DIFFERING ISOMETRIC CONTRACTIONS CAN AFFECT NEURAL EXCITABILITY

Kevin Wyld

A thesis submitted to the University of Bedfordshire in

partial fulfilment of the requirements for the degree of MSc by research

University of Bedfordshire

May 2011

Differing isometric contractions can affect neural excitability

Kevin Wyld

Abstract

Postactivation potentiation (PAP) of human skeletal muscle has been credited for improved performance in complex training situation, were a conditioning exercise is performed prior to a performance task. The mechanisms behind PAP have not been fully elucidated; it has been proposed that an increase in phosphorylation of the myosin regulatory light chains and/or increased spinal excitability could explain performance changes. However, which mechanism induces PAP has not been investigated as yet, while the optimum intensity of the conditioning exercise or the best rest period to induce optimal PAP levels has not been established. The purpose of the current investigation was to examine a range of different intensity conditioning contractions over a 60 minutes recovery period, on PAP response. **Method:** to gain reliability of the patellar tendon tap test a rubber tipped hammer was embedded into a machine. Twelve participants (8 males age 23.7 ± 4.9 yr, mass 78.3 ± 12.9 kg, height 1.75 ± 0.1 m and 4 females age 22 ± 3.2 yr, mass 60.6 ± 4.1 kg, height 1.66 ± 0.1 m) had three differing hammer tap forces (270 ± 0.79 N, CV 0.2 %, middle 252 ± 0.74 N, CV 0.2 % and lowest 121 ± 0.64 N, CV 0.5 %) delivered in a randomised order over 3 x 10 minute periods with sporadic intervals between each tap. The hammer tap force that reported the highest reliability was then used in a follow up study. The second study investigated skeletal muscles response to differing intensities of conditioning exercise, over a 60 minute rest period. The conditioning exercises consisted of 3 sets

of isometric leg extensions of the dominant leg at 100%, 90%, 80% and 70% of a 1 RM, each set consisted of a 5 s contraction followed by 55 s passive rest. Subsequent neural excitability and intra-muscular activation were assessed in response to the patellar tendon tap test. Neural excitability was assessed via integrated EMG responses and goniometer movement of the lower leg. **Results:** The highest force (270 ± 0.79 N) gave the best reliability for hammer tap contact to the start of lower limb movement (17.3 %) compared to the other two hammer forces, this was used in the second study. In the second study no significant differences were observed between the hammer tapping the tendon and the start of muscle activation ($F = 1.843$, $p>0.05$) or muscle activation to the start of lower limb movement ($F=1.587$, $p>0.05$) between any of the conditioning contraction intensities or between any recovery periods. After 2 minutes recovery there was a trend for the maximal intensity conditioning exercise to reduce neural excitability. After 4 minutes rest all intensities of conditioning exercise caused a trend for an increase in neural excitability and intra-muscle activation. **Conclusion:** The poor reliability of the patellar tendon tap test maybe due to individual variations in tendon biology. Although this study improved the reliability compared to previous work, the technique was still too varied to ascertain conclusive results, beyond trends in data. Therefore, reliability of this technique needs to be addressed further to allow it to be recognised as a method to measure spinal excitability. At this moment in time no definitive rest period guidelines can be given to coaches for complex training or even if it enhances performances over traditional training methods. It is therefore recommended that coaches should view this training modality with caution,

and not rely solely on this method, when more established valid methods to improve athletes' explosive power performance, are readily available.

Declaration

I declare that this thesis is my own unaided work. It is being submitted for the degree of MSc by research at the University of Bedfordshire.

It has not been submitted for any degree or examination in any other University

Name of Candidate: **Kevin Wyld** Signature: **.....**

Date; 1st May 2011

Acknowledgements

I would like to thank my supervisors Dr Paul Castle and Iain Fletcher for their support throughout this MSc by research project, which without their guidance would not have been possible.

I am also grateful to Warwick Riley for his technical support in building the contraption to house the patellar hammer and guidance with the other equipment.

A great deal of gratitude also goes to all those who participated for their commitment to the studies.

Table of Contents

Illustrations

Abbreviations

ATP: Adenosine Triphosphate

EMG: Electromyography

H-Reflex: Hoffman Reflex

IMVC: Isometric Maximal Voluntary Contraction

MHC: Myosin Heavy Chain

MLC: Myosin Light Chain

MLCK: Myosin Light Chain Kinase

MRLC: Myosin Regulatory Light Chains

MREC: Myosin Regulatory Essential Chains

PAD: Postactivation Depression

PAP: Postactivation Potentiation

PTR: Patellar Tendon Reflex

RFD: Rate of Force Development

1 RM: 1 Repetition Maximum

TT: Tendon Tap Test

Chapter 1

1.0 Introduction

1.0 Introduction

Many sports rely on actions that require maximal force production in a minimal time provided (Siff, 2003) and this is termed as explosive power, or the rate of force development (RFD). In sports where success is measured in milliseconds or hundredths of a millimetre, such as sprinting, achieving high percentages of maximal force in the restricted time may give athletes an advantage over their competitors. However, many sporting actions are completed in time spans that restrict the attainment of maximal force (Aagaard et al, 2002).

Coaches use a variety of training methods to increase the explosive power of athletes. Traditional strength and power exercises such as the back squat and power cleans have been shown to improve explosive power (Siff, 2003).

During the early 1970s the East Germans introduced the theory of complex training (Ebben, 2002). It was reported that by completing a traditional strength exercise prior to a biomechanically similar dynamic exercise, improved performance in the latter exercise occurred (Ebben, 2002). The first exercise was proposed to act as a conditioning exercise that produced a muscle contractile history that influenced the following exercise (Sale, 2004). Such performance enhancement has been called postactivation potentiation (PAP) (Ebben, 2002: Sale, 2004), attributed to increased excitation at the neuromuscular and intra muscular level (Mahlfeild et al, 2004: MacIntosh, 2003: Gullich and Schmidtbleicher, 1995).

The efficacy of this type of training still remains unclear, however due to the many variables that may influence performance. Differences in the type and intensity of the initial conditioning exercise as well as differences in the duration of rest, prior to the performance exercise exist within the literature. Therefore, the primary aim of this thesis was to investigate the impact of various intensities of conditioning exercise and durations of recovery upon PAP.

The thesis is presented in the following chapters.

Chapter II provides a review of relevant literature starting with an overview of muscle contraction, followed by an explanation of PAP and the literature that has investigated PAP on athletic performance. The literature review culminates with a section on the current limitations within the literature and measurement of PAP before presenting the aim and hypothesis of the thesis.

Chapter III presents the first experimental study that examined the reliability of the patellar tendon tap test for the accurate determination of PAP.

Chapter IV presents the second experimental chapter that examined four different intensities of conditioning exercise and a variety of rest periods upon the PAP response.

Chapters V presents the concluding remarks of the thesis.

Chapter 2

2.0 Review of the Literature

2.0 Review of Literature

2.1 Skeletal muscle contraction

Skeletal muscle contraction consists of a number of stages. Firstly, action potentials travel through the afferent nerves to the motor junction on the muscle cell membrane (McArdle et al, 2001), where the chemical Acetyl-Choline is released and diffuses across the synaptic gap to receptors located on the sarcolemma (Marieb, 2001). This chemical allows the subsequent transfer of action potentials to propagate across the cell membrane and down through the T-tubules (McArdle et al, 2001).

Calcium (Ca^{2+}) is then released by the sarcoplasmic reticulum lateral sacs into the sarcolemma (Marieb, 2001). Calcium then binds with troponin-tropomyosin, releasing the binding site of the actin protein filament to interact with myosin protein filament. During the muscle action actin combines with myosin ATPase to split Adenosine Triphosphate (ATP), creating an energy release that produces a tension and myosin cross-bridge movement (McArdle et al, 2001).

Adenosine Triphosphate binds with the myosin S1 head breaking the actin-myosin bond, creating a sliding action where the two protein filaments cross each other in a ratchet fashion, thus causing the sarcomeres to shorten (McArdle et al, 2001). This movement is then transmitted through the passive components of skeletal muscle (connective tissue) and applied through the tendon to the musculo-

tendinous junction attaching muscle to bone. When these passive components have reeled in external movement is then possible (McArdle et al, 2001).

When neural action activation ceases Ca^{2+} is pumped back into the sarcolemma, allowing the troponin-tropomyosin complex, to inhibit actin's interaction with myosin, thus allowing the muscle to relax (McArdle et al, 2001). However, if the neural activity is continuous, high levels of Ca^{2+} remain in the sarcoplasm allowing an extended contraction time for the muscle to produce maximal force (McArdle et al, 2001).

It should be noted that myosin is thicker than actin, giving the muscle a striated effect (Marieb, 2001) which can be split into two components: the S1 head and its fibrous body or myosin heavy chain (MHC) (Gardiner, 2001). Wrapped around the lever arm of the S1 sub-fragment are two sets of myosin light chains (MLC) that help to transmit and stabilize movements of the S1 head, to the fibrous backbone of the myosin molecule (Gardiner, 2001). These MLC can be sub-divided further into two elements, the myosin essential light chains (MELC) and the myosin regulatory light chains (MRLC). The primary function of the MRLC is to affect the cross-bridge cycling of actin and myosin through phosphorylation, whilst MELC may influence shortening velocity (Gardiner, 2001).

Dynamic and isometric muscle contractions have been used to induce the PAP phenomenon. A dynamic contraction involves the muscle creating a force by working either through shortening (concentric) or lengthening (eccentric) or a combination of both (Siff, 2003). Isometric contractions involve creating a force whilst the joint stays at the same angle. Each type of contractions requires time to gain peak force, known as rate of force development (RFD) (Siff, 2003). If the time from the muscle being stimulated to the muscle being activated can be decreased, an increase in RFD will be produced.

2.2 Physiological mechanisms of PAP

Three mechanisms have been proposed to explain the PAP phenomenon. These are increased neuromuscular excitability, increased phosphorylation of the myosin light chains and changes in muscle pennation angle (Tillin and Bishop, 2009). Each mechanism will now be discussed.

2.3 Neuromuscular excitability

Two mechanisms have been proposed to increase neuromuscular excitability. Firstly, Gullich & Schmidtbeicher (1996) proposed stimulation of the afferent nerves; activate the adjacent α-motor neurons, elevating the transmittance of excitation potentials across the synaptic junctions at the spinal level that may last several minutes. This allows the subsequent exercise to benefit from increased post-synaptic potentials for the same amount of pre-synaptic potentials. This can

improve the RFD and may last between 4 and 11 minutes (Hrysomallis and Kidgell, 2001: Hultborn, et al, 1996).

However, immediately post exercise, a lack of neurotransmitters released pre-synaptically can cause postactivation depression (PAD) (Hultborn, Lilert, Neilson, et al, 1996) (fig 1), and may decrease exercise performance for several minutes (Hultborn et al,1996) depending on training status (Trimble and Harp,1998)

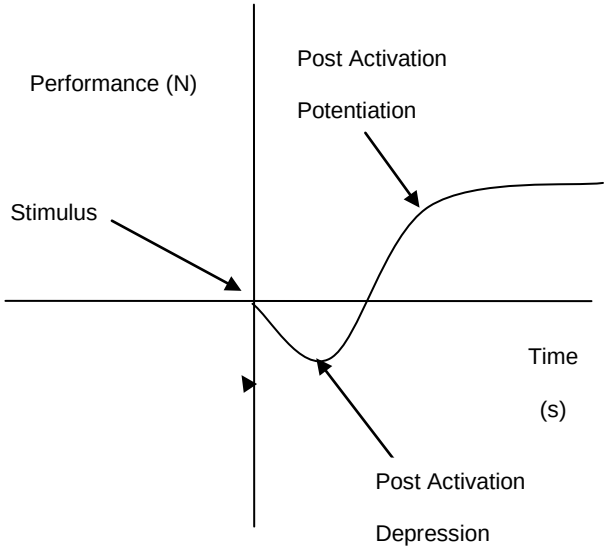


Fig.1: Effects of Post Activation Depression (PAD) and Post Activation Potentiating (PAD) upon force (N) after an electrical stimulus at the spinal column.

The second proposed mechanism to explain PAP is that a reduction in neurotransmitter failure across the synaptic junctions occurs due to the autonomic, protective, activation safety mechanism (Hirst et al, 1981, cited in Tillin & Bishop, 2009). Alpha-motor neurons are recruited in an all-or-none fashion, where pre-synaptic neurotransmitter release, coincides with post-synaptic receptor sensitivity (Luscher et al, 1983, cited in Tillin & Bishop, 2009). Several high intensity muscle contractions may decrease neurotransmitter failure, through enhanced neurotransmitter release, or a reduction in branch point failure along the afferent neural nerve fibres (Enoka, 2002). Completing a set of resistance type exercise training may induce this effect that can last several minutes post contraction.

Which of the two mechanisms suggested for increased neural excitability is more prominent has not been elucidated. It is possible that they may contribute together to gain improved muscle activation.

2.4 Phosphorylation of the Myosin Regulatory Light Chain

Postactivation potentiation has also been proposed to occur due to changes at the muscle level. With repeated muscle contractions, increased concentrations of Ca^{2+}, activates the myosin light chain kinase (MLCK) enzyme (MacIntosh, 2003). This enzyme phosphorylates MRLC, which in turn enhances the sensitivity of the actin-myosin binding sites to calcium (MacIntosh, 2003). This promotes a quicker

cross bridge cycling in future muscle contractions that promotes a greater RFD (Grange et al, 1993). Light-chain phosphatase production dephosphorylates MRLC, but acts relatively slowly compared to myosin light chain kinase (MacIntosh, 2003). This time frame allows an improved RFD, before it degenerates through the action of light-chain phosphatase.

There is little evidence that PAP increases acute maximal strength (Tillin and Bishop, 2009). As a consequence of myosin's sensitivity to calcium ions entering the cell at a faster rate, a quicker rate of cross bridge interaction occurs, rather than increased total calcium saturation that is required for maximal strength This suggests that athletes who require explosive power in a short time, to move their own bodyweight may utilize PAP to greater effect than those who predominantly require maximal strength.

2.5 The Pennation Angle of a Muscle

There is evidence that muscle's pennation angle may change with a conditional contraction. Malhfield et al, (2004) reported a 3 second isometric maximal voluntary contraction (IMVC) of the vastus lateralis resulted in a decrease in its pennation angle by 14.4º ($p<0.05$) and this lasted between 3-6 minutes. A relatively small increment in force production (0.9%) was reported which may be due to the counter force production activity of increased connective tissue/tendon compliance (Kubo et al, 2001).

Although this is not considered to be a primary mechanism of PAP, a decrease in pennation angle may aid the other two mechanisms already discussed to induce PAP and improved subsequent athletic performance.

The individual contributions of increased neuromuscular excitability, phosphorylation of the MLRC and change in angle of pennation have not been elucidated (Sale, 2004). This is in part due to the majority of literature being of an applied nature focused upon enhancement of performance outcomes, rather than mechanistic understanding of muscle physiology.

2.6 Literature showing that Postactivation Potentiation does affect athletic performance.

Radcliffe and Radcliffe (1996) reported an increase in horizontal counter-movement jump height performance after completing a warm up in addition to loaded jumps with a 3 minute rest between exercises. However, improved performance was only reported in males. No explanation was given for the increase in performance as the results were only reported in abstract form.

Young et al, (1998) reported an increase in loaded counter-movement jump height by a mean 1.1 cm after performing 2 sets of loaded counter-movement jumps followed by 1 set of 5 repetitions of half squats at 5 repetition maximum (RM) with a 4 minute rest between exercises. Though no mechanisms were measured, the

authors suggested that an increase in performance was due to increased spinal excitability.

Esformes et al, (2010) observed that repeated 3 x 3 heavy squats at 3 with 5 minutes rest compared to 24 contacts of lower body plyometric exercises improved counter-movement jump height, though they did not report the height gained. The authors acknowledged both spinal excitability and phosphorylation of the MLRC as the mechanisms, but did not indicate which explained the increase in performance. Due to the design of the study the authors couldn't explain why plyometrics did not induce PAP though they did indicate two possibilities, namely insufficient recruitment of muscle fibres to elevate post-synaptic potentials or the onset of fatigue as the exercises lasted over 70 seconds.

Similarly, Chui et al, (2003) reported an increase in explosive power after performing 5 sets of 1 rep of 90 % 1 RM back squats after 18.5 minutes in trained subjects. No mechanism was pinpointed to explain the results, although they provided a general discussion of all potential mechanisms.

