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The effects of a heavy resistance training intervention of the plantar flexors on the recovery of strength, power, acceleration, and agility in recreational athletes

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The effects of a heavy resistance training intervention of the plantar flexors on the recovery of strength, power, acceleration, and agility in recreational athletes.

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ABSTRACT

Resistance training is a highly utilised form of exercise that is used to develop strength, power, speed and muscular endurance. Although it is associated with many positive benefits it also has some potentially unfavourable effects. These are manifested in the form of altered muscle function through the effects of muscle fatigue and exercise-induced muscle damage. Various aspects muscle fatigue and damage have been well studied, however research into the effects of these on tests of strength, power, acceleration and agility is sparse. Therefore the aim of this study was to investigate the effects of a heavy resistance intervention on the recovery of the above measures of performance. Performance of these parameters were examined through the application of functional performance measures such as maximal voluntary isometric strength, vertical jump height, standing broad jump, 10m sprinting speed, and the Illinois Agility run. The subjects were recreationally active, but non-resistance trained, males between the age of 18 and 45. The subjects completed 10 testing sessions, four on the day of the heavy resistance intervention (prior, immediately post, 2 and 6 hours post) and 2 measurements taken 3 hours apart for the following 3 days. Results analysed via a one-way analysis of variance (ANOVA) with repeated measures, and simple contrasts to baseline were used to identify any significant relationships. Statistical significance was set at $p<0.05$. The results revealed significant decreases in performance of maximal isometric strength, vertical jump and 10m sprinting ability immediately following the resistance training intervention and during the following two days for maximal isometric strength and 10m sprint. When compared to baseline results the Illinois agility run showed significant improvement in performance from the 2^{nd} testing session of day 2 progressively to the final testing session of the study. Standing broad jump performance also improved over the testing period to be significantly different to baseline results on the last testing day. The presence of soreness was significant in all testing sessions following the resistance training intervention while tenderness was most prominent in the medial compared to the lateral and midline sites. The decrements in performance (maximal isometric strength, vertical jump, 10m sprint) were attributed to the effects of muscle fatigue and exercise-induced muscle damage, while the improvement in performance (standing broad jump, Illinois agility tests) is believed to result from the effects of learning and practice.

DECLARATION

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ABBREVIATIONS

ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
Ca^{2+}	Calcium ions
CK	Creatine Kinase
CMJ	Countermovement Jump
CPK	Creatine phosphokinase
CSA	Cross Sectional Area
E-C coupling	Excitation-Contraction Coupling
EMG	Electromyographic
Hz	Hertz
ICC	Intraclass coefficient
K^{+}	Potassium ions
kPa	Kilopascals
LFF	Low Frequency Fatigue
MIS	Maximal Isometric Strength
mmol	Millimoles
MRI	Magnetic Resonance Imaging
MVC	Maximum Voluntary Contraction
N	Newtons
Na^{+}	Sodium ions
Nm	Newton metres
PCr	Phosphocreatine
pH	Potential of Hydrogen
RM	Repetition Maximum
RTI	Resistance Training Intervention
SBJ	Standing Broad Jump
SD	Standard Deviation
SJ	Squat Jump
SR	Sarcoplasmic Reticulum
VAS	Visual Analogue Scale
VJ	Vertical Jump

CHAPTER 1

INTRODUCTION

1.1 Background to Study

Resistance training is a commonly used training method for a variety of athletes in a wide range of sports. The inclusion of resistance training in athletes training programs is linked to its ability to be adapted to train multiple fitness components. Research has shown resistance training to be effective in the development of strength (Kraemer, Ratamess, Volek, Mazzetti, & Gomez, 2000b), power (Fatouros et al., 2000; Kraemer et al., 2002), speed (Harris, Stone, O'Bryant, Proulx, & Johnson, 2000; Hennessy & Watson, 1994) and muscular endurance (Kraemer et al., 2002; Zatsiorsky, 1995).

The majority of athletes who utilise resistance training within their exercise program devote significant effort to strength improvement. As specific aspects of athletic performance have been shown to improve with strength development, it is common practice for athletes to base phases of their periodized training program on increasing maximum strength. Programs designed with this in mind are characterised by high intensity, low volume protocols incorporating lengthy rest periods between sets. These characteristics along with the type of contractions involved seem to influence strength gains. Research results from some laboratories suggest that eccentric contractions, where the muscle lengthens while producing force, are more effective in strength development than concentric or isometric contractions (Higbie, Cureton, Warren, & Prior, 1996; Hortobagyi et al., 1996). This contraction type is considered by some researchers to be more effective in strength development due to its ability to apply greater overload to the activated muscles and thereby provide greater neural and muscular stimuli for adaptation (Hortobagyi et al., 1996). Although in a chronic sense

eccentric training may be effective for developing strength and enhancing sporting performance, from an acute perspective it is associated with temporary 'unfavourable' effects which may compromise athletic ability. These 'unfavourable' effects can occur immediately following resistance training and persist for a number of days, with the phenomenon often being referred to as the 'washout period'. During this period muscle function may be altered and athletic performance adversely affected due to the symptoms of muscle fatigue and exercise-induced muscle damage.

The effects of muscle fatigue are generally limited to the short term, while those of exercise-induced muscle damage usually occur in the days following the resistance training session and may affect performance for a protracted period. Muscular fatigue may impair performance due to factors affecting the neural and/or motor processes involved in athletic performance (Green, 1997). These are, however, generally overcome following periods of adequate rest. The effects of exercise-induced muscle damage are prevalent for longer and are associated with an extended recovery period due to physical damage resident within the muscle structure. The magnitude of exercise-induced muscle damage is dependent upon the intensity, duration, rest periods utilised, prior exposure to the damaging exercise, and the type of muscle actions employed in the exercise intervention (Nosaka, Lavender, Newton, & Sacco, 2003). Eccentric muscle actions have been shown to be the contraction type likely to cause the greatest magnitude of muscle damage (Clarkson, Byrnes, McCormick, Turcotte, & White, 1986). Studies employing interventions focused entirely on eccentric exercise have reported significant symptoms of exercise-induced muscle damage in which recovery is protracted for periods ranging from days to over a month. (Clarkson, Nosaka, & Braun, 1992). However once recovery is complete, exposure to a similar intensity and volume of eccentric exercise results in a significantly reduced magnitude of muscle damage and soreness, and an expedited recovery period (Nosaka, Sakamoto, Newton, & Sacco, 2001).

Despite the abundance of research focusing on resistance training programs, there remains a dearth of scientific data relating to the effects of such exercise in the hours and days following a strength based training session. As the effects of muscle fatigue

and exercise-induced muscle damage may affect athletic performance it is important that the athlete, coach, and strength and conditioning specialist be cognisant of the effects that resistance training sessions may have on subsequent performance. A sound knowledge of this specialised area is also important when designing effective and efficient training practices, and for tapering processes prior to important competition.

1.2 Purpose of Study

The purposes of this study were to determine whether functional performance tests are affected by a single heavy resistance training intervention (RTI), and if so are the recovery rates different between the types of tests. The functional performance tests examined the training parameters of strength, power, acceleration and agility.

1.3 Research Questions

1. What affect will a heavy RTI of the plantar flexors have on the criterion measures of:
    - Maximal Isometric Strength (MIS)
    - Vertical Jump (VJ) Height
    - Standing Broad Jump (SBJ)
    - 10 metre Sprinting Speed
    - Illinois Agility Run
    - Creatine Kinase (CK) Activity at 3 days post intervention
    - Muscle Soreness and Tenderness.

2. For what time period will the criterion measures remain significantly different to pre-intervention (baseline) levels?

1.4 Hypotheses

It is hypothesised that following the heavy RTI:

1. MIS would be significantly lower than baseline levels immediately, and during the first two days, following the resistance intervention.

2. Vertical jump performance would significantly decline immediately following and during the subsequent two testing days compared to pre-intervention performance.

3. Standing broad jump performance would be significantly depressed immediately following and continue for the subsequent two testing days as compared to pre-intervention performance.

4. The time taken to complete the 10m sprint would significantly increase immediately following the RTI and for the following two days as compared to pre-intervention results.

5. Performance time to complete the Illinois agility run would be significantly increased immediately, and for the two days following the RTI compared to baseline levels.

6. Measures of muscle soreness and tenderness will be significantly elevated above baseline measures in the two days following RTI.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

The following review will examine relevant background information on the main components of the study. The primary focus will include the Development of Strength, Muscular Fatigue, Exercise-Induced Muscle Damage, and Selected Tests of Performance.

2.2 Strength Development

Muscular strength is an important physical component for most sports and physical activities as well as being important in general physical well-being. Increases in strength may assist improvements in performance in a variety of sports and skills (Kraemer, Duncan, & Volek, 1998). The degree of improvement however is influenced by factors such as the fitness status of the athlete and their initial strength levels (Fatouros et al., 2000; Kraemer et al., 2002). Athletes initially possessing low levels of strength usually produce the most profound improvements in strength, power and speed following strength training (Baker, 1996; Fatouros et al., 2000). Strength improvements can occur through stressing the muscles past the level that they are unaccustomed to, however specific training practices can specialise the adaptation.

2.2.1 Factors Contributing to Strength Development

2.2.1.1 Neural Adaptations

Muscles are activated through stimulation from the nervous system therefore strength training may result in neural adaptations (Kraemer et al., 2002). Neural adaptations which occur with strength development include the ability to fully activate all the available motor units, improved rate of force development and improved motor unit synchronisation (Jones, Rutherford, & Parker, 1989b; Sale, 1988). It has been found that untrained athletes may not be able to fully activate all of the motor units in a given muscle (Enoka, 1997; Sale, 1988) or be able to fully activate muscle groups at certain speeds or joint positions (Jones et al., 1989b). Therefore, the early phases of strength improvement may be due to the improved ability to activate all available motor units (Jones et al., 1989b; Sale, 1988). Along with the activation of all available motor units the frequency of firing (rate coding) of active motor units is also important to the development of strength (Sale, 1992). Firing frequency refers to the number of nerve impulses that muscle fibres receive from the motoneuron (Sale, 1992). Improvement in firing frequency and motor unit synchronisation can improve the rate of force development, which is important for many athletic movements (Sale, 1992; Sale, 1988). Improvement in synchronisation indicates changes in the neural connectivity amongst the last interneurons and motor neurons (Enoka, 1997). Motor unit synchronisation has been found to be greater in weight lifters than in untrained subjects (Gonyea & Sale, 1982). The co-ordination of a movement may also influence initial strength gains. Novel movements often have extraneous movement and neural activation. Extraneous neural activity is associated with the co-activation of the agonist and antagonist muscles, and is a default strategy employed by the nervous system when uncertainty in a task is present (Enoka, 1997). The activation of the antagonist muscles can cause inconsistent strength measures, however, training or practice has been found to improve coordination of the movement and reduce antagonist activation (Enoka, 1997). These neural adaptations usually occur within the first few weeks of training in relatively untrained subjects (Enoka, 1997; Moritani & deVries, 1979). Although these can bring about considerable performance enhancements there is however a limit to the degree of improvement that can occur without a concomitant increase in the contractile elements (Gonyea & Sale, 1982).

2.2.1.2 Muscular Adaptations

Strength improvements following resistance training result from increases in muscle size and/or improvements in neuromuscular function (Hakkinen, Alen, & Komi, 1985; Higbie et al., 1996; Staron et al., 1994). Increases in muscle size plays an important role in increasing strength as larger muscles are capable of producing greater force (Sale, 1992). Muscular adaptations resulting in greater muscle circumference may result from either hypertrophy of muscle fibres and/or through muscle fibre hyperplasia. The role that both of these mechanisms plays within increasing muscle size remains controversial with research providing support for the role of both methods.

Muscle fibre hypertrophy is a well established response to resistance training in human subjects (MacDougall, 1992). The concept of the muscle fibre hypertrophy mechanism in increasing muscle size is based upon the notion of enlargement of existing muscle fibre through the addition of contractile and structural proteins to individual myofibrils (Kraemer et al., 1998; Staron et al., 1994). The addition of contractile and structural proteins occurs through increases in protein synthesis which can be induced by a single resistance training session (Staron et al., 1994). During exercise protein synthesis decreases while protein degradation increase due to injury to the muscle fibres (Antonio & Gonyea, 1993). In response to this during recover a super-compensatory effect occurs to the levels of protein synthesis producing a net anabolic effect (Antonio & Gonyea, 1993). This results in the myofibrils thickening and increasing in number and the formation of additional sarcomeres (Alway, Grumbt, Gonyea, & Stray-Gundersen, 1989). Enhanced protein synthesis peaks approximately 24 hours post exercise and but can remains elevated from 2-3 hours up to 36-48 hours post exercise (Kraemer et al., 2002).

Although there is large support for the muscle fibre hypertrophy model for explaining increases in muscle size, there are some studies, which have proposed the muscle hyperplasia mechanism to explain the enlargement of muscles. In this proposed mechanism the muscle enlarges through increasing the number of muscle fibres within the muscle (Antonio & Incledon, 2000). It is proposed that this occurs through the

development of new muscle fibres from dormant satellite cells or through a process of longitudinal splitting of large muscle fibres into two or more smaller fibres(Antonio & Gonyea, 1993). Support for this mechanism has developed from research from animal and cross sectional studies. Animal studies using rodent, feline and avian species have provided direct and indirect evidence of muscle fibre hyperplasia, however it is difficult to generalise these finding to human subjects or provide similar research with human subjects due to technical and ethical constraints (Antonio & Gonyea, 1993). Research from cross sectional studies has however provided evidence that the possibility of muscle fibre hyperplasia within human may occur. Cross sectional studies have investigated hyperplasia by utilising athletes such as bodybuilders for subjects, who despite having muscle circumferences larger than normal sedentary controls have shown no difference in muscle fibre area (MacDougall, Sale, Elder, & Sutton, 1982; Tesch & Larsson, 1982). Therefore, the large circumference of muscle could not be explained by increased CSA of muscle fibres and has led to the suggestion of an increased number of muscle fibres (MacDougall et al., 1982; Tesch & Larsson, 1982). The role of hyperplasia in the development of muscle CSA remains controversial especially within human studies due to the technical and ethical constraints imposed on the involvement of human subjects (Antonio & Gonyea, 1993). Therefore at present it is generally accepted that in human subjects undertaking heavy resistance training the associated increase in overall muscle size results mainly from hypertrophy of existing muscle fibres (Antonio & Gonyea, 1993; MacDougall, Sale, Alway, & Sutton, 1984; McCall, Byrnes, Dickinson, Pattany, & Fleck, 1996).

2.2.2 Training to Improve Strength

Resistance training can be adapted to condition selected components of physical fitness through manipulation of the intensity, volume, and rest periods between repetitions, sets, and days of training. Training to improve physical fitness components such as hypertrophy and muscular endurance involve low intensity high volume programs while training for strength and power is characterised by high intensity low volume programs (Kraemer et al., 2002). Traditional strength training programs involve heavy weights (usually above 85% of 1 repetition maximum (RM)), moderate volume (6 or less

repetitions for 2-6 sets), as well as lengthy rest periods between sets of between 2-5 minutes (Baechle & Earle, 1994; Kraemer et al., 2002).

The type of contraction employed in resistance training may relate to the degree of strength development. Three forms of contractions that are generally used to develop strength are concentric, eccentric and isometric. Concentric contractions are performed when the muscle produces force while shortening, such as the flexion phase of a bicep curl. The extension phase of the bicep curl is an example of an eccentric action as the muscle lengthens while producing force to control the motion. Isometric contractions occur when the muscle produces force but no movement occurs at the joint. This usually occurs when the muscle produces force against an object, which it physically cannot over come, an example of which would be pushing against a brick wall.

