent to a 0.9% improvement in potential force transmission to the tendon (Mahlfeld et al., 2004). In that study, the qualification of 0.9% improvement was done via calculation only and no assessment of functional changes in force transmission was investigated. As a result the area remains largely unsubstantiated and further investigation is warranted.

Other research has shown changes in muscle-tendon stiffness as a key mechanism in potentiation, increasing excitation of the myotatic reflex and improving the function of the SEC (Baker, 2003; Kubo, Kawakami & Fukunaga, 1999). Positive benefits associated with acute increased muscle stiffness include an increased RFD (through attenuated electromechanical delays) and improved stretch-shortening cycles (SSC). The chronic (positive) adaptations in RFD and improved SSC in response to high load conditioning stimuli are well established (Albracht & Arampatzis, 2013; Baker, 2003; Kubo et al., 1999; Wilson & Flanagan, 2008). Acute changes in muscle-tendon stiffness remain less clear however, with conflicting results reported between the unique muscular and tendonous units (Kubo, Kanehisa, Ito & Fukunaga, 2001). Certainly, more passive forms of movement such as static stretching appear to have a

deleterious effect on muscle-tendon stiffness (Cè, Rampichini, Maggioni, Veicsteinas & Merati, 2008; Morse, Degens, Seynnes, Maganaris & Jones, 2009). During active movement, stiffness of the muscular unit exceeds that of the tendonous unit (Brughelli & Cronin, 2008). As a result, increments in muscle stiffness may outweigh any concomitant increase in tendon passiveness (Brughelli & Cronin, 2008).

In addition, the respective hormonal, psychomotor, metabolic and thermal contribution to beneficial changes in physiological state has also been examined and has produced similarly unclear trends, though limited numbers of studies have been conducted in each area (Cook, Kilduff, Crewther, Beaven & West, 2014; Crewther, Kilduff, Cook, Middleton, Bunce & Yang, 2011; Etnyre & Kelley, 1989; Etnyre & Kinugasa, 2002; Guggenheimer, Dickin, Reyes & Dolny, 2009; Thatcher, Gifford & Howatson, 2012; Zois, Bishop, Ball & Aughey, 2011). What is apparent is that the physiological mechanisms that contribute to PAP involve a highly complex and interrelated series of processes; the magnitude of each appearing to vary according to the specific stimulus received.

### 2.3.2 PHYSIOLOGICAL CHARACTERISTICS OF POTENTIATION

The characteristics of evoked potentiation are seemingly reflective of the complex physiological mechanisms that elicit it. To this end, the examination of twitch potentiation (TP) and reflex potentiation (RP) methodologies has produced significant findings regarding understanding of these characteristics (Hodgson, Docherty & Robbins, 2005; Tillin & Bishop, 2009).

A sole muscular twitch, in response to either a single presynaptic action potential or a synchronised volley of action potentials, is modulated by its own

previous contractile history (Hodgson et al., 2005). Examination of the changes in twitch properties following an electrically induced condition stimulus or MVC provides a means by which one can assess the effect of a stimulus upon TP response (Hodgson et al., 2005)

Central to twitch potentiation studies has been an observed initial increase in twitch peak force and RFD at lower frequencies, and an increase in RFD solely at higher frequencies (Hodgson et al., 2005). The magnitude of this response is modulated according to both the relative intensity and volume of stimulation (Hodgson et al., 2005). Interestingly, researchers have established a specific time course for the onset of potentiation. A study by Hamada, Sale, MacDougall & Tarnopolsky (2000), demonstrated a peak potentiation of an increase in peak torque of about 71% in response to a conditioning stimulus. However, this potentiation began to subside rapidly (-44% and -31%) within the first 30- and 60-seconds respectively, remaining 12% above pre-stimulus levels (Hamada et al., 2000). Other research suggests that twitch potentiation appears to follow an exponential decline function following maximal isometric stimulation (Baudry & Duchateau, 2004; Gossen & Sale, 2000).

For example, examination of twitch potentiation in human tibialis anterior (TA) and plantarflexor (PF) muscles showed an optimal potentiation response following a 10-second isometric MVC (Vandervoort, Quinlan & McComas, 1983). Contraction durations in excess of a 10-second stimulus exhibited little or no observable level of potentiation (Vandervoort et al., 1983). Given the fatigue associated with a MVC, manipulation of the relative duration of stimulus may impact the concomitant level of both fatigue and potentiation present (Vandervoort et al.,

1983). Additionally, the study reported that at contraction intensity of less than 75% of isometric MVC, little or no potentiation was observed (Vandervoort et al., 1983). In contrast, other researchers have demonstrated a twitch potentiation effect with an intensity as low as 20% of MVC (Baudry & Duchateau, 2007). However the study utilised a dynamic conditioning stimulus (as opposed to an isometric), suggesting that the type of conditioning stimulus is a key consideration in eliciting a potentiation response (Baudry & Duchateau, 2007).

Muscle fibre type classifications have been shown to correlate with the magnitude of measurable twitch potentiation, with faster twitch fibres (IIA and IIX) expressing a greater response than slower twitch fibres (Hodgson et al., 2005). This phenomenon may be counterbalanced owing to research indicating that fast twitch fibres elicit a greater fatigue response relative to that of slow twitch (Hamada et al., 2000). This is likely attributable to an increased utilisation of anaerobic energy stores, and the corresponding accumulation of metabolite by-products as a result (Tillin and Bishop, 2009). From an applied functional perspective however, the frequency of stimulation that best induces a twitch response in a specific muscle and its respective fibres differs, creating an added complication when considering compound musculature and athletic performance (Hughes, 1958). Furthermore, findings supporting the influence of muscle temperature on twitch potentiation response and, although findings are unequivocal, the impact of temperature manipulation upon myogenic and neurogenic processes must be considered (O'Leary, Hope & Sale, 1997).

An additional research finding of note involving twitch potentiation studies was an observed inverse relationship between both muscle fibre lengths and twitch

response, whereby the magnitude of potentiation is greatest when the contractile response is taken from a shorter, rather than longer, muscle length (Rassier & MacIntosh, 2000; Stuart et al., 1988; Vandervoort et al., 1983). Furthermore, a synergistic muscle contribution to potentiation has been demonstrated to be determined by a combination of both muscle fibre type and joint angle, and therefore length (Miyamoto, Mitsukawa, Sugisaki, Fukunaga & Kawakami, 2010).

Examination of the Hoffman reflex (H-reflex) has been the primary method used to examine the effect of a pre-load conditioning stimulus on motoneuron recruitment and efficacy (Gullich & Schmidtbleicher, 1996; Palmieri, Ingersoll & Hoffman, 2004; Trimble & Harp, 1998; Tillin & Bishop, 2009). When measured via electromyography, the H-reflex is a reflex analogous to the mechanically induced spinal stretch reflex and results from an afferent neural volley travelling to the spinal cord (Palmieri et al., 2004; Tillin & Bishop, 2009). In theory, any increase in H-wave amplitude following a pre-load stimulus would indicate a decrease in pre- and post-synaptic transmitter failure and a subsequent increase in higher order motoneuron recruitment. Examination of the modulation of H-reflex amplitude is often cited as the examination of reflex potentiation (RP) and, in conjunction with TP, the two methodologies have helped to establish the presence of measurable potentiation, whilst simultaneously increasing awareness of the characteristics and mechanisms of PAP (Hodgson et al., 2005).

Scientific investigations into the practical implications of changes in H-wave amplitude are inconclusive. A study examining the effect of a 5-second isometric MVC on H-wave response at the gastrocnemius, found an initial depression (-24%) in amplitude 1-minute post MVC, but a subsequent potentiation (20%) of amplitude

during a period of time 5- and 13-minutes following (Gullich & Schmidtbleicher, 1996). A very strong correlation ( $r=0.90$ ) was reported between the time course of H-reflex and force output of the gastrocnemius (Gullich & Schmidtbleicher, 1996). Of interest to the specific endurance population examined in this thesis, correlations for predominately slow twitch muscle are modestly less ( $r=0.75$ ) (Gullich & Schmidtbleicher, 1996). This suggests that the time course following pre-load stimulus may be an important consideration in any attempt to acutely enhance physiological output via H-wave potentiation, particularly as it differs to that of twitch potentiation (Baudry & Duchateau, 2004; Gossen & Sale, 2000; Gullich & Schmidtbleicher, 1996; Vandervoort et al., 1983).

It has also been suggested that there is a relationship between reflex potentiation and the training age, or inherent strength level, of participants (Gullich & Schmidtbleicher, 1996). Greater levels of potentiation were observed in participants classified as speed-strength athletes, with a high correlation ( $r=0.89$ ) between explosive force production and the time course of response, when compared to untrained participants (Gullich & Schmidtbleicher, 1996). When considering the potential impact of reflex potentiation on motor unit recruitment, specifically that of higher order motor units, this is perhaps not surprising.

Failure to normalise the H-wave response to the maximal M-wave, the electrical counterpart of the activation of all motor units in the pool, raises concerns that factors removed from increased neural drive contributed to these findings (Maffiuletti, Martin, Babault, Pensini, Lucas & Schieppati, 2001). It has been suggested instead that increased  $\text{Na}^+ - \text{K}^+$  pump activity at the specific musculature may have been responsible, serving to reinforce the necessary consideration of multiple



physiological systems when attributing mechanistic cause. Subsequently, two studies have reported a potentiated response in normalised H-wave amplitude following both dynamic and isometric MVC, albeit allowing sufficient recovery of between 3- and 10-minutes and 5- and 11-minutes respectively (Folland, Wakamatsu & Fimland, 2008; Maffiuletti et al., 2001).

With consideration given to physiological characteristics of potentiation, it is apparent that both similarities and discrepancies between twitch and reflex characteristics exist. These differences are likely attributable to the varying complex and interrelated processes that influence their expression. The ultimate expression of PAP within the scope of functional performance is likely to be driven by mechanisms occurring both centrally and peripherally, and further mediated by the conditioning stimulus itself.