Gilbert and Lees (2005) compared two modes of exercises; strength versus power, reporting 2 minutes was the optimal rest period for vertical jump performance, after completing 5 back squats at a weight that generated maximal power. Whilst 5 x 1 RM back squats reported peak vertical jump performance after

20 minutes rest, the authors suggest the phosphorylation of the MRLC was the mechanism behind PAP and improved performance.

From these studies, it is suggested that PAP can be induced to improve performance by several differing protocols though all studies used subjects that were used to doing the exercises prescribed (Esformes et al, 2010: Gilbert and Lees 2005: Chui et al, 2003: Young et al, 1998)

2.7 Literature showing that Postactivation Potentiation does not affect athletic performance.

Chadwick-Smith & Fry (2007) took muscle biopsies after performing leg extensions at 70 % of 1 RM followed by a 5 minutes rest and then another set of leg extensions finished the session. The authors reported an increase in phosphorylation of the MRLC though no difference in leg extension performance was seen.

Several reasons may explain the lack of enhanced performance. The IMVC may have produced central fatigue, and the rest period between the two exercises may not have been of sufficient time to decrease fatigue to the PAP phenomenon. The time of the conditioning contraction would have increased accumulation of hydrogen ions ($H^{+)}$ and phosphates (P_i) that may have interfered with neuromuscular activity. Another possibility is that the intensity and volume of the

conditioning exercise may not have induced sufficient PAP. Also the extra time required after recovery, to enable the muscle biopsies to be taken prior to the last set of leg extension was carried out, could have negatively affected subsequent performance.

Jensen and Ebben (2003) compared performance of a counter movement jump after rest periods of 10 seconds, 1, 2, 3, and 4 minutes after performing back squats at 5 RM. They reported no significant difference upon jump height, between treatments, although a decrease in performance after 10 seconds was reported which was not surprising due to insufficient time for phosphocreatine resynthesis.

Chattong et al, (2010) investigated the effects of individuals wearing a weighted vest completing box jumps on vertical jump performance after 2 minutes rest. They reported a small increase in performance although this was not significant and once again no mechanism was reported in relation to this finding. Furthermore, McCann and Flanagan (2010) observed no difference in counter-movement jump performance after performing either heavy back squats or hang cleans, with 4 and 5 minutes rest. However, the authors did report PAP was highly individualized with several of their subjects improving after either one of the rest periods.

2.8 Postactivation Potentiation and short duration sprint performance

Several articles/papers have focused primarily on sprint performance due to the explosive power requirements for such events, such as the 100 metre sprint, or intermittent sprinting in games play. Athletes training in such sports may benefit the most from integrating PAP into training regimes.

Mathews et al, (2004) recruited 20 male rugby players and reported a mean improvement in 20 metre sprint times (0.098 s, $p<0.0001$), after completing 5 back squats at their predetermined 5 repetition maximum (5 RM) approximately 5 minutes prior to sprinting.

Chatzopoulos et al, (2007) used 9 repetitions at 90 % of 1 RM, 3 and 5 minutes prior to sprinting 30 m. The authors reported that after completing the squats, sprint time decreased significantly both after 10 m (1.89 s ± 0.03 to post exercise 1.84 s ± 0.02, $p<0.05$) and 30 m (4.51 s ± 0.07 to post exercise 4.43 s ± 0.06 $p<0.05$) after 5 minutes rest but not after 3 minutes rest in either 10 m sprint (1.90 s ± 0.02 to post exercise 1.91 s ± 0.03 $p>0.05$) or 30 m (4.52 s ± 0.07 to post exercise 4.54 s ± 0.08 $p>0.05$). These studies indicated that by completing a biomechanically similar exercise to the performance exercise, a conditioning stimulus can improve performance; however, the rest period may be an important factor in whether enhanced performance may be seen.

Comyns et al, (2010) investigated the effect of repeated exposures to a complex training session upon PAP. Eleven elite male rugby players, completed one control and four identical testing sessions of 3 repetitions at 93 % 1RM squat on subsequent 30 m sprint times after a 4 minute rest. Sprint split times were measured at 10, 20 and 30 metres. The results showed no evidence of PAP in any session despite sprint velocity at the 20 metre and 30 metre distances improving between the first and fifth session ($p < 0.05$). As sprinting technique can affect velocity (Cissik, 2004) the inter subject variations in sprint technique may explain why no evidence of PAP was observed

Bevan et al, (2010) reported that non-significant, but athletically important improvements in 5 and 10 m sprint velocities occurred in most subjects due to 8 minutes' rest, after performing 1 set of 3 reps of back squats at 91 % RM. However, some subjects achieved peak velocities after 12 or 16 minutes rest, supporting the individual nature of PAP suggested by McCann and Flanagan (2010). Due to the lack of physiological measurements, the authors speculated that all mechanisms mentioned were responsible for PAP and increased performance.

Boulas and Tuimil (2009) investigated the effects of two different fatiguing running protocols, namely a graded test versus a constant running test, on counter-movement jump performance in distance runners. They reported increased

counter-movement jump performance after 2 minutes' rest after each test protocol ($p<0.05$). However, again no mechanistic explanations were offered with the authors similarly stating that the mechanisms for PAP in endurance athletes had not as yet been elucidated.

Clearly the literature is equivocal with some of studies showing enhanced athletic performance due to PAP whilst others showed no discernable effects. What is obvious within the literature is the lack of consistency. Although not always statistically significant, changes have been observed and athletically important, performance improvements for power / sprint events are likely to be achieved by using PAP. However, the understanding of how this occurs is not clear. Some literature favours the phosphorylation of the MRLC (Batista et al, 2007; Chui et al, 2006; Comyns et al, 2006), while other authors discuss all mechanisms (Gilbert and Lees, 2005) and many do not offer any explanation for the improvements in performance (Gilbert and Lees, 2005; Yetter and Moir, 2008; Radcliffe and Radcliffe, 1996). Some studies have reported enhanced neuromuscular excitability post muscle contractions that may play a role in the inducement of PAP (Trimble et al, 1998; Tubman, et al, 1996: Gullich and Schmidtbleicher, 1995). However, other factors could also be responsible for PAP, such as the rehearsal of co-ordinated movements associated with warming up prior to exercise (Doherty and Hodgson 2007).

2.9 Discrepancies within the literature pertaining to factors that affect Postactivation Potentiation and athletic performance.

All skeletal muscle actions induce PAP (Sale, 2004); however, improvements in the subsequent performance will depend upon the intensity, volume and rest period between contractions. The majority of studies investigating complex training and PAP have not used one specific rest period between the conditioning contraction and performance which has led to conflicting results (Rixon et al, 2007; Jensen and Ebben, 2003; Gargoullis et al, 2003; Hamada et al 2000).

Variations exist for prescribing the conditioning exercise in a complex training protocol. A low intensity, low volume exercise may not sufficiently induce PAP, but a low intensity, high volume exercise, may induce sufficient PAP and improve performance. Nevertheless, it is generally accepted that to gain maximal PAP and thus a positive influence on performance, the conditioning exercise needs to be of a high intensity. Although this presents the issues of fatigue that may counteract PAP and performance (Rassier & MacIntosh 2000). High / heavy conditioning exercises that recruit type 2a and type 2x muscle fibres increases the sensitivity of the muscle spindles to muscle activity, with raised spinal excitability of the α-motor neurons that may improve the RFD and the muscle's explosive power capability. These muscle fibre types are larger in size than type 1 fibres, anaerobic in nature, easily fatigued (Martini, 2006) and produce strength and power actions (Siff, 2003).

Within a large study, Hamada et al, (2000) examined muscle biopsies of four subjects who showed the highest PAP, and compared them to the four subjects who showed the lowest PAP after a 10 second isometric MVC. The subjects with the highest PAP response had the greatest percentage of type II muscle fibres. Though this study identified the prominent muscle fibre type to induce PAP, type II muscle fibres also fatigue at a greater rate than type 1 fibres and require a sufficient amount of time to replenish the ATP-PCr energy system (Martini, 2006) for PAP to occur. Further, different skeletal muscle groups are composed of varying percentages of type 1 and type 2 muscle fibres (Enoka, 2002) which also vary between individuals, which may explain the disparity in PAP research.

However, high intensity / volume conditioning exercises that can induce fatigue and negate the positive effects of PAP. Rassier & MacIntosh (2000) suggested that as PAP and fatigue are factors that coexist (immediately post exercise) and both fade over time. The factor that fades the least will outweigh the other, thus influencing performance (Rassier & MacIntosh, 2000). Therefore, the intensity of the conditioning exercise needs to be matched with the appropriate rest period prior to the performance exercise to gain optimal performance.

Differing modes of conditioning contractions may also influence PAP and fatigue. Dynamic and isometric conditioning exercises differ in their effects on the neuromuscular system and the inducement of PAP. Isometric contractions recruit

a higher percentage of muscle fibres due to a higher number of motor units firing compared with dynamic contractions. The higher percentage of muscle fibres recruited increases the phosphorylation of the MRLC in the muscle, hence increasing performance (Tillin and Bishop, 2009). Dynamic exercises induce PAP through the eccentric phase of an action by increasing the firing of the muscle spindles. This activates the Ia neural fibres which enhance afferent neural volley at the spinal level. Transmission failure decreases from the Ia neural fibres to bordering α-motor neurons resulting in an enhanced recruitment of higher order motor units in future exercise (Tillin and Bishop, 2009).

Isometric exercise firstly develops central fatigue, followed by peripheral fatigue, due to an excessive build up of hydrogen (H^+ and potassium ions (P_1) (Tillin and Bishop, 2009). This excessive build up of H^+ and P_1 reduces the sensitivity of the small diameter lll and lV afferent neural fibres (Babault et al, 2006). This inhibits α-motor neuron activation and decreases the neural volley and / or reduces the motor neuron firing rate (Linnamo et al, 1998). This could lead to a decrease in neural excitability and therefore PAP.

The training status of an individual may also affect neural efficiency and muscle fibre type distribution. A highly trained explosive / strength trained individual will experience hypertrophy of all type 2 fibres as well as a shift in the type 2a fibre type to be more anaerobic (Siff, 2003). The hypertrophied state may increase

phosphorylation of the MRLC after the conditioning exercise compared to the less well trained individual. Hence, issues may arise surrounding sample recruitment, as in order to fulfil the criteria for acceptance onto a study all the individuals need to be of the same training status.

Factors contributing to, or affecting the outcome of PAP, are summarised in Figure 2.

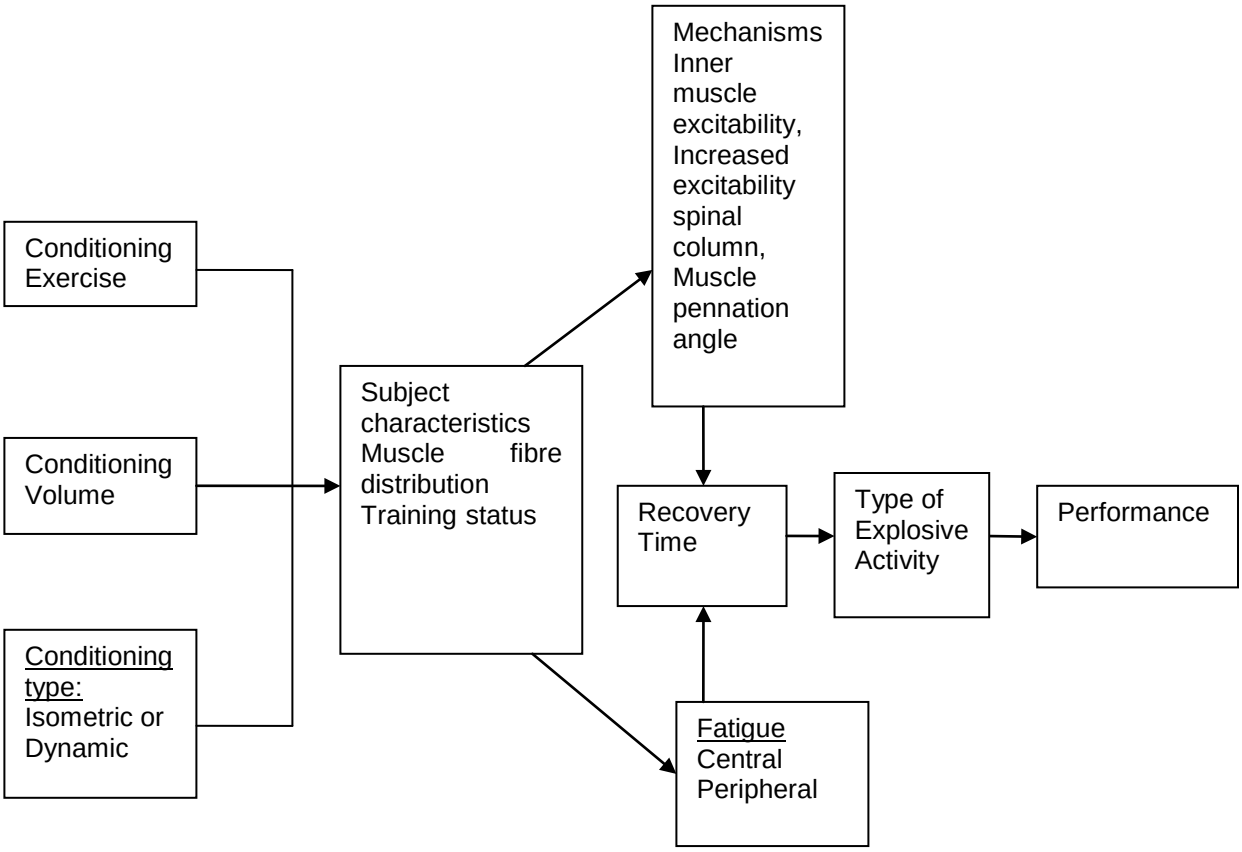


Figure 2: Schematic diagram showing the factors contributing to PAP and complex training (Tillin and Bishop, 2009).

2.10 Measurement of Post activation Potentiation

Muscle biopsies for the assessment of phosphorylation of the MRLCs (MacIntosh, 2003) have been used although due to the fast changes in cellular biology are not quick enough to yield accurate data. The biopsy procedure can be an uncomfortable experience for the participant and can only be repeated a finite number of times in a single exercise session.

Two methods can be been used to measure neuromuscular excitation for PAP and these are the Hoffmann reflex (H-reflex) (Trimble and Harp, 1998; Gullich & Schmidtbeicher, 1995; Palmieri, et al, 2004) and the stretch reflex response, also known as the Tendon Tap Test (TT). The H-reflex requires a superimposed electrical stimulus to the peripheral, sensory nerve of a specific muscle. The response of the muscle can then be measured by electromyography (EMG) activity where a high EMG amplitude represents a greater level of spinal excitability. The frequency and amplitude of the stimulus can be controlled, resulting in good internal validity. However, the H-reflex technique removes the natural neuromuscular stimulation because the stimulus by passes the muscle spindles that may play a role in spinal excitability through the stretch reflex mechanism. So although the H-reflex technique assesses spinal excitability, it has poor external validity and therefore its use for application to PAP is limited.

The mechanical equivalent of the H-reflex is the tendon tap test (Voerman et al, 2005) which involves swinging a hand held, rubber-tipped hammer and striking, usually, the patellar tendon. The TT induces a rapid muscle stretch firing the muscle spindles as a reaction to the rapid stretch, sending sensory signals up and the across the alpha motor neurons of the spinal column and back through the somatic nervous system to the muscle inducing a protective muscle contraction against the stretch. A heightened reflex response may indicate increased

excitability of the muscle spindles, sensory, somatic nervous system and motor neurons at the spinal level (Voerman et al, 2005; Lemoyne et al, 2008).

Though this method is quick, cost effective and easy to administer, it currently lacks acceptable scientific reliability owing to the lack of consistency in its measurement due to human error, as the test needs repeated consistent hammer tap force hitting the same area of the tendon to gain reliable reflex responses.

The force of the hammer tap can manipulate muscle spindle recruitment, with high tap forces required to elicit, in healthy adults, a reflex response (Zhang et al, 1999). However, the exact level of force required to reach maximal muscle spindle recruitment to gain a maximal stretch reflex response is not known. This is of relevance as forces above the ceiling threshold will be ineffective (Stam and Tan, 1987) and uncomfortable for the participant, thus affecting the reliability of the method, as participants may begin to anticipate the tap. Conversely, delivering low hammer forces elicits minimal, or no reflex response due to the lack of muscle spindle recruitment. A combination of high and low hammer tap forces delivered by hand will give a varied array of reflex responses throughout testing, producing poor reliability of the method.