Numerous studies have investigated the effectiveness of different muscle contractions on the development of strength, however, results have been equivocal due to differing protocols and methods of assessment (Higbie et al., 1996). The method of assessment is an important consideration when determining the effectiveness of strength development as strength measures tend to be greatest when assessed using the same muscle actions as those employed during training (Higbie et al., 1996). It has been suggested that eccentric contractions can generate greater maximum forces than concentric or isometric contractions, therefore training involving eccentric contractions may be more effective in developing strength (Higbie et al., 1996). Studies performed by Higbie et al., (1996) and Hortobagyi et al., (1996) examined the strength development following eccentric and concentric training programs. Both studies found that eccentric training increased strength when measured eccentrically more so than when concentric training was evaluated concentrically. Hortobagyi et al., (1996) also measured strength isometrically and found that eccentric training increased strength in this to a greater degree than concentric training. Eccentric actions may provide a superior stimulus for strength increases through more potent neural and intrinsic muscular adaptations (Hortobagyi et al., 1996).

A consequence following resistance training is the 'washout' period during which muscle function is altered. Altered muscle function has been found in terms of peak force development, neural activation and changes in force time curves (Hakkinen, 1993). Alterations in neuromuscular function may result from muscular factors such as muscular fatigue and exercise-induced muscle damage, or neural factors such as neural inhibition or central fatigue. The degree of altered muscle function is dependent on the volume, intensity and type of loading employed (Hakkinen, 1993).

2.3 Muscular Fatigue

Muscular fatigue refers to a class of effects that impair performance involving both motor and sensory processes (Enoka, 1994). The effects of muscular fatigue are manifested through a reduction in the ability to produce force following intense activity and may persist for days or weeks (Green, 1997; Kawakami, Amemiya, Kanehisa, Ikegawa, & Fukunaga, 2000). Intense muscular work leads to fatigue which can be classified by locality into 'central' or 'peripheral' (Behm, Baker, Kelland, & Lomond, 2001; Kawakami et al., 2000; Linnamo, Hakkinen, & Komi, 1998). Central fatigue may result from poor motivation of the subject and/or alteration in the neural transmission and motor unit recruitment (Kirkendall, 1990). Alterations to neural transmission and recruitment may occur from decreases in activation of new motor units and/or the firing frequency of active motor units (Linnamo et al., 1998). Central fatigue may occur as a result of conscious or unconscious mechanisms (James, Sacco, & Jones, 1995). Conscious mechanisms involve the subject deciding that the sensations are unacceptable and deliberately reducing activity, while unconscious mechanisms involve the inhibition of motor activity through afferent information from the muscle, joints or tendons (James et al., 1995). Peripheral fatigue primarily occurs in the contractile processes (Linnamo et al., 1998) with impaired junctional transmission, muscle electrical activity and activation (Kirkendall, 1990) and/or impairment of the contractile apparatus (Kawakami et al., 2000).

Peripheral fatigue can further be classified into metabolic and non-metabolic components (Green, 1997). Non-metabolic components of peripheral fatigue result from generation of high repetitive forces and usually result in muscle damage (Green, 1997). Metabolic components involve energetic changes in the muscle and is dependent on the ratio of contraction and recovery time (Green, 1997). The breakdown (hydrolysis) of the adenine nucleotide adenosine triphosphate (ATP), which is the primary energy source within muscle cells, is implicated in muscle fatigue. ATP is found in limited supply within the body (Green, 1997; Hirvonen, Rehunen, Rusko, & Haerkoenen, 1987) with the average 70 kg male storing approximately 24 mmol per kilogram (dry mass) intramuscularly which is enough to power muscular work for approximately two seconds (Maughan, Gleeson, & Greenhaff, 1997). Substantial depletion of ATP is prevented through the resynthesis of ATP by the supply systems oxidative phosphorylation, glycolysis and high energy phosphate transfer (Green, 1997). These processes use substrates such as phosphocreatine (PCr) and glycogen in order to resynthesise ATP. When these substrates become depleted ATP resynthesis and performance will consequently decline, therefore it is important to restore energy supplies through the intake of high caloric liquid and solid foodstuffs (Keizer, Kuipers, van Kranenburg, & Geurten, 1987). During repeated high intensity demanding exercise involving large muscle groups depletion of muscle glycogen may be a factor involved in the development of fatigue (Green, 1997). Whole muscle glycogen depletion doesn't seem to have a large influence in short term anaerobic exercise, however specific fibre depletion may have some impact on muscle fatigue (Kirkendall, 1990). In fast glycolytic fibres it has been suggested that cytoskeletal and myofibrillar structures may be compromised by fatigue due to low levels of ATP causing the fibres to enter a high stiffness state which when stretched by eccentric actions cause mechanical disruption (Friden & Lieber, 1992).

Another cause of metabolic peripheral fatigue is not primarily the reduction in ATP but rather the metabolic by-products that result from ATP breakdown, which advances the fatigue process (Green, 1997). The build up of hydrogen ions seems to have a significant influence on the development of fatigue. An increase in hydrogen ion concentration can lead to reductions in pH of the muscle (Kirkendall, 1990). pH

changes impact on a number of process within the cell including effects on enzyme kinetics which could limit ATP production, membrane excitability and calcium ion requirement and release for tension development (Kirkendall, 1990). A major impact concerning muscle fatigue are the effects on the excitation-contraction (E-C) coupling phenomena. E-C coupling is the process in which communication to contract is transmitted from the surface of the sarcolemma to the contractile apparatus (Kirkendall, 1990). The process as described by Warren, Ingalls, Lowe and Armstrong (2001) begins at the neuromuscular junction where an action potential results from the alpha motor neuron. The action potential propagates along the sarcolemma (plasmalemma) to the t-tubule where it travels down deep into the fibre. The action potential causes depolarisation of the t-tubular membrane, which changes the embedded voltage sensors (dihydropyridine receptors). The change in the dihydropyridine receptors signals the sarcoplasmic reticulum (SR) ryanodine receptors via an undetermined mechanism to open the SR calcium release channels. With the SR calcium channels open calcium ions are released into the cytosol, where they can bind to the troponin complex and initiate the crossbridge cycle. It has been found that E-C coupling failure could account for 57-75% of strength deficits observed in the first 5 days following injury with the remainder of the strength loss being attributed to physical disruption and or alteration of force bearing structures (Warren et al., 2001). The E-C coupling process involves intricate mechanisms, which remain relatively undetermined. However it is believed that the failure in the E-C coupling process occurs between the voltage sensors of the t-tubule and the SR calcium release channels (Warren et al., 2001).

2.4 Exercise-Induced Muscle Damage

Responses to exercise - induced damage include decreases in voluntary and electrically stimulated force production, increases in muscle soreness, leakage of muscle proteins into the circulation, decreased ROM, increases in muscle circumference, and abnormalities in magnetic resonance images (MRI) (Brown, Child, Day, & Donnelly, 1997; Nosaka & Newton, 2002c). The symptoms of muscular damage, in particular strength loss, can have a profound adverse effect on subsequent performance (McHugh et al., 1999). Gleeson, Blannin, Zhu, Brooks, and Cave (1995) reported that exercising

in the presence of the effects of muscle damage involves greater metabolic stress and can result in premature fatigue.

The effects of exercise-induced muscle damage can be experienced after performing unaccustomed or high intensity eccentric and concentric exercise (Behm et al., 2001). Exercise involving primarily eccentric actions has been found to elicit a greater degree of muscle damage than concentric or isometric actions (Clarkson et al., 1986). The greater degree of altered muscle function and damage associated with eccentric contractions may be due in part to eccentric actions activating 35-60% less motor units than concentric contractions (McHugh, Connolly, Eston, & Gleim, 2000). With less motor units being activated during eccentric contractions there is greater stress placed upon the fibres which is consequently associated with the greater muscle damage induced with eccentric actions (McHugh et al., 2000). Mechanical disruption is another factor that is associated with eccentric contractions and altered muscle function and damage. The loading profile of eccentric actions, in which the muscle lengthens while producing force, probably leads to mechanical disruption of the actin - myosin bonds placing high stresses and strains on the associated structures and contributes to damage (Enoka, 1996). Research focusing on muscle function following isometric contractions is limited, however it has been shown that following isometric exercise significant increases in serum CK and soreness are also possible (Clarkson et al., 1986).

The type of exercise from which muscle damage is incurred has been shown to affect the magnitude of disruption and the recovery process (Newham, Mills, Quigley, & Edwards, 1983; Nosaka & Clarkson, 1997; Nosaka & Newton, 2002a, 2002b). As mentioned above, eccentric muscle actions are associated with a greater degree of muscle damage than concentric and isometric exercise (Clarkson et al., 1986; Higbie et al., 1996; Hortobagyi et al., 1996). The mechanism by which exercise results in structural damage to myofibrils remains some what unclear however the majority of the damage appears around the area of the Z-line (Nosaka & Clarkson, 1997). Other abnormalities following unaccustomed exercise include sarcolemma disruption, a dilated transverse tubule system, distortion of myofibrillar components, damage to the sarcoplasmic reticulum, lacerations to the plasma membrane, cytoskeletal damage,

extracellular myofiber matrix changes, and swollen mitochondria (Enoka, 1996; Gibala, MacDougall, Tarnopolsky, Stauber, & Elorriaga, 1995).

It is believed that exposure to exercise-induced muscle damage may have a beneficial effect in the long term through conditioning muscles to become more resilient to the effects of a second bout of similar exercise (Clarkson & Tremblay, 1988; Kuipers, 1994). Not only are the muscles more resilient to the immediate effects of exercise-induced muscle damage but they are also able to repair at a faster rate (Clarkson & Tremblay, 1988). This phenomenon is commonly referred to as the 'repeated bout effect' (McHugh, Connolly, Eston, Gartman, & Gleim, 2001; Nosaka, Clarkson, McGuiggin, & Byrne, 1991; Nosaka & Newton, 2002d; Nosaka et al., 2001; Paddon-Jones, 2000). The repeated bout effect is characterised by reductions in the magnitude of indicators of exercise-induced muscle damage. It has been reported that strength recovers faster, muscle soreness and swelling is reduced, ROM is affected to lesser extent as is the concentration of muscle specific proteins within the blood, and fewer MRI abnormalities are apparent (Clarkson et al., 1992; Newham, Jones, & Clarkson, 1987; Nosaka et al., 2001). These adaptations may be detected for several weeks (Newham et al., 1987; Nosaka et al., 1991; Triffletti, Litchfield, Clarkson, & Byrnes, 1988) and may extend up to 6-9 months following the damaging exercise (Nosaka et al., 2001).

2.4.1 Indicators of Exercise-Induced Muscle Damage

2.4.1.1 Strength Loss

Force loss is a common consequence of both muscle fatigue and exercise-induced muscle damage. Maximal voluntary isometric contractions are routinely used in studies to measure muscular strength, and provide the primary means of determining muscle function after damaging exercise (Byrne & Eston, 2002a). Prior research has demonstrated that isometric strength can be reduced immediately following unaccustomed exercise with recovery occurring over hours (Newham et al., 1983), days

(Gibala et al., 1995; Hortobagyi et al., 1996), and in some circumstances a week or longer (Byrne, Eston, & Edwards, 2001; Clarkson et al., 1992). Within maximal eccentric exercise protocols strength loss has been reported as high as 50% of pre-exercise values (Clarkson et al., 1992). In contrast, studies in which the exercise intervention involved resistance exercises with both concentric and eccentric components the loss in strength has been less with figures of 35% of baseline levels reported (Byrne & Eston, 2002b; Vincent & Vincent, 1997). Concentric and isometric exercises are also associated with decrements in isometric strength, especially when the exercise is fatiguing in nature (Behm & St. Pierre, 1998; Behm & St-Pierre, 1997). This latter form of exercise, however, is not usually noted for protracted periods of strength loss with recovery generally being measured in minutes rather than hours or days (Behm & St. Pierre, 1998; Behm & St-Pierre, 1997).

2.4.1.2 Measures of Creatine Kinase (CK)

Measures of the enzyme CK have been used extensively in studies as an indicator of muscle damage (Clarkson et al., 1986). CK, also known as creatine phosphokinase (CPK) is a muscle specific protein (Sayers, Clarkson, & Lee, 2000), which is important in energy production and is generally confined within cells (Armstrong, 1990). When large quantities of CK are present in the blood it suggests that cell membranes have been compromised allowing the enzyme to efflux from the muscle cells and indicates that some measure of muscle tissue breakdown has occurred (Armstrong, 1990). Following periods of heavy training, increases in CK and other muscle specific proteins have been found to be several times greater than resting levels (Clarkson et al., 1992), with males generally producing a larger response than females (Roth, Gajdosik, & Ruby, 2001).

Substantial increases in blood CK concentration have been found following eccentric exercise. This is in stark contrast to concentrically biased exercise after which little or no change is detected (Sorichter et al., 1995). CK levels within the blood peak approximately 3-5 days post exercise which reflects the release of CK from the damaged muscle and its clearance by the reticuloendothelial system (Sayers et al.,

2000). The response of CK activity within the blood is however highly individualised with some subjects having high responses while others had only low responses despite being similarly trained and completing an identical exercise intervention (Nosaka & Clarkson, 1996; Sayers et al., 2000). Although elevated blood concentrations of CK remain a positive indicator of muscle damage the large inter and intra-participant variability leads researchers to view it as a controversial quantifier of myofibre injury (Nosaka & Clarkson, 1996; Sayers et al., 2000).

2.4.1.3 Muscle Soreness and Tenderness

Muscle soreness and tenderness is a common condition that most people have experienced to some extent. Exposure to unaccustomed physical activity, even at a moderate intensity or duration, can result in the development of muscle soreness, regardless of the general fitness level of the athlete (Armstrong, 1984). Although there are many proposed causes of muscle soreness they are generally associated with damage to muscle ultrastructure, accumulation of calcium, release of intracellular proteins and inflammation which stimulates pain receptors (Szymanski, 2001). Muscle soreness may be described as pain, tenderness or deep aching sensations, which usually begins 8 - 12 hours after exercise (Szymanski, 2001), peaking by 72 hours post exercise and subsiding thereafter (Armstrong, 1984; Dierking & Bemben, 1998; Lee et al., 2002). The soreness is usually significantly lower or absent by 5 - 7 days post exercise (Armstrong, 1984) but may, depending upon the intervention and individual response, continue for 8 - 10 days after onset (Dierking & Bemben, 1998). Muscle tenderness differs to soreness by definition and is considered as soreness upon palpation (Eston, Finney, Baker, & Baltzopoulos, 1996).

Muscle soreness and tenderness are often used as indirect markers of muscle damage as they are assumed to reflect structural damage to the muscle (Kuipers, 1994). Armstrong (1984) has suggested that muscular performance maybe reduced due to the effects of muscle soreness and that this may be caused by either diminished voluntary effort due to sensations of soreness and/or lowered force producing ability of the muscle. However it has also been found that subjects are able to perform maximal contractions despite the presence of muscle soreness and tenderness (Hamlin & Quigley, 2001).

The assessment of soreness is a common and important outcome in many studies (Vickers, 1999). The assessment of soreness is, however, complicated and involves evaluation of subjective pain states (Vickers, 1999). Methods used to assess soreness include the use of visual analogue scales (VAS), Likert scales, and pressure or palpation techniques (Vickers, 1999). VAS involve subjects marking a point on a 50 or 100mm line that represents their current level of pain upon palpation of specific sites on the skin overlying the muscle (Nosaka & Newton, 2002d; Nosaka, Newton, & Sacco, 2002b) or during movement of a muscle throughout a ROM (Nosaka & Newton, 2002a, 2002b). VAS may otherwise incorporate numbers in which the subject relates their pain level to a number usually between 0 and 10 (Brown et al., 1997; Clarkson & Tremblay, 1988; McHugh et al., 2000). Pressure techniques are similar but use a probe attached to a load cell which when pressed into the muscle quantifies the pressure coinciding with the onset of perceived discomfort (Eston et al., 1996; McHugh et al., 2000). This method is generally used in the assessment of muscle tenderness.