#### 2.4 PHYSIOLOGICAL RELEVANCE TO SPORT PERFORMANCE

The ability to maximise muscular power is critical to the successful outcome of a number of athletic functions (Young, 2006). Specifically, power is the force (F) developed over a specific range of motion (d), in a specific period of time (t) ( $P=Fxd/t$ ), or as force multiplied by velocity (v) ( $P=Fxv$ ) (Newton & Kraemer, 1994). In theory, utilisation of PAP protocols offers a means by which specific variables associated with power production may be manipulated to achieve a potentially beneficial modulation of expressed power and performance (MacIntosh, Robillard & Tomaras, 2012; Wilson et al., 2013). Given the established characteristics of potentiation, there has been considerable interest by practitioners in the implications of this response to physiological output and functional sports performance (Wilson et al., 2013). This context has yet to fully differentiate between the examination of PAP

as a means of either acutely enhancing a single performance, or providing a potentiated training stimulus to engender more chronic adaptation, as with the use of complex and contrast training (Ebben, 2002). Regardless, research has increasingly focused on methods of eliciting PAP, and a functional improvement in performance, through a series of differing activities, often incorporated into existing warm-up routines (Wilson et al., 2013).

Whilst the inclusion of a specific PAP protocol into an existing warm-up or pre-competition strategy is supported in theory, care must be taken to ensure that the net result is one that enhances the performance of athletes as opposed to subtracting from it due to excessive fatigue (Docherty & Hodgson, 2007; Wilson et al., 2013). As previously reported, the sum physiological state following a conditioning stimulus is dependent upon the balance of both fatigue and potentiation and modulated by several dependent and independent variables (Kilduff et al., 2008; Sale, 2002; Tillin & Bishop, 2009; Wilson et al., 2013).

As the manner of functional sports performance is predominantly reliant on the completion of compound motor patterns as opposed to patterns in isolation, studies focusing on isolated muscle groups have been excluded from the following review. In addition, in response to the prevailing acceptance and validation of the required need for moderate to maximal, or near maximal activation, required to optimise PAP responses, studies utilizing a low-intensity/frequency protocol have similarly been excluded (Rahimi, 2007; Saez Saez de Villarreal, Gonzalez-Badillo & Izquierdo, 2007; Weber et al., 2008).

#### 2.4.1 RECOVERY PERIOD EFFECT ON PAP

The time course following performance of a functional conditioning stimulus appears to be a significant factor in the magnitude of PAP response (Tillin & Bishop, 2009). A study by Gullich and Schmidtbleicher (1996) reported a negative response in isometric RFD of -13% immediately following performance of a heavy-load conditioning stimulus. However, given sufficient recovery, RFD levels increased between 5- and 13-min post-performance of the conditioning stimulus, with peak RFD increasing 19% above that of pre-test levels (Gullich & Schmidtbleicher, 1996).

A study examining the time course of potentiation response reported a similar immediate attenuation in RFD followed by later potentiation (Gilbert, Lees & Graham-Smith, 2001). Measurement of RFD response via isometric MVC in seven recreationally trained men in response to a heavy back squat conditioning stimulus (1x5 back squat at 100% of 5RM) showed an immediate decrement in output for up to 10-minutes following (Gilbert et al., 2001). However, potentiation was observed when RFD was assessed at both 15- and 20-minutes post conditioning; an increase of 10.0% and 13.0% respectively (Gilbert et al., 2001). No significant effect was observed at the final assessment interval of 30-minutes (Gilbert et al., 2001). This study reports both a lengthier window of RFD attenuation and potentiation than the earlier study (Gullich & Schmidtbleicher, 1996).

In another study, twenty professional rugby players performed a countermovement jump (CMJ) at baseline and at differing intervals following a heavy conditioning stimulus (3x3 back squat at 87% of 1RM) (Kilduff et al., 2008). Power output, jump height, and peak RFD were determined for all CMJs and, despite an immediate decrease in all baseline measures in response to the stimulus, performance

increased significantly following 8-minute recovery (Kilduff et al., 2008). Additionally, another study established a similar relationship between conditioning stimulus and net state, when examining the effects of a heavy stimulus protocol (10x1 back squat at 90% of 1RM) on maximal sprint performance over 30-meters (Chatzopoulos et al., 2007). Whilst no change in performance was observed at 3-minutes post stimulus, a 3% improvement in 0-10-meter time and a 2% improvement in total 30-meter time was reported (Chatzopoulos et al., 2007).

In addition, several studies have shown that, regardless of the window of recovery, there are positive net state changes that impact upon performance. Gourgoulis, Aggeloussis, Kasimatis, Mavromatis and Garas (2003) reported an immediate +2.4% improvement across both recreationally trained and untrained subjects in CMJ performance following a heavy stimulus (1x2 back squat at 90% of 1RM). Furthermore, a significant improvement in both depth jump (DJ) performance (5.0%) and knee extension power (6.1%) following MVC with no recovery window has been reported (French, Kraemer & Cooke, 2003).

However, there have been several studies that have failed to observe any subsequent beneficial change in net state following stimulus. The effects of back squats (1x1 at 90% of 1RM) on CMJ performance in a group of untrained subjects showed no change in jump height 3-minutes following (Mangus, Takahashi, Mercer, Holcomb, McWhorter & Sanchez, 2006). Similar observations are reported in another study, which found decrements in the peak power of both CMJ and loaded squat jump (SJ) over an extended recovery period of 5-, 6- and 7-minutes following stimulus (5x1 back squat at 90% of 1RM) in untrained subjects (Chiu et al., 2003).

On the balance of current evidence, research suggests that, whilst twitch properties would likely result in an immediate positive contribution to the performed stimulus, that mechanisms responsible for fatigue may be more influential in their effect during early stages (Hamada et al, 2000; Tillin & Bishop, 2009). Potentiation through neurogenic contribution may better account for this as well (Baudry & Duchateau, 2004; Gossen & Sale, 2000; Gullich & Schmidtbleicher, 1996; Vandervoort et al., 1983). It is also likely that the differing combination of other factors, such as stimulus volume and the diverse nature of participant characteristics, accounts for the varied findings (Chiu et al., 2003; Hodgson et al., 2005). When examining group mean responses to varying loaded squat jumps on an ensuing repeated jump performance across multiple time points, Sotiropoulos, Smilios, Douda, Christou and Tokmakidis (2013) found no acute effect on jump height or power. However when peak individual responses were considered irrespective of time point, large increases in both jump height performance and power were observed for some participants. The authors recommended that the rest duration should be individually determined in order to optimise response. A recent meta-analysis on the effect of differing factors on magnitude of PAP expression suggested that rest periods between 7- and 10-minutes in duration had a greater effect size ( $ES=0.70$ ) on magnitude of PAP response than periods of 3- and 7-minutes ( $ES=0.54$ ) and in excess of 10-minutes ( $ES=0.02$ ) (Wilson et al., 2013).

#### 2.4.2 CONDITIONING VOLUME AND INTENSITY EFFECT ON PAP

As stated previously, the volume and relative intensity of stimulus used to elicit a PAP response is likely to significantly impact upon the degree to which potentiation and fatigue is generated (Hamada et al., 2000). Variation in the prescription of repetitions, sets, contraction durations as well as the relative intensity of the lifts

performed, often expressed in relation to percentages of a RM, is prevalent in the scientific literature (Wilson et al., 2013). It is widely acknowledged that each unique conditioning stimulus activates, to varying degrees, differing magnitudes of potentiation and fatigue, and is further mediated by the conditioning type and recovery afforded (Tillin & Bishop, 2009; Wilson et al., 2013).

For example, a study by Lowery et al. (2012) examining the effects of intensity-volume interactions on time course response, reported that higher loads increased the magnitude of response and extended the window by which to observe potentiated performance. Furthermore, a study by Comyns, Harrison, Hennessy and Jensen (2007) showed equally beneficial responses following performance of 3-back squat repetitions at low (65% of 1RM), moderate (80% of 1RM), and high (95% of 1RM) loads.

In contrast to the findings of Comyns et al. (2007), work by Brandenburg (2005) failed to note any change in performance of an explosive bench press throw (BPT) in response to differing loads. Specifically, Brandenburg (2005) examined changes in muscular power following 5-repetitions using loads of 50, 75 and 100% of 1RM. Using a load of 45% of 1RM on BPT, no change in pre-test measures was reported (Brandenburg, 2005). However, it has been reported that optimum load for power production for the BPT is ~55% 1RM (Baker, Nance & Moore, 2001). Given that PAP is considered to occur predominantly towards the central portion of the force-velocity curve, the load used on the BPT may have been insufficient (Sale, 2002).

In a unique examination of the effect of two differing densities of conditioning stimulus, continuous repetitions versus a 'cluster-training' protocol with reps distributed 30-seconds apart; Bouldosa, Abreu, Beltrame and Behm (2013) reported equal benefits

in performance, albeit along a differing time course. The 'cluster' protocol afforded almost immediate benefits in peak power performance, whereas a more traditional protocol saw optimal peak power occur 9-minutes subsequent to the conditioning stimulus (Boullousa et al., 2013).

A recent meta-analysis by Wilson et al. (2013) established effect size changes for the differing combinations of intensity and volume on potentiation. Wilson et al. (2013) reported that moderate intensity activity, as denoted by loads between 60-84% of 1RM, was observed as having a large effect size (ES=1.06) than the small effect observed with higher intensity activity of between 85-100% of 1RM (ES=0.31) (Wilson et al., 2013). The authors suggested that, as the magnitude of muscle damage is proportional to the intensity of exercise, that moderate loads were sufficient to achieve a PAP response while concurrently attenuating any concomitant rise in fatigue (Wilson et al., 2013). However the reverse was suggested with regard to exercise volume, with data indicating that multiple sets of a conditioning stimulus had a larger effect (ES=0.66) than a single set on potentiation (ES=0.24). This was qualified however, by the authors stating that this finding was likely mediated extensively by participant training history and the rest period afforded (Wilson et al., 2013).

#### 2.4.3 CONDITIONING MODE EFFECT ON PAP

While research suggests that any type of conditioning effect will elicit PAP, the degree to which potentiation occurs is likely to be modulated by type of contraction performed (Sale, 2004; Tillin & Bishop, 2009). It is proposed that the methodological differences in contraction type prescription utilised in studies, predominantly isometric and concentric, likely accounts for the often conflicting findings (Tillin & Bishop, 2009). Specifically, Tillin and & Bishop (2009) postulate that the two differing

contraction types evoke differing physiological responses. Dynamic contractions, due to its eccentric component, would theoretically act predominantly upon the central, neurogenic mechanisms of potentiation with a reduction in transmitter failure from fibres to motor units; whilst isometric contractions, and governed by the size-principle, would preferentially affect increased contribution of fast-twitch fibres and, subsequently, RLC phosphorylation (Tillin & Bishop, 2009). However, it is this author's opinion that the responses evoked are not exclusive to the conditioning mode.