Several studies have tried to improve the reliability of the TT, by delivering a consistent hammer tap force by mounting the hammer into a device that releases

the head of the hammer from a constant height swinging in a pendulum action that gives consistent force (Ohtaki et al, 2009; Lemoyne et al, 2008; Yan et al, 2007; Mamizuka et al, 2007; Kim et al, 2002; Zhang et al, 1999; Stam and Tan, 1989). However, only four studies reported their hammer tap force (Ohtaki et al, 2009, Mamizuka et al, 2007, Yan et al, 2007, Zhang et al, 1999,) with these ranging between 32.7 N – 198.3 N. Hence, no consistent conclusions between studies can be made as one hammer tap force may give one set of results whilst another may produce a totally differing result due to the varying recruitment of muscle spindles in the production of the stretch reflex response.

Only three studies have reported the reliability of their method. Two reported very low reliability Stam and Tan (1987) (31.7 %) and Zhang et al, (1999) (27 %), whilst Frijins et al, (1997) reported increased reliability 15 %, though they did not report their hammer tap force. The low reliability reported may suggest other variables may be influential. Mounting the hammer onto a machine, not only allows consistent tap force, but also a consistent striking zone that should give a high reflex reliability.

To the author's knowledge, no study has investigated the stretch reflex, using the patellar tendon tap test as a measure of spinal excitability, in a complex training situation for the assessment of PAP.

2.11 Aims and Hypotheses

The first aim of this was to develop a method of the tendon tap test that improved reliability. This was completed by using a stable machine to deliver the tap at three different levels of force.

The second aim of this thesis was to compare the intensities of 70, 80, 90, and 100% of isometric maximal voluntary contraction (IMVC) as the conditioning exercise and various rest periods 2,4,6,8,10,15,20,30,,40,50 and 60 minutes, upon the subsequent PAP response.

The first hypothesis was that the tendon tap test would show an improved reliability at one of the three tap forces used compared to previous literature.

The second hypothesis was that higher hammer tap forces will elicit a quicker stretch reflex response compared to lower forces.

The third hypothesis was that the isometric maximal voluntary contractions would elicit the greatest PAP response.

The fourth hypothesis was that the PAP response would peak before 15 minutes of rest and fade consistently thereafter.

Chapter 3

Does hammer tap force change the reliability of the Patellar Tendon Tap Test.

3.0 Method

3.1 Study 1: Does hammer tap force change the reliability of the Patellar Tendon Tap Test.

Low reliability for the tendon tap test has been reported by several studies (Frijins et al, 1997; Zhang et al, 1999; Stam and Tan, 1987). Several issues can be raised that may produce low reliability and these include inconsistent hammer tap force, tapping inconsistent spots on the tendon, the use of different hammer tap forces and the lack of strategies to stop the participants from anticipating the hammer tap. These issues will be addressed in study one.

3.2 Participants

Twelve participants, 8 males (age 23.7 ±4.9 yr, mass 78.3 ±12.9 kg, height 1.75 ±0.1 m) and 4 females (age 22 ±3.2 yr, mass 60.6 ±4.1 kg, height 1.66 ±0.1 m) with no reported history of neurological disorders, participated in a randomised counter-balanced, single-blinded, repeated measures experiment, consisting of a series of patellar tendon hammer taps administered at varying forces. Prior to testing, all participants completed a health screen (Par-Q) (see Appendix 3), followed by a written informed consent document (see Appendix 2). The study was ethically approved by the Institutional Ethics Committee.

3.3 Experimental Design

A rubber-tipped tendon hammer (MLA93 Tendon Hammer, Chalgrove, UK) was mounted into a mechanical device (Fig 3). The hammer was released from a

constant height, by a button operated through a solenoid switch that allowed the hammer to swing freely in a pendulum action.

Figure 3: The hammer tap machine

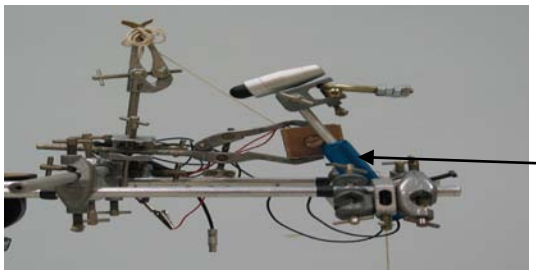


Figure 4: The hammer set up, with the extra mass attached to the hammer shaft

The tendon tap hammer impact force was varied by adding mass to the hammer shaft (Fig 4). Ten taps at each chosen mass were delivered to a load cell fixed to a wall; the force of each strike was recorded by Powerlab (AD Instruments, Chalgrove, UK). From this data three impact forces were established and categorized as highest (270 ±0.79 N, CV 0.2 %), middle (252 ±0.74 N, CV 0.2 %) and lowest (121 ±0.64 N, CV 0.5 %) impact forces. The hammer's rubber tip was

observed to compress on contact with the load cell, producing a time delay until maximum impact force was reached. This was calculated to be 0.41 ms for the highest force, 0.39 ms for the middle force and 0.24 ms for the lowest force. This information was used to standardise the hammer tap's effect for all three impact forces, each time delay was subsequently subtracted from each hammer tap's initial strike when used to hit the participant's patella tendon.

Two bipolar 40 mm silver/silver chloride electromyographic electrodes (Cardiocare Limited, Romford, UK) with an inter electrode distance of 20 mm, were attached to the participant's vastus medialis of their dominant leg. Electrode sites were shaved and cleaned with alcohol wipes, in accordance with Seniam (1997), before the electrodes were attached onto the skin on the belly of the muscle under contraction, aligned parallel to the direction of the underlying fibres (Clarys & Cabri, 1993). EMG activity was recorded by a Powerlab isolated amplifier (AD Instruments, Chalgrove, UK) at a sampling frequency of 1000 Hz. The high pass filter was set at 20 Hz and the low pass filter set at 500 Hz, with a mains notch filter (50 Hz) (Enoka 2002). The data was then saved and analyzed offline using Chart version 5.4.1, (AD instruments, Chalgrove, UK).

The raw EMG signal was processed by root mean square (RMS). The data collected, included the time from hammer contact to the start of muscle activation; the time from hammer contact to the start of lower limb movement (indicating the

patellar tendon reflex response) and the time from muscle activation to the start of the lower limb movement. The start of muscle activation was regarded to occur when two standard deviations from the mean baseline EMG value had been reached (Burden et al, 2003).

A two planed Electron Goniometer (AD Instruments, Chalgrove, UK) was attached to the lateral aspect of the knee joint to measure lower limb movement. Movement was recorded in millivolts (Powerlab, AD Instruments, Chalgrove, UK) and analyzed offline by Chart version 5.4.1 (AD instruments, Chalgrove, UK) where the signal was converted into degrees of movement. The time period from the hammer tap to the first negative goniometer recording from the baseline reading was established as the time to the start of the patellar tendon's reflex response (PTR), indicating knee flexion prior to reflex extension.

3.4 Experimental Protocol

The participants were instructed to sit naturally on a high chair, with the upper part of their thigh strapped to the chair allowing free movement of the lower limb. Their eyes and ears were covered throughout testing to decrease anticipation of the hammer contact. Several light taps were administered to different parts of the patellar tendon, prior to testing, to establish the most sensitive area of the tendon. This was an attempt to gain the optimal reflex response, established through

observation of the largest lower limb movement. This area was then marked to allow the same position to be struck throughout the test session.

One set of 10 taps at each force was administered in a random order and at sporadic intervals (less than 10 seconds) between each tap, to decrease any participant anticipation (Voerman et al, 2005).

3.5 Data Analysis

Data were analysed by a one way repeated measures ANOVA and following this a Pairwise comparisons post-hoc test was performed with a Bonferoni adjustment for any data with significant F values. The alpha value was set at $p \leq 0.05$. Reliability over multiple taps was assessed for all measurements using a coefficient of variance (CV) (CV= SD/mean x 100). All statistics were performed using the SPSS software version 17 (SPSS INC, Chicago, IL).

3.6 Results

Of the three hundred and sixty tendon taps administered, 27% were discarded (36 from highest tap force, 30 middle force taps and 32 lowest force taps). These were deleted due to participants either anticipating the tap, determined by no observable time difference between the hammer tap and the initiation of muscle activity or no lower limb movement distinguishable from the resting baseline level.

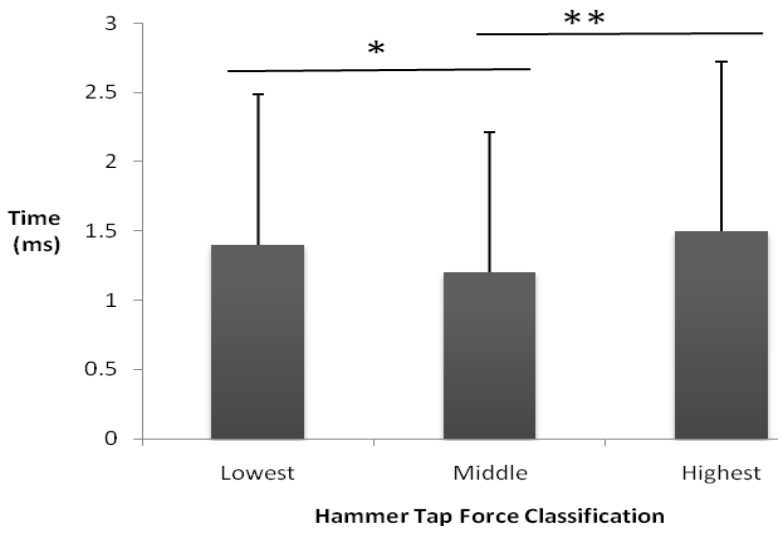


Figure 5: The time from the hammer tapping the tendon to the start of the muscle activation.

** Denotes a significant difference between the lowest and middle forces.*

*** Denotes significant difference between the highest and middle forces*

When the time from the hammer tap to the start of muscle activity was analysed, a significant main effect was established (F=12.59, p<0.001, effect size=0.097). Pairwise comparisons (see figure 5) indicated that the middle tap force had produced a significantly (p<0.001) quicker time to muscle activation (20.1%), compared to the highest force and significantly (p<0.001) quicker time (14.3%) than the lowest force measure. Marginal differences between the lowest and highest force were found to be non significant (p>0.05).

.

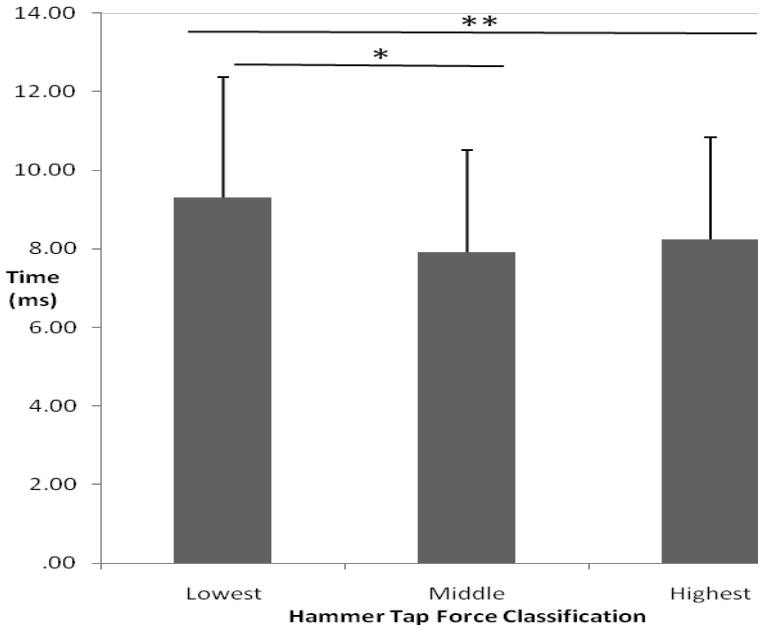


Figure 6: The time from the hammer tap to the initiation of lower limb movement

* *Denotes a significant difference between the middle and lowest force.*

** *Denotes a significant difference between the highest and lowest forces*.

When the time from hammer contact with the patella tendon to the start of lower limb movement was analysed, a significant main effect was established ($F=15.238$, $p<0.001$, effect size=0.123). Post hoc analysis indicated that the middle tap force and the highest tap force had significantly ($p<0.001$) faster times then the lowest impact force. This was calculated as a 15% (middle force) and 11.6% (highest force) faster time to movement than the lowest force (see figure 6). Differences between the middle and highest force were found to be non significant ($p>0.05$).

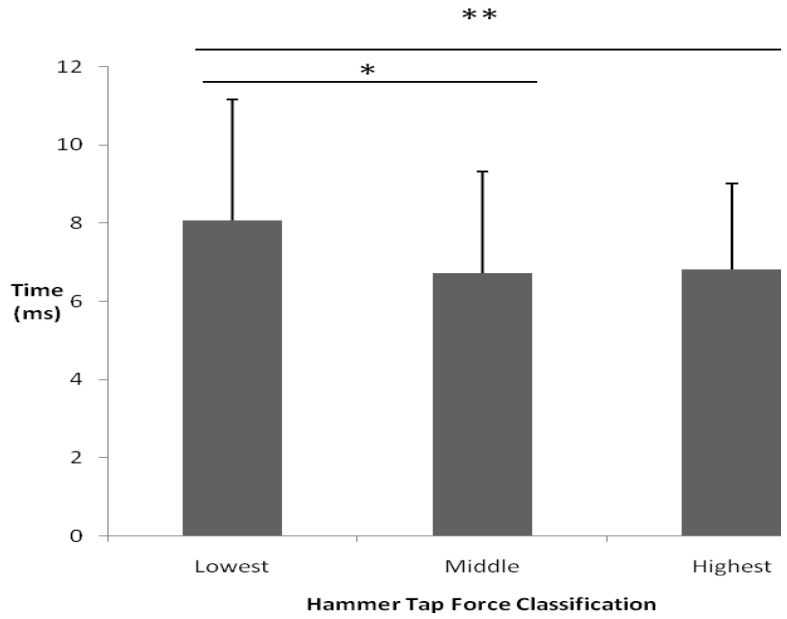


Figure 7: The time span from muscle activation to the start of lower limb movement

** Denotes a significant difference between the middle and lowest force.*

*** Denotes a significant difference between the highest and lowest forces*

When the time taken from the start of muscle activation to the start of the lower limb movement was analysed a significant (F=15.895, p<0.001, effect size=0.127) main effect was found. Pair wise comparisons of the three experimental forces showed that the lowest impact force had a significantly (p<0.001) slower time compared to the middle force (16.7%) and the highest force (15.5%). Minor differences between the middle and highest force were found to be non significant (p>0.05), (see figure 7).

When the reliability of the measures was examined, using coefficients of variation, it was found that the highest impact force produced the most reliable data in all measurements. Hammer tap impact to the start of muscle activation (CV 26.2 %) compared to middle force (CV 36.3 %) and lowest force (CV 40. 2%); hammer tap impact to the start of the lower limb (CV 17.3 %) compared to middle force (CV 19.4 %) and lowest force (CV 23 %) and muscle activation to the start of lower limb movement (CV 17.7 %) middle force (CV 22.7 %) and lowest force (CV 28.8 %).

Table 1: A comparison of the coefficients of variance reported for the stretch reflex response.

Study	Coefficient of Variance
Stam & Tan (1987)	31. 7 %
Frijins et al (1997)	27 %
Zhang et al (1999)	15 %
Present study	17 .1%

3.7 Discussion

Study 1 was designed to explore the effect of three different impact forces on the patella tendon reflex response. The results suggest that the lowest impact force

caused a significantly slower reflex response compared to the middle or highest tap force. The time lag from tap impact to muscle activation was significantly shorter with the middle force compared to the lowest force, and though faster than the highest impact force that was not statistically significant. The time from hammer impact to lower limb movement and muscle activation to lower limb movement had the same pattern of response, with the lowest force causing a significantly large time lag when compared to both middle and high force impacts.

For healthy adults, higher tap forces are required to gain a measurable stretch reflex response (Zhang et al, 1999). The two highest forces used in the present study seem to support this statement, with the lowest force failing to stimulate the patellar tendon reflex response to the same extent as the two higher impact forces. The middle force reported the quickest reflex response, suggesting the middle force may have reached maximal muscle spindle recruitment to affect the patellar tendon reflex. The highest force gave rise to a slower response time compared to the middle force, which could suggest that the higher force increased compression of the underlying tissues onto the bone resulting in a slower PTR (Zhang et al, 1999).

Interestingly, no study has looked at the reliability of differing hammer tap forces on the PTR. The highest force resulted in a greater reliability, at all measures, when compared to the middle and lowest forces. Only Frijin et al, (1997) reported

lower intra-individual PTR reliability (15 %) than this study, though they selected 10 subjects from a sample of 102 with no reported selection criteria or hammer tap force. Other studies reported have lower patellar tendon response reliability: by 31.7 % (Stam and Tan, 1987) and 27 % (Zhang et al, 1999), but used, as in the present study, all of their subjects.