2.5 Selected Tests of Performance

2.5.1 Maximal Isometric Strength (MIS)

MIS is most commonly assessed using isometric maximal voluntary contractions (MVC). Isometric strength tests involve muscular contractions in which the length of the muscle remains relatively unchanged (Brown & Weir, 2001). The muscle length remains relatively constant due to an absence of movement as the muscle contracts against an immovable resistance that it physically can not overcome (Brown & Weir, 2001). Isometric strength testing has several advantages. The tests are easily standardised, and are reproducible with high levels of reliability (Brown & Weir, 2001; Wilson, 2000). They are also simple to administer and perform, and require relatively inexpensive equipment (Wilson, 2000). However the disadvantages of isometric strength testing include isolation of the muscle being tested (Trappe, Trappe, Lee, &

Costill, 2001), only being able to record measures at specific joint angles, and measurements being determined in a static form (Brown & Weir, 2001). As data is recorded at specific joint angles, and not across the entire range of movement, peak force measurements may not be obtained if the chosen joint positions are sub-optimal. Measurements determined in the static form are often extrapolated to indicate dynamic strength, however the validity of this extrapolation is questionable (Brown & Weir, 2001; Wilson, 2000).

Joint position is very important in isometric testing. The relationship between joint angle and torque is influenced by force-length relationships of muscle fibres, geometric arrangement of the muscles with respect to the joint, and the architectural characteristics of the muscle (Kawakami, Ichinose, & Fukunaga, 1998). The optimal joint position for maximal isometric strength measurements have been found to be at an ankle angle of 86 to 92° of plantar flexion with the knee at an angle of 160° (Trappe et al., 2001). Specificity of joint angle is not only important during strength measurement but also for exercise training. Kitai and Sale (1989) showed that isometric strength training of the plantar flexors at an angle of 90° improves voluntary strength significantly ($p<0.05$) at that angle as well as the two adjacent angles of 5° in the plantar and dorsi flexion directions. Voluntary strength significantly increased by 18% at 90° following the training while the two adjacent angles of 85° of plantar flexion and 95° of dorsi flexion increased by 13.6 and 16.8 % respectively.

2.5.2 Vertical Jump

The vertical jump test is primarily a measure of muscular power (Young, MacDonald, & Flowers, 2001a) and has been included in many performance related studies (Ashley & Weiss, 1994; Baker, 1996; Byrne & Eston, 2002a) due to it's relative ease in testing and high validity and reliability (Aragon-Vargas, 2000). There are many variations of vertical jump tests, which can include arm swings, counter-movements, drop jumps, steps and/or bounds. The method used can have a large influence on the height attained during the jump, as it has been shown that the inclusion of an arm swing can improve

performance by 10 – 21% (Young et al., 2001a). Via limiting the inclusion of an arm swing within a vertical jump test, the test has a greater focus on measuring leg power (Young et al., 2001a).

The contribution of the various muscles to vertical jump performance has been studied and emphasis has been placed on the leg being made up of three main joints, the hip, knee and ankle and three main muscle groups, being the hip extensors, knee extensors and the plantar flexors (Hubley & Wells, 1983; Jaric, Ristanovic, & Corcos, 1989; Robertson & Fleming, 1987). Hubley & Wells (1983) and Jaric et al., (1989) reported that the knee extensors were the main contributors to vertical jump height, contributing 49% of the work. The hip and ankle were found to contribute approximately 23 and 28% of the work, respectively. This data is in contrast to the results reported by Robertson & Fleming (1987), which showed that the hip contributed approximately 40%, the knee 24% and the ankle 36% to the total work done in the propulsive phase of the vertical jump. The different results found between the studies may be due to the different analysis techniques used. Hubley and Wells (1983) used a work-energy approach to analyse the jump with the hands situated on the hips. Robertson and Fleming (1987) also analysed the jump with hands situated on the hips however they used linked segmental analysis and inverse dynamics to analyse the jump. Jaric et al., (1989) analysed the jump via kinetic parameters however it is unclear whether the jump was performed using the hands on the hips technique.

Substantial research has been conducted on training methods used to improve vertical jump performance. Although dependent on the strengths and weaknesses of the athlete, improvements in strength through the utilisation of traditional strength training methods, explosive weight training, plyometrics and Olympic lifts have been found to effective in improving vertical jump height (Baker, 1996; Kraemer & Newton, 1994). Despite the common finding of improved jump height following methods of resistance training, Bobbert and Van Soest (1994) have suggested that jump height may not increase despite increases in leg strength. Within their simulation study they found that unless neural and muscular control was adapted to obtain the greatest benefit of the improved muscular properties jump height would be retarded or decreased (Bobbert & Van Soest, 1994). This is concept is also present within the studies of Rodacki, Fowler and Bennett (2001; 2002). Within these studies the effects of fatigue on movement

control in vertical jumping was investigated. It was found that despite the effects of fatigue the control of the movement was not changed despite the altered muscle properties, and as such performance was less than optimal. The influence of control and coordination along with strength and maximal rate of force development are important to vertical jump performance due to the relationships between the agonist and antagonist muscle groups and the utilisation of energy transfer within the stretch shortening cycle (Kraemer & Newton, 1994).

2.5.3 Standing Broad Jump

The SBJ, or standing long jump as it is also known, is also used as a measure of muscular power (Morriss, Tolfrey, & Coppack, 2001). The technique of the standing broad jump can be manipulated similarly to the vertical jump, with variations in technique including performance with or without arm swing, and/or counter-movements as well as running or stepping starts. Manipulating the technique used in standing broad jump performance allows it to focus on varying qualities or skills. As per the vertical jump, limiting the use of arm swing in the standing broad jump allows performance to focus on the contribution of leg power (Robertson & Fleming, 1987). Robertson & Fleming (1987) analysed the kinetics of the lower leg in the standing broad jump using a restricted arm swing technique. They reported that the muscles of the ankle joint contributed approximately 50% of the total work produced in the propulsive phase of the standing broad jump while the knee and hip were found to contribute approximately 4% and 46%, respectively. Stefanyshyn and Nigg (1998) investigated the standing broad jump with a running take off and reported that the increase in horizontal velocity did not have a large influence on the energy contribution. They reported contributions of the hip and ankle joints of similar values as those reported by Robertson and Fleming (1987), with the hip generating approximately 36% and the ankle joint approximately 49% of the total work in the performance of a running SBJ. As the contribution of energy generation at the ankle joint is larger for the standing broad than the vertical jump, the SBJ may provide greater specificity for evaluating interventions focusing on the plantar flexors.

Training influences on SBJ performance have been found to be limited to specific training practices for improvement. Harris et al., (2000) used the SBJ as a measure to investigate the transfer of different resistance training methods to various athletic performance variables. Within this study three training groups were formed; 'high force', 'high power' and a combination of both of these training methods. Following training 4 days per week for 9 weeks, only the high power group had significantly improved SBJ performance. Studying the effects of 'high resistance' and 'high velocity' training programs on sprinting performance Delecluse et al., (1995) also found that high velocity training resulted in significant improvement in SBJ. While in a 6 week isokinetic training program of the quadriceps and hamstrings SBJ performance did not significantly change despite improvements in both quadriceps and hamstring strength (Morriss et al., 2001).

2.5.4 Sprinting Ability

The most common method of measuring sprinting ability is through the use of specific sprint tests. These tests range from as short as 5 metres to over 100 metres in distance and are usually designed to replicate specific sports, events or skills. Sprint tests covering a distance of up to 20 metres are ideal for many team sports as analysis of team games shows that the majority of sprints are between 5 and 20 metres (Pyne, 2002) and rarely extend beyond 30 metres (Benton, 2001). A 10 metre sprint test primarily measures initial acceleration, and has been shown to improve with heavy resistance and high velocity training programs in conjunction with running training (Delecluse et al., 1995). Delecluse et al., (1995) investigated the effects of heavy resistance and high velocity training sessions on different phases of 100 metre sprint performance. The high resistance training involved using heavy weights (3-5RM) in a variety of exercises for the legs, back, abdominals and arms. The high velocity training involved unloaded plyometrics exercises focussing on maximum speed of movement. Both training programs where found to improve initial acceleration (10 metre sprint performance) when performed in conjunction with running training.

Studies examining sprinting have often correlated the results recorded for sprint time with other anaerobic measures of performance such as tests of agility (Draper & Lancaster, 1985; Pauloe, Madole, Garhammer, Lacourse, & Rozenek, 2000), cycle ergometry (Baker, Ramsbottom, & Hazeldine, 1993; Fitzsimons, Dawson, Ward, & Wilkinson, 1993), jumping (Baker & Bell, 1994; Berthoin, Dupont, Mary, & Gerbeaux, 2001; Nesser, Latin, Berg, & Prentice, 1996), and isokinetic strength, work and power (Manning, Dooly-Manning, & Perrin, 1988). The studies that have compared sprinting ability with laboratory cycle ergometer tests revealed that sprinting was well correlated to mean power output on both cycle and treadmill ergometers (Baker et al., 1993). Manning et al., (1988), however, have reported low correlations between sprint time in the 40-yard dash and isokinetic dynamometer determined strength measures.

Studies correlating sprinting ability to anaerobic test have found that jumping tests are better predictors than cycle ergometry tests (Baker & Bell, 1994; Berthoin et al., 2001; Nesser et al., 1996) and isokinetic strength measures (Nesser et al., 1996). Baker and Bell (1994) found significant correlations ($p<0.05$) of $r = 0.91$ and $r = 0.87$ for vertical and standing broad jump with 30m sprint time. Nesser et al., (1996) investigated physiological and performance variables, which may account for variations in 40 metre sprint performance. They found that 10 metre sprint time and a 5 – step jump were the best predictors of 40 metre sprint performance. Berthoin et al., (2001) investigated the relationship between anaerobic tests and selected phases of a 100m sprint. A counter-movement (CMJ) and squat jump (SJ) were used in this study with a technique involving the hands remaining on the hips. It was found that the CMJ was the best predictor of 100m sprint time and was significantly correlated ($p<0.05$) to maximal acceleration, mean acceleration during the first 2-seconds ($p<0.001$), maximal running velocity ($p<0.01$), as well as time taken to run 20, 50 and 100m ($p<0.01$). The SJ was also significantly ($p<0.01$) correlated to mean acceleration during the first 2-seconds, maximal running velocity, and time taken to run 50 and 100m. Time taken to run 20m was also significantly correlated to the SJ ($p<0.05$).

2.5.5 Testing Agility

Agility is generally defined as "the ability to change body direction and position rapidly" (Draper & Lancaster, 1985). A more recent definition of agility is "the ability to change direction in a sport specific fashion at the highest possible speed" (Pyne, 2002). Numerous tests have been developed to test agility in a variety of sports and activities. Examples of these include the Illinios Agility test, the Up and Back test and the 505 test (Draper & Lancaster, 1985), the T test, and Hexagon test (Pauloe et al., 2000). Tests for agility can be designed to be sports specific, such as the Run-a-Three agility test for cricket (Pyne, 2002) or may include the use of equipment and specific game skills.

Most agility tests involve several changes in direction along with various sprints over several metres. These tests, therefore, measure not only an athlete's agility but also their sprinting ability (Draper & Lancaster, 1985). Draper and Lancaster (1985) examined three agility tests: the 505 test, the Up and Back test and the Illinios Agility Run. These tests were studied in relation to a 20 metre sprint to determine which test(s) minimised the influence of velocity that athletes can attain over set distances, and depended highly on the levels of acceleration in changing direction. The study revealed that the Illinios and Up and Back tests had the highest correlation with the 20 metre sprint test. This suggests that these tests partly assess sprinting ability along with agility. Pauole et al., (2000) measured the reliability and validity of the T-Test as a measure of leg speed, leg power and agility. They found that leg speed and the T-Test had a higher partial correlation than the other variables. Therefore, from these results it seems that agility tests which involve sprinting several metres can be used as a measure of sprinting ability as well as agility.

2.5.6 Factors Affecting Test Results

2.5.6.1 Specificity

Specificity is important in both resistance training and fitness testing. The greatest improvements in motor performance following resistance training occur when the

training is task or activity specific (Kraemer et al., 2002). Physiological adaptations to resistance training are specific to the muscle actions concerned, speed of movement, range of motion (ROM), joint angle and muscle groups trained (Kraemer et al., 1998), as well as the energy systems utilised, and the volume and intensity of training (Kraemer et al., 2002). Specificity is also an important consideration when designing and implementing testing sessions. Testing should be as specific as possible to the situation in which the information gained from testing will be applied (Hopkins, Schabort, & Hawley, 2001).

2.5.6.2 'Washout Period'

The 'washout period' is the period of time in which muscle function and performance is altered following a resistance training session. This period of altered performance and muscle function is believed to be the result of varying contributions of muscle fatigue and exercise-induced muscle damage (Behm et al., 2001). The effect of the 'washout period' on performance is an area which has received very little research. The effects following a resistance training session has been mainly investigated in terms of force development and loss. Hakkenin (1993) investigated force development following 20 x 1RM squats and found that heavy resistance loading resulted in acute neuromuscular fatigue, which affected force production as well as muscle activation. Vincent and Vincent (1997) employed practical exercise interventions on the knee flexors and extensors that would be used within a training setting. The results from this study exhibited significant losses in strength with recovery to pre-intervention levels occurring 10 days post exercise. Recently Bryne and Eston (2002a) investigated the effects of strength and three varieties of vertical jumping following 100 barbell squats. This is the only study that has been found to examine the effects of a resistance training intervention on a performance measure using practical field tests. Other measures such as sprinting ability, agility and standing broad jump performance have not been assessed within the 'washout period' following resistance training.

2.5.6.3 Learning Effects

Learning effects have a large influence on any task in which the subjects are not experienced. Increased familiarity and comfort with the task will result in improved

results during subsequent performance (Brown & Weir, 2001). It is therefore recommended that novice subjects perform familiarisation or practice trials in order to reduce the effects of learning during the testing period (Brown & Weir, 2001). There is clear evidence of practice effects occurring between the first two trials of a test and that these rarely extended to any substantial effect past the second trial (Hopkins et al., 2001).

2.5.6.4 Subject Motivation

The motivation of subjects is an important consideration for measurements which require maximal effort. Verbal encouragement and incentives may prompt the subject to perform maximally throughout all tests (Hopkins et al., 2001). However factors such as soreness and fatigue (both metabolic and psychological) may impact on voluntary effort during performance testing. Personality and psychological traits may also influence the motivation of the subjects to perform maximally, as may variations in pre-trial physical activity, training and diet (Hopkins et al., 2001). In summary, the difficulty in minimising differences in subject motivation seems to be best controlled by providing standardised encouragement and incentives.

2.5.6.5 Standardisation

Standardised protocols should be employed during all testing sessions in order to reduce the likelihood of producing invalid results. Standardisation of testing protocols reduces the chances of committing a type II error, and increases the reliability of testing practices (Wilson & Murphy, 1996). Standardisation of both instructions and procedures has been shown to increase the reliability of the collected data (Abernethy, Wilson, & Logan, 1995; Brown & Weir, 2001; Wilson & Murphy, 1996).

2.5.6.6 Recovery between Trials, Tests and Testing Sessions

The recovery provided between trials, individual tests and testing sessions is important in obtaining accurate results that are not affected by prior performance. When evaluating whole muscle functional characteristics adequate rest and recovery is of great

importance (Parcell, Sawyer, Tricoli, & Chinevere, 2002). The recovery required between trials and tests will vary according to the demands of the test on the subjects metabolic, hormonal, and cardiovascular responses (Kraemer et al., 2000a). Exercise programs or interventions which involve repeated contractions often result in muscular fatigue and decreases in force producing ability (Parcell et al., 2002). Such fatigue is associated with depletion of fuel sources and accumulation of metabolic by products (Hirvonen et al., 1987; Parcell et al., 2002). During repeat bouts of high intensity exercise with inadequate rest periods rapid accumulation of hydrogen ions and reductions in PCr stores and glycolytic rates results in strength and performance decrements (Hirvonen et al., 1987; Parcell et al., 2002). Evaluation of isokinetic rest protocols revealed that the recovery of force occurred following a rest period of 60 seconds (Parcell et al., 2002). During strength training it is recommended that rest periods of at least 2-3 minutes between sets be used for multiple joint exercises using heavy loads (Kraemer et al., 2002) to allow for complete recovery to occur before the next set (Baechle & Earle, 1994).