Studies examining the use of isometric MVCs on functional performance have produced ambiguous results however. The aforementioned studies by Gullich and Schmidbleicher (1996), and French et al. (2003) both reported positive potentiation responses utilizing an isometric conditioning stimulus. Of specific interest to this review as it specifically examines an endurance athlete population, is a study investigating the use of a series of isometric contractions upon subsequent 1,000-meter ergometer rowing performance (Feros et al., 2012). This is a unique study within the PAP literature in that it not only utilised middle distance endurance athlete subjects, but elite athletes as well (Feros et al., 2012). The key findings of the study were that a PAP condition resulted in a faster 1,000-meter rowing ergometer time (-0.8%, ES=0.21) than the control condition. In addition, mean stroke power (2.6%, ES=0.26) and mean stroke rate (4.6%, ES=0.51) were improved over this distance. The effects of the PAP condition were even more marked during the initial 500-meters of the ergometer assessment, recording a faster split time (-1.9%, ES=0.62), greater mean stroke power (6.6%, ES=0.64) and greater mean stroke rate (5.2%, ES=0.54). However, the failure to standardise ergometer stroke rate, as well as capture the change in stroke length and, in turn, the work (Joules) per stroke performed, were limitations in the study design.



The PAP response to isometric contractions has been disputed by some authors (Behm, Button, Barbour, Butt & Young, 2004; Gossen & Sale, 2000; Robbins & Docherty, 2005). Robbins and Docherty (2005) examined the effect of a 7-second MVC in the squat position (100° knee angle) on subsequent CMJ performance 4-minutes following, performed three times. This protocol was contrasted to a cross-over control where the performance of the MVCs was removed (Robbins & Docherty, 2005). No significant changes in jump height, peak power, peak velocity, peak force and RFD was recorded, nor any significant difference between the two protocol groups, concluding that the execution of a MVC was an inadequate means of eliciting an acute performance increase in a power movement. However, the volume of the MVC may have been insufficient to elicit a PAP effect, both in the duration of contraction and the single repetition nature of the protocol used (Vandervoort et al., 1983; Wilson et al., 2013).

Insufficient volume of MVC may also account for the lack of potentiation in a more recent study (Pearson & Hussain, 2013). Utilising three differing volumes of MVC: 3-, 5- and 7-second durations, the study examined changes in twitch torque in relation to changes in CMJ height, jump power, RFD and take-off velocity (Pearson & Hussain, 2013). No significant change in any CMJ measure was noted. Additionally, no association between changes in jump performance and twitch torque was reported following either the 3- ( $r=0.25$ ), 5- ( $r=0.28$ ) and 7-second ( $r=-0.47$ ) MVCs (Pearson & Hussain, 2013).

The effect of dynamic, as opposed to isometric, contraction types on PAP expression has similarly produced varied responses. Several studies have produced favourable changes in acute performance following varied dynamic contractions (Batista, Ugrinowitsch, Roschel, Lotufo, Ricard & Tricoli, 2007; Chatzopoulos et al.,

2007; Gourgoulis et al., 2003; Kilduff et al., 2011; Kilduff et al., 2008; Mitchell & Sale, 2011, Young et al., 1998). An interesting study that examined the effect of a back squat protocol (1x3 back squat at 87% of 1RM) upon CMJ and start performance in elite sprint swimmers reported a significant improvement in jump height obtained ( $34.1 \pm 4.7\text{cm}$  vs.  $35.7 \pm 5.6\text{cm}$ ), albeit with no beneficial change in start performance (Kilduff et al., 2011). A study by Mitchell and Sale (2011) utilized a dynamic back squat protocol and examined its effect on CMJ performance, noting improved jump height (2.9%) in contrast to a control group who did not perform the back squats. Additional findings showed an increase in twitch torque (10.7%) in response to the protocol, suggesting that twitch properties were in some way responsible for the acute increase in performance (Mitchell & Sale, 2011). In contrast, several studies have failed to establish any change in performance following dynamic muscular contraction (Cabrera, Morales, Greer & Pettitt, 2009; Hanson, Leigh & Mynark, 2007; Jensen & Ebben, 2003).

Few studies have directly compared the efficacy of isometric and dynamic protocols in terms of PAP responses on the same performance task (Tillin & Bishop, 2009). Lim and Kong (2013) examined the efficacy of differing contraction types on subsequent 30-meter sprint performance. Participants performed four protocols in a randomised cross over order, either: a control (4-minutes passive rest), a maximum voluntary isometric knee extension (3x3-second isometric knee extension), maximum voluntary isometric back squat (3x3-second isometric squat), and dynamic back squat (3x-repetitions at 90% of 1RM) (Lim & Kong, 2013). There was a 4-minute window of recovery prior to completing the sprint. The analysis revealed there were no significant differences in 30-meter performance across all four conditions (Lim & Kong, 2013). However, the authors observed significant individual variability in response to the protocols, with some individuals reporting large benefits in performance, whilst others

responded negatively. This finding further emphasises the importance of individual consideration that must be afforded to design of PAP protocols. A meta-analysis of the effect of conditioning type influence on subsequent PAP response reported ES for dynamic contractions (ES=0.42) being slightly greater than isometric contractions (ES=0.35) (Wilson et al., 2013).

#### 2.4.4 TRAINING STATUS EFFECT ON PAP

Inter-subject variability appears to be a significant determinant of respective response to conditioning stimulus (Tillin & Bishop, 2009; Wilson et al., 2013). The confounding effects of subject training status and the inherent variability associated with differences in muscular strength and fibre-type distributions is highly prevalent throughout the literature (Wilson et al., 2013). For example, it has been reported that subjects with at least one year weight training experience demonstrated a negative correlation ( $r=-0.77$ ) between the optimal recovery period and back squat 1RM (Jo et al., 2010).

Chiu et al. (2003) separated subjects into two distinct groups: recreationally trained (RT) and untrained (UT), and reported no significant improvement in CMJ or SJ performance in UT subjects following performance of a conditioning stimulus. However, a 1-3% change in jump performance was reported in the RT group; a greater level of fatigue resistance proposed as the cause, creating a more favourable balance between fatigue and potentiation (Chiu et al., 2003). Indeed, it has been shown that trained individuals express greater RLC phosphorylation activity than untrained, and that improved performance may be bi-directionally mediated; with greater PAP characteristics and lesser fatigue characteristics experienced (Wilson et al., 2013).

It appears on the balance of evidence that an individual's level of muscular strength may modulate PAP response. Kilduff et al. (2008) reported a positive correlation between 3RM back squat strength and change in potentiation following 8 minutes of recovery ( $r=0.49$ ). A more recent study established a relationship between not only strength level and the magnitude of PAP response, but the ability to express PAP characteristics more quickly than those of lesser strength as well (Seitz, de Villarreal & Haff, 2014). A group of 18 junior elite rugby league players were categorised into strong (1RM squat  $>2.0x$  body weight) and weak (1RM squat  $<2.0x$  body weight) and performed squat jumps across an extended time period in response to a conditioning stimulus (1x3 back squats at 90% of 1RM) (Seitz et al., 2014). Absolute peak power in the stronger group was greater than baseline at 3- (ES=0.87), 6- (ES=1.00), 9- (ES=0.95) and 12- (ES=0.21) minutes post conditioning stimulus, as well as greater in comparison to the weaker group (Seitz et al., 2014). In further support of the observation of those of greater strength producing greater PAP response, Young et al. (1998) and Duthie, Young and Aitken (2002), similarly reported significant correlations between the magnitude of performance change and individual measures of strength ( $r=0.73$  and  $r=0.66$ , respectively).

As an overview of the differing magnitude of effect training status has on PAP response, the recent meta-analysis by Wilson et al. (2013) differentiated subjects into three categories: UT, RT and athletes (AT) and examined the respective effect size. The AT group was reported as having a moderate ES response (ES=0.89), with the UT and RT groups expressing trivial (ES=0.14) and small (ES=0.29) modulation of power following conditioning stimulus respectively (Wilson et al., 2013). Potentially mediating the effect of muscular strength, and thus the effect of training status further, is that fibre-type distribution has been shown to influence the PAP response (Tillin &

Bishop, 2009). In keeping with characteristics of twitch and reflex potentiation, greater responses in power modulation in response to stimulation in fast-twitch muscle fibre is greater than that seen in slow-twitch fibre, albeit with a greater rate of fatigue at high volumes (Hamada, Sale, MacDougall & Tarnopolsky, 2003). To this author's knowledge, no PAP study examining fibre type contribution has been performed using elite subjects.

## 2.5 SUMMARY AND IMPLICATIONS OF LITERATURE REVIEW

Changes in functional performance are ultimately the primary consideration within the context of athletic performance; the majority of studies fail to directly quantify performance changes with twitch and reflex methodologies (Nibali et al., 2013). Whilst the study by Mitchell and Sale (2011) assessed the impact of a 5RM back squat load on subsequent CMJ and twitch torque response, reporting both were present, the two variables were not examined concurrently. To the knowledge of the author the only other studies that have attempted to establish causality did so using movement patterns that do not reflect the dynamic multi-joint nature of movement inherent to elite athlete performance (Folland et al., 2008; Gullich & Schmidtbleicher, 1996). Recent work by Nibali et al. (2013) has established the ecological validity of jump squats, as measured by force platform, as a means of measuring PAP. In particular, concentric jump squat mean power was observed to have a large correlation to muscle twitch peak force ( $r=0.50$ ), whereas peak power ( $r=0.36$ ), mean force ( $r=0.42$ ), and RFD ( $r=0.45$ ) all expressed moderate correlations (Nibali et al., 2013). As such, this study gives validation to the use of jump squats as a means to assess PAP.

The degree to which any protocol can acutely enhance performance appears highly specific to the group and more specifically, the individual examined (Wilson et

al., 2013). While the current body of literature may provide a starting point by which to create a protocol, practitioners must be cognizant of the variation in individual responses. In addition, consideration should be given to the environment one wishes to employ PAP protocols. Given the highly complex and seemingly intricate balancing of variables required to produce a PAP response, one might consider the use of PAP protocols more suited to a training environment, looking to facilitate chronic adaptations in power, through the use of complex training, as opposed to introducing new aspects to warm-up within a competitive environment (Ebben, 2002; MacIntosh et al., 2012).