Though increased reliability has been established in the present study, the CV's are still high and therefore, this still needs to be improved upon, before the patellar tap test can be used to help explore reflex responses. One problem related to reliability may be the rest period between the hammer taps; this may have led to fatigue at the spinal level that may influence subsequent reflex responses (Cohen et al, 2000). After a reflex response has been induced, time is needed for inter-neuron neurotransmitters to recuperate, and minimise fatigue in future reflex responses (Cohen et al, 2000). If the time between taps is not long enough, fatigue may be present, which can depress future reflex responses. The present study used sporadic intervals between the taps as a strategy to decrease the participant's anticipation of the hammer impact. Though this strategy may have helped decrease the amount of data which was rejected, the different recuperation times may have given rise to differing fatigue levels, inducing varying levels of stretch reflex response and ultimately low reliability. This problem may be resolved by the implementation of a consistent rest time, which is long enough between each hammer tap, to allow maximal neurotransmitter recuperation and

the opportunity for consistent reflex responses. However, this time span has, as yet, not been established.

The method used in the present study involved multiple taps delivered over a short period of time. Some data had to be removed from the analysis due to a lack of a reflex response. The highest tap force reported the largest number of hammer taps being discarded (36 taps or 10 %). This level of impact force could be uncomfortable to withstand for some of the participants, leading them to anticipate the taps, by pre activating the leg musculature to help dissipate the impact forces. The level of rejected hammer taps may also be explained by the novelty of the method for the population used. The patellar tap test is not commonly used in everyday situations, but merely in clinical neuromuscular and research settings and the participants recruited for the study were naïve to the method used, which may have increased the problems with regard to reliability. The action of an implement striking below their patella, and then witnessing an involuntary movement of their lower limb could be disturbing, causing an attempt to anticipate subsequent taps, to prevent this unconscious movement. This effect could be limited by the use of extensive familiarization sessions, and would be recommended to any researcher using this method.

No past study has reported using a familiarization session prior to testing. However, several studies completed an ad hoc familiarization process by

delivering multiple taps, with hammer forces increasing in strength, in an attempt to acertain the optimal hammer force for that particular tendon site for maximal PTR (Stam and Tan, 1987; Zhang et al, 1999; Yan et al 2007). Although this may have introduced a level of familiarization it may also have increased spinal excitability through the inducement of a PAP response, or had the reverse effect by inducing reflex fatigue (Cohen et al, 2000).

3.8 Conclusion

This study indicates that higher tap forces will improve the reliability and velocity of the PTR. This may be due to the muscle spindles' firing rate reaching a threshold capable of delivering maximal sensory nerve information to the α-motor neurons of the spinal cord, and thereby sending a maximal stimulus to muscle fibres, allowing a quicker PTR. Reliability of measurement of the patellar tendon reflex was better when higher impact forces were used.

Several areas could be developed to increase this reliability further and these include implementation of a familiarization session and increasing the time between hammer taps to decrease reflex fatigue. An interesting point was raised by several participants, who they noted that by having their eyes and ears covered and silence in the room, their anticipatory awareness was increased, inadvertently allowing participants to focus on the time aspect and when the next tap was due, causing a bracing effect with the knee musculature. This may be overcome by

engaging the participant in general conversation throughout the testing period, thereby distracting them from consciously thinking about when the next hammer tap was due to occur.

In conclusion, the second hypothesis; that higher hammer tap forces will elicit a quicker stretch reflex response compared to lower forces can be rejected. On the other hand the first hypothesis; that the tendon tap test would show an improved reliability at one of the three tap forces investigated can be accepted.

Chapter 4

An investigation of the effect of different isometric contractions on neural excitability

4.0 Method

4.0 Method

4.1 Study 2

Postactivation potentiation (PAP) is a phenomenon associated with improved performance linked to a muscle's contractile history. However, due to the many variables that can influence performance, including contraction intensity and rest period post-conditioning contractions, past results have been inconsistent.

Much of the literature focuses on phosphorylation of the myosin regulatory light chains as the mechanism responsible for PAP, although neural excitability may also contributing factor. This study will look at neural excitability after completing a range of isometric contraction intensities.

4.1.1 Pilot Work

Three participants were recruited to analyse the effect of a hammer tap force of 270 ±0.79 N on the stretch reflex response of the patella tendon. The same method as outlined in study one was used, with repeated hammer taps applied to the participant's patella tendon, while the participant was seated in a high chair. Three of the quadriceps muscle group (vastus medialis, vastus lateralis and rectus femoris) and the on the hamstring biceps femoris were analysed through EMG to see which muscle would give the greatest reflex response. The vastus medialis and vastus lateralis gave very similar EMG readings, with the rectus femoris activation noticeably lower. No discernable activity could be observed from the

biceps femoris. The decision was made to use the vastus medialis as electrode placement was less problematic than with the vastus lateralis.

4.2 Participants

Seven male participants (age 20 ±1.64 yr, mass 71.7 ±7 kg, height 1.77 ±0.1 m) with no reported history of neurological disorders, participated in a randomised counter-balanced, single-blinded, repeated measures experiment, consisting of a series of patella tendon hammer taps administered after an isometric contraction of the quadriceps was performed at different intensities. The participants attended the University of Bedfordshire's Sport Science laboratories on seven separate occasions, with a minimum of 72 hours rest between each session. They were also advised to refrain from any strenuous lower limb activity 72 hours prior to the testing session. Prior to testing, all participants completed a health screen (Par Q), followed by a written informed consent document. The study was ethically approved by the Institutional Ethics Committee.

4.3 Experimental Protocol

The participants were seated comfortably, on a high chair that allowed their lower limbs to hang freely with no contact with the floor and they were asked to relax as much as possible. The dominant leg was determined by asking participants what their preferred kicking leg was; this was the limb used throughout testing.

The most sensitive site on the patellar tendon was established by applying several taps at the predetermined force of 270 ±0.79 N, established in study 1. The taps were administered by a rubber-tipped hammer (MLA93 Tendon Hammer, ADINSTRUMENTS, UK), modified for use with a Biometrics Datalog. Both observational and participant feedback was gained after each tap, to gauge the stretch reflex response and the tap site adjusted accordingly until the optimal tap reflex response was found. This site was measured from the inferior border of the patella and marked with an indelible water resistant ink pen. A pen was issued to each of the participants, who were instructed to keep the mark visible throughout the testing period; this was to help increase the reliability of the tap contact site.

EMG of the dominant leg's vastus medialis was measured in accordance with Seniam (1997) using a Blue Tooth telemetry EMG system (Biometrics Ltd, Gwent, Wales, UK). EMG sites were shaved and cleaned with an alcohol swab (to reduce electrode impedance to below 55 (kΩ)), with the reference electrode strap attached to the dominant ankle in a line with the lateral malleolus. Electrodes were attached onto the skin on the belly of each muscle, with the muscle under contraction; with a standardised inter electrode distance of 2 cm, aligned parallel to the direction of the underlying fibres (Clarys and Cabri, 1993). SX230 surface pre-amplified (1k) electrodes were used at a sampling frequency of 1000 Hz. A main amplifier (0.3-1 k) was used with a common mode rejection ratio of >96 (dB), with an input impedance of 10,000,000 (MΩ) and input referred noise <5. A pre-

amplified high pass eight order elliptical filter (550Hz) was set, with EMG measured using analogue inputs directly via a PC using a DLK900 Datalink software.

Raw EMG wave forms were rectified, integrated and averaged over time (average rectified value). Electrode placement sites were marked with a water resistant ink pen, with participants instructed to keep the marks visible throughout testing.

A two plane electrogoniometer (SG150 Biometrics Ltd) was attached to the lateral aspect of the knee joint, in accordance with the manufacturer's instructions. Only one plane was used for data collection, consisting of flexion to extension. The participants were then instructed to sit comfortably on the high chair, and relax their lower limbs; this was taken as the zero point for the goniometer, with shank movement measured from this point after each tap.

Normal everyday activities, such as walking to the testing labs, may have given a degree of spinal excitation and intra-muscular stimulation. To minimise this and therefore obtain near resting levels of spinal excitation and intra-muscular stimulation, the participants were asked to sit quietly on the high chair with no lower limb movement for ten minutes prior to the hammer taps commencing. An eye mask and ear plugs were worn, and the researcher engaged the participants

in conversation throughout testing to decrease participants anticipation of the hammer's contact with the patellar tendon.

The first test session served as a familiarization, with single hammer taps (force 270 ±0.79 N) administered at 0, 2, 4, 6, 8, and 10 minutes, after a ten minute rest period. A five minute self regulated warm up followed on a stationary bike (Monarch Ergomedic 314 E, Switzerland), after which the participant was transferred to an isokinetic dynamometer (Kin Com 125E CHATTECX CORPORATION, Chattanooga, Tennessee, USA). The participant sat upright and relaxed, the centre of the knee was aligned to the dynamometer axis of rotation under isometric conditions, with the ankle and hip stabilised at a standardised angle (Baltzopoulos, 1997) and a manual universal goniometer (Baseline, UK) was used to establish a knee joint angle of 120° (Marcora and Miller, 2000). Three 5 second maximal isometric voluntary contractions were completed at this joint angle with a 55 second rest interval between each contraction.

The second test session acted as a control condition (see figure 8). Initially, the participants had single hammer taps striking the patella tendon at intervals of 2, 4, 6, 8, 10, 15, 20, 30, 40, 50 and 60 minutes after a ten minute rest period. This tap protocol was repeated after a 5 minute self regulatory warm up on a stationary bike (Monarch Ergomedic 314 E, Switzerland), that gained a heart rate of between 120 and 130 bpm, monitored by a heart rate monitor (Polar Heart Rate

Monitor, Finland). The muscle was then re-warmed by using the same protocol. Three isometric maximal voluntary contractions (IMVC) of the quadriceps following the same protocol as the familiarisation session were then completed. A 5 minute self regulatory cool down on a stationary bike was then performed. The three IMVC scores were analysed and a mean peak isometric force established. This was used to calculate 90 %, 80 % and 70 % of each participant's IMVC.

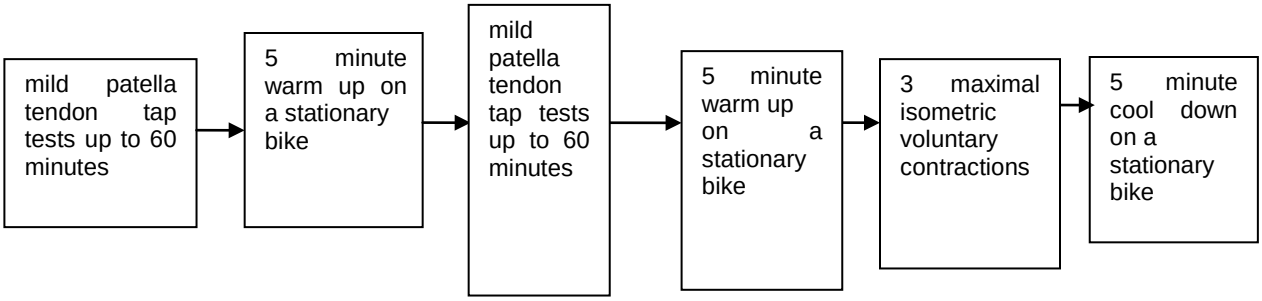


Figure 8: Control Protocol

The participants were than required to perform four test sessions in a random order (figure 9). Each test protocol included a ten minute rest period, where the participants sat in a high chair; this was followed by a 5 minute warm-up on a stationary bike at the same intensity as the control trial. Three 5 second isometric contractions of the quadriceps, with a 55 second rest interval between each contraction, were performed at intensities of 70 %, 80 %, 90 % or 100 % of their IMVC on a Kin Com Isokinetic Dynamometer. On completion of the prescribed contraction, the participants had a two minute rest, prior to the first hammer tap.

The hammer taps followed the same protocol as in the control trial. A 5 minute cycle ergometer cool down completed each test session.

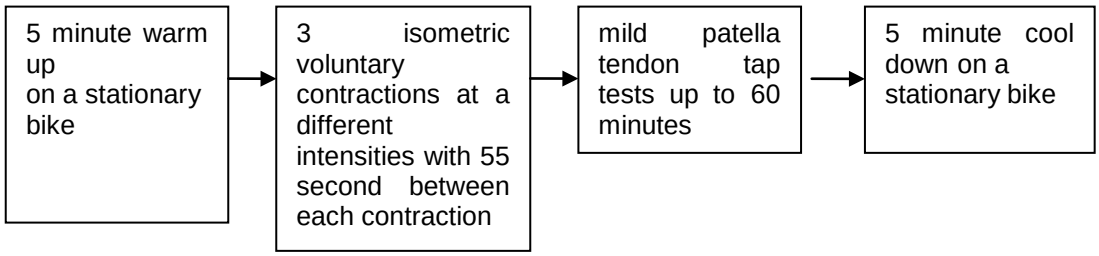


Figure 9: Treatment protocol

4.4 Data Collection

Measurements included the time from the hammer contact to the start of muscle activation, and muscle activation to the start of lower limb movement. A decrease in the time span from hammer contact to muscle activation signified increased spinal excitability, whilst a decrease in the time span from muscle activation to the start of lower limb movement signified increased intra-muscular stimulation.

4.5 Statistical Analysis

The data was normalised by using the control condition as a 0% reference marker. The treatment data was then reported as means and ± SD calculated as a percentage compared to the control trial. Negative % signified faster times in both neural excitability and intra-muscular activation.

The data was analysed statistically by a one way repeated measures ANOVA, and following this a Pairwise comparisons post-hoc test was performed with a Bonferoni adjustment for any data with significant F values. The alpha value was set at $p \leq 0.05$. Test-retest reliability was measured using a coefficient of variance (CV) with comparisons between the familiarization and control trials. All statistics were performed using the SPSS software version 17 (SPSS INC, Chicago, IL).

4.6 Results

Of the 462 hammer taps administered, 56 (12.1%) were removed from analysis because of either an increase in EMG activity prior to the hammer making contact with the patella tendon, indicating participants anticipating hammer contact, or no noticeable EMG being recorded, negating any reflex response.

CV for hammer contact to the start of muscle activation was calculated at 9.17 ±6.65%, while muscle activation to the start of lower limb movement produced a CV of 35.18 ±28.42%.

4.7 Time integral between hammer contact and start of muscle activation

When the time frame from hammer contacting the patellar tendon to the start of muscle activation, was analysed by a repeated measures ANOVA, no significant difference across all time points and intensities ($F = 1.843$, $p > 0.05$) was found. However, it is worth looking at this data in more detail as several trends were

discernable, which may make future research in this area more rewarding. At the two minute time period, the 100% intensity session reported a slower time to muscle activation (+23 %) while the 80 % and 70 % tests reported quicker times (-10 % and -5 %). Post-warm up and 90 % sessions reported no difference in time from hammer contact to the start of muscle activation.

Table 2: Hammer contact to the start of muscle activation (normalised as a % of the control trial)

Time (min)	Post-warm Session (%)	100% IMVC	90% IMVC	80% IMVC	70% IMVC
2	0 ±10	23 ± 37	0 ±6	-10 ±6	-5 ±7
4	-44 ±4	-29 ±26	-40 ±8	-45 ±7	-45 ±15
6	9 ±3	15 ± 12	9 ±5	2 ±14	9 ±8
8	-3 ±8	-7 ± 10	-3 ±6	-7 ±10	4 ±12
10	77 ±18	0 ± 10	77 ±9	0 ±11	1 ±8
15	2 ±10	-1 ± 9	2 ±9	-7 ±15	-7 ±15
20	13 ±7	16 ±12	13 ±9	9 ±10	13 ±8
30	1 ±9	-11 ±8	1 ±10	-4 ±7	0 ±12
40	13 ±10	16 ±23	13 ±11	25 ±41	2 ±8
50	11 ±9	100 ±23	11 ±10	7 ±15	11 ±11
60	5 ±19	10 ±8	5 ±11	8 ±10	3 ±11

The four minute point saw all intensities report faster times from hammer contact to muscle activation, post-warm (-45 %), maximal (-29 %), 90 % (-40 %), 80 % (-45 %) and 70 % (-45 %). At 6 minutes post IMVC, all intensities reported slower

times than those found at rest in the control trial, post-warm (+9 %), maximal (+15 %), 90 % (+9 %), 80 % (+2 %) and 70 % session (+9 %).