2.6 Conclusion

Resistance training is a commonly used form of training, which can be manipulated to develop specific aspects of performance. This type of training is most commonly associated with increases in strength, which result from adaptations of both neural and muscular function. Although chronic resistance training can result in improvements in strength and sports performance the acute effects of muscular fatigue and exercise-induced muscle damage brought about by such training has been shown to negatively impact on performance measures during the 'washout period'. To date there is a dearth of literature available on the 'washout period' following resistance training and future research focusing on this area will provide much needed data allowing for the development of more effective and efficient coaching and training practices.

CHAPTER 3

METHOD

3.1 Subjects

Fourteen male volunteers between the ages of 18 and 45 were recruited from the students and staff attending Edith Cowan University. The subjects were selected from recreational athletes who were not currently undertaking nor had participated in any structured lower body resistance training for a period of at least six months prior to participation in the study. Subject physical characteristics are outlined in Table 1. Subjects' completed a physical activity and medical questionnaire (Appendix A) to ensure that they qualified for inclusion in the study and that there were no medical contraindications that would preclude their participation. Subjects also completed an informed consent form (Appendix B), which outlined the risks and the requirements of the study and contained a statement outlining that subjects were free to withdraw from the study at any time without prejudice. Ethics clearance was obtained from Edith Cowan University Ethics Committee prior to the subjects' involvement in the study.

Table 1.

Subject Characteristics (mean ± SD)

n = 14	(mean ± SD)
Age (years)	27.2 ± 6.24
Height (cm)	177.7 ± 6.47
Weight (kg)	77.3 ± 6.77

3.2 Equipment

Customised Standing Calf Raise Machine (RM Sporting Supplies) (Figure 1)
1000 Kg Load Cell (Bongshin, model 1000-DBBP) with Digital Indicator (Ranger Instruments, model 2100) (Figure 2)
Swift Timing Mat (Swift Performance Equipment)
Constant Tension Measuring Tape
Speed Light Sports Timing System (Swift Performance Equipment)
Marking Cones/Chairs
Reflotron Mass Spectrophotometer (Boehringer-Mannheim)
Creatine Kinase (CK) Testing Strips (Boehringer-Mannheim)
Equipment for Fingertip Blood Sample
Myometer (Dobros)

3.2.1 Customised Calf Raise Machine

The customised calf raise machine was designed and purpose built for the present study. The machine was based upon the standard design of most commercial standing calf raise machines. In addition, however, it also incorporated specific adaptations that allowed the footplate to be removed and replaced with a portable force plate, and attachment points to position the strain gauge. The dimensions of the machine are displayed in Figure 1. The attachment points for the strain gauge were positioned at the base of the frame and on the lifting shaft. The machine was constructed with 100mm of padding, however an additional 50mm of padding was strapped onto the shoulder pads for extra comfort following reports from subjects during the pilot testing.

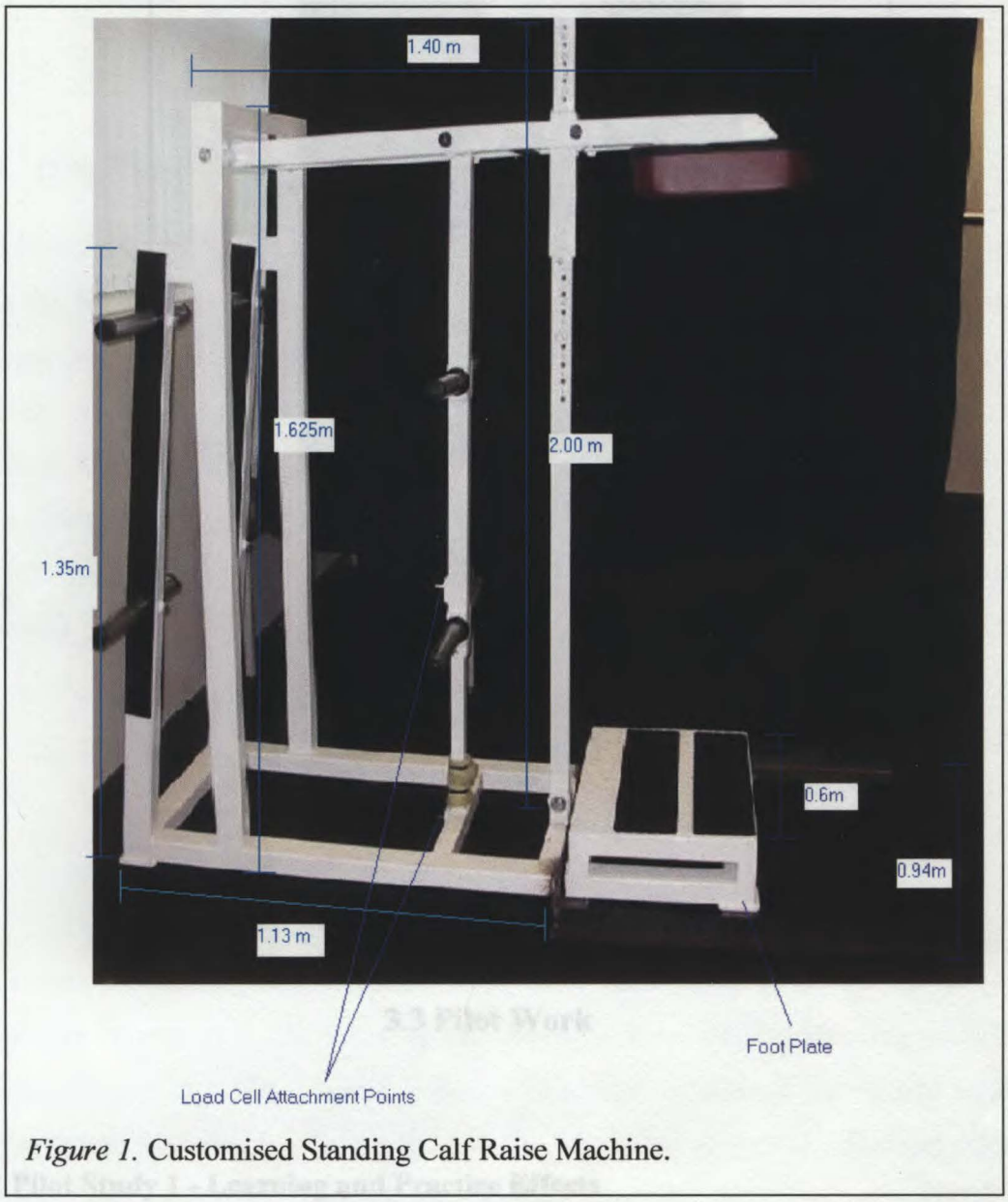

Figure 1. Customised Standing Calf Raise Machine.

3.2.2 Load Cell Set Up

A commercial 1000kg load cell (Bongshin, model 1000-DBBP) was used within the study to obtain isometric force measures (Figure 2). The load cell was held in position with 14mm high tensile chain connected by two ball-jointed bolts that were attached to the load cell. The load cell display was programmed to capture the peak force to the nearest 0.5kg. Commercial calibration of the load cell revealed a correlation of 1.00 between the applied load and the observed output from the load cell. Test re-test reliability was high with a coefficient of variance of 0.03% calculated using the method error approach.

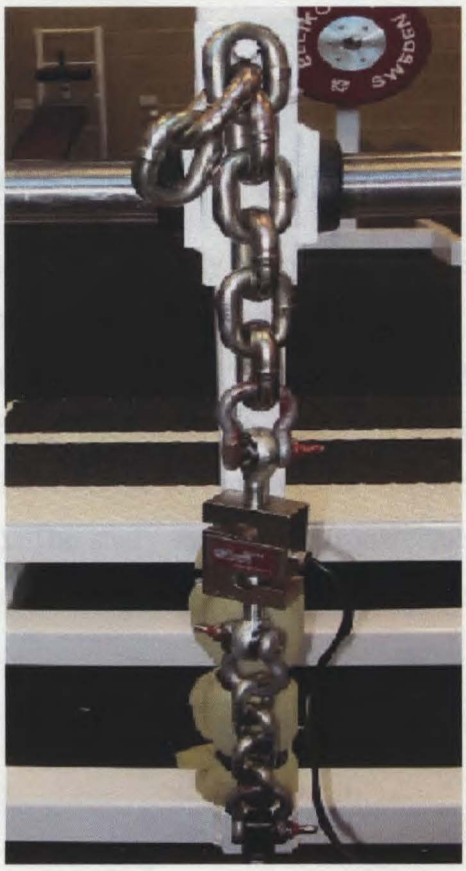

Figure 2. Load Cell Setup.

3.3 Pilot Work

3.3.1 Pilot Study 1 - Learning and Practice Effects

Two pilot studies were performed. The first was to assess the effects of learning and practice on the criterion measures of SBJ, 10m Sprint and the Illinois agility run. Five male subjects who matched the subject selection criteria of the main study participated within this pilot study. Results were analysed to determine significant differences in performance between the testing sessions. The testing protocol of this study was limited to 1 testing session per day over 4 days. Each criterion measure was performed multiple times until three jumps, two sprints and two agility runs were executed in accordance to the guidelines outlined in sections 3.6.2 - 3.6.5. Rest periods of 30 seconds between jumps and 3 minutes between attempts of the sprint and the agility runs were used to minimise the effects of fatigue.

3.3.2 - Pilot Study - Correlation and Reliability of MIS Measures

The second pilot study assessed the reliability of performing MIS measures. Within this study the MIS measures obtained from the strain gauge were correlated to measures obtained from a portable force plate (Kistler, Quatro Jump 929OAD) positioned under the feet. The reliability of the MIS measures were calculated via the method error approach, while correlation between the force measures was performed using Microsoft Excel (Microsoft Office 97). The study employed 10 male subjects who matched the selection criteria for the main study and followed the same testing protocol timeline (Figure 3).

3.4 Resistance Training Intervention

The resistance training intervention employed in this study involved the subjects performing 10 sets of 5 RM standing calf raises on a customised standing calf raise machine (Figure 1). The subjects' 5 RM weight was determined during one of two familiarisation sessions, 5 - 7 days prior to the beginning of testing. The appropriate resistance was determined such that on the fifth repetition the subject was unable to perform another repetition. Between each of the 10 sets the subjects passively recovered for a period of three minutes.

3.5 Procedure

3.5.1 Familiarisation Sessions

In the 5 - 7 days prior to commencement of the RTI the subjects attended two familiarisation sessions allowing them to practice the physical performance criterion measures (see 3.6). Practice of the physical performance measures was performed to cater for any effects of learning or 'practice' prior to the commencement of the study. Subjects became accustomed to performing standing calf raises through determining the correct 5 RM weight. If the 5RM weight was not identified within three attempts, the subjects were asked to return the following day to attempt to identify the correct resistance. MIS was recorded at ankle angles of approximately 90°, which was based upon prior research indicating that the greatest forces could be developed by the plantar flexors at an ankle joint angle between 86 and 92° of plantar flexion (Trappe et al., 2001).

3.5.2 Testing of Criterion Measures

The criterion measures were evaluated over a period of four consecutive days. During the first day of testing the subjects had their criterion measures recorded on four occasions. The first testing session of the criterion measures was under-taken before the RTI (Pre-RTI) and used to establish baseline data. The RTI was subsequently performed followed immediately by further testing of the criterion measures (Imm-Post RTI). Subjects were then allowed to passively recover for a period of one hour before being tested again. This resulted in the testing session (2hr-Post RTI) commencing two hours after the RTI. Following a further recovery period of three hours the criterion measures were recorded for the final time on day 1, being six hours following the exercise intervention (6hr-Post RTI).

On days 2, 3 and 4 of the study the subjects were tested twice each day, with 3 hours recovery between the tests. A diagram of the testing procedure is shown in Table 2. During the course of the study subjects were instructed not to perform any physical activity other than that set by the investigators but to otherwise go about their usual daily activities. In order to reduce the effects of fatigue the criterion measures (see 3.6) were performed in the following order: CK measurement, Muscle Soreness and Tenderness, MIS, Vertical and Standing Broad Jump, 10m Sprint and Illinois Agility Run. Rest intervals between the trials for the vertical and standing broad jump were 30 seconds, while the strength, sprint, and agility trials had rest periods of 3 minutes. Between the testing sessions the subjects were encouraged to consume a high glycemic snack, to minimise the effects of fatigue associated with low glycogen levels.

Table 2. Testing Protocol Timeline.

<table>
<tr><th>Day 1</th><th>Day 2</th><th>Day 3</th><th>Day 4</th></tr>
<tr><td>Pre-RTI</td><td>Test 1</td><td>Test 1</td><td>Test 1</td></tr>
<tr><td>RTI</td><td rowspan="5">3 Hour Recovery Period</td><td rowspan="5">3 Hour Recovery Period</td><td rowspan="5">3 Hour Recovery Period</td></tr>
<tr><td>Imm Post RTI</td></tr>
<tr><td>1 Hour Recovery Period</td></tr>
<tr><td>2 Hour Post RTI</td></tr>
<tr><td>3 Hour Recovery Period</td></tr>
<tr><td>6 Hour Post RTI</td><td>Test 2</td><td>Test 2</td><td>Test 2</td></tr>
</table>

Table 3.

Theoretical Framework of Testing.

Measure	Pre	Imm Post	2 hrs Post	6 hrs Post	Day 2 Test 1	Day 2 Test 2	Day 3 Test 1	Day 3 Test 2	Day 4 Test 1	Day 4 Test 2
MIS	X	X	X	X	X	X	X	X	X	X
VJ	X	X	X	X	X	X	X	X	X	X
SBJ	X	X	X	X	X	X	X	X	X	X
Sprint	X	X	X	X	X	X	X	X	X	X
Agility	X	X	X	X	X	X	X	X	X	X
Soreness	X	X	X	X	X	X	X	X	X	X
CK	X									X

Note: 'X' refers to the evaluation of each criterion measure over the testing period.

3.6 Criterion Measures

3.6.1 Maximal Isometric Strength (MIS):

Maximal isometric strength was measured using the customised standing calf raise machine and a commercial load cell, the set up of which is shown in Figure 2. Subjects performed an isometric standing calf raise by maximally pushing against the immovable shoulder pads of the calf raise machine attempting to maximally plantar flex the feet while keeping the knees locked in an extended position. The peak tension generated at the level of the load cell was amplified and the resulting analogue signal was relayed to the analogue to digital card of the Ranger 2100 and digitally displayed on the indicator in kilogram units of measure. Two trials were performed with a three minute intervening rest period. The average of the trials was used for analysis purposes.

3.6.2 Vertical Jump Test

The vertical jump test involved the subjects completing three maximal jumps with rest periods of 30 seconds between attempts. The test required that subjects jump maximally in a vertical direction landing on the same area as take off. In order to complete the jump without an arm swing subjects were instructed to perform the test with hands situated on the hips. The use of a countermovement was permissible with the subjects individually determining the degree of movement used. A timing mat (Swift Timing Equipment) was used to measure time spent in the air. The timing system was activated upon leaving the mat and terminated upon touchdown on the mat. The height of the jump was calculated from the flight time of the jump by the Swift timing system software, which bases the calculation of jump height on the equation:

$$S = ut+0.5at^2$$

Where S = distance, u = initial velocity, t = time and a = acceleration due to gravity (9.81m/sec^2).