In conclusion, PAP is suggested to improve power and RFD in subsequent muscular contractions, though the specific interplay of mechanisms remains unclear. Similarly, the influence of intensity, volume, contraction mode, rest periods and inter-subject characteristics upon the magnitude of response is highly varied. It has been reported that PAP may benefit the performance of complex athletic actions such as sprinting and jumping (Batista et al., 2007; Chatzopoulos et al., 2007; Gourgoulis et al., 2003; Kilduff et al., 2008; Mitchell & Sale, 2011, Young et al., 1998). Given that elite rowers possess a predominance of type I muscle fibres (Steinacker, 1993), it may be expected that this endurance population would not generally respond to, or benefit from, a PAP protocol. However, despite the lack of scientific investigation, it has been proposed that endurance subjects may still in fact benefit from PAP protocols, owing to a greater capacity for myosin light chain phosphorylation and improved resistance to fatigue in comparison to other populations (Hamada et al., 2000). Feros et al. (2012) examined the effects of a PAP protocol on rowing 1,000m ergometer performance, reporting improved timed performance (0.8%). However, the study utilized an isometric conditioning stimulus, which may not be as effective as a dynamic stimulus in eliciting

PAP. In addition, the study by Feros et al. (2012) appears to be the only published work examining the use of a conditioning stimulus upon any functional performance in an elite endurance population.

## CHAPTER 3 – METHODOLOGY

### 3.1 EXPERIMENTAL APPROACH TO THE PROBLEM

This study utilized a repeated measures crossover design to examine the magnitude of PAP effects of a back squat exercise protocol (3 sets x 3 repetitions at 80% of 1RM, 5-minute rest) on subsequent CMJ performance in an elite rowing population. Reliability of measures was determined over two separate days in order to establish the typical error (TE) as a coefficient of variation (CV), smallest worthwhile change (SWC) and intraclass correlations (ICC) of each of the CMJ variables.

### 3.2 PARTICIPANTS

Nineteen elite male rowers volunteered to participate in this study, conducted during the international rowing off-season (November). Participant characteristics are summarised in Table 3.1. The participants were members of the Rowing New Zealand summer training squad and were of World Championship and Olympic calibre, having recently competed in the 2013 World Championships (consisting of 8-gold and 4-silver medallists). All participants were informed of the study requirements; potential risks and benefits, and signed their informed voluntary consent forms prior to participation in the study. The study was approved by the Auckland University of Technology Ethics Committee (Approval number: 13/293). Participants were excluded from the study if they were injured or ill within the preceding two week timeframe.

*Table 3.1.* Physical characteristics of rowers (mean  $\pm$  standard deviation (*s*)).

No. of participants	Age (years)	Height (cm)	Body mass (kg)
19	22.8 $\pm$ 2.6	182.1 $\pm$ 4.8	87.4 $\pm$ 10.6

### 3.3 BACK SQUAT 1RM ASSESSMENT



Participants were assessed to determine 1RM back squat load one week prior to commencement of the study. Participants completed a standardised warm-up protocol of 15-minutes that comprised of gentle and progressive mobility and flexibility work. All participants were familiar with the back squat exercise and had performed the exercise in training over the preceding 6-months. Participants utilised a progressive increase in back squat load, starting at an estimated load of 70% of 1RM based off previous training records, and had to reach their 1RM load within 5-sets (e.g. 70%, 85%, and 95%, then 100% attempt 1, 100%+ attempt 2). Rest intervals were self-regulated, though typically exceeded 2-minutes, and the entire back squat 1RM assessment was concluded within a 30-minute period. Verbal encouragement was given for all participants. Back squat depth was standardised to a hip depth that ensured a ninety degree angle of knee flexion. During assessment verbal cueing was given by the same strength and conditioning coach on each test attempt, to ensure correct depth. Attempts requiring assistance for completion, or which failed to meet depth criteria, were deemed invalid. The reliability of 1RM testing in our facility using this protocol is high (CV=2.5% and ICC=0.96).

A relative measure of the 1RM was established by dividing each participant achieved load by their bodyweight, allowing for examination of the relationship between relative strength and magnitude of PAP response.

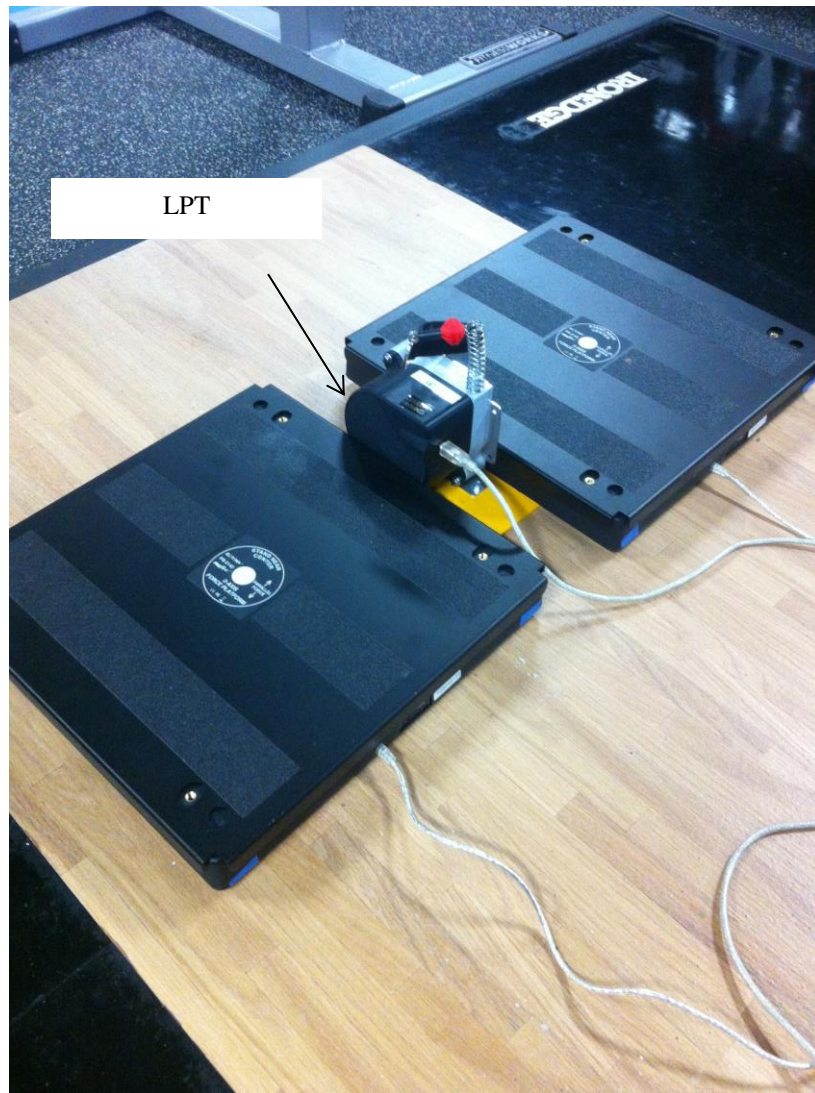
### 3.4 COUNTERMOVEMENT JUMP ASSESSMENT

CMJ protocols have been shown to be a valid ecological measure of potentiation, capable of detecting changes in performance in response to PAP (Nibali et al., 2013). In particular, changes in mean power (Watts) and mean RFD ( $N \cdot s^{-1}$ ) were observed to be strong correlates to changes in PAP (Nibali et al., 2013). Additional

performance measures collected for this study included: mean and peak force (N), mean and peak velocity ( $\text{m}\cdot\text{s}^{-1}$ ), peak power (W), and jump height (cm).

Participants performed 3-repetitions of a CMJ from a standing position on a force platform, with cueing given to participants to jump for ‘maximal height’. Countermovement dip was to a self-selected depth. Participants were instructed to ‘place hands on hips’ and to keep them there during all jumps to eliminate the contribution of arm swing. Repetitions were non-consecutive, with participants allowed to set themselves again before performing subsequent jumps (~3-seconds). The linear position transducer was secured at the waist via harness (see Figure 3.1); with instruction given to ensure that the connection was as tight as possible to reduce the risk of slack in the tether during jump performance.

Data were collected via a PASCO 2-axis force platform system (PASCO Scientific, Roseville, California), integrated with a Linear Position Transducer (Celesco, Chatsworth, California), sampling at a frequency of 200Hz. All variables were calculated using custom developed software developed by High Performance Sport New Zealand (Goldmine, Auckland), with force measures captured via the force platform, velocity and displacement measures via LPT, and power measures calculated through integration of input.



*Figure 3.1.* Force platform and Linear Position Transducer set-up.

### 3.5 BACK SQUAT PAP INTERVENTION

A load of 80% of the established 1RM was calculated for each participant for the PAP intervention, rounded to the nearest 2.5-kilograms. The PAP intervention consisted of two warm-up sets at 65% and 75% of 1RM followed by 3x3 sets of back squat at the individualised 80% 1RM load, with sets alternated with a partner to ensure a 2-minute rest period was achieved. Performance criteria for squatting were held to the same depth requirements as that of the 1RM assessment, with spotting provided for safety and verbal encouragement given to ensure participants maximised intended speed of the concentric portion of the squat.

### 3.6 PROCEDURES

During an orientation session, participants were familiarised with the jump squat assessment protocol and provided technical instruction, allowing time to practice the test and ask any questions. Additionally, test procedures were rehearsed to allow assessment of effectiveness and safety of athlete flow through the protocol. Participants were then assessed to determine 1RM back squat

Experimental data collection took place over two consecutive sessions one week apart and at the same time of day, with the control condition taking place first. Participants completed a standardised warm-up protocol of 15-minutes that comprised of gentle and progressive mobility and flexibility work. Once completed, participants performed baseline CMJ.

Following completion of all baseline jump trials, during the control condition participants remained seated for a rest period of 5-minutes before then concluding with the post measured jump tests. In contrast, during the experimental session conducted 7-days later, participants performed the back squat PAP intervention after baseline jumps. Participants remained seated for 5-minutes after the PAP intervention before performing a final set of assessed CMJs.

The rest interval between pre and post CMJ design conditions were chosen owing to the magnitude of ES observed in a published meta-analysis (Wilson et al., 2013). Whilst a longer rest period of 7- to 10-minutes produced a larger ES overall in the meta-analysis, when accounting for training status, a larger ES was observed between 3- to 7-minutes

in better trained populations, and therefore the 5-minute rest period decided upon for this study (Wilson et al., 2013).