4.8 Time integral between start of muscle activation to the start of lower limb movement

When the time frame from the start of muscle activation to the start of knee movement was analysed by a repeated measures ANOVA, no significant difference across all time points and intensities ($F=1.587$, $p>0.05$) was found. Again, on examining the data in greater detail, several trends were noted and these are worth further investigation as they may help inform future studies in this area.

After two minutes rest, two IMVC intensities (100 % and 70 %), showed slower time from muscle activation to the start of lower limb movement (+9 % and +19 % respectively). The post-warm up, 90 % and 80 % intensity sessions, however, reported quicker times from muscle activation to the start of lower limb movement (-17 %, -7 % and -21 % respectively). At the 4 minute point, all intensity sessions reported faster times from the muscle activation to the start of lower limb movement. The 90 % session reported the quickest time (-67 % ± 8) followed by the maximal session (-55 % ± 36) compared to the control session. All intensities reported slower times from muscle activation to the start of lower limb movement at the 6 minute point with the 70 % session reporting the slowest time (+124 % ±

24). After 4 minutes the 70 % session reported slower muscle activation to lower limb movement (-23 % ± 62) at all time points except at the 10 minute point.

Table 3: Muscle activation to the start of lower limb movement (normalised as a % of the control trial).

Time (min)	Post-warm Session (%)	100% IMVC	90% IMVC	80% IMVC	70% IMVC
2	0 ±10	-8 ± 56	0 ±6	-21 ±59	19 ±11
4	-44 ±4	-55 ±36	-67 ±8	-40 ±58	-23 ±62
6	9 ±3	48 ±118	9 ±5	47 ±13	124 ±24
8	-3 ±8	-7 ± 85	-3 ±6	-1.5 ±10	53 ±15
10	77 ±182	-15 ± 55	77 ±9	-29 ±66	-39 ±66
15	2 ±10	-37 ± 25	2 ±9	-28 ±67	-54 ±13
20	13 ±7	21 ±71	13 ±9	-32 ±64	12 ±11
30	1 ±9	-27 ±56	1 ±10	-33 ±54	32 ±11
40	13 ±10	-24 ±51	13 ±11	-32 ±50	-1 ±93
50	11 ±9	-43 ±39	11 ±10	-42 ±50	28 ±96
60	5 ±19	16 ±58	5 ±11	-9 ±88	38 ±12

The 90 % session when compared to the control session, only reported a slower time from muscle activation to the start of lower limb movement at the 20 minute point . the 100 % and 80 % sessions, reported faster times for muscle activation to the start of lower limb movement after the 6 minute time point and up to the 60 minute test interval. The post warm up session reported two time points where the

time period between the muscle being activated to the start of lower limb movement was quicker (30 and 50 minute), when compared to the control session.

4.9 Discussion

The purpose of this study was to investigate the effect of different intensities of IMVC on the patallar tendon's stretch reflex response .

Neural excitation was investigated by measuring the time span between hammer contact to the start of muscle activation. A decrease in this time frame signified increased neural excitation. No statistically significant differences were reported at any time point post IMVC across any of the contraction intensities. When the start of muscle activation to the start of lower limb movement was measured, no statistically significant difference was reported between time points across the IMVC contraction intensities. However, on closer examination of the data collected, some trends were noticeable and these may be important to explore further as this study was an attempt to examine the potential mechanisms behind the PAP phenomonon, raither than look at performance changes after a conditioning exercise. Therefore, though this data is not significant in terms of neural activation, it could still have an important role in explaining performance changes demonstrated in many PAP studies.

The 2 minute time point reported different results when the intensities were compared. This post warm up and 90 % sessions reported no difference in neural excitability, the 80 % and 70 % sessions saw increased neural excitability and the 100% intensity session reported a decrease in neural excitability. The 4 minute point produced peak neural excitability across all conditioning intensities, with the lowest intensities (80 % and 70 %) reporting the highest spinal excitability and the 100% session reporting the lowest increase in neural excitation (see Table 2).

Similiar trends were seen for the start of muscle activation to the start of lower limb movement movement at the 2 and 4 minute points. The 100% session reported a small increase and the 80 % session a decrease in time to movement of the shank. The other intensities either had no, or an increase in time to shank movement. The 4 minute point saw all intensities linked to faster times, with 90 % intensity reporting the quickest time from start of muscle activation to the start of lower limb movement and 70 % session reporting the lowest. The 6 minute point saw all intensities record slower times than being at rest, except the 90% IMVC (see Table 3). No other discernable trends could be seen from the data.

Two main mechanisms have been proposed for PAP, namely phosphorylation of MRLC, which has been widely accepted as the mechanism of choice, and neural excitability, which has had several studies (Trimble and Harp, 1998; Gullich and Schmidtbleicher, 1995) supporting it as a mechanism of PAP. The present study

was the first to measure the neural pathway, including spinal excitability, directly through the stretch reflex response, rather than through the Hoffman Reflex.

Several studies recommend near maximal intensity for the conditioning contraction (Chatzopoulos et al, 2007; Gilbert and Lees, 2005; Chui et al, 2003), with 4 minutes rest period believed to induce optimal potentiation (Batista et al, 2007; Young et al, 1998) and state the phosphorylation of the MRLC as the sole mechanism. However, if a single mechanism was responsible for PAP, then it would not be expected that any changes in muscle activation would be recorded in the present study. Though not statistically significant, the 4 minute marker does seem to show increased muscle activation across the conditioning intensities utilised in this study. This may indicate that phosphorylation of the MRLC is not the only mechanism associated with the PAP phenomenon.

Interestingly, the only exercise intensity which showed decreases in time to lower limb movement at the 2 minute mark was the 100% intervention, all other exercise intensities producing either no change or faster times to lower limb movement. By the 4 minute mark, all measures displayed decreases in time to lower limb movement, however the 100% intensity intervention had half the decrease in time compared to the other trials. This may indicate that maximal intensity isometric contractions cause greater fatigue than submaximal conditioning exercises, therefore needing a longer rest period to reach their peak potentiating effect.

Any muscle contractile history produces PAP (Sale, 2004) a factor vital to appreciate when constructing a methdology designed to examine any aspect of PAP through a complex training regime. Many studies (Chattong et al, 2010; Comyns et al, 2010; Bevan et al, 2009; Kilduff et al, 2008; Gilbert et al, 2005; Jenson and Ebben, 2003; Young et al, 1998) as part of their method, completed a warm up prior to the conditioning exercise, but did not recognise that the warm up they used may have played a role in their conditioning protocol and in gaining their results. Despite this these studies still recommend their conditioning exercise as optimal for inducing potentiation. To date, no study has looked at the effects of a warm up on PAP. The present study, looked at the effect of a 5 minute aerobic warm up on neural excitability time from muscle activation to the start of lower limb movement. The data suggests an aerobic warm up may increase neural excitability and decrease time from muscle activation to the start of lower limb movement, peaking at the 4 minute post warm up point. This pattern was mirrored by the IMVC conditions with very little difference in neural excitability across isometric intensities compared to the warm up trial at the 4 minute mark. Warm ups need to be taken into account to gain a true picture of the influence of a conditioning exercise on PAP. It must be remembered that these findings are tentative, as no statistically significant differences were was found, but they do give a useful starting point for any future studies examining complex training intensities and rest times.

The combination of the conditioning contraction intensity and the rest period are critical considerations for improvements in any subsequent performance exercise. The present study suggests that a 4 minutes rest period seems to be optimal across all intensities greater then 70 % of maximal isometric contraction. However, this is not in agreement with many other studies. Gilbert et al, (2005) compared strength and power exercises. Power was measured by counter-movement jumps and strength by 5 x 1 RM back squats at different time intervals (1, 2, 3, 9, 10, 11, 19, 20, 21, 59, 60, 61 minutes). The conditioning power exercise reported its peak performance after 2 minutes rest, whilst the maximal strength exercise reported 20 minutes rest for optimal performance. This part can only be used in comparison to the present study. Gilbert et al. (2005) inferred the phosphorylation of the MRLC's as their mechanism of choice for their results, though the present study saw a trend at 4 minutes rest to produce an enhanced time to knee movement and neural excitability, no performance exercise was investigated. The different conditioning exercise methods used in each study may have led to these conflicting results. Gilbert et al. (2005) used dynamic compound contractions, whilst the present study used isometric isolated contractions. It may be that the completion of a compound exercise may create higher levels of PAP and fatigue through the increased number of muscles working in a synergistic fashion, producing a co-ordinated movement, compared to an isolated isometric

contraction. It may be suggested that compound exercises may need a longer period of rest to gain a positive balance in favour of excitation over fatigue.

Gullich and Schmidtbleicher (1995) investigated spinal excitability after 5 x 5 second maximal isometric voluntary contractions of the gastrocnemius. The H-reflex recorded a depression in the H-wave amplitude 1 minute post conditioning exercise, followed by a 20 % increase in excitation creating a potentiation effect from 5-13 minutes. Gullich and Schmidtbleicher (1995) used a higher volume of maximal contractions than the present study, which may help explain why the H-reflex took until 5 minutes post exercise to recover from the fatigue caused by the isometric conditioning exercise. However, it should be noted that one of the limitations of using the H-reflex as a measure of PAP is that it by passes the muscle spindles and normal reflexive movement patterns. A high intensity contraction may leave the muscle spindles in a high state of excitation that could last several minutes and assist in the inducement of PAP (Ross et al, 2001), thereby reducing the time of optimal neural excitability to below 5 minutes. A major criticism of the Gullich and Schmidtbleicher (1995) study is they did not normalise their data against the maximal M-wave. Therefore, other physiological factors not relating to spinal excitability, including increased activity by the Na^{+}-K^{+} pump, may explain their results (Hamada et al, 2000).

Trimble and Harp (1998) compared 8 sets of dynamic maximal contractions against a 10 second isometric contraction, reporting a potentiating effect from 3-10 minutes post dynamic contractions, and 5-11 minutes post isometric contractions, using the H-reflex method to determine muscle excitability. These results show that either mode of muscle conditioning exercise will induce PAP, though different delays in potentiation may be due to the effects of fatigue and isometric contractions show a slower time to peripheral fatigue than dynamic contractions (Babault et al, 2006). This, however, does not concur with the present study where peak activation was found to be present in all intensities at 4 minutes post conditioning exercise. This could be due, in part, to the present study using shorter contraction times with rest periods between each conditioning contraction, which may have allowed fatigue to build up to a lesser extent than that shown in Trimble and Harp's (1998) work. It should be remembered that Trimble and Harp (1998) used a single 10 second isometric contraction that may have not allowed for the dissipation of H^+ ions, hence causing a detrimental effect on potentiation and therefore performance. This may be supported by the fact that the dynamic contractions were not continuous and could have allowed an enhanced dissipation of H^+ ions, giving the excitation coupling an opportunity to work more efficiently, leading to the potentiating effect after only 3 minutes rest.

Chadwick-Smith et al. (2007) investigated intra muscular activation through the phosphorylation of the MRLC in 12 male subjects with at least 12 months

resistance training experience. A 10 second isometric voluntary contraction at 70 % of a 1 RM of the quadriceps acted as the conditioning exercise. Following a 5 minute rest period, a muscle biopsy was taken and another leg extension, acting as the performance exercise, at the same 70% intensity was completed. A significant mean 23 % increase in myosin regulatory light chain phosphorylation was reported in 7 out of the 12 subjects but, importantly, no improvement was seen in the leg extension performance exercise. This study suggests that there is no one mechanism responsible for PAP, as no improvement was reported in leg extension performance despite an increase in the phosphorylation of the MLRC. The study implies that, as there was no increase in leg extension performance, than it is unlikely that any positive changes in muscle excitation occurred at the 5 minute mark; however, as no performance measures were taken before 5 minutes, it cannot be ascertained whether excitation was present prior to the muscle biopsy. It could be that the volume of the conditioning isometric contraction may have allowed enhanced phosphorylation to take place, but it may also have caused sufficient fatigue at the neuromuscular or excitation coupling level (Enoka, 2003) to prevent any increases in performance being achieved.

Jensen and Ebben (2003) compared performance of a counter-movement jump after rest periods of 10 s and 1, 2, 3 and 4 minutes, post a back squat at 5 RM, reporting no significant difference between time points. They concluded that short rest periods do not allow sufficient time to allow performance increases; though it

should be noted that, though not statistically significant, the authors indicated 4 minutes rest seemed to be more optimal than other rest intervals in terms of helping increase jump height. However, a limitation to this study is that all testing was carried out on one day. This would mean multiple jumps were performed at each time interval, possibly causing an a detrimental effect on the fatigue/potentiation balance inherent within PAP, masking the true rest period required to optimise potentiation.

Chui et al, (2003) compared squat jump performance in recreational athletes to elite athletes, after performing rebound and concentric only squat jumps at 30 %, 50 % and 70 % of a 1 RM at 5 and 18.5 minutes following either a control or a warm up consisting of 5 x 1 reps, at 90 % of a 1 RM back squat. The authors indicated that the potentiation effect could be affected by training status as the elite athletes recovered faster than the recreational athletes. Though no mechanisms were measured, the authors acknowledged that a combination of enhanced spinal excitability and increased phosphorylation of the MRLC could induce PAP and increase performance. Chui et al, (2003) first measure however was taken after 5 minutes rest, which did not allow the opportunity of examining whether PAP was optimal before the 5 minute time point. It is also plausible that PAP is an individualistic concept that can only be stimulated in certain individuals, may explain the large standard deviations reported by the present study.

Esformes et al, (2010) reported that heavy squats increased counter-movement jump height to a greater extent than plyometric exercise, acting as a conditioning exercise, after 5 minutes' rest. The authors did not offer a mechanism for their results, but indicated that plyometric exercise did not induce an adequate amount of post-synaptic potential, to leave a legacy of post exercise spinal excitability to substantially improve counter-movement jump performance. Though different modes of exercise were used, the study indicates that it is the mode of exercise rather than the type of contraction which induces PAP and performance improvements. Both conditioning exercises used a stretch shortening cycle, but the squat is performed at a much slower velocity than the plyometric movement. Unfortunately, comparisons with the present study are problematic as Esformes et al, (2010) did not examine shorter rest periods than 5 minutes and did not investigate any mechanistic data. Therefore, the results are limited to this time frame. It is not possible to establish whether the plyometric exercise or the squat movement, could have produced superior results at either shorter or longer rest periods. Therefore, the optimal time to induce PAP and increase performance may have been on either side of the 5 minute time point used in the study.

Hodgson et al, (2008) reported significant potentiation through improved isometric force, after a conditioning 3 x 5 second maximal isometric voluntary contractions, with a 55 second rest interval between each contraction. The authors used the H-reflex to measure spinal excitability and found no enhanced performance in the

soleus muscle and suggested that the likely mechanism for PAP was the phosphorylation of the MRLC, in support of previous literature. The trend seen by the present study indicated that there could be a muscle potentiation effect, however, it should be remembered that the present study used the stretch reflex response to show muscle excitation, rather than the H-reflex. Also Hodgson et al. (2008) used the soleus muscle; whereas the present study used the vastus medialis. The two muscles have a very different fibre composition; the soleus has a high percentage of slow twitch muscle fibres, while the vastus medialis has a higher level of type II fibres (Enoka, 2002), which are thought to induce PAP more readily (Tillin and Bishop, 2009).

4.10 Limitations to the Present Study

Several methodological limitations may help to explain the lack of statistical significance found in study 2. Only seven male participants took part in the study, which may have resulted in inadequate power to give a significant statistical difference. Not only this, but the high variability in the chosen measures reported (indicated by the large SD), may be due to the individual responses of participants to the hammer tap administered. This has been reported in the complex training literature (Chui et al, 2003). In particular, the level of training of study participants is vital; more highly trained individuals exhibit a greater propensity for PAP due to a predominance of fast twitch muscle fibres, which have demonstrated an inclination to produce greater performance changes linked to PAP. The level of

training of participants in the present study was not explored above them being healthy individuals. The training status of the participants may have been different; especially those who were resistance trained, as this type of training increases neural efficiency and may increase the potential for a greater potentiation response. A minimum training status was not specified as a criterion for entry onto the study and it would be recommended that in future studies a minimum level of resistance training should be specified in order to produce a more homogeneous response to the conditioning exercise.

CV's were calculated for both the time from hammer contact to the start of muscle activation (9.17 ± 6.65%) and muscle activation to the start of knee movement (35.18 ± 28.42%). Several explanations may be given for the large range of CV's for the hammer contact to the start of muscle activation measure (0.3% to 19.97%) and for muscle activation to the start of knee movement (5.73% to 94%). It may be possible that the patellar tendon tap test is a more reliable measure in some individuals than in others. The reflex response caused by the hammer tap, resulted in a flexion/extension movement of the lower limb. Though not measured, there may have been some lateral movement, which may have caused the point of contact on the patella tendon to shift. Some participants may also have been better at fixating their dominant limb, allowing repeated hammer taps to have a more consistent contact point.