To ensure correct air time subjects were instructed not to land in an exaggerated squatting position (tucking the legs upon landing). The average of the jumps was used for analysis purposes.

3.6.3 Standing Broad Jump

The SBJ commenced from a stationary position with feet together and involved jumping as far as possible in a horizontal forward motion. Subjects were required to start behind a line with hands on hips, to minimise the effects of an arm swing, and jump forward maximally landing on two feet. A countermovement was encouraged, the extent of which was individually set by each subject. The length of the jump was measured from the starting position to the rear most landing point of the feet. Each subject performed three jumps with 30 seconds of rest between jumps. The average of the three jumps was used for analysis purposes.

3.6.4 10m Sprint

The 10m sprint was performed indoors using electronic timing gates (Speed Light Sports Timing System, Swift Performance Equipment). Subjects started from a standing position 0.03 metres from the starting gate. Starting from 0.03 metres behind the starting gate allowed for forward lean to occur while still triggering the timing gates as soon as the subject moved (Young, McDowell, & Scarlett, 2001b). Subjects were instructed to sprint at maximal speed throughout the sprint and not to decelerate until past the final timing gate. Subjects were encouraged to wear the same athletic shoes throughout the study. Two trials were conducted with a 3-minute rest interval between the trials to minimise the effect of fatigue. The average of both trials was used for analysis purposes.

3.6.5 Illinois Agility Run

The Illinois agility course was set up in a rectangle measuring 9.15m by 3.66m. The subjects began at the starting area in a prone position, rising on the "go" command and sprinting through the course as shown in Figure 3. The time taken to complete the course was manually determined by way of a stopwatch. The trial was disqualified if the subject *a)* ventured outside the rectangle; *b)* failed to touch the lines and/or *c)* touched any cones either purposely or accidentally. The subjects performed two valid trials of the agility run with 3 minutes rest between the trials, with the average of the trials used for analysis purposes. The investigator provided verbal encouragement to the subjects throughout the trials.

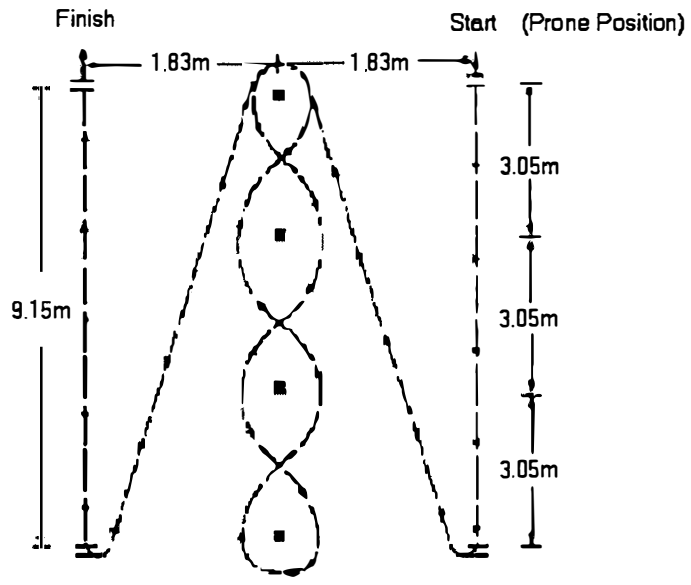

Figure 3. Set up of the Illinios Agility Run. (Adapted from Hastad & Lacy (1994) p.196).

3.6.6 Measurements of Creatine Kinase (CK)

CK was measured through analysis of a small sample of blood (30 µl), which was obtained from the subjects' fingertip. Blood samples were taken during baseline measurement, and on the final day of the study before performance of the other criterion measures. The blood sample was collected in a heparinized capillary tube, and analysed using Boehringer-Mannheim CK testing strips and a Reflotron Spectrophotometer (Boehringer-Mannheim).

3.6.7 Measures of Soreness and Tenderness

Muscle soreness and tenderness were measured at the beginning of each testing session. Different techniques were used to determine a measurement of general

soreness and tenderness of the posterior calf musculature. Subjects were asked to describe their posterior calf pain whilst standing on a numerical 10-point scale for a measure of general soreness with 0 representing no soreness and 10 representing extreme soreness. A specialised pressure sensor (myometer, Dobros) was used to measure tenderness at specific sites on the posterior compartment of the calves. The sites were marked with a surgical marker and remarked daily for the entirety of the study. Sites were measured and marked at distances of 5, 10, 15, 25, and 30 centimetres from the crease of the knee down the midline of the muscle. A further three sites were marked on both the medial and lateral sides three centimetres from the 5, 15, and 25 centimetre midline sites. The marked sites are shown in Figure 4. The myometer was placed on the marked sites and pushed into the relaxed muscle until the subject signalled the first signs of discomfort. At this point the myometer was retracted and the peak pressure in kilopascals (kPa) was recorded from the analogue display. A score of 100 was assumed at the various sites when the full pressure of the myometer was applied without causing discomfort to the subjects.

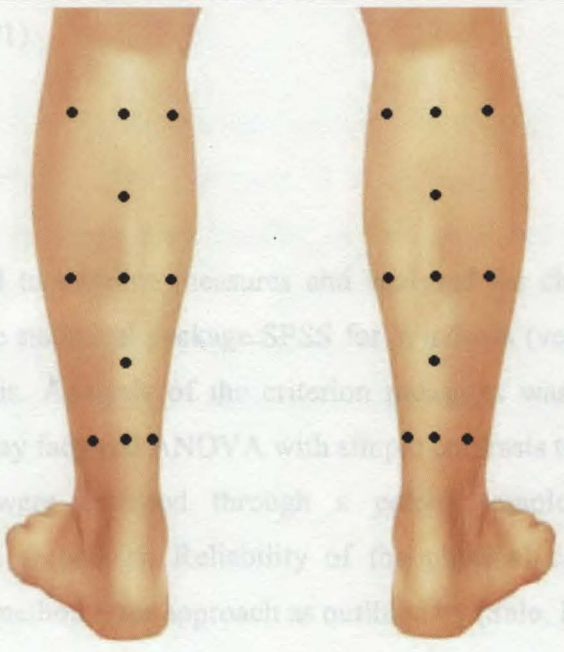

Figure 4. Tenderness assessment sites. The sites were measured from the knee crease with the midline sites being 5 cm apart, while the medial and lateral sites were measured 3-5 cm from the midline sites. Adapted from Anatomica on CD Rom (2000).

3.7 Analysis of Results

3.7.1 Pilot Data

Pilot study 1 assessed the learning and practice effects during the testing period through comparing results from the first testing session to all subsequent sessions. Analysis was performed using the statistical package SPSS for Windows Version 10 by the means of repeated measures ANOVA with simple contrasts to the first testing session. Further analysis of the Illinois agility run results used the same technique to determine whether performance in days 3 and 4 were significantly different to that of day 2 (see 4.1.1).

Pilot study 2 assessed the reliability and correlation of forces measured with a load cell and portable force plate. The correlation of forces was analysed using the Microsoft Excel program 97 version. The between trial reliability was calculated using the average data for each trial and the standard deviation of repeated trials method as outlined by Sale (1991).

3.7.2 Main Study

Data was normalised to baseline measures and analysed for changes as compared to baseline results. The statistical package SPSS for Windows (version 10) was used for the statistical analysis. Analysis of the criterion measures was performed over time using a 1 x 10 one-way factorial ANOVA with simple contrasts to baseline. Changes in CK concentration were assessed through a paired sample T-Test. Statistical significance was set at $p<0.05$. Reliability of the physical criterion measures was calculated using the method error approach as outlined by (Sale, 1991).

3.8 Limitations and Delimitations

3.8.1 Limitations

There were two major limitations to this study. The first related to the research time available, as this was very limited it impacted on the number of subjects that were included within the study and the number of measurements that were able to be examined. The number of subjects able to be included also impacted on the statistical analysis of study. As multiple one-way ANOVA's were used the probability of experimental error increases. However this is a generally accepted limitation of human studies of this type. The second limitation of the study concerned the motivational levels of the subjects. The criterion measures examined within this study required the subjects to provide maximal effort, which may be influenced by motivational and psychological factors. In order to minimise these effects similar verbal encouragement was provided to all subjects throughout each testing session.

3.8.2 Delimitations

Delimitations of the study are imposed through the selection of subjects. The study was restricted to male subjects who exercised at a recreational level and who had not performed any structured resistance training of the lower limbs within the 6 months prior to testing. Subjects were limited to males to reduce the possible effects of gender differences in the results. Subjects in this study were also limited by activity level, therefore, any findings may not extend to include sedentary or well-trained male populations.

CHAPTER 4

RESULTS

4.1 Pilot Work

4.1.1 Pilot Study 1 - Learning and Practice Effects

The analysis of this data was used to assess the degree of learning and practice effects over repeated trials for the criterion measures of 10m sprint, SBJ and Illinois agility run. The results revealed that there were no significant differences in performance within the SBJ and the 10m sprint over the 4 testing days. The results of the Illinois agility run did however display significant differences in performance in days 3 and 4 ($p=0.02$, 0.016) when compared to the first testing day, respectively. Further analysis in which the results of the first testing day were removed revealed that there were no significant differences between performances of days 3 and 4 as compared to day 2.

4.1.2 Pilot Study 2 - Force Correlation and Reliability

The correlation of force measures sampled through the load cell and those obtained from a portable force plate can be seen in Figure 5. Although the results collected from the two measures had an average difference of approximately 2000 N they were shown to be highly correlated with a R^2 value of 0.94. The reliability of the strength measures was also determined within this study. The coefficient of variation for the between trial reliability was calculated to be 2.31% for the load cell and 1.54% for the force plate measures, respectively.

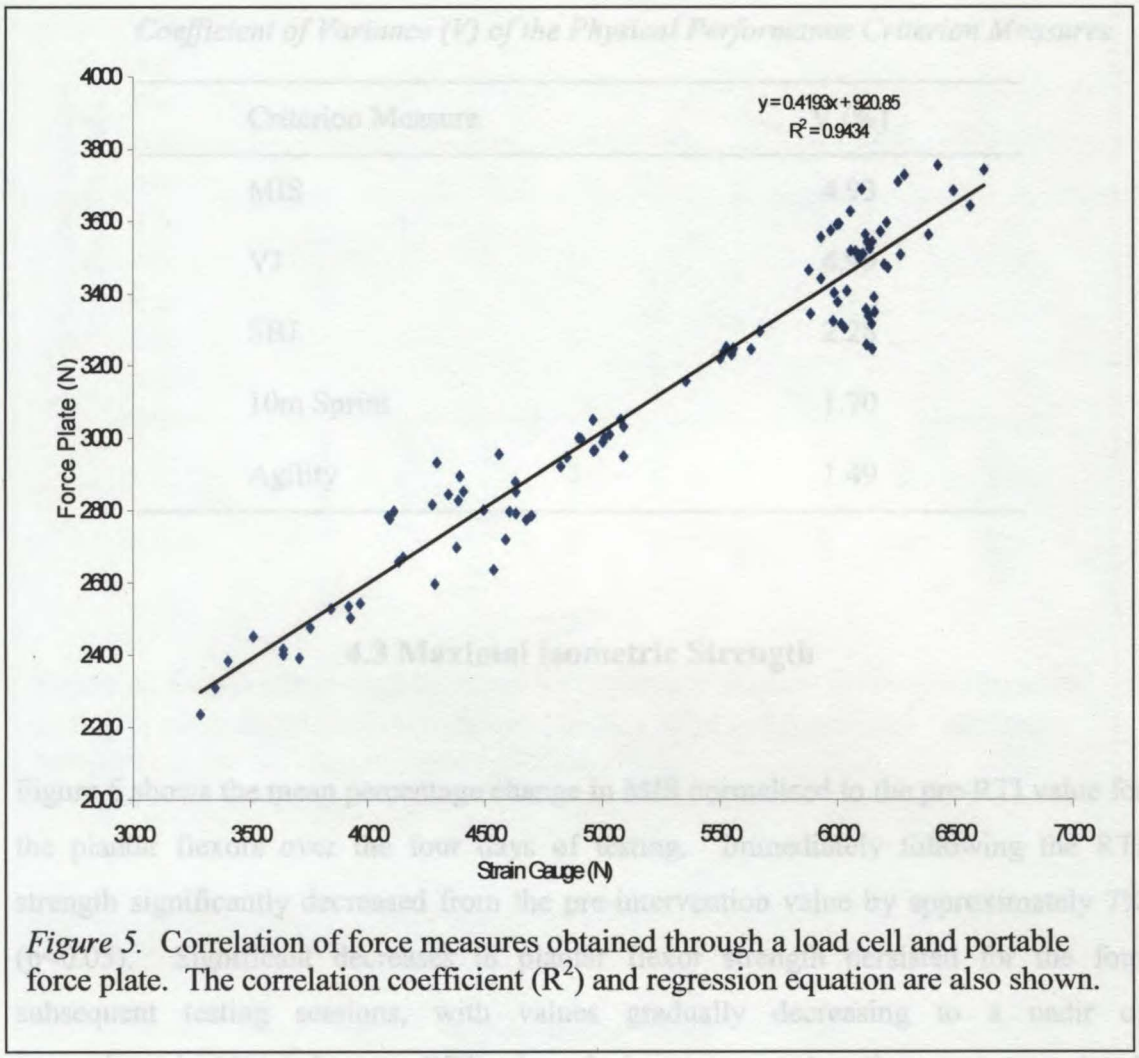

Figure 5. Correlation of force measures obtained through a load cell and portable force plate. The correlation coefficient (R^2) and regression equation are also shown.

4.2 Reliability of Criterion Measures

In order to establish measures of reliability, coefficients of variation were computed for the MIS, vertical and standing broad jump, 10m sprint and agility. The calculations were performed with data from the familiarisation sessions and baseline measures. The coefficient of variation for the criterion measures as shown in Table 4 were all less than 5%.

Table 4.

Coefficient of Variance (V) of the Physical Performance Criterion Measures

Criterion Measure	V (%)
MIS	4.93
VJ	4.99
SBJ	2.28
10m Sprint	1.70
Agility	1.49

4.3 Maximal Isometric Strength

Figure 6 shows the mean percentage change in MIS normalised to the pre-RTI value for the plantar flexors over the four days of testing. Immediately following the RTI strength significantly decreased from the pre-intervention value by approximately 7% ($p<0.05$). Significant decreases in plantar flexor strength persisted for the four subsequent testing sessions, with values gradually decreasing to a nadir of approximately 11% below pre-RTI values during the second testing session on day 2 (Figure 6). The strength measures obtained within the 3rd testing day show a considerable recovery of strength, which continued into the 4th testing day to be only slightly lower than pre-RTI results during the final testing session. It should be noted that these results were obtained from 12 of the 14 subjects used within this study. Two of the subjects were excluded from the data due to the development of pain within the back and shoulder, which was exacerbated within this test. The pain experienced did not however impede their performance within the other criterion measures.