### 3.7 STATISTICAL ANALYSIS

The reliability of tests was evaluated to quantify % TE calculated from within-subject CV as well as ICCs. Reliability data were derived from the initial 3-jump trials done on both the control and intervention days and analysed using a spreadsheet for analysis of reliability (Hopkins, 2011). Measurement precision or the TE was expressed as a CV and was calculated after log transformation to allow a more meaningful interpretation of the magnitude of error, irrespective of scaling. Log transformation was performed to normalise any positive kurtosis or skewing of data distribution and to avoid heteroscedastic errors commonly associated with ICC calculations (Hopkins, 2000). ICCs were determined as they provide some sense of within-participant repeat-test rank order. The lower and upper confidence intervals (90% confidence interval (CI)) of measurements were reported. In order for test inclusion in this study, both satisfactory precision ( $CV \leq 5\%$ ) and test-retest reliability ( $ICC \geq 0.90$ ) were required (Hopkins, Schabort & Hawley, 2001). The magnitude of % SWC was calculated as 0.2 times the  $s$  of the between-participant mean of all trials (log-transformed data), to provide a sense of measurement sensitivity (Cohen, 1988).

All pre and post intervention data for control and experimental PAP conditions were derived from the average of all 3-jump trials and analysed using a spreadsheet for analysis of “pre post controlled trials” (Hopkins, 2006). Raw data was examined initially, before log transformation was performed before analysis to reduce observed non-uniformity of error. Change in the means between trials, which are inclusive of random (sampling or random error) and systemic change, were calculated and compared

using paired *t*-tests. Percentage mean changes in performance and differences between the changes were calculated, along with 90% confidence intervals (CI). Magnitudes of standardised percentage effects were calculated by dividing the appropriate between-rower standard deviation and using a modified Cohen scale as follows: <0.20 = trivial; 0.2-0.59 = small; 0.6-1.19 = moderate; 1.2-1.99 = large; >2.0 = very large (Hopkins, 2006). The effect was deemed unclear if its CI overlapped thresholds for both positive and negative effects (Hopkins, 2006).

Pearson correlation coefficients were calculated to determine the relationship magnitude between changes in CMJ measures, as well as between participant absolute and relative 1RM back squat loads and changes in CMJ performance measures. The determination and interpretation of correlation coefficients was dependent on fulfilment of statistical criteria, namely the assumption of normality, linearity and homoscedasticity in the distribution of data. These criteria were examined using normal probability plots and bipolar plots. The interpretation of correlation coefficients was  $r=0.0-0.09$  (trivial);  $0.1-0.29$  (small);  $0.3-0.49$  (moderate);  $0.5-0.69$  (strong);  $0.7-0.89$  (very strong);  $0.9-0.99$  (nearly perfect); and  $1.0$  (perfect) (Hopkins, 2002). A paired *t*-test was used to establish statistical significance of correlations between variables (where  $p \leq 0.05$ ).

## CHAPTER 4 – RESULTS

Results of participant 1RM, calculated relative load with respect to bodyweight, and prescribed 80% of 1RM intervention load are reported in Table 4.1.

*Table 4.1.* Back squat results of rowers (mean  $\pm$  standard deviation (s)).

1RM (kg)	Relative (kg.bw)	80% 1RM Load (kg)
132.6 $\pm$ 27.5	1.52 $\pm$ 0.26	106.2 $\pm$ 22.3

The summary of percent typical error as a CV, ICCs and SWC are shown in Table 4.2. Overall, all test-retest measures were high (i.e. ICCs $\geq$ 0.91), with the exception of peak velocity (ICC=0.78). Similarly, measurement precision was satisfactory for all measures (CV $\leq$ 5%), with the exception of RFD (CV=6.6%). Given the inclusion criteria for assessment variables in this study (CV $\leq$ 5%, ICC $\geq$ 0.90), both peak velocity and RFD exceed the acceptable boundaries of statistical reliability and measurement precision, making accurate inference from the findings difficult. For both velocity and force, the mean measures showed lesser typical error in comparison to their respective peak measures (precision of 2.7% versus 4.2%, 2.1% versus 3.2%, respectively), whereas mean power showed greater typical error in comparison to its peak measure (precision of 2.9% versus 2.3%). The CV both for mean and peak velocity, RFD and jump height exceeded that of the SWC, therefore requiring larger changes in these measures in order for meaningful PAP effects.

Table 4.2. Summary of reliability measurements.

	CV (%) (90% CI)	ICC (90% CI)	SWC (%)
Mean Power (W)	2.9 (2.5-3.5)	0.97 (0.94-0.98)	3.1
Peak power (W)	2.3 (2.0-2.7)	0.99 (0.98-0.99)	3.8
Mean velocity (m.s <sup>-1</sup> )	2.7 (2.3-3.2)	0.91 (0.85-0.94)	1.7
Peak velocity (m.s <sup>-1</sup> )	4.2 (3.7-5.1)	0.78 (0.67-0.86)	1.7
Mean force (N)	2.1 (1.8-2.5)	0.97 (0.95-0.98)	2.4
Peak force (N)	3.2 (2.8-3.9)	0.97 (0.95-0.98)	3.8
Mean RFD (N.s <sup>-1</sup> )	6.6 (5.7-8.0)	0.95 (0.92-0.97)	5.8
Jump height (cm)	3.9 (3.4-4.7)	0.95 (0.92-0.97)	3.4

Notes: RFD = rate of force development, CV = coefficient of variation, SWC = smallest worthwhile change, ICC = intraclass correlation; reliability statistics calculated from average of all trials.



A summary of percentage change in control and experimental jump squat performance means, delta change in means ( $\Delta\%$  mean), ES, and qualitative outcome are reported in Table 4.3. A small and beneficial effect (positive) was observed in both mean power (5.7%, ES=0.36, 90%CI 0.13-0.59,  $p=0.01$ ) and in mean velocity (3.3%, ES=0.39, 90%CI 0.11-0.67,  $p=0.03$ ) following the PAP condition

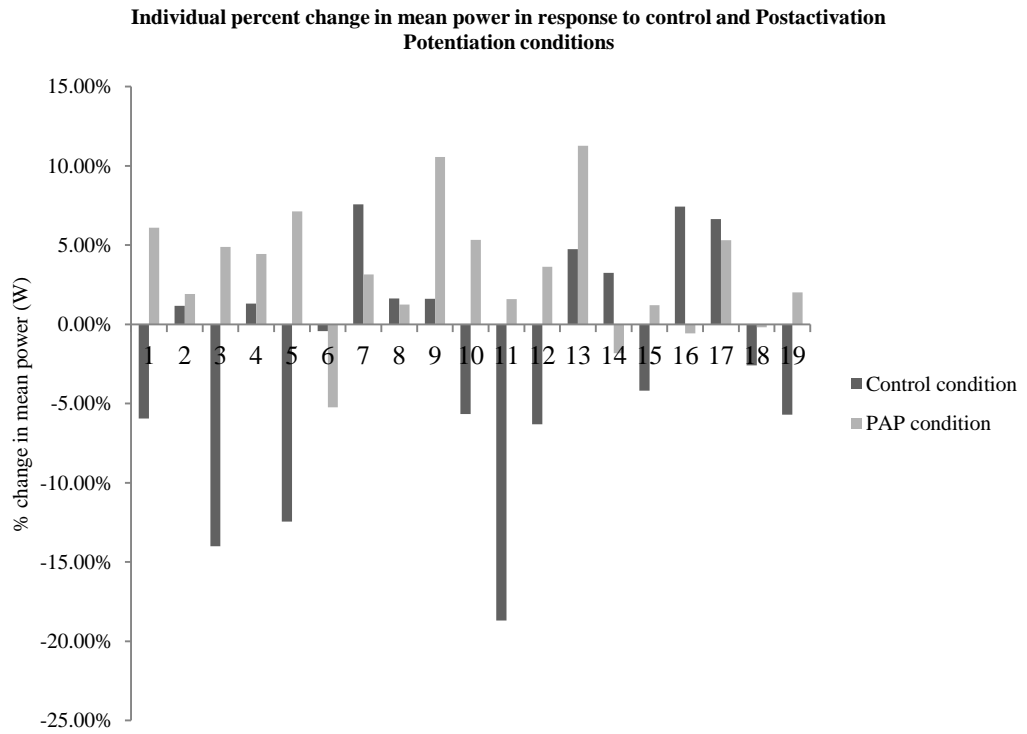
In general, greater percent changes (positive) were observed in all other performance measures following the experimental PAP protocol when compared to the control condition, with the exception of peak force. However, these differences were unclear and trivial and likely due to constraints of measurement error or individual differences in responses affecting overall mean measures. Mean measures of velocity, power and force expressed greater change in change in means and ES, when compared to their respective peak measures. Several jump squat variables (mean velocity, mean and peak power, and jump height) were observed to have negative responses following the control condition.

*Table 4.3.* Summary of percent change in control (CON) and back squat Postactivation Potentiation intervention (PAP) countermovement jump performance means ( $\pm s$ ), delta change in means ( $\Delta\%$  mean) between CON and PAP conditions, with effect size and 90% confidence limits (CL), and qualitative interpretation of PAP intervention ( $N=19$ ; log transformed data).

	% change CON $\pm s$	% change EXP $\pm s$	$\Delta\%$ mean (90% CL)	ES (90% CL)	Qualitative outcome
Mean Power (W)	-2.4 $\pm$ 8.0	3.2 $\pm$ 4.0**	5.7 (2.1-9.5)**	0.36 (0.13-0.59)**	Small (positive)
Peak power (W)	-0.2 $\pm$ 5.9	2.4 $\pm$ 5.0	2.7 (-0.6-6.0)	0.14 (-0.17-0.45)	Unclear (no effect)
Mean velocity (m.s <sup>-1</sup> )	-0.9 $\pm$ 6.0	2.4 $\pm$ 3.7**	3.3 (0.9-5.7)*	0.39 (0.11-0.67)*	Small (positive)
Peak velocity (m.s <sup>-1</sup> )	0.9 $\pm$ 3.9	1.5 $\pm$ 4.4	0.7 (-1.6-3.0)	0.08 (-0.20-0.36)	Unclear (no effect)
Mean force (N)	0.3 $\pm$ 1.5	0.8 $\pm$ 2.4	0.5 (-0.5-1.5)	0.04 (-0.04-0.12)	Unclear (no effect)
Peak force (N)	1.9 $\pm$ 3.3	1.9 $\pm$ 5.3	0.0 (-1.9-1.9)	0.00 (-0.10-0.10)	Unclear (no effect)
Mean RFD (N.s <sup>-1</sup> )	1.4 $\pm$ 8.1	4.0 $\pm$ 10.5	2.6 (-2.1-7.5)	0.09 (-0.07-0.25)	Unclear (no effect)
Jump height (cm)	-1.1 $\pm$ 7.8	1.8 $\pm$ 6.8	3.0 (-1.5-7.6)	0.17 (-0.09-0.43)	Unclear (no effect)

*Notes:* RFD = rate of force development; ES = effect size; \*( $p \leq 0.05$ ) and \*\*( $p \leq 0.01$ ) denote statistically significant difference.