Other issues derive from the hammer tap force implemented (270 ±0.79N) and the participants' genetics. Patellar tendon thickness has been reported to be individual (Basso et al, 2001) and this may influence the response of the stretch reflex to the hammer tap. Another issue, the hammer tap force used, may have caused maximal muscle spindle recruitment threshold for some participants, giving a significant stretch reflex response, while, other participants may not have achieved maximal muscle spindle recruitment. This could of left a segment of muscle spindles awaiting activation, giving a potential scope for a lower stretch reflex response.

Study 2 only 12 % of the recorded data had to be deleted; this percentage is less than in previous literature (Stam and Tan, 1987; Zhang et al, 1999) and less than in study 1 which was used as part of this thesis. Therefore, the method used in study 2 may make the patella tendon hammer tap test a more useable tool in exploring the stretch reflex, particularly in light of the CV reported for the time from hammer contact to the start of muscle activation, again lower than in any other published work. It appears that if this CV can be further reduced, by implementing some of this study's recommendation, the research community may have a simpler and ecologically more valid test than the H-reflex.

4.11 Conclusion

The purpose of study 2 was to identify whether different conditioning contractions required different rest periods to enhance neuromuscular excitation. Though not statistically significant, trends were apparent at the 4 minutes post isometric measure suggesting the possibility of enhanced neural excitation for all the conditioning contraction intensities.

It is possible that a 4 minute rest period, post isometric contractions at >70 %, is the most favourable protocol in terms of neuromuscular enhancement. Several applied studies looking at complex training have recommend 4 minutes rest to improve performance (Young et al, 1998; Batista et al, 2007). However, it should be noted that the large standard deviations seen throughout this study may indicate that PAP effects are specific to individual athletes, or an indication of the low reliability of the technique used, allowing other variables to influence hammer tap measures. Therefore, for future studies aiming to investigate different conditioning exercise intensities, the 4 minute rest period might be an important time slot to include in their methodologies. However, it can be concluded that the third hypothesis, namely that maximal isometric voluntary contractions would elicit the greatest PAP response and the fourth hypothesis, that PAP response will peak before 15 minutes, need to be rejected as no significant differences were found between any isometric contraction intensity or time points.

Chapter 5

5.0 Overall Conclusions

5.0 Overall Conclusion

The poor reliability of the patellar tendon tap test may be due to individual variations in tendon biology. Although this study improved reliability compared to previous work, the technique was still too varied to ascertain conclusive results, beyond the trends previously outlined around the 4 minute mark. Therefore, future studies wishing to use the patellar tendon tap test to measure neurological excitation, need to address its reliability issues first. New and innovative strategies need to be found to allow the test to be as a realistic research tool.

From the data trends it was seen that spinal excitability and excitation within the muscle peaked after 4 minutes rest post all exercise intensities. This may indicate that to gain an optimal PAP response, the mechanisms put forward work in conjunction with each other. However, the high variability seen by this study may provide evidence that the mechanisms may be an individual concept which may explain why some of the previous PAP studies report negative results.

Future PAP studies need to investigate neural exciation and phosphosrylation of the myosin regulatory light chains and the mechanism behind the PAP phenomenom further by designing studies that allowed both mechanisms to be to measured in conjunction with each other. This will give an insight into whether one of the mechanisms plays a greater role in PAP than the other.

All previous studies investigating PAP's mechanisms have done so acutely and not after chronic training. Coaches prescribe training regimes over a period of time to gain certain physiological adaptations that will improve performance. The lack of long term complex training studies and the effects these have on PAP may give differing results to those found in acute studies. Future studies need to address this issue by investigating the mechanism pre and post chronic training regimes.

No definitive guidelines can be given for the intensity of the conditioning exercise with the correct rest period that improves explosive power in a complex training situation. At this moment in time, coaches cannot rely solely on complex training to improve their athletes' explosive power performance over the more traditional methods (strength, power and plyometric exercises). However, it may be used conjunction with the other more reliable traditional methods in a periodized fashion giving a variation of training that may improve athletes' performance and stop the tedium of training.

6.0 References

Aagard, P., Simonsen, J.L., Anderson, P., Magnusson, P., Dyhre-Poulson, P. (2002) Neural adaptations to resistance training: Evoked V-wave and H-reflex, *Journal of Applied Physiology,* 92, 2309-2318.

Babault, N., Desbrosse, K., Fabre, M.S. (2006) Neuromuscular fatigue development during concentric and isometric knee extensions, *Journal of Applied Physiology,* 100, 3, 780-785.

Baltzopoulos, V. (1997) Isokinetic Dynamometry. *In* Biomechanical Analysis in Sport and Exercise*. Edited by* Bartlett. R. British Association of Sports Sciences, Leeds.

Basso, O., Johnson, D.P., Amis, A. A. (2001) The anatomy of the patellar tendon, *Knee Surgery Sports Traumatology Arthroscopy,* 9, 2-5.

Batista, M.A., Ugrinowitsch, C., Roschel, H. (2007) Intermittent exercise as a conditioning activity to induce postactivation potentiation, *Journal of Strength and Conditioning Research,* 3, 837-840.

Bevan, H.R., Cunningham, D.J., Tooley, E.P., Owen, N.J., Cook, C.J., Kilduff, L.P. (2010) Influence of postactivation potentiation on sprinting performance in

professional rugby players, *Journal of Strength and Conditioning Research,* 24,3, 701-705.

Burden, A.M., Trew, M., Baltzopoulis, V. (2003) Normalisation of gait EMGs: a re-examination, *Journal of Electromyography and Kinesiology,* 13, 519-532.

Burke, D., Gandevia, S.G., and McKeon, B. (1983) The afferent volleys responsible for spinal proprioceptive reflexes in man, *Journal of Physiology,* 339: 535-552 .

Chadwick-Smith, J.C., Fry, A.C. (2007) Effects of a ten-second maximum voluntary contraction on regulatory myosin light-chain phosphorylation and dynamic performance measures, *Journal of Strength Conditioning Research,* 21,1, 73-6.

Chattong, C., Brown, L.E., Coburn, J.W., Noffal, G.J. (2010) Effect of a dynamic loaded warm-up on vertical jump performance, *Journal of Strength and Conditioning Research*, 24,7, 1751-1754.

Chatzopoulis, D.E., Michalidis, C.J., Giannakos, A.K., Alexiou, K.C., Patikas, D.A., (2007) Postactivation potentiation effects after heavy resistance on running speed, *Journal of Strength and Conditioning Research,* 21, 4, 1278-1281.

Chiu, L.Z.E., Fry, A.C., Weiss, L.W. Schilling, B.K., Brown, L.E., Smith, S.L. (2003) Postactivation potentiation response in athletic and recreationally trained individuals, *Journal of Strength and Conditioning Research,* 17, 4, 671-677.

Cissik, T.M. (2004) Means and methods of sprint training part 1, *Strength Training Journal,* 26, 24-29.

Clarys, J.P., and Cabri, J. (1993) Electromyography and the study of sports movements: a review. *Journal of Sports Sci*ence, 11, 379-448.

Cohens, J.A., Miller, S., Chambers, I.R., Mendelow, A.D. (2000) Monitoring of head injury by myostatic reflex evaluation, *Journal of Neurology Neurosurgery and Psychiatry,* 68, 5, 581-588.

Comyns. T.M., Harrison, A.J., Hennessy, L.K. (2006) The optimal complex training rest interval for athletes from anaerobic sports, *The Journal of Strength and Conditioning Research,* 20,3, 471-476.

Comyns, T.M., Harrison, A.J., Hennessy, L.K. (2010) Effect of squatting on sprinting performance and repeated exposure to complex training in male rugby players, *Journal of Strength and Conditioning Research, 24,3,610-618* .

Dixon, J., De Luca, C., and Erim, Z. (1994) Common Drive of Motor Units in Regulation of Muscle Force, *Trends in Neuroscience*, It may be that neurological combined with increased muscle excitation produces PAP. However, the high variability seen may provide evidence that PAP may be an individual concept and increases in performance may not been seen by everyone
299-305.

Doherty, D., Hodgson, M.J., (2007) The application of Postactivation potentiation, to elite sport, *International Journal of Sports Physiology and Performance,* 2, 439-444.

Enoka, R (2002) *Neuromechanics of Human Movement*, 3rd ed, Champaign, Human Kinetics.

Esformes, J. I., Cameron, N. Bampouras, T. (2010) Postactivation Potentiation following different modes of exercise, *Journal of Strength and Conditioning Research,* 24, 7, 1911-1916.

Frijins, C.J.M., Laman, D.M., van Duijn, M.A.J., van Duijn, H. (1997) Normal values of patellar and ankle tendon reflex latencies, *Clinical Neurology and Neurosurgery,* 99.

Gardiner, P.F., (2001), *Neuromuscular Aspects of Physical Activity*, Leeds, Human Kinetics.

Gargoulis, V., Aggeloussis, N., Kasmatis, P., Mavromatis, G., Garas, A. (2003) Effect of half squats warm up programme on vertical jumping ability, *Journal of Strength & Conditioning Research,* 17, 2, 342-344.

Gilbert, G., Lees, A., (2005) Changes in the force development characteristics of muscle following repeated maximal force and power exercise, *Ergonomics,* 48, 11-14, 1576-1584.

Gullich, A. Schmidtbleicher, D. (1995) Short term potentiation of power performance induced by maximal voluntary contractions, XVth Congress of the International Society of Biomechanics, 348-349.

Hamada, T., Sale, D.G., MacDougall, J.D. (2000) Postactivation potentiation, fibre type and twitch contraction time in human knee extensor muscles, *Journal of Applied Physiology,* 88, 6, 2131-2137.

Hodgson, M.J., Docherty, D., Zehr, P.E. (2008) Postactivation potentiation of force is independent of the H-reflex excitability, *International Journal of Sports Physiology and Performance,* 3, 219-231.

Hopkins, J.T., Fredricks, D., Guyon, P.W., Parker, S., Gage, M., Feland, J.B. ,Hunter, I. (2009) Whole body vibration does not potentiate the stretch reflex, *International Journal of Sports Medicine,* 30, 124-129.

Howe, T.E. (2005) Quadriceps force generation in patients with osteoarthritis of the knee and asymptomatic participants during patellar tendon reflex reactions: an exploratory cross-sectional study, *BMC Musculoskeletal Disorders,* 6, 46.

Hrysomalis, C., Kidgell, D. (2001) Effect of heavy dynamic resistive exercise on acute upper body power, *Journal of Strength and Conditioning Research*, 15, 4, 426-430.

Jenson, R.L., Ebben, W.P. (2003) Kinetic analysis of complex training rest interval effect on vertical jump performance, *Journal of Strength and Conditioning Research,* 17, 2, 345-349.

Karelis, A.D., Marcil, M., Peronnet, F., Gardiner, P.F. (2004) Effect of lactate infusion on M-wave characteristics and force in the rat plantaris muscle during repeated stimulation in situ, *Journal of Applied Physiology,* 96, 6, 2133-2138.

Kilduff, L.P., Owen, N. Bevan, H., Bennett, M., Kingsley, M.I.C., Cunningham, D. (2008) Influence of recovery time on post-activation in professional rugby players, *Journal of Sport Sciences,* 26,8, 795-802.

Kim, K., Hwang, I., Wertsch, J.J. (2002) Development of a quantative reflex hammer for measurement of tendon stretch reflex, *IEEE Transactions for neural systems and rehabilitation engineering,* 10, 3, 165-169.

Kubo K., Kanehisa H., Kawakami Y., Fukunaga, T. (2001) Effects of repeated muscle contractions on the tendon structures in humans, *European Journal of Applied Physiology*, 84, 1-2, 162-6.

Kuruoglu, H.R., Oh, S. J. (1993) Quantitation of tendon reflexes in normal volunteers, *Electromyography Clinical Neurophysiology,* 33*,* 347-351.

Lemoyne, R., Dabiri, F., Jafari, R. (2008) Quantified deep tendon reflex device, second generation, *Journal of Mechanics in Medicine and Biology,* vol 8, 1, 75-85.

Linnamo, V., Hakkinen, K, Komi, P.V. (1998) Neuromuscular fatigue and recovery in maximal compared to explosive power loading, *European Journal of Applied Physiology,* 77, 1-2,176-178.

Martini, F.H. (2006) *Fundamentals of Anatomy & Physiology, 7th Edition,* London, Pearson, Benjamin Cummings.

McCann, M.R., Flanagan, S.P. (2010) The effects of exercise selection and rest interval on postactivation potentiation of vertical jump height, *Journal of Strength and Conditioning Research,* 24, 5, 1285-1291.

Mahlfeld, K., Franke, J., Awiszus, F. (2004) Postcontraction changes of muscle architecture in human quadriceps muscle, *Muscle Nerve*, 29, 4, 597-600.

Mamizuka, N., Masataka, S., Kaneoka, K., Hori, N., Ochiai, N. (2007) Kinematic quantitation of the patella tendon reflex using a tri-axial accelerometer, *Journal of Biomechanics,* 40, 2107-2111.

Marcora, S., Miller, M.K. (2000) The effect of knee angle on the external validity of isometric measures of the lower body neuromuscular function, *Journal of Sports Science,* 18, 5, 313-319.

Mariab, E.N, (2001) *Human Anatomy & Physiology, 7th Edition,* London, Pearson, Benjamin Cummings.

Morishita, K., Kasal, Y., Ueta, T., Shiba, K., Akeda, K., Uchida, A. (2009) Patellar tendon reflex as a predictor of improving motor paralysis in complete paralysis due to cervical cord injury, *Spinal Cord,* 640-642.

Nicol, C., Avela, J., Paavo, K. V. (2006) The stretch shortening cycle: A model to study naturally occurring neuromuscular fatigue, *Sports Medicine,* 36, 11, 977-999.

Ohtaki, Y., Mamizuka, N., Fard, M., Harada, Y., Minakuchi, Y., Ochiai, N. (2009) Identification of patellar tendon reflex based on simple kinematic measurement, *Journal of Biomechanical Science and Engineering,* 4,2, 265-273.

Physical Activity Readiness Questionnaire (PAR-Q), (2002), Canadian Society for Exercise Physiology, http://www.csep.ca./forms.asp

Rassier, D.E., MacIntosh, B.R., (2000), Coexistence of potentiation and fatigue in skeletal muscle, *Brazilian Journal of Medical Biological Research,* 33, 5, 499-508.

Rixon, K.P., Lamont, H.S., Bemben, M.G., (2007) Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance, *Journal of Strength and Conditioning Research,* 21, 2, 500-505.

Ross, A., Leveritt, M., Riek, S. (2001) Neural influences on sprint running: Training adaptations and acute responses, *Sports Medicine,* 31,6, 409-425.

Sale, D., (2004), Postactivation potentiation: role in performance, *British Journal of Sports Medicine,* 38, 386-387

Seniam (1997) European recommendations for Surface Electromyography,downloaded from http://seniam.org/ site accessed 1st Setember 2008

Siff, M. (2003) Supertraining, Denver

Stam, J., Tan, K.M. (1987) Tendon reflex variability and method of stimulation, *Electroencephalography and Clinical Neurophysiology,* 67, 463-467.

Tillin, N.A., Bishop, D. (2009) Factors modulating post-activation potentiation and its effects on performance of subsequent explosive activities, *Sports Medicine, 39, 2, 147-166*.

Trimble, M., Harp. S. (1998) Postexercise potentiation of the H-reflex in humans, *Medicine Sciences and Sport Exercise,* 30, 6, 933-941.

Tubman, L.A., MacIntosh, B.R., Maki, W.A., (1996), Myosin light chain phosphorylation and posttetanic potentiation in fatigued muscle, *Pflügers Arch European Journal of Physiology,* 431: 882-887.

Uysal, H., Mogyoros, I. Burke, D. (1999) Reproducibility of tendon jerk reflexes during a voluntary contraction, *Clinical Neurophysiology,* 110. 1481-1487.

Voerman, G.E., Gregoric, M., Herman, H.J. (2005) Neurophysiological methods for the assessment of spasticity: The Hoffman reflex, the tendon reflex and the stretch reflex, *Disability and Rehabilitation,* 27, 33-68.