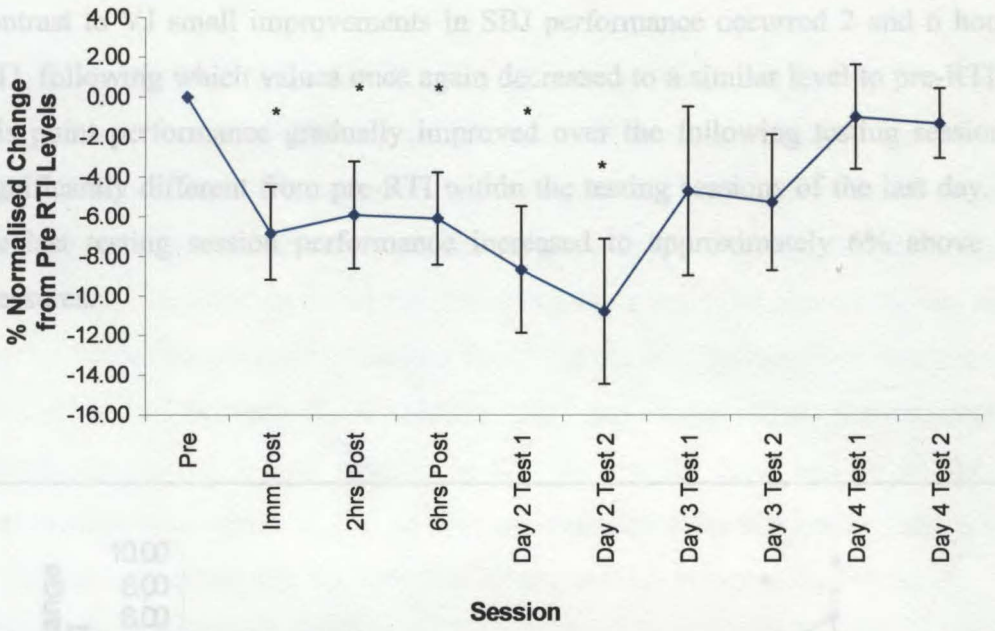

Figure 6. Percentage change from pre-RTI measures of mean normalised maximal isometric strength of the plantar flexors (mean ± SEM). * Significant difference compared to pre-RTI performance ($p<0.05$). N=12

4.4 Jumping Tests

Normalised mean vertical and standing broad jump performance changes are shown in Figure 7. A significant decrease in vertical jump performance of approximately 4% was evident immediately following the RTI and within the testing sessions of 2 and 6 hours post RTI ($p<0.05$) (Figure 7). VJ performance improved slightly within the following 3 testing sessions before a more pronounced improvement in performance within the second testing session of day 3. From this point performance continued to improve producing a supercompensatory response by the final testing session of the study.

Figure 7 shows that SBJ performance exhibited a very different result to that of VJ. In contrast to VJ small improvements in SBJ performance occurred 2 and 6 hours post-RTI, following which values once again decreased to a similar level to pre-RTI. From this point performance gradually improved over the following testing sessions to be significantly different from pre-RTI within the testing sessions of the last day. Within the last testing session performance increased to approximately 6% above pre-RTI measures.

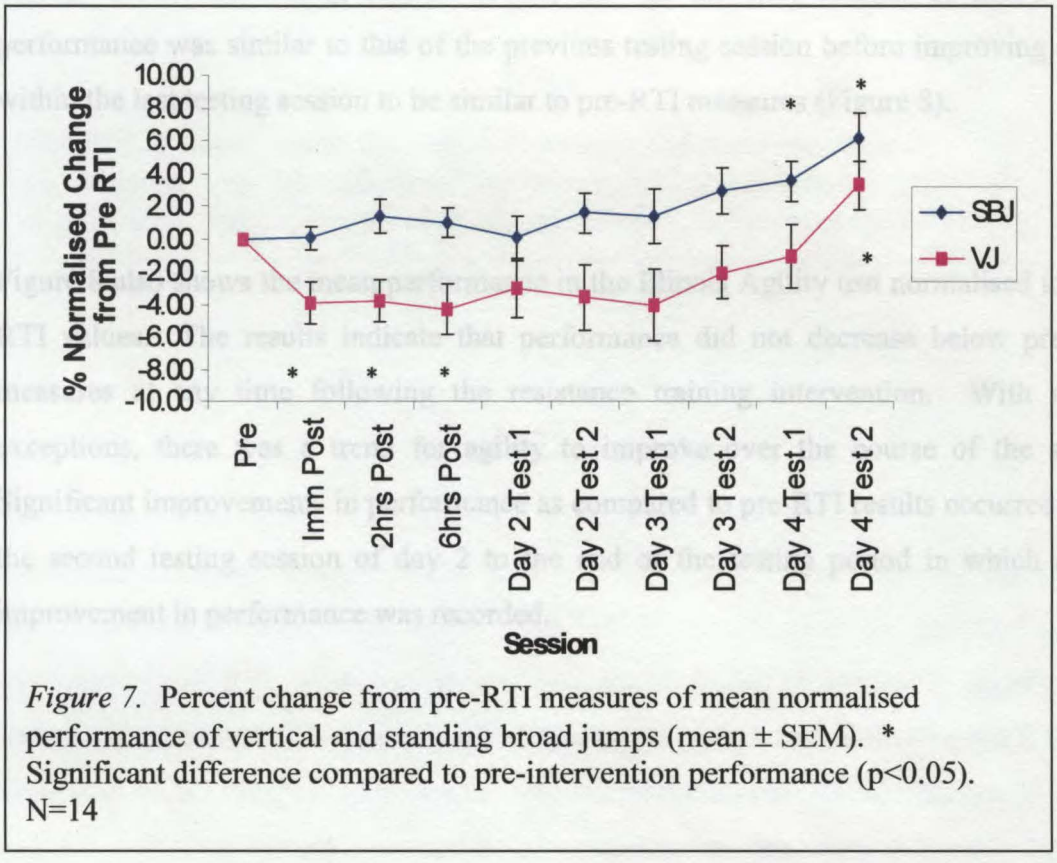

Figure 7. Percent change from pre-RTI measures of mean normalised performance of vertical and standing broad jumps (mean ± SEM). * Significant difference compared to pre-intervention performance ($p<0.05$). N=14

4.5 Sprint and Illinois Agility Tests

Results for the 10m sprint and Illinois Agility tests are shown in Figure 8. All values are presented as percentage changes in mean performance measures normalised to the pre-RTI test times. 10m sprint performance showed a significant decrease of approximately 2.5% immediately following the RTI. Performance continued to be significantly impaired in all of the testing sessions until the second testing session of day 3. Across the six testing sessions following the RTI performance was impaired to a similar level of between 2-3%. Mean sprint time improved by approximately 1.5% during the second testing session of day 3. In the first session of the 4^{th} day performance was similar to that of the previous testing session before improving again within the last testing session to be similar to pre-RTI measures (Figure 8).

Figure 8 also shows the mean performance in the Illinois Agility test normalised to pre-RTI values. The results indicate that performance did not decrease below pre-RTI measures at any time following the resistance training intervention. With minor exceptions, there was a trend for agility to improve over the course of the study. Significant improvements in performance as compared to pre-RTI results occurred from the second testing session of day 2 to the end of the testing period in which a 4% improvement in performance was recorded.

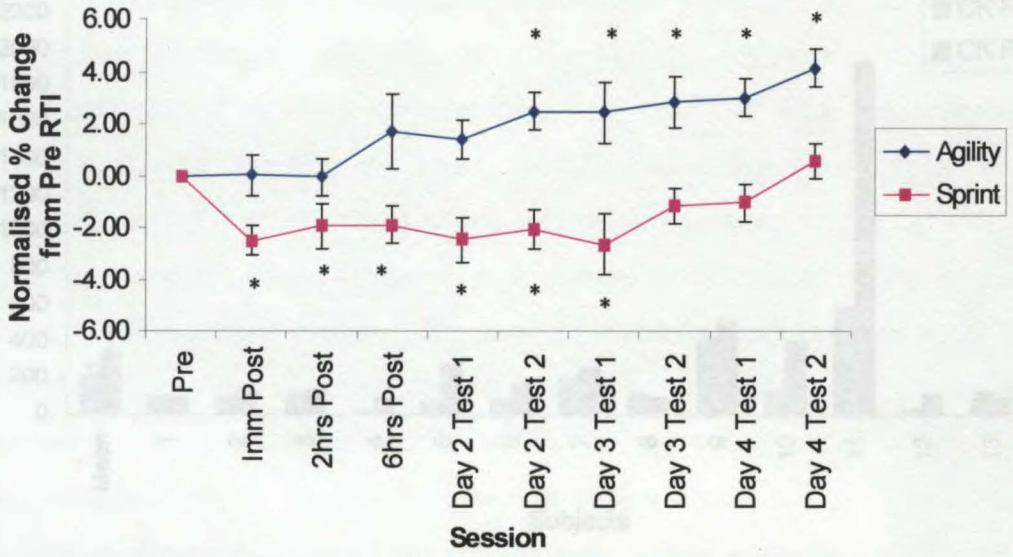

Figure 8. Percent change from pre-RTI measures of mean normalised performance in the 10m Sprint and the Illinois Agility tests (mean ± SEM). * Significant difference compared to pre-intervention performance ($p<0.05$). N=14

4.6 CK Concentration

Individual and mean changes in CK activity prior to and 3 days following (ie. Day 4) the RTI are shown in Figure 9. There was a 61% increase in mean CK activity from pre to 3 days post RTI, however, it was not found to be of statistical significance. Individual variance in CK concentration between subjects 3 days following the RTI was large with values ranging from 24.4 to 1940 international units (IU/L). Eleven of the 14 subjects (~78%) produced increases in CK concentration three days following the RTI, with the remaining 4 subjects exhibiting lower values than their baseline measurement (ie. pre-RTI). Subject 11 is noteworthy in that their CK increased dramatically following the RTI. Despite their pre-RTI concentration being the second highest recorded at 584 IU it still increased 3 fold to return a post-RTI reading of 1940 IU/L.

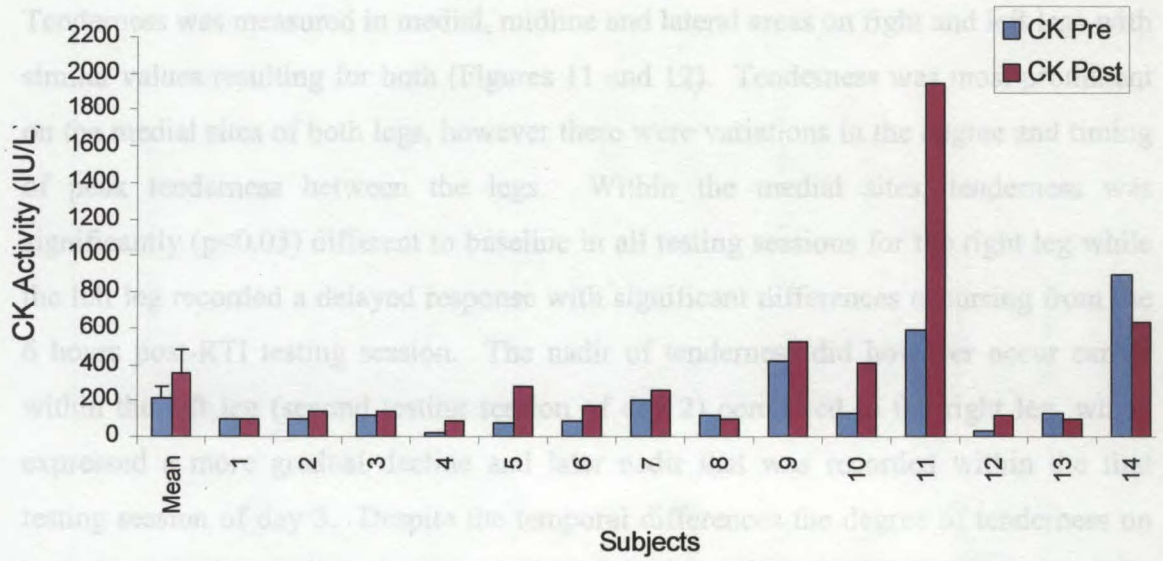

Figure 9. Mean (± SEM) and individual subject changes in CK activity pre (CK Pre) and 3 days following (CK Post) the RTI. N=14

4.7 Soreness and Tenderness

The development of soreness is shown in Figure 10, while Figures 11 and 12 show the progression of tenderness in the right and left legs, respectively. There was a large variation in the soreness and tenderness responses between individuals with some experiencing extreme soreness and tenderness while others reported no or minimal pain throughout the testing period. On average the development of soreness occurred immediately following the RTI and remained significantly ($p<0.05$) elevated for all testing sessions within the study. Within the testing sessions immediately, 2 hours and 6 hours post RTI, soreness was reported to be of a similar degree (Figure 10). By the first testing session of day 2 there was a further rise in soreness where it peaked before plateauing slightly below this point for the next two testing sessions. A mild decrease in soreness was recorded in the second testing session of day 3 with further decreases occurring during day 4. By the last testing session soreness had not completely dissipated, however it had returned to a level similar to that experienced immediately following the exercise intervention.

Tenderness was measured in medial, midline and lateral areas on right and left legs with similar values resulting for both (Figures 11 and 12). Tenderness was most prominent on the medial sites of both legs, however there were variations in the degree and timing of peak tenderness between the legs. Within the medial sites, tenderness was significantly ($p<0.05$) different to baseline in all testing sessions for the right leg while the left leg recorded a delayed response with significant differences occurring from the 6 hours post-RTI testing session. The nadir of tenderness did however occur earlier within the left leg (second testing session of day 2) compared to the right leg, which expressed a more gradual decline and later nadir that was recorded within the first testing session of day 3. Despite the temporal differences the degree of tenderness on both legs at the medial sites were similar with nadirs of slightly above 80 kPa. Complete recovery had not occurred at the medial sites by the last testing session with both legs continuing to experience tenderness with the application of 90 kPa of pressure. The lateral sites of the plantar flexors exhibited less tenderness than the medial section with only one testing session experiencing significant differences to baseline within the right leg (day 2 test 2). Although both legs recorded similar nadir's of approximately 88kPa, the temporal relationship between the legs were slightly different with the right leg experiencing the most pronounced tenderness one testing session earlier than the left leg. Tenderness recovered with subjects being able to tolerate over 92 kPa on both legs before the onset of discomfort during the last testing session. Midline sites demonstrated the least tenderness with over 90 kPa able to be applied before discomfort was signalled throughout the testing period. The right leg produced a nadir for midline tenderness during the 6-hours post testing period while in the left leg this did not occur until the following testing session (day 2 test 1). Following the nadirs, midline tenderness recovered to approximately 98% of pre-RTI levels in both legs during the final testing session.