The individualised variation in participant response to the control and PAP conditions is reported in Figure 4.1.



*Figure 4.1.* Individual percent change in mean power in response to control and Postactivation Potentiation conditions.

A summary of Pearson correlation coefficient between magnitude of delta change in jump squat performance measures, as well as between participant 1RM and relative 1RM back squat loads and delta change in jump squat performance are reported in Table 4.4 and Table 4.5, respectively.

An increase in mean velocity was associated with strong ( $r=0.63, p=0.14$ ) increases in mean power whilst a small ( $r=0.23, p=0.03$ ) increase in peak velocity was associated with increases in mean power. Similarly, strong Pearson moment correlations were also observed between changes in peak power and peak velocity ( $r=0.76, p=0.12$ ) and peak force and RFD ( $r=0.69, p=0.45$ ). No significant relationship between 1RM scores (both absolute and relative) and the magnitude of change in jump squat variables was observed.

Table 4.4. Correlations between individual participant  $\Delta\%$  change following control and experimental jump squat conditions, with 90% confidence intervals (CI) ( $N=19$ ; log transformed data).

	Mean velocity	Peak velocity	Mean Power	Peak power	Mean force	Peak force	Mean RFD	Jump height
Mean velocity		0.57 (0.23-0.79)*	0.63 (0.32-0.82)	0.57 (0.23-0.79)	-0.20 (-0.55-0.21)	0.17 (-0.24-0.52)	0.55 (0.2-0.77)	0.48 (0.11-0.73)
Peak velocity			0.24 (-0.16-0.58)*	0.76 (0.53-0.89)	0.06 (-0.34-0.44)	-0.06 (-0.44-0.34)	0.21 (-0.2-0.55)	0.56 (0.22-0.78)
Mean Power				0.33 (-0.07-0.64)	-0.14 (-0.5-0.26)	0.30 (-0.1-0.62)**	0.42 (0.04-0.7)	0.05 (-0.43-0.35)
Peak power					-0.10 (-0.47-0.3)	0.15 (-0.25-0.51)	0.31 (-0.09-0.62)	0.23 (-0.18-0.57)
Mean force						0.05 (-0.35-0.43)	-0.30 (-0.62-0.1)	0.25 (-0.15-0.58)
Peak force							0.69 (0.41-0.85)	0.04 (-0.36-0.42)
Mean RFD								0.22 (-0.19-0.56)
Jump height								

Notes: RFD = rate of force development; \*( $p \leq 0.05$ ) and \*\*( $p \leq 0.01$ ) denote statistically significant difference.

*Table 4.5.* Correlations between participant absolute and relative 1RM and  $\Delta\%$  change in jump squat performance, with 90% confidence intervals ( $N=19$ ; log transformed data).

	Mean velocity	Peak velocity	Mean Power	Peak power	Mean force	Peak force	Mean RFD	Jump height
1RM	-0.15 (-0.51-0.25)	0.03 (-0.36-0.41)	-0.08 (-0.32-0.46)	-0.14 (-0.5-0.26)	0.03 (-0.36-0.41)	-0.08 (-0.32-0.46)	-0.22 (-0.56-0.19)	-0.07 (-0.45-0.33)
Relative 1RM	-0.24 (-0.58-0.16)	0.07 (-0.33-0.45)	-0.24 (-0.58-0.16)	0.09 (-0.31-0.46)	-0.06 (-0.44-0.34)	-0.19 (-0.54-0.22)	-0.21 (-0.55-0.2)	-0.17 (-0.52-0.24)

*Notes:* RFD = rate of force development; \*( $p \leq 0.05$ ) and \*\*( $p \leq 0.01$ ) denote statistically significant difference.

## CHAPTER 5 – DISCUSSION

The primary finding of this research was that an elite endurance-trained rowing population exhibited unclear to small (positive) changes in CMJ squat performance measures in response to a conditioning stimulus that aimed to elicit a PAP response. Mean power showed a small positive magnitude of change following the experimental PAP condition, likely achieved through a greater mean velocity. The methods used to measure the magnitude of change were predominantly shown to be reliable and sensitive; however measurement errors constrain the interpretation of some variables. Given the findings of this study and the scope of existing research, consideration should be given to PAP effects as indistinguishable from that of individualised warm-up effects, and it is proposed that it is in this context by which practitioners should view the practical applications. Furthermore, the measurement of these effects may underpin or influence other practical applications currently utilised in the training of endurance athletes.

Based off the current scope of PAP research, this study exposed participants to conditions to theoretically induce a PAP response; a multiple-set, concentric-speed emphasized, and moderate-load intensity (with appropriate rest) protocol, using a squat activity that biomechanically simulated the criterion CMJ assessment. Additionally, we recruited an elite level, endurance-trained population of rowers which intentionally contrasts populations used to establish currently accepted conditions to optimise PAP responses.

Of specific interest therefore was the greater (positive) magnitude of change in CMJ mean power in response to the conditioning stimulus than in the control condition, in this study. These findings are in keeping with other PAP studies that have reported

beneficial improvements in power where a CMJ was used as the determinant task (Boullosa et al., 2013; Kilduff et al., 2011; Kilduff et al., 2008; McCann & Flanagan, 2010; Mitchell & Sale, 2011; Nibali et al., 2013; Seitz et al., 2014). It appears in this study that change in mean power is strongly associated with changes in peak and mean velocity ( $r=0.76$  and  $r=0.63$ , respectively). This is perhaps unsurprising given some of the proposed mechanisms of PAP and the nature of jump task; an upwards and rightwards shift of the force-velocity curve, wherein the muscular velocity obtained improves for the same system load (Sale, 2002). However, we did not observe meaningful changes in RFD (3.0%, ES=0.17), in contrast studies which have reported positive changes in this measure from PAP protocols (Gilbert et al., 2001; Kilduff et al., 2008; Nibali et al., 2013). The unclear effect is likely due to constraints of measurement error or reflective of the characteristics of the participant group.

In order to fully examine the magnitude by which participants respond to PAP and, in the case of elite athletes where responses may be relatively small, assessments must be both reliable and sensitive enough in order to detect meaningful changes. Overall methodologies of assessment of ballistic capabilities, such as vertical jump performance, have been deemed highly reliable (ICC=0.83-0.99, CV<6.5%). Consideration must also be given to the specific system of measurement used, the protocol utilized and the practicality of use (McMaster, Gill, Cronin & McGuigan, 2014). With respect to the continuum of variables assessed in this thesis, all but two variables, RFD (CV=6.6%; ICC=0.95) and peak velocity (CV=4.2%, ICC=0.78), exceeded the determined criteria for suitability of inclusion (CV≤5%, ICC≥0.90). It is an acknowledged limitation of the thesis that dip depth during the CMJ was not standardised, with participants self-selecting the range by which performed the test. However, while no change in average dip height between control and PAP conditions



was observed (-1.2%, ES=-0.9), individual variation in the CMJ strategy used or further systematic bias in the execution of the task (i.e. familiarity, learning experiences and/or motivation) accounts for observed error of measurement in these variables (Cormack, Newton, McGuigan & Doyle, 2008). It is possible that using a different cueing strategy (e.g. 'jump for speed') to the instruction employed ('jump for height') may have been able to reduce the magnitude of error of these measures (Cormack et al., 2008).

Research suggests PAP responses are highly individualised; participants responding either positively or negatively for the same conditioning stimulus, even amongst relatively homogenous participant groups (Feros et al., 2012; Lim & Kong, 2013; Nibali et al., 2013; Weber et al., 2008). Our study further supports this contention, with large variation in mean power observed in individual PAP responses (Figure 4.1). While on the average the magnitude of change was small, certain individual changes were more markedly improved following the experimental condition than others. We are unable to draw accurate conclusions as to how the PAP protocol may or may not have influenced the magnitude of individual change with only one experimental PAP condition utilised. For example, given that PAP is a combination of both physiological potentiation and fatigue, and that the manifestation of these are influenced by external factors such as the intensity and volume exercise stimulus, experimental conditions that further manipulated these variables may have made more clear the relative influence of protocol variables upon the magnitude, or lack of, PAP response in individuals.

We found no meaningful relationships between 1RM scores (both absolute and relative) and the magnitude of change in jump squat variables. This is in contrast to several studies which have shown a strong relationship between strength and the

magnitude of PAP response (Duthie et al., 2002; Kilduff et al., 2008; Seitz et al., 2014; Young et al., 1998). Ruben et al. (2010) suggested that very strong individuals (back squat  $\geq 2.0x$  bodyweight) produced significantly greater degrees of potentiation in comparison to weaker individuals ( $< 1.7x$  bodyweight). Given the lack of studies involving endurance trained participants, the strength and PAP responses relationship is predominantly based upon studies recruiting strength and power athletes, who inherently possess a higher proportion of faster twitch fibres (IIA and IIX) (Hodgson et al., 2005). Hamada et al. (2000) reported that participants who possess a predominance of fast twitch fibres will elicit greater magnitudes of PAP response than those who possess a majority of slower twitch fibres. As elite rowers possess a predominance of type I muscle fibres, it would seem imprudent to compare and apply the observations of studies involving more explosive participants to the rowing population (Steinacker, 1993).

Unsurprisingly in this study, the relative 1RM (1.52x bodyweight) was comparatively lower when compared to that of studies recruiting strength-trained participants. However, acknowledging individual variations in 1RM, PAP responses and noting weight training experience ( $> 3$ -years), we expected some relationship between strength and PAP response to exist given the current body of literature (Seitz et al., 2014). It can only be concluded that the PAP responses evoked did so via mechanisms independent of both absolute and relative strength. It may potentially be the case that this phenomenon may be attributed to slow twitch fibre type composition or the endurance training of rowers (Hamada et al., 2000). If not fibre type or training history, it is perhaps interesting to consider that the PAP conditioning stimulus instead may have influenced, through reflex potentiation pathways, the ability to better activate and coordinate muscular contraction (Trimble & Harp, 1998). The often negative

responses seen in during the control condition may simply be reflective of a lack of adequate neural stimulation assisting with muscular coordination during a high velocity task (Etnyre & Kinugasa, 2002).