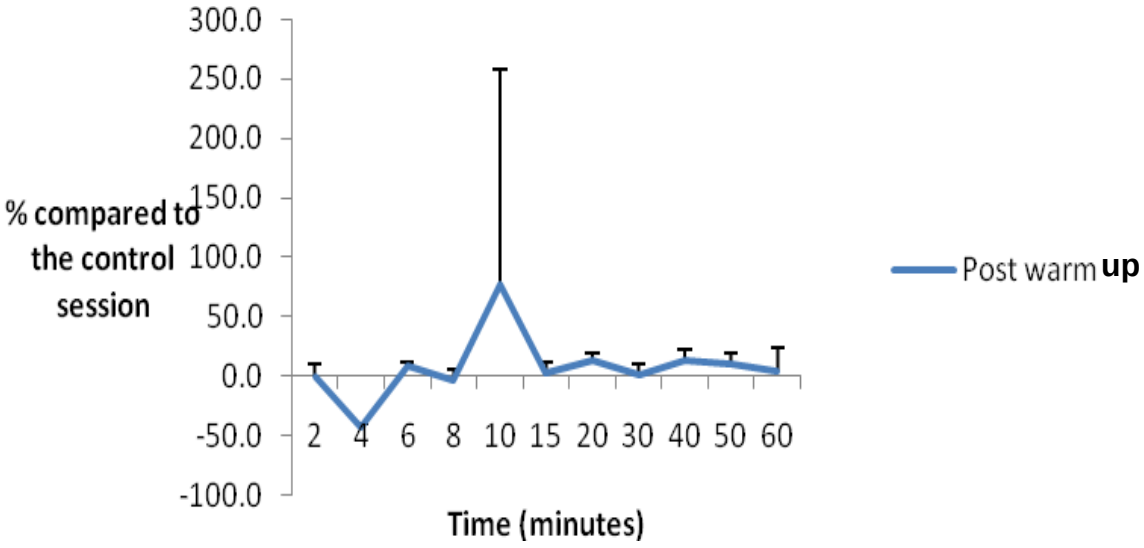
Yan, J., Mamizuka, N., Noriyuki, H., Naoyuki, O. (2007) A study of dependence in the patellar-tendon-reflex on tapping locations, *Proceedings of the 26th Chinese Control Conference,* July 26-31.

Young, W.B., Jenner, A., Griffiths, K. (1998) Acute enhancement of power performance from heavy load squats, *Journal of Strength and Conditioning Research,* 12, 2, 82-84.

Zhang, L.Q., Huang, H., Sliwa, J. A., Rymer, W. Z. (1999) System identification of tendon reflex dynamics, *IEEE Transactions on Rehabilitation Engineering*, 7, 2, 193-203.

Appendices

Appendix 1 Graphs depicting the results from study 2



-

Figure 10: The warm up effects on the time span between peak hammer tap force and muscle activation as a % compared to being at total rest.

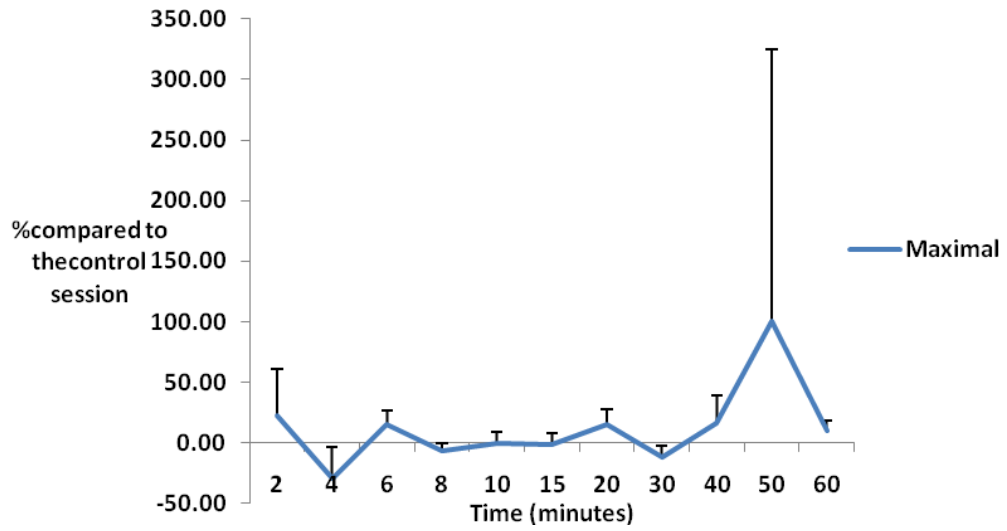


Figure 11: The maximal muscle contraction session effects on the time span between peak hammer tap force and muscle activation as a % compared to being at total rest.

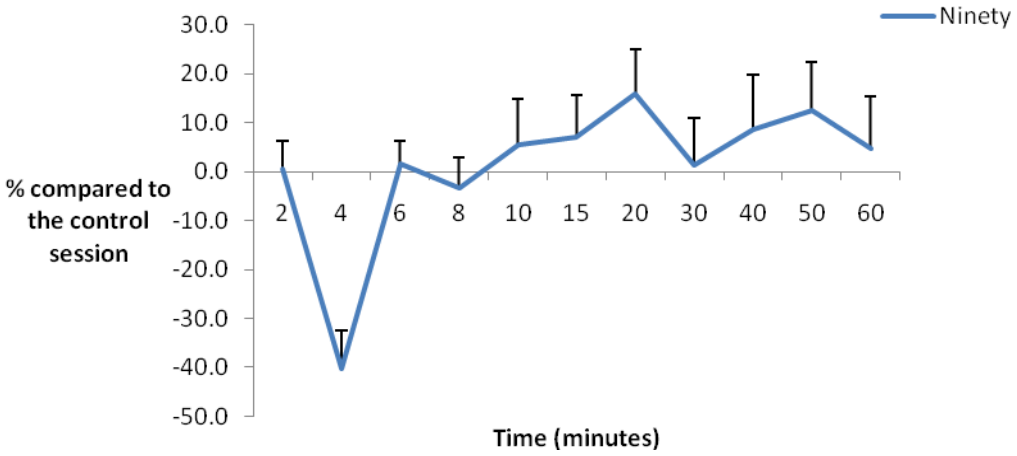


Figure 12: The effects of the 90 % of a 1 RM muscle contraction session on the time span between peak hammer tap force and muscle activation as a % compared to being at total rest.

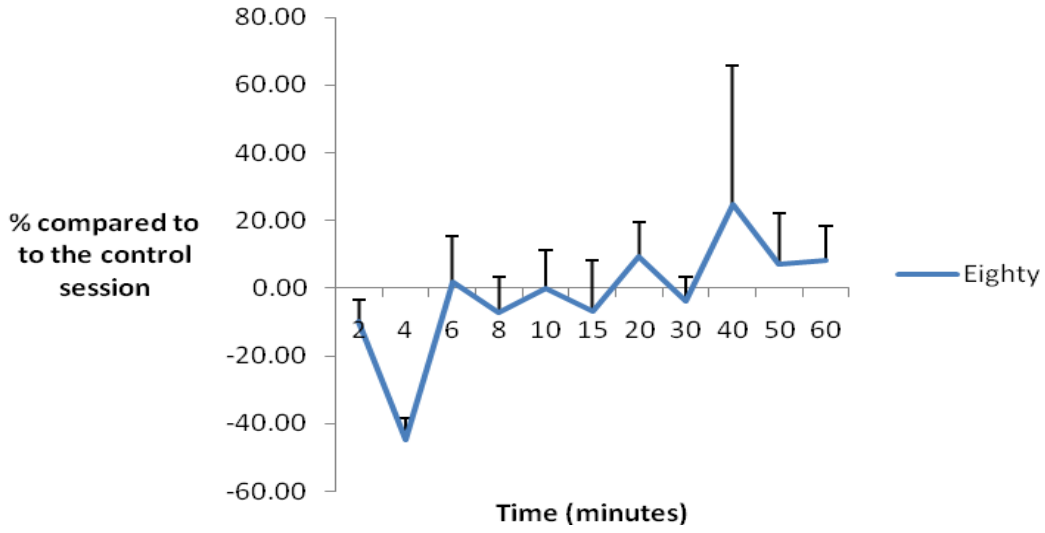


Figure 13: The effects of the 80 % of a 1 RM muscle contraction session on the time span between peak hammer tap force and muscle activation as a % compared to being at total rest.

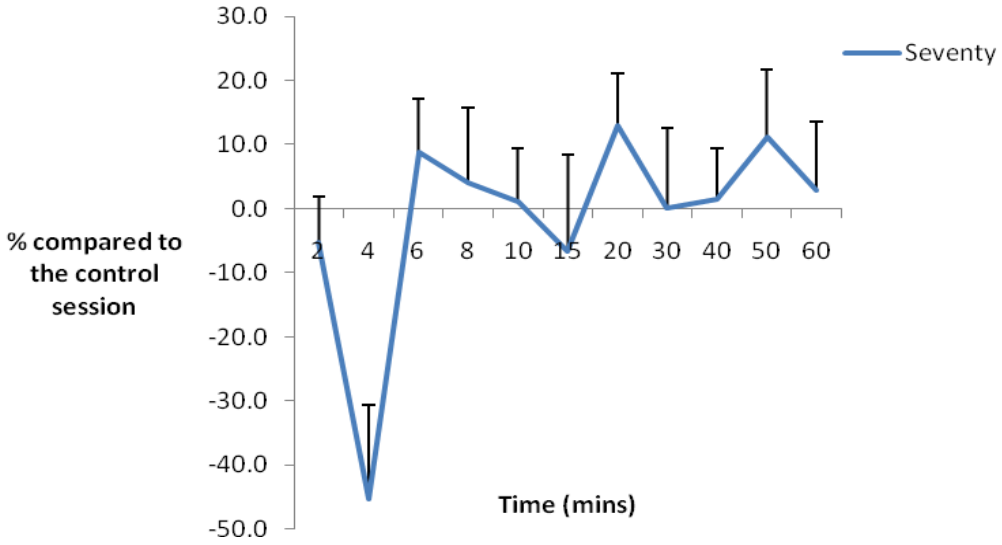


Figure 14: The effects of the 70 % of a 1 RM muscle contraction session on the time span between peak hammer tap force and muscle activation as a % compared to being at total rest.

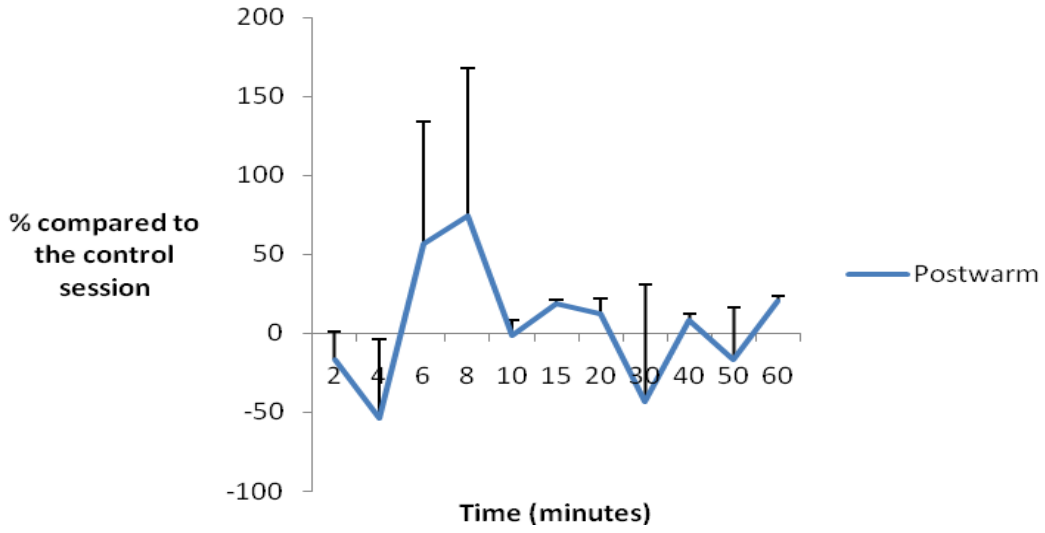


Figure 15: The effects of the warm up session on the time span between muscle activation and the start of knee movement as a % compared to being at total rest.

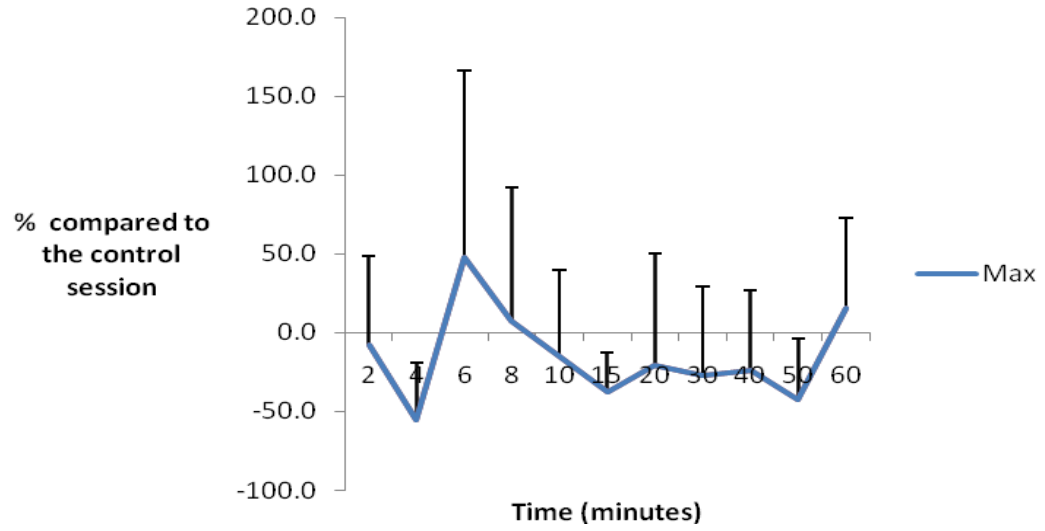


Figure 16: The effects of the maximal muscle contraction session on the time span between muscle activation and the start of knee movement as a % compared to being at total rest.

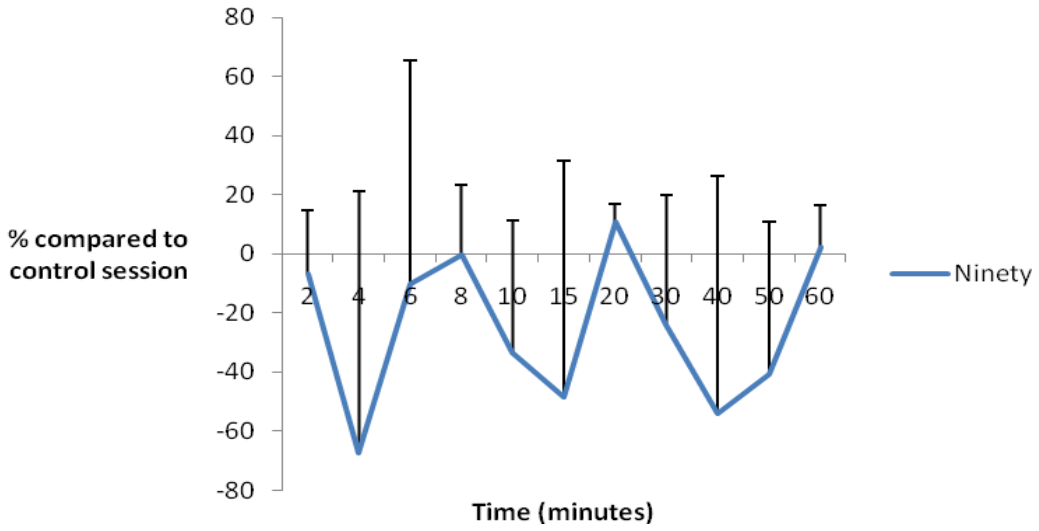


Figure 17: The effects of the 90 % of a 1 RM muscle contraction session on the time span between muscle activation and the start of knee movement as a % compared to being at total rest.