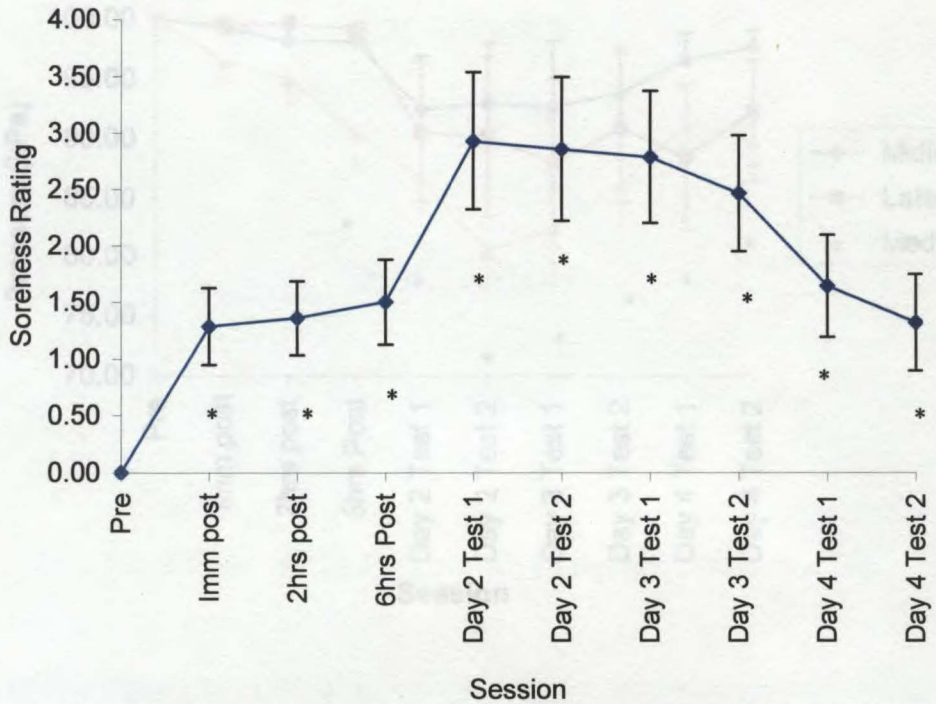

Figure 10. Rating of perceived soreness during the testing period (mean ± SEM). * Significant difference compared to pre-intervention levels ($p<0.05$). N= 14

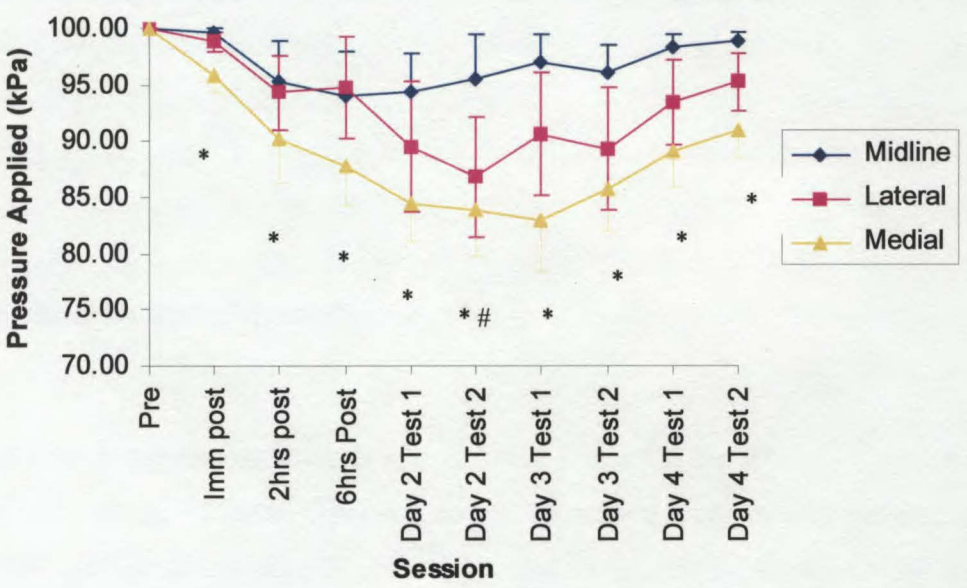

Figure 11. Muscle tenderness of the plantar flexors of the right leg divided into medial, midline and lateral sites (mean ± SEM). * Significant difference to pre-intervention levels for medial sites and # lateral sites ($p<0.05$). N=14.

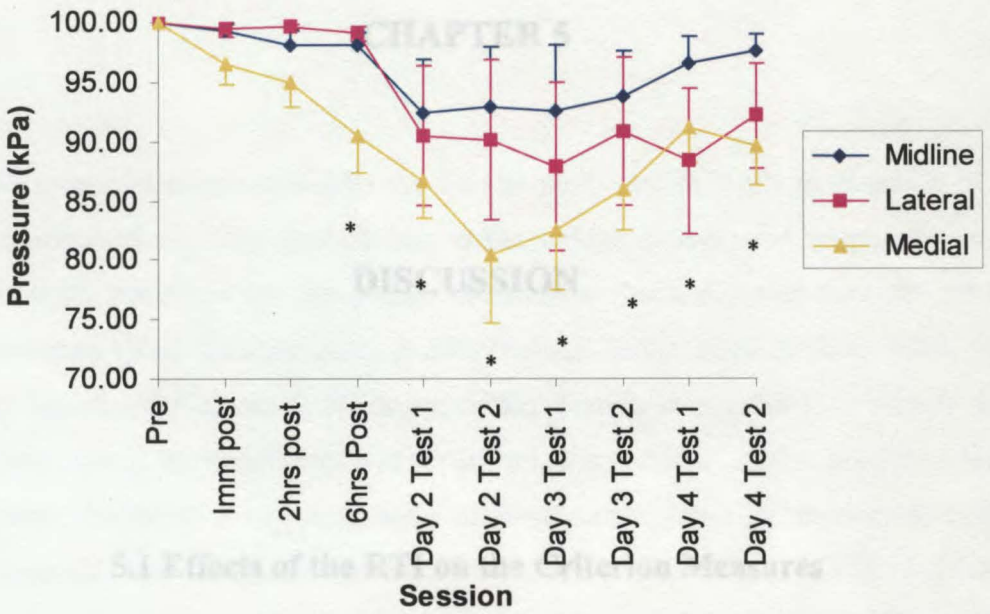

Figure 12. Muscle tenderness of the plantar flexors of the left leg divided into medial, midline and lateral sites (mean ± SEM). * Significant difference to pre-intervention levels for medial sites ($p<0.05$). N=14.

CHAPTER 5

DISCUSSION

5.1 Effects of the RTI on the Criterion Measures

The aim of this study was to investigate the effects of a single resistance training session of the plantar flexors on physical performance measures of MIS, VJ, SBJ, 10m sprint and the Illinois Agility run. The results suggest that following a single strength training session consisting of 10 sets of 5RM standing calf raises significant decreases in MIS, VJ and 10m sprinting ability can be expected. However the study also found significant improvements in performance of the SBJ and the Illinois Agility run within the testing period.

5.1.1 Maximal Isometric Strength

Within this study significant strength loss occurred following the RTI of 10 sets of 5RM standing calf raises. Plantar flexion strength decreased immediately following the intervention and remained significantly depressed in all testing sessions until the 3rd testing day. The testing sessions on days 3 and 4 did not display significant changes as compared to pre-RTI levels but were not fully recovered to baseline levels. Therefore the first hypothesis stating that strength loss would occur immediately and remain depressed for the next two testing days following the RTI, cannot be supported due to

results only being significantly different to pre-RTI values for the day following the RTI.

The MIS measures obtained within the current study are difficult to compare to the measures reported by other studies due to the unique set-up used within the study. MVC strength measures for the plantar flexors has been reported between 89-180 Newton metres (Nm) (Fowles, Sale, & MacDougall, 2000; Kitai & Sale, 1989; Sale, Quinlan, Marsh, McComas, & Belanger, 1982; Trappe et al., 2001). Within these studies force about the ankle joint was measured in a seated or supine position using a strain gauge device or a torque velocity dynamometer. Jaric, Ristanovic, & Corcos (1989) reported mean maximal isometric force for the plantar flexors of 2580 ± 570N as measured from a force plate under the feet with the subject in a seated position. This result is comparable to the data gathered within pilot study 2 of the present study. Within pilot study 2, force was measured concurrently from a portable force plate positioned under the feet and through the load cell setup described in section 3.2.2. The average MIS force measured through the portable force plate was 3117 ± 399N while the measures obtained from the load cell when converted from kilograms to Newtons was 5238 ± 926N. From this data the force measures obtained from the load cell are greater by approximately 2000N when compared to the force measures obtained from the force plate. The difference between the measures can be explained by the positioning of the load cell. The calf raise machine creates a lever arm from the point of force contact at the shoulder pads to the position of load cell. This is one reason for higher force levels obtained within the current study as compared to Jaric et al., (1989). The application of basic physics allows the force at the shoulders (Fs) to be calculated from the force measures obtained at the load cell (Ft), the distance of the shoulder to the location of the load cell (ds), and the distance of the shoulders from the pivoting point of the machine (dp).

Where: $Fs=(Ft * ds)/dp$

Employing the formula provided above, force at the shoulders was calculated to be 3841N. This measurement is more comparable to the force measured through the force plate.

The higher force measures within the current study may also be due to the positioning during testing. The position of the knee in force measures of the plantar flexors is important because the gastrocnemius crosses over the knee joint to insert into the femoral condyles. When the knee is flexed, as occurs with a seated position, the gastrocnemius is in a shortened position in which it's contribution to force production is reduced (Fowles et al., 2000; Sale et al., 1982). Therefore, as the knee was extended within the current study and flexed within that of Jaric et al., 1989, the difference between the force measures reported may be partly due to a larger contribution of force production by the gastrocnemius within the current study. Although the contribution of the gastrocnemius was maximised with the setup of the MIS used within the present study, the measures of force cannot be assumed to be developed solely by the plantar flexors. During the action of performing the MIS measure within the current study activation of other muscle groups located in the legs, back and shoulders also occurred which may have had a minor influence on the forces produced at the load cell.

Prior research has reported large decreases in MIS following resistance based exercise, therefore it was expected that similar strength losses would occur within this study. However, the greatest strength loss was limited to an 11% deficit from pre-intervention performance. Byrne and Eston (2002a) used an exercise intervention of 100 barbell squats and reported significant reductions in strength for four days after the exercise intervention. They reported reductions from pre-intervention performance of approximately 20% one hour after the exercise intervention, 25% and the largest decrement occurred at day 1, 21% at day 2, 15% at day 3, and 13% below baseline at day 4. Similar results were reported by Vincent and Vincent (1997) who used an exercise intervention that simulated a program of a trained body builder or weightlifter for the knee flexors and extensors. Significant reductions in peak torque of 30% and 24%, respectively, were found for trained and untrained groups immediately following knee extensor exercises. Significant reductions of 25% (trained) and 17% (untrained) were also found for the knee flexors following the knee extensor exercises and further significant reductions immediately following the knee flexor exercises. A possible cause for the smaller decrements in the present study may relate to the muscle group employed. The muscles stressed in the RTI of this study are comparatively smaller than

the knee flexors and extensors used within the studies presented above. As larger muscles are generally capable of producing greater forces, a higher magnitude of damage may result and thus have a larger impact on measures of MIS. The repetitive use of the plantar flexors associated with daily activities may also have an impact on the degree of force loss. The high daily use may result in the muscles being more resilient to fatigue and damage resulting in smaller decrements in strength than observed for other muscles. Another factor that may contribute to the smaller extent of strength loss involves the load used for the RTI. The RTI in the present study involved lifting a 5RM load, therefore, the eccentric action of the calf raise was submaximal due to the greater loads that are able to be maintained eccentrically than concentrically (Kraemer, 1992). Previous research has shown that submaximal eccentric actions affect MIS and muscle function to a lesser degree than maximal eccentric actions (Nosaka & Newton, 2002b).

The nadir of peak force loss in the present study corresponded with Bryne and Eston's (2002a) study, which found strength loss was greatest the day following the RTI. This is in contrast to studies using primarily eccentric exercise protocols in which force loss is generally greatest immediately following the exercise (Clarkson et al., 1992; Clarkson & Tremblay, 1988; Newham et al., 1987). The differing timelines reported for force loss are likely due to the various exercise protocols and the types of contractions utilised. Exercise-induced muscle damage and muscle fatigue are both capable of negatively affecting muscle function and may manifest themselves to varying degrees depending upon the nature of the exercise intervention.

The decrements in MIS observed in the current study may be related to the effects of muscle fatigue and exercise-induced muscle damage resulting from the RTI. Limitations in the measurement techniques of this study make it difficult to quantify the influence of these on performance. However the effects of muscle fatigue and exercise-induced muscle damage were both expected to influence performance during the testing sessions of immediately post, 2 and 6 hours post RTI, while the decrements in performance in the subsequent testing sessions was assumed to be primarily due to the effects of exercise-induced muscle damage. This assumption was made due to the

degree of recovery experienced between the testing sessions counteracting the possible effects of muscle fatigue.

The degree of muscle fatigue in the MIS results of the present study may be related to decreases in the activation levels of the muscles. Studies that have employed electromyographic (EMG) analysis have found that immediately following a resistance based exercise protocol the level of activation of the stressed muscles is decreased along with strength measures (Hakkinen, 1993; Linnamo et al., 1998). The activation levels may have decreased due to central or peripheral responses to fatigue. Central responses refer to impairments in the drive from the central nervous system to the motor neuron pool while peripheral fatigue involves impairment to the transmission conductance and/or the contractile apparatus (James et al., 1995; Kawakami et al., 2000; Kirkendall, 1990; Linnamo et al., 1998). Central fatigue may have reduced MIS through decreases in central drive due to conscious mechanisms from motivational issues of the subjects perhaps due to painful sensations or due to unconscious mechanisms of the body to limit further injury (Byrne & Eston, 2002b).

Peripheral fatigue may decrease the activation levels of muscles due to the diminished transmission of action potentials or due to impairment within the contractile apparatus. Muscle fatigue within the context of the present study refers to the effects of decreased performance, which if present were assumed to be restored following periods of rest. Diminished transmission of action potentials and impaired function of the contractile apparatus may result from changes within the ionic environment of the myofibril and/or through decreases in the fuel supply, both of which can be restored with rest (Green, 1997). The ionic environment within the myofibril is important for the transmission of the action potential and the reproduction of fuel supplies. Alterations of the ionic environment following muscular activity can impede the transmission of action potentials due to changes in ion gradients such as sodium (Na^+) and potassium (K^+) at the sarcolemma, and calcium (Ca^{2+}) levels at the t-tubule charge sensor and at the contractile apparatus (Fitts, Balog, & Thompson, 1991). Ionic changes have also been shown to affect the resynthesis of the ubiquitous fuel supply of cells, ATP (Edwards & Gibson, 1991). Although ATP is required in virtually all energy related cell functions,

the intramuscular storage of the molecule is limited to approximately 24 mmol per kilogram (dry mass) which is enough to perform maximal level contraction for about two seconds (Maughan et al., 1997). This storage limitation is overcome by the ability to rapidly regenerate the molecule. Regeneration of ATP during intense exercise is derived primarily from the anaerobic hydrolysis of stores of PCr and muscle glycogen (Spriet, 1995). The liberation of energy from ATP and the regeneration of ATP from these above mentioned substrates, however, can be inhibited due to increases in the acidity of the cell (Edwards & Gibson, 1991). Decreases in pH (increase in acidity) occur due to increases in metabolic by-products created from the reactions of high energy phosphates (PCr), glycogen breakdown, and the hydrolysis of ATP (Green, 1997). Although some studies have shown that acidity levels (as measured via blood lactate levels) did not increase appreciably following resistance training exercises (Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988; Linnamo et al., 2000) others have reported sizeable increases to 12 and 15 $mmol.L^{-1}$ following heavy strength based protocols (Hakkinen & Pakarinen, 1993; Linnamo et al., 1998). As inconsistent results have been reported following resistance based exercise protocols, and acidity levels were not monitored within the current study, it is not possible to establish whether decreases in pH affected MIS performance.

The depletion of PCr and muscle glycogen substrates has profound effects on ATP production and in turn muscular contraction. It has been revealed that following intense exercise the stores of PCr and muscle glycogen can be selectively depleted within type II fibres (Hargreaves, 1995; Spriet, 1995). The depletion of these substrates can be offset to some degree through adequate recovery periods and dietary manipulation. Although recovery periods were incorporated into the current study to minimise the effects of muscle fatigue on performance both between trials and tests, the demands of the testing protocol cannot rule out the possibility that performance was inhibited due to this factor in the testing sessions following the RTI. In order to avoid substrate depletion at the commencement of each testing session subjects were encouraged to consume some form of high glycemic food during the recovery periods. Although this was not monitored it was assumed that some food was consumed during these periods. Future studies may consider providing an eating checklist to monitor food intake between testing sessions to identify possible decrements in performance due to dietary

intake. It has however been shown that despite withholding food consumption during recovery periods substrates can still be replenished from endogenous carbon sources (Bangsbo, Madsen, Kiens, & Richter, 1997; Fournier et al., 2002; Nikolovski, Faulkner, Palmer, & Fournier, 1996). From the results of the present study, future studies may also wish to perform fewer testing sessions. Within the present study testing sessions were performed a number of times of the day of the RTI and twice on the subsequent three days. This protocol was chosen due to the unknown consequences the RTI would have on the performance measures and when recovery would occur. The results from this study indicate that performing one testing session per day for the three days following the RTI would be adequate to trace performance changes and minimise the effects of testing fatigue and learning and practice.