This study is unique in that few studies have examined PAP response in elite, Olympic level participants. Additionally, to the author's knowledge, only one other study has attempted to examine the PAP response of elite endurance athletes in response to a functional conditioning stimulus. Feros et al. (2012) examined the effectiveness of a conditioning stimulus in eliciting improved performance in 1,000-meter rowing ergometer performance in elite rowers. In contrast to the present study, Feros et al. (2012) utilized a seated 5x5-second isometric conditioning stimulus, with 15-second rest intervals, on a rowing ergometer (~110° knee flexion, relatively upright trunk position, and elbows slightly flexed). The rationale for the relatively high-intensity/low-volume protocol was an attempt to maximise PAP responses whilst reducing the onset of fatigue (Feros et al., 2012).

Feros et al. (2012) noted that, whilst performance over the initial 500-meter splits was greater for the PAP condition, increased fatigue over the final 500-meter to 1,000-meter splits was evident. Interestingly, they observed mean power output was decreased and the mean split time was slower over the final 300-meters (i.e. 700-meters to 1,000-meters) after the PAP condition. Given that rowing competition is performed over a distance of 2,000-meters, it is difficult to advocate the application of the PAP protocol utilized by Feros et al. (2012) as part of preparations. Further to this, a greater increase in accumulated blood lactate (14.3%) was noted after the PAP condition. Additionally, methodological issues may limit the extent to which these findings can be attributed to PAP, fatigue or changes in rowing technique and race-pacing strategy

employed. An examination of the PAP protocol using a set stroke-rate assessment would go some way to providing a clearer understanding of changes in stroke power, length or force. Subsequently, for practitioners, the findings of Feros et al. (2012) and the current study may together provide a more appropriate framework from which to view PAP: our study observing increases in velocity and power during each rep (jump) at a fixed rating.

The physiological mechanisms responsible for PAP responses as reviewed appear to be multifactorial and highly individualised. It is an apparent constraint within the field of PAP research in the opinion of this author, that not one study has comprehensively related magnitude of changes in performance with changes across the multiple and seemingly interrelated physiological responses to contractile work (e.g. neural, architectural, hormonal, metabolic, psychomotor) in a unified model. It is the author's opinion that the vast spectrum of mechanisms complicates our understanding and application of the phenomenon for a practitioner. As a result, several applied studies instead attribute acute performance improvements to PAP, whilst failing to quantify change in accepted PAP mechanisms (Nibali et al., 2013). For a practitioner, such discrepancies, combined with conflicting results within the literature about any plausible performance benefits to PAP, is confounded by what appears to be an ever broadening array of the suspected mechanisms. Furthermore, as proposed physiological mechanisms are inseparable from traditional aspects of a 'warm-up', it is difficult to comprehensively define all probable causes of potentiation presently. Thus to establish a simple or unified model of PAP is unlikely. While a 'unified' physiological mechanism model is not without merit, practitioners are more interested in changes in performance, and in adjusting PAP protocols to increase these observed benefits, than the possible mechanisms explaining enhancement benefits (MacIntosh et al., 2012).

To that end, it is proposed by this author that there should be a redefinition of the PAP phenomenon. This definition would instead encapsulate the two predominant mechanisms of PAP, namely twitch and reflex potentiation, within a broader acute physiological enhancement (APE) concept inclusive of all other recognised physiological responses to contractile work reported in the literature i.e. mechanical, hormonal, metabolic, thermal, psychomotor (Crewther et al., 2011; Etnyre & Kelley, 1989; Etnyre & Kinugasa, 2002; Guggenheimer et al., 2009; Thatcher et al., 2012; Zois et al., 2011). As the contributing mechanisms are better understood and the clarity of parameters to examine PAP refined, the individualisation of protocols will likely remain.

In light of this, it is critical for practitioners to be cognizant of the intended practical applications of this present study, as with previous PAP studies. Within the pre-competitive context, the intended benefit of a PAP response is ultimately driven by the desire to optimise ones physical state to compete or perform work maximally (DeRenne, 2010). For elite level competition, marginal PAP benefits is magnified in importance, as performance improvements of as little as 0.3 times the typical error can have a meaningful impact on final rankings (Hopkins, 2004).

Most research has examined PAP as phenomenon independent of performance, when viewed in context of competition, PAP methodology and purpose can be considered indistinguishable from that of the intended of traditional warm-ups (Perrier, Pavol & Hoffman, 2011; Smith, 1994). Complimenting PAP evidence, the effects of a warm-up also appear to differ according to the stimulus, and the suitability of protocols used, on any subsequent task. For example, increased levels of lactate, induced by a

high-intensity warm-up (e.g. at anaerobic threshold), may benefit subsequent explosive performance (e.g. 20-meter sprint performance) via attenuation of fatigue-induced loss of force (Anderson, Landers & Wallman, 2014).

The trivial and often negative responses observed in the control condition in our study may suggest that the standardised warm-up on average failed to prepare participants for CMJs. Alternatively, it may be the case that any enhancement achieved dissipated within the 5-minute rest period provided before CMJ performance assessment. With this in mind, warm-up and PAP effects can be considered mutually inclusive of each other and, arguably, this contention could be made for all studies examining PAP on performance. The practical implication for practitioners therefore places considerable emphasis upon the individualised assessment and monitoring of broader PAP strategies prior to critical performance tasks. With context to rowers, it may be appropriate to examine the efficacy of any intended PAP strategies upon measures of peak stroke-power initially at fixed ratings as suggested earlier, before expanding to time-trial performance.

In the same context, it may be more applicable to consider whether small increases in mean power and velocity have any practical or meaningful benefit as a training stimulus to induce any chronic adaptations or performance benefits, as intended with complex training. Complex training is effectively predicated on the utilisation of current PAP concepts, alternating high-load with low-load exercises of similar biomechanical movements (Carter & Greenwood, 2014). For the strength and conditioning coach, the ability of endurance trained rowers to elicit small positive responses may provide validation for the use of complex training methods in this population. Additionally for rowing athletes, where strength training sessions may be

constrained due to the requirements of on-water training, the ability to better optimise warm-up strategies to ensure greatest utilisation and adaptation to sessions would seem a logical extension.

For rowing athletes, work by Lawton, Cronin and McGuigan (2013) has established that lower body power is a strong predictor of 2,000-meter rowing ergometer performance. Although the requirement for individualisation of PAP protocols is highly recommended, it stands to reason that complex training may prove a suitable addition to the annual strength and conditioning plan for endurance athletes as a means of improving muscular power output and therefore, rowing performance. It may also prove advantageous to incorporate intra-set rest or cluster training methodologies, utilising the intermittent performance of exercises and manipulating small periods of rest, for increased stimulus in both the conditioning and determinant task (Boullosa et al., 2013; Girman, Jones, Matthews & Wood, 2014; Lawton, Cronin & Lindsell, 2006). However, further work is required to determine the specific chronic adaptations elicited from, and effectiveness of, these training methods with this population.

The wider examination and utilisation of PAP may also have practical applications for practitioners with regards to the assessment of fatigue. Specifically, the use of CMJs has been proposed as a means of assessing neuromuscular fatigue indexes in athletic populations, both acutely and chronically (Cormack, Newton & McGuigan, 2008; Hoffman, Nussle & Kang, 2003; McGuigan, Doyle, Newton, Edwards, Nimphius & Newton, 2006; Thorlund, Aagaard & Madsen, 2009). Whilst baseline measure of fatigue may provide some information as to the effective net state of an individual, we contend that additional assessment of the individual magnitude of response to PAP strategies may be a more contextual and practical assessment, particularly amongst

endurance athletes. Given that endurance athletes will continuously train under a degree of accumulated fatigue, evidence of neuromuscular fatigue will not be an uncommon or even unintended observation (Lehmann, Baur, Netzer & Gastmann, 1997). Instead, for the practitioner it is perhaps more valid to assess the extent to which any observed fatigue can be mediated by a targeted PAP intervention with the intent to maximise training response and efficacy. It may be that failure to elicit a PAP response in an athlete with an individually designed protocol is a more significant indication of fatigue than that used in the presence of little or no prior contractile work. Conversely however, care must be taken to ensure that the conditioning protocol itself doesn't further contribute to any fatigued state. The application of individualised monitoring approaches in differing training and competitive contexts warrants further investigation.

Methodological limitations, in addition to the CMJs not being standardised to a set dip height, place constraints upon the utilisation of findings in this thesis. Central to this is the use of only one experimental condition. The design of the experimental condition itself was predominantly based off the findings of a recent meta-analysis which, due to the lack of relevant research, was not focused on the specific responses of endurance trained individuals (Wilson et al., 2013). Greater manipulation and recording of experimental variables such as rest intervals and intensity may have resulted in the ability to present a framework exhibiting more homogenous findings. Further scientific examination of the influence of stimulus variables upon the magnitude of response is strongly recommended.

In addition, whilst every step was taken to ensure that test-retest environments were as reproducible as possible, the fact remains that the research participants, influenced by crew allocations, had differing training requirements to each other during



the week long wash out. As such, it is probable that participants were subject to varying levels of accumulated fatigue that likely impacted upon results.

## **CHAPTER 6 – SUMMARY, PRACTICAL APPLICATIONS AND FUTURE RESEARCH DIRECTIONS**

### **6.1 SUMMARY**

In the quest to acutely enhance physiological performance, PAP has been proposed as a means by which to achieve greater physiological power through manipulation of previous contractile work (Chiu et al., 2003). However, there is a lack of applied PAP studies conducted with elite, Olympic level athletes, and only one study identified that examined an elite endurance-trained population (Feros et al, 2012). Whilst the mechanisms responsible for PAP are increasingly complex, and further mediated according to the properties of the conditioning stimulus, it appears that PAP effects are greatest amongst highly-trained strength and power subjects (Chiu et al., 2003; Kilduff et al., 2008; Seitz et al., 2014). Therefore, highly-trained endurance rowers presented a unique opportunity to examine PAP in an applied setting within a highly specialised population.

A multiple-set, concentric, and moderate-load intensity experimental condition that biomechanically simulated the criterion assessment with appropriate rest afford was constructed in order to examine the possible effects of PAP amongst this specific population. The reliability and precision of the measurement assessment was deemed to be suitable for most of the variables of interest, with RFD and peak velocity exceeding the limits of the inclusion criteria. The magnitude of observed changes ranged from unclear to small (positive). Specifically, mean power (5.7%, ES=0.36) and mean velocity (3.3%, ES=0.39) exhibited the greatest magnitude of change between control and experimental conditions. These findings are in keeping with the currently accepted model of PAP, yet add value to the current body of literature given the endurance trained and elite nature of participants. Furthermore, and in keeping with findings of other

studies, responses exhibited a high level of individual variation. In contrast to the majority of studies, no relationship between both the absolute and relative levels of strength and magnitude of change in observed variables was noted.