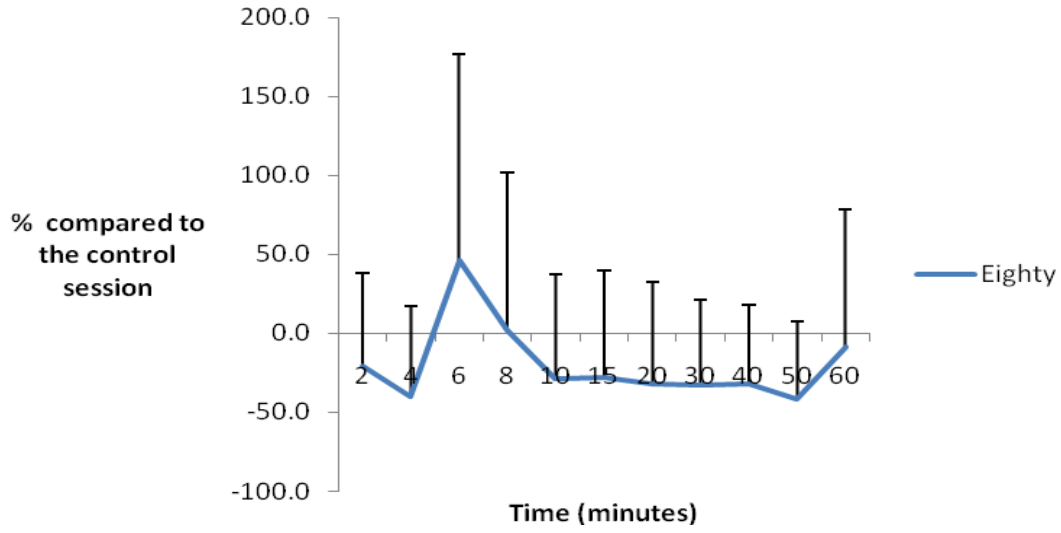


Figure 18: The effects of the 80 % of a 1 RM muscle contraction session on the time span between muscle activation and the start of knee movement as a % compared to being at total rest.

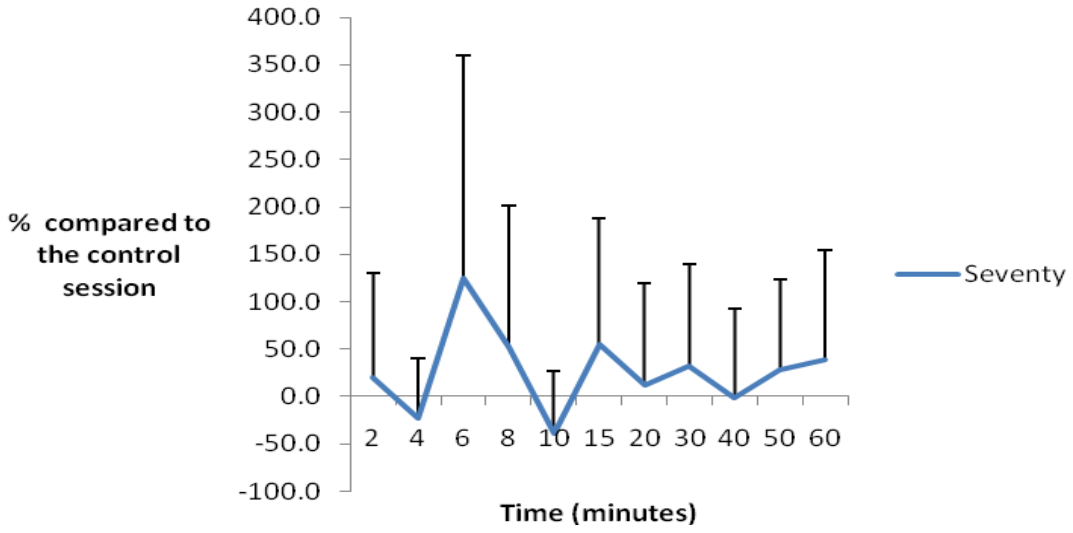


Figure 19: The effects of the 70 % of a 1 RM muscle contraction session on the time span between muscle activation and the start of knee movement as a % compared to being at total rest.

Appendix 2

Informed Consent

You are being asked to volunteer to partake in a research project looking at explosive power development in the lower leg. This form provides you with information about the project and how your information will be kept confidential.

The researcher will explain the project, your contribution and answer questions you may have relating to the project. Before you decide whether or not to take part, read the information below and ask questions about anything you do not understand.

Participating in the study is completely voluntary and you can decide to pull out at any stage of the study without any questions being asked.

1. Name of Participant

_____

2. Title of Research Study

What is the optimal force required to gain the stretch reflex action in the knee.

3.0 Researcher's Details

Kevin Wyld

P0.67

University of Bedfordshire

Polhill Avenue

Bedford

Bedfordshire MK41 9EA

01234 793022 Ext 4022

4.0 Source of Funding or Other Material Support

University of Bedfordshire

5. What is the purpose of this research study?

To investigate the optimal force that will maximally stimulate the central nervous system giving an enhanced stretch reflex.

6. What will be done if you take part in this research study?

You will be asked to attend the sport science laboratories at Polhill campus Bedford on 1 occasion.

The session will consist of completing the relevant forms and body mass and height being measured. You will then be asked to sit on a high chair and have your dominant leg stretch reflex elicited by having a mild patella tendon tap test with a rubber tipped reflex hammer. The hammer will tap just below the patella at

a predetermined force 10 times. Another weight will be added to the hammer twice and a further 10 taps will be completed.

You will be asked not to take any ergogenic supplements and abstain from caffeine and alcohol ingestion 24 hours prior to testing. You will also be asked to refrain from completing any strenuous exercise 72 hours prior to testing.

7. If you choose to participate in this study, how long will you be expected to participate in the research?

One occasion and approximately 30 minutes duration

8. How many people are expected to participate in this research?

No more than fifty.

9. What are the possible discomforts and risks?

All exercise, has certain risks and discomfort may apply. The risks involved in the exercise protocol may include abnormal blood pressure, fainting, disorder of heartbeat, and in the most extreme instances, heart attack, stroke or death. You may feel minimal muscle soreness in the lower limb up to 72 hours after the sessions. Every effort will be made to minimise these risks by medically screening and continuously monitoring participants throughout the procedures. It is the

participants' responsibility to inform the researcher if you feel dizzy, ill-feeling or other symptoms during or after the exercise. This study may also include risks that are unknown at this time.

Participation in more than one research study or project may further increase the risks to you. Please inform the researcher (listed in Item 3 of this consent form) before enrolling in this or any other research study or project. Throughout the study, the researchers will notify you of new information that may become available and might affect your decision to remain in the study. If you wish to discuss the information above or any discomforts you may experience, you may ask questions now or call the researcher or contact person listed on the front page of this form.

10a. What are the possible benefits to you?

There are no personal benefits from participating in this study.

10b. What are the possible benefits to others?

This study may assist other researchers in future research into muscle performance and coaches to prescribe exercise programmes.

11. If you choose to take part in this research study, will it cost you anything?

No

12. Will you receive compensation for taking part in this research study?

No

13 . What if you are injured because of the study?

If you suffer any injury please report this to the researcher immediately.

If you suffer from an injury outside of the study please inform the researcher as soon as possible as this could affect your safety in the study.

14. Withdraw from this research project?

You have the right to withdraw from the study at anytime without any questions being asked.

If you decide to withdraw from the study could please inform the main researcher Kevin Wyld telephone number 01234 793022 ext 4022 or email me on Kevin.Wyld@beds.ac.uk.

Information obtained prior to your withdrawal will only be used with your written consent.

The researcher has the right to withdraw you from the project without your consent for:

Risk factors associated with the medical questionnaire

Non compliance of research protocol

15 . How will your privacy and the confidentiality of your research records be protected?

Information collected about you will be stored in locked filing cabinets or in computers with security passwords. Only certain people have the legal right to

review these research records, and they will protect the secrecy (confidentiality) of these records as much as the law allows. These people include the researchers for this study, certain University of Bedfordshire officials, the hospital or clinic (if any) involved in this research, and the Institutional ethics Committee (a group of people who are responsible for looking after the rights and welfare of people taking part in research). Otherwise your research records will not be released without your permission unless required by law or a court order.

If the results of this research are published or presented at scientific meetings, your identity will not be disclosed.

16. What benefits will the researcher receive through your involvement in the project?

The study is part of the researcher masters of philosophy degree.. The researcher will present the results in scientific meeting and in scientific journals.

18. Signatures

As a representative of this study, I have explained to the participant the purpose, the procedures, the possible benefits, and the risks of this research study; the alternatives to being in the study; and how privacy will be protected:

_____ Signature of Person Obtaining Consent

_____ Date

_____ Signature of volunteer

_____ Date

University of Bedfordshire **Informed Consent Study 2**

You are being asked to volunteer to partake in a research project looking at explosive power development in the lower leg. This form provides you with information about the project and how your information will be kept confidential.

The researcher will explain the project, your contribution and answer questions you may have relating to the project. Before you decide whether or not to take part, read the information below and ask questions about anything you do not understand.

Participating in the study is completely voluntary and you can decide to pull out at any stage of the study without any questions being asked.

1. Name of Participant

---

2. Title of Research Study

An investigation of the effect of different isometric contractions on neural excitability.

3. Researcher's Details

Kevin Wyld

S3

University of Bedfordshire

Polhill Avenue

Bedford

Bedfordshire MK41 9EA

01234 793022 Ext 4022

4. **Source of Funding or Other Material Support**

University of Bedfordshire

5. What is the purpose of this research study?

To investigate the influence of the excitability of the central nervous system after completing an isometric quadriceps muscle contraction over a period of time.

6. What will be done if you take part in this research study?

You will be asked to attend the sport science laboratories at Polhill campus Bedford on six different occasions with at least 72 hours rest between testing.

The first testing session will consist of completing the relevant forms and body mass and height being measured. You will then be familiarised with the equipment. You will be asked to sit on a high chair for 10 minutes and then have your dominant leg stretch reflex elicited by having a mild patella tendon tap test

with a rubber tipped reflex hammer tap underneath your patella. The hammer will tap just below the patella at a predetermined force of 270 N at intervals of 2, 4, 6,8,10 minutes. Your eyes will be covered and ear muffs worn throughout testing. Next, you will become familiar with Isokinetic Dynamometer (Kin Com) machine where you will do a maximal isometric strength test on your dominant leg.

The next occasion (figure 1) you will sit stationary on the high chair for 10 minutes before completing another set of mild patella tendon tap tests on the dominant leg at the previously predetermined force at intervals of 2,4,6,8,10,15, 20,30,40,50, and 60 minutes. This will be followed by 5 minute exercise on a stationary bike at a moderate intensity monitored by a heart rate monitor. Another set of mild patella tendon tap tests on the dominant leg, the same as prior to the warm up. Another five minutes of exercise will be performed on the stationary bike followed by 3 x 5 second maximal isometric muscle contractions with a 55 second interval on your dominate leg. A 5 minute cool down on the stationary bike (Figure 1) finishes the session.

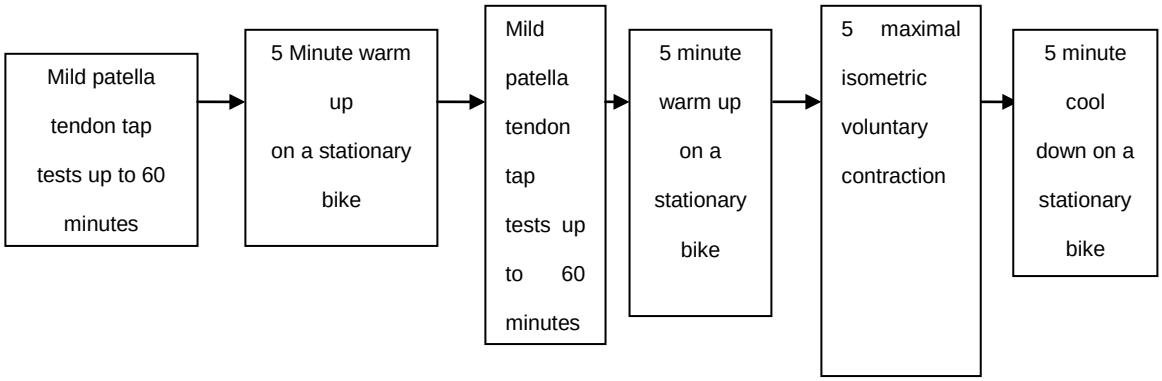


Figure 1: The first session's procedure

The next five sessions (figure 2) will involve sitting stationary on the stationary bike for 10 minutes then completing a 5 minute warm up on the bike as in the second session. You will then be randomly assigned to completing a strength test on the Isokinetic Dynamometer on your dominant leg at a percentage of your maximal quadriceps strength from the previous visit. Another set of mild patella tendon tap tests on the dominant leg will be performed at 2, 4, 6,8,10,20,30,50, and 60 minutes. A 5 minute cool down on a stationary bike at a moderate intensity will finish the session.

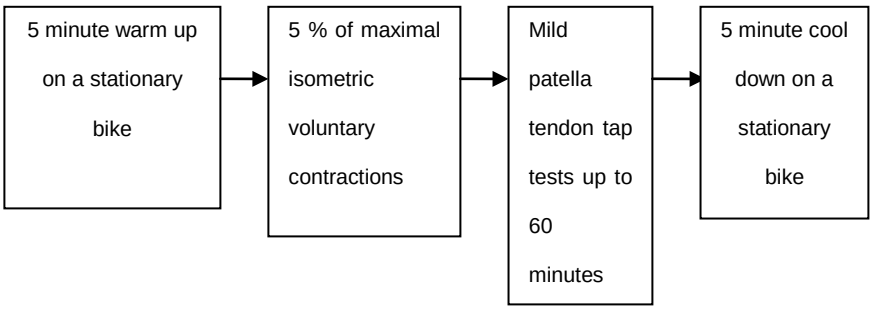


Figure 2: Session including the isometric maximal voluntary contractions

You will be asked to refrain from any ergogenic supplements and abstain from caffeine and alcohol ingestion 24 hours prior to testing. You will also be asked to refrain from completing any strenuous exercise 72 hours prior to testing.

7. If you choose to participate in this study, how long will you be expected to participate in the research?

Approximately 5 weeks

8. How many people are expected to participate in this research?

No more than fifty.

9. What are the possible discomforts and risks?

All exercise, has certain risks and discomfort may apply. The risks involved in the exercise protocol may include abnormal blood pressure, fainting, disorder of heartbeat, and in the most extreme instances, heart attack, stroke or death. You may feel minimal muscle soreness in the lower limb up to 72 hours after the

sessions. Every effort will be made to minimise these risks by medically screening and continuously monitoring participants throughout the procedures. It is the participants' responsibility to inform the researcher if you feel dizzy, ill-feeling or other symptoms during or after the exercise. This study may also include risks that are unknown at this time.

Participation in more than one research study or project may further increase the risks to you. Please inform the researcher (listed in Item 3 of this consent form) before enrolling in this or any other research study or project. Throughout the study, the researchers will notify you of new information that may become available and might affect your decision to remain in the study. If you wish to discuss the information above or any discomforts you may experience, you may ask questions now or call the researcher or contact person listed on the front page of this form.

10a. What are the possible benefits to you?

There are no personal benefits from participating in this study.

10b. What are the possible benefits to others?

This study may assist other researchers in future research into muscle performance and coaches to prescribe exercise programmes.

11. If you choose to take part in this research study, will it cost you anything.

No

12. Will you receive compensation for taking part in this research study?

No

13. What if you are injured because of the study?

If you suffer any injury please report this to the researcher immediately.

If you suffer from an injury outside of the study please inform the researcher as soon as possible as this could affect your safety in the study.

14. Withdraw from this research project?

You have the right to withdraw from the study at anytime without any questions being asked.

If you decide to withdraw from the study could please inform the main researcher Kevin Wyld, telephone number 01234 793022 ext 4022 or email me on kevin.wyld@beds.ac.uk.

Information obtained prior to your withdrawal will only be used with your written consent.

The researcher has the right to withdraw you from the project without your consent for:

Risk factors associated with the medical questionnaire

Non compliance of research protocol

15. How will your privacy and the confidentiality of your research records be protected?

Information collected about you will be stored in locked filing cabinets or in computers with security passwords. Only certain people have the legal right to review these research records, and they will protect the secrecy (confidentiality) of these records as much as the law allows. These people include the researchers for this study, certain University of Bedfordshire officials, the hospital or clinic (if any) involved in this research, and the Institutional ethics Committee (a group of people who are responsible for looking after the rights and welfare of people taking part in research). Otherwise your research records will not be released without your permission unless required by law or a court order.

If the results of this research are published or presented at scientific meetings, your identity will not be disclosed.

16. What benefits will the researcher receive through your involvement in the project?

The study is part of the researcher masters of philosophy degree. The researcher will present the results in scientific meeting and in scientific journals.

17. Signatures

As a representative of this study, I have explained to the participant the purpose, the procedures, the possible benefits, and the risks of this research study; the alternatives to being in the study; and how privacy will be protected.;

You have been informed about this study's purpose, procedures, possible benefits, and risks; the alternatives to being in the study; and how your privacy will be protected. You have received a copy of this form. You have been given the opportunity to ask questions before you sign, and you have been told that you can ask other questions at any time.

You voluntarily agree to participate in this study. By signing this form, you are not waiving any of your legal rights.

_____ Signature of person volunteering to do the study

_____Date

_____ Signature of researcher

_____Date