The use of a CMJ has been shown to be a valid ecological assessment of some aspects of PAP (Nibali et al., 2013); however we were unable to infer the influence of other physiological responses and their impact upon the observed magnitude of change. Traditionally, twitch and reflex potentiation confer the greatest level of attribution to the current model of PAP, it is apparent that they do not do so in isolation of each other and other physiological responses. The lack of a unified construct as to the specific interaction of individual physiological responses to contractile work, and the additional influence of conditioning stimulus variables upon it, exists as a noted constraint of the field. However, this does not necessarily diminish the significance of studies that have shown positive and beneficial responses in physiological performance to varying protocols.

## 6.2 PRACTICAL APPLICATIONS

Critically, this thesis has shown that elite endurance athletes may elicit small (positive) responses in mean power and velocity to a PAP conditioning stimulus, although individualisation appears to be a critical consideration with respect to optimising benefits. Given the findings of this thesis and the current state of PAP research, it may be appropriate to consider and redefine this area of research using a different context; one more reflective of the multifactorial nature of responses to contractile work. Our suggested redefinition of the PAP phenomenon as Acute Physiological Enhancement, encapsulates currently accepted mechanisms of PAP and seemingly synonymous warm-up methodologies and their intended purpose is proposed.

It is hoped that this more inclusive model will help to give better clarity and context to practitioners as to the critical outcome intended to be achieved by this field of research: an optimal and individualised strategy to enhance performance.

Additionally, practitioners may consider the use of these findings with regards to better individualising and improving the efficacy of pre-training and pre-competition strategies, incorporating complex and cluster training methodologies into endurance strength training regimes and examining the appropriateness of acute changes as a measure of fatigue.

### 6.3 FUTURE RESEARCH DIRECTIONS

With respect to the logical extension of the findings of this thesis, several avenues exist. Given the paucity of evidence regarding the magnitude of response in highly trained endurance trained participants the further manipulation of conditioning stimulus variables is suggested. With only one experimental condition examined, our ability to examine the specific way this highly specific group of participants, was limited. An examination of possible differing effects of stimulus including the load, volume, recovery interval and contraction type would appear to be appropriate research avenues and may serve to help establish a more accurate framework from which to develop individual protocols.

With this in mind, future research in endurance-trained participants would hopefully extend into performance benefits for specific sporting tasks. With rowers, the creation of better frameworks may allow for extension to additional tasks such as peak stroke power and, ultimately, on-water performance tests.

Future research may want to examine the efficacy of differing training methods that incorporate PAP methodologies such as complex and cluster training methods, and their acute and chronic responses in endurance athletes. In addition, the potential utilisation of acute responses as a more relevant method of monitoring fatigue may also exist as a worthwhile research endeavour.

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## APPENDICES

*Appendix 1. Ethics approval, Auckland University of Technology Ethics Committee*



29 October 2013

Mike McGuigan  
Faculty of Health and Environmental Sciences

Dear Mike

Re Ethics Application: **13/293 Influence of athlete training experience on post activation potentiation response in elite rowers.**

Thank you for providing evidence as requested, which satisfies the points raised by the AUT University Ethics Committee (AUTECSecretariat).

Your ethics application has been approved for three years until 29 October 2016.

As part of the ethics approval process, you are required to submit the following to AUTECSecretariat:

- A brief annual progress report using form EA2, which is available online through <http://www.aut.ac.nz/researchethics>. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 29 October 2016;
- A brief report on the status of the project using form EA3, which is available online through <http://www.aut.ac.nz/researchethics>. This report is to be submitted either when the approval expires on 29 October 2016 or on completion of the project.

It is a condition of approval that AUTECSecretariat is notified of any adverse events or if the research does not commence. AUTECSecretariat approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTECSecretariat grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at [ethics@aut.ac.nz](mailto:ethics@aut.ac.nz).

All the very best with your research,



Kate O'Connor  
Executive Secretary  
**Auckland University of Technology Ethics Committee**  
Cc: Ryan Turfrey [ryan.turfrey@hpsnz.org.nz](mailto:ryan.turfrey@hpsnz.org.nz)

## Participant Information Sheet

### Date Information Sheet Produced:

01/11/2013

### Project Title

Magnitude of Postactivation Potentiation Response in Elite Rowers.

### An Invitation

I, Ryan Turfrey, am a Masters student based through the Sports Performance Research in New Zealand at AUT-Millennium Institute, School of Sport and Recreation, Faculty of Health and Environmental Sciences. Additionally, I am a Strength and Conditioning Specialist with High Performance Sport New Zealand.

I would like to invite you to participate in a research study using power profiling to assess changes in power production following a lifting based warm-up protocol. Participation is entirely voluntary and you may withdraw at any time without any adverse consequences.

### What is the purpose of this research?

The purpose of this study is to investigate the changes in power production following loaded squats in endurance athletes based on training age. This study makes up part of my proposed Master of Sport and Exercise Science degree.

### How was I identified and why am I being invited to participate in this research?

You were identified as a participant for this research based on your level of involvement in Rowing New Zealand's program, responding to a poster advertisement, and by meeting all inclusion criteria as outlined in advertising for this research project. All participants are national level and highly trained athletes.

Exclusion criteria includes any injuries current, or in the past 2 weeks which have hindered or stopped normal training.

### What will happen in this research?

You will undergo pre-test assessment by means of a three repetition countermovement jump (CMJ) at bodyweight, with data captured via force platform and linear position transducer. During the Experimental condition group participants will undergo a three repetition by three sets back squat at  $\geq 80\%$  of their 1-repetition maximum, with 2 minute rest period between work sets. The back squat has been chosen owing to the familiarity of the exercise to all potential participants. Participants will then rest a

further 5 minutes before completing a post-test three repetition CMJ, again via force platform and linear position transducer. The C condition, following pre-test CMJ assessment, will rest the 5 minute period without further physical activity before completion of the post-test assessment. You will then cross-over condition on the following assessment day and follow the same protocol.

#### **What are the discomforts and risks?**

There are minimal anticipated discomforts and risks from participating in this testing. The training induced discomfort and fatigue will be similar to or less than that of your regular sport training and testing sessions.

You may experience some mild fatigue in your legs; this response is normal and triggered by the onset of any exercise. The other possible discomfort is delayed onset of muscle soreness (DOMS) on the day following or subsequent two days after testing, however due to the low level of activity this is unlikely.

#### **How will these discomforts and risks be alleviated?**

You will have the opportunity to familiarize yourself with the testing procedures.

If you do not feel you are able to complete the testing requested, you should notify the researcher immediately and the testing will be terminated.

Finally, you should notify the researcher, if you have a current injury or have had an injury within the last two weeks that might affect your performance, or that might be worsened or aggravated by the required activity. For example, any strains and sprains must be reported, specifically to the hip, knee and ankle.

#### **What are the benefits?**

By participating in this study, you will receive specific information about your body responds to a weighted warm-up protocol and how this may influence power production following. You will also improve our understanding of how potentiation protocols can be influenced by athlete experience, which will help improve the practice of our physiotherapists, strength and conditioning specialists and coaches.

#### **What compensation is available for injury or negligence?**

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

#### **How will my privacy be protected?**

The identity and results of each participant will be kept confidential. However due to the small number of elite participants that are being recruited for this research, it is possible but unlikely that people will be able to identify who participants are when the results are published. Only my primary supervisor (Prof. Mike McGuigan) and I will have access to, and analyze your results.

### **What are the costs of participating in this research?**

There is no cost to participation in this study. Time for study will be contained within your already allocated weight lifting sessions at Rowing New Zealand.

### **What opportunity do I have to consider this invitation?**

A response to this invitation would be appreciated by no later **than COB Friday 15<sup>th</sup> November, 2013**

### **How do I agree to participate in this research?**

If you would like to participate in this research, you need to sign the attached *Consent Form*, and return it to myself prior to participating in any of the tests. If at any stage after volunteering, you do not wish to participate in this research, please notify me as soon as possible. You may withdraw at any time without any prejudice.

### **Will I receive feedback on the results of this research?**

Yes, you can receive a summary of individual results once the information is ready for distribution (around one month after completing the study). Please check the appropriate box on the *Consent Form* if you would like this information. The results of your testing performance will only be given to your coach and/or physiotherapist (if applicable) with your permission (please check the appropriate box on the *Consent Form*).

### **What do I do if I have concerns about this research?**

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Prof. Mike McGuigan, [michael.mcguigan@aut.ac.nz](mailto:michael.mcguigan@aut.ac.nz), or mobile 021 605 179

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEK, Kate O'Connor, [ethics@aut.ac.nz](mailto:ethics@aut.ac.nz), 921 9999 ext 6038.

### **Whom do I contact for further information about this research?**


#### **Researcher Contact Details:**

Ryan Turfrey; email: [ryan.turfrey@hpsnz.org.nz](mailto:ryan.turfrey@hpsnz.org.nz) or cell 021 069 4774

#### **Project Supervisor Contact Details:**

Supervisor, Prof. Mike McGuigan, [michael.mcguigan@aut.ac.nz](mailto:michael.mcguigan@aut.ac.nz), mobile 021 605 179

**Approved by the Auckland University of Technology Ethics Committee on 29  
October 2013, AUTEK Reference number 13/293.**

<h1>Consent Form</h1>	 <p><b>AUT</b> UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKĀU RAU</p>
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**Project title: Magnitude of Postactivation Potentiation Response in Elite Rowers.**

**Project Supervisor: Prof. Mike McGuigan**

**Researcher: Ryan Turfrey**

- I have read and understood the information provided about this research project in the Information Sheet dated 01/11/2013
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I am not suffering from any injury, heart disease, high blood pressure, any respiratory condition (mild asthma excluded), any illness or any infection that will impair my physical performance (or that might be aggravated by the tasks requested).
- I agree to take part in this research.
- I wish to receive a copy of the report from the research (please tick one): Yes  No
- I agree to share the research results with my coach (please tick one): Yes  No

Participant signature:

.....

Participant name:

.....

Participant contact details (if appropriate):

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.....  
.....  
.....

Date:

**Approved by the Auckland University of Technology Ethics Committee on 29 October 2013 AUTEK Reference number 13/293**