The force loss observed in the current study may also have been affected by the presence of exercise-induced muscle damage. Some degree of exercise-induced muscle damage probably occurred within the study due to the RTI being novel to the subjects and incorporating eccentric actions during the heel return phase of the movement. Eccentric actions have been found to cause a greater magnitude of muscle damage than concentric actions (Gibala et al., 1995). This may be due to the larger forces that can be developed during eccentric contractions, and to the loading profile in which force is produced while the muscle actively lengthens. The aetiology of force loss has been attributed to physical disruption of force generating structures and to impaired activation of the contractile apparatus due to E-C uncoupling (Warren et al., 2001).

Physical disruption to the force generating structures has been observed using histological and electron microscopic techniques. These have revealed alterations to the myofibrillar organisation, t-tubule damage, and altered sarcomere structure (Friden & Lieber, 1992; Proske & Morgan, 2001). Sarcomere damage is thought to occur during eccentric contractions when the structures are stretched and become weaker (Proske & Morgan, 2001). The sarcomeres can be stretched beyond the point of myofilament overlap which results in the structure being unable to function and produce force (Morgan & Allen, 1999). Following contraction the muscle relaxes and the majority of the sarcomeres will reintegrate, however, when this fails to take place disrupted

sarcomeres result (Proske & Morgan, 2001). During repeated eccentric contractions a large number of sarcomeres may be disrupted which in turn may lead to significant decrements in force production.

Impaired activation of the contractile apparatus is thought to be another possible mechanism causing force loss following eccentrically biased exercise. Such impairment to the activation of the contractile apparatus is thought to occur through a process known as E-C uncoupling. The mechanism underlying E-C uncoupling remains to be elucidated, however it refers to impairment of the activation process somewhere between the neuromuscular junction and the contractile apparatus. Warren et al., (2001) have proposed that the transmission failure site occurs within the t-tubule between the dihydropyridine voltage sensors and the ryanodine receptors of the sarcoplasmic reticulum. Physical disruption to these receptors is proposed to impair the opening of the calcium release channels of the sarcoplasmic reticulum and results in a reduction of calcium ions released to the contractile apparatus (Fitts et al., 1991). Calcium ions are required by the contractile apparatus to allow for the myosin cross bridges to bind to the active sites on the actin monomers during the cross-bridge cycle in order for tension to develop and the muscle fibre to contract (Morgan & Allen, 1999). Warren et al., (2001) have proposed that E-C uncoupling is the major contributor to force loss following damaging exercise. They have reported that 75% of force loss immediately following eccentric exercise and 57% five days later can be accounted for by E-C uncoupling and that the remainder of the force loss in the first two days is due to physical disruption to force generating structures. The figures presented above were drawn from data collected during studies involving mice in which injury was induced by electrical stimulation. Whether the contributions of E-C uncoupling and physical disruption to force generating structures differ in human subjects following a heavy resistance intervention is less clear.

E-C coupling failure within human subjects has been inferred indirectly through the measurement of force at various frequencies of electrical stimulation (Jones, Newham, & Torgan, 1989a). Low frequency fatigue (LFF) is said to occur when there is a disproportional loss of force at low stimulation frequencies (Jones et al., 1989a), that is

to say there is a larger loss of force following an exercise intervention at low frequency stimulation than at high stimulation frequencies. The disproportional force loss at low frequency stimulation is alleged to occur due to a reduction in contractile activation produced from the activation potential, the smaller effect observed at high frequency stimulation is due to the summation of action potentials producing only a small change to the contractile activation levels (Edwards, Hill, Jones, & Merton, 1977). Studies using this technique following box stepping with a constant lead leg, and uphill and downhill walking, have revealed that the eccentric components produced the greatest degree of LFF (Davies & White, 1981; Sargeant & Dolan, 1987). Davies and White (1981) reported a marked decrease in maximal twitch and tetanic tensions at 20 Hz for the triceps surae with recovery taking greater than 20 hours. Although this work differs to the present study in terms of exercise intervention and duration, the effects of LFF within the plantar flexors suggests the possibility of this phenomenon (LFF) negatively impacting on force production following the current RTI.

5.1.2 Vertical Jump

Vertical jumping ability was also significantly decreased following the exercise intervention and remained so during testing sessions immediately, 2 hours, and 6 hours post-RTI. Therefore hypothesis 2 stating that vertical jump performance would be significantly decreased in the testing sessions immediately following the RTI and would remain so for the next two days cannot be supported. However, the results indicate that VJ performance was significantly impaired during the day of the RTI, and although lacking statistical significance remained depressed for the following two days. Such decrements in VJ performance would in all likelihood be considered significant from an athletic perspective.

Vertical jump tests are routinely used as an assessment of muscular power of the legs (Brown & Weir, 2001). However, to date limited research has been undertaken investigating the effects of exercise-induced muscle damage on dynamic muscle

function using VJ tests. The sole study located examining VJ performance following resistance based exercise protocol was one conducted by Bryne and Eston (2002a). They reported reductions in VJ performance 1 hour after and for 3 days following an exercise protocol consisting of 100 barbell squats with 70% of the subjects body mass. The reduced performance reported in their study was attributed to the effects of exercise-induced muscle damage on the knee extensors. The differences in results between the present study and the Bryne and Eston (2002a) study may be explained by the muscles stressed within the respective exercise interventions. Bryne and Eston damaged the knee extensors, while in the present study the plantar flexors were stressed. The knee extensors have been reported to contribute the greatest work in VJ performance (Hubley & Wells, 1983; Jaric et al., 1989) and as such may explain the significant decreases observed for 3 days following Bryne and Eston's exercise intervention. However as shown in the present study, stressing the plantar flexors in isolation only resulted in significant decreases in performance during the testing sessions immediately, 2 hours and 6 hours post RTI.

The decrements in performance in the current study may also be associated with the effects of muscle fatigue and exercise-induced muscle damage. The effect of these factors on the ability to generate force was discussed in the preceding section focusing on MIS and also has the potential to affect VJ performance by way of attenuating force production of the calf musculature. This can be observed by comparing the results of the VJ and MIS tests which show a similar time course and decrement in performance. In addition to the potential decreases in force production, the rate at which force can be produced may also be negatively affected. Following resistance based exercise changes in the shape of the isometric force time curve, indicating decreases in explosive force production, has also been observed (Behm et al., 2001; Hakkinen, 1993; Hakkinen et al., 1988; Linnamo et al., 1998; Linnamo et al., 2000). Bryne and Eston (2002a) associated the decreases in vertical jumping ability observed in their study to decreases in the ability to generate initial force rather than the ability to maintain force. Therefore the decreases in VJ performance observed within the present study may relate to both decreases in the absolute force able to be produced and the rate at which that force can be produced.

Bryne and Eston (2002a) studied the effects of muscle damage on the CMJ, squat, and drop jump variations. Upon examining each of these jumping styles they reported that muscle damage affected the squat jump significantly more than the aforementioned jumps. It was reported that the way strength was utilised was an important determinant of performance due to the counter-movement and drop jump involving an active pre-stretch while the squat jump does not (Byrne & Eston, 2002a). The pre-stretch involved with the counter-movement and the drop jump may alter the intensity or duration of the active state and develop greater force at the beginning of the concentric action. This may counteract E-C coupling impairment attenuating strength loss following muscle damaging exercise (Byrne & Eston, 2002a). This may in part explain the lack of statistical significance observed one and two days post RTI in the current study, as the VJ test used was a self selected CMJ. Had a squat jump been employed to test VJ performance, statistically significant decrements may have extended to the testing periods of one and two days post RTI.

5.1.3 Standing Broad Jump

Standing broad jump performance improved during the testing period to be significantly different from pre-intervention levels on the last testing day. This result was unexpected, as a decrement in performance was hypothesised due to the effects of the RTI. There was a slight decrease in performance during the first testing session on day two as compared to the previous testing sessions although this did not approach statistical significance. The slight decrease in performance may be due to the effects of muscle damage incurred during the RTI. However the ensuing testing sessions showed a steady improvement in performance of the jump despite the preceding high intensity RTI. As with VJ the contribution of the calves to the overall performance may partly explain the lack of an appreciable decrement in jumping length following the RTI.

The improved performance of the SBJ may be explained by the effects of learning and practice of repeated tasks. Prior to the commencement of the study two familiarisation

sessions were provided to reduce the effects of learning and practice on the criterion measures. The number of familiarisation sessions was decided upon after analysing the results of a pilot study, which indicated no significant improvement in performance between the second and third testing sessions. However the pilot study only performed testing sessions daily, while the current study performed testing sessions twice per day. Therefore, as the number of testing sessions doubled from those of the pilot study the effects of learning and practice may have had a greater effect.

The occurrence of significant learning and practice effects found in the performance of the SBJ may be explained through the complexity of the task. In the present study performance of the SBJ used a technique in which the arms were not employed. Performance of the SBJ with this technique was reported to feel "awkward" and "uncoordinated" by the subjects. Therefore, the learning and practice effects may have occurred as the subjects adapted and became accustomed to the jumping technique. Of the criterion measures that did not exhibit significant learning effects (MIS, VJ, 10m sprint) VJ and the 10m sprint are primary motor skills that the subjects are highly likely to have experienced prior to the study and developed the fundamental motor patterns. The effect of the RTI may well have caused a decrement in SBJ performance had it not been masked by the effects of learning and practice. Future studies should incorporate a greater number of familiarisation sessions when including SBJ tests.

5.1.4 10m Sprint

Many studies have analysed the effects of different resistance training methods and modes on the effectiveness of improving sprinting ability (Delecluse, 1997; Delecluse et al., 1995; Harris et al., 2000; Kraemer et al., 2000b; McBride, Triplett-McBride, Davie, & Newton, 2002). However to date there have been no studies investigating the acute effects over the days following a single resistance training session on sprinting ability. Within the present study the effect of the RTI on the performance of a 10m sprint was examined. The results showed that following the RTI, acceleration, as measured by the 10m sprint, was significantly decreased immediately following the RTI and did not

recover appreciably until the second testing session of the third day. Therefore the hypothesis that sprinting ability would be decreased immediately and for the next two days cannot be supported due to the lack of significance during the second testing session of day 3. It is important to note that although non-significant, 10m sprint time was still 1.17% below baseline during this particular testing session and remained 1.03% below pre-RTI in the subsequent session. In performance terms these depressed values would in all likelihood be perceived as 'clinically' significant by coaches and athletes due to their ability to be able to change the result of a 'race' or 'sporting challenge'.

There was a slight improvement in performance from immediately post-RTI to the 2 and 6 hour post-RTI testing sessions. This could be an indication that muscle fatigue may have impacted to some degree on sprinting performance immediately following the RTI and that the rest period between the testing sessions may have allowed for some recovery to occur. The impairments in the testing session immediately post RTI may have been due to decreases in central drive due to tiredness from completing a testing session (pre-RTI) and the RTI. The effects of fatigue could have also been manifested through changes in the ionic environment of the muscle fibres and/or from reductions in the fuel supplies due to prior performance as discussed within the MIS criterion measure (section 5.1.1).

5.1.5 Illinois Agility Run

The ability to change direction quickly is an important component in many sports. Research into agility performance has received little research especially in regard to performance following resistance training sessions. However due to its importance to many sporting activities it was deemed necessary to assess the effects of a RTI on the ability to change direction. The Illinois agility run is a test that is widely known and used within the field to assess agility. However it's use within research has been minimal. Within the current study, performance in the Illinois agility run steadily

improved over the testing period to be significantly different from pre-intervention results from the second testing session of day 2 to the end of the testing period. Therefore the hypothesis that agility performance would decrease following the RTI was not supported. This could be one reason for the limited use of the Illinois agility run within research studies. The improvement in performance of the Illinois agility run within the current study is probably due to the effects of learning and practice with the subjects becoming accustomed to the layout and procedure of the test. This was an unexpected finding and was surprising based upon the pilot work, which showed no significant increase in performance on this test following two familiarisation sessions. The differences between these two studies however may partly explain the varying results. The pilot study only used 5 subjects to assess the effects of learning and practice on this criterion measure, therefore the small sample size may have biased the results. However the largest difference between the two studies, as discussed within the SBJ (section 5.1.3), was that the pilot study used a single testing session per day over the 4 day testing period. Future studies should consider incorporating a simpler agility test that may reduce the impact of learning and practice on the results.

A large improvement in performance from the 2 hours post-RTI to the 6 hours post testing session is clearly visible (see figure 8) in the results of the current study. This improvement may be due to the effects on muscle fatigue of the rest periods and food consumption between the testing sessions, which has been discussed above (see section 5.1.1). However as with performance of the SBJ, a decrease in performance can be seen during the first testing session of day 2 as compared to the preceding testing sessions. This decrease in performance compared to the prior testing may be due to the effects of exercise-induced muscle damage. Therefore, as all the criterion measures show a diminished performance in the first testing session of day 2, as compared to former testing sessions, there is a strong indication that the effects of muscle damage will affect performance the day following the heavy RTI.

5.1.6 CK Responses

Damage to the integrity of the cell membrane that may occur during damaging exercise can result in muscle specific proteins such as CK and myoglobin being released into the blood stream (Nosaka et al., 2003). There wasn't a significant change in CK concentration from pre-intervention levels to the last testing day within the present study, therefore hypothesis 7 could not be supported. This result was also unexpected as the subjects were non-resistance trained and the exercise intervention involved a heavy resistance load, which was considered to be of high enough magnitude to induce a rise in CK concentration due to some degree of muscle damage. Studies employing primarily eccentric exercise interventions have shown CK responses of above 10 000 $IU.l^{-1}$ (Clarkson et al., 1992; Nosaka, Newton, & Sacco, 2002a) while those using resistance training procedures involving concentric and eccentric contractions report values that are usually substantially lower (Newham, Jones, & Edwards, 1986; Vincent & Vincent, 1997).

Although there wasn't a significant increase in CK concentration other indicators of muscle damage such as muscle soreness, tenderness and force loss do allude to the presence of some degree of damage to the involved muscles. A possible reason for the low CK response within the present study was that the damaging effects of the heavy RTI may have been at a level which significantly affected strength levels but was not of enough magnitude to compromise the integrity of the cell membranes and allow efflux of intramuscular proteins into the blood. The insignificant change in CK concentration may also be due to variability of CK response between subjects (Nosaka & Clarkson, 1996) and/or the timing of the rise and peak of this enzyme in the blood (Byrne & Eston, 2002a). As shown in Figure 9 one subject within the study exhibited a pronounced rise in CK concentration while the other subjects either had lower or slightly higher concentrations than baseline 3 days post-RTI. This may be an example of variability of CK responses between subjects which has been shown to be highly individualised with some subjects being high responders while others are classed as low responders despite being similarly trained and completing the same exercise intervention (Nosaka & Clarkson, 1996).

A further possible reason for finding only one substantial increase within the subject group may be due to CK measurements being restricted to the first and last days of the study. With this testing schedule the rise and clearance of CK may have been greatest between the measurement points. Therefore the majority of CK measures may have been taken during the recovery slope or when levels had completely recovered. The timeline of CK release and recovery has been found to differ depending on the type of damaging exercise. Eccentric exercise has been shown to exhibit a delayed response (2 days) and peak (4-7 days) while 'traditional' weight lifting exercises result in a rapid rise and peak in CK activity (Byrne & Eston, 2002a; Paul, DeLany, Snook, Seifert, & Kirby, 1989). This may be due, in part, to the nature of 'traditional' weight (resistance) training. Although this type of exercise incorporates high-intensity work, by the very nature of the training the eccentric component usually remains submaximal. Eccentric work, as compared to pure concentric work, has been found to elicit a much greater CK response (Newham et al., 1986). Eccentric work is characterised not only by large and delayed CK release but also by a biphasic response (Newham et al., 1986). Newham, et al., (1986) were among the first to report the biphasic response following a down hill walking intervention. Their results showed that a distinct CK rise occurred 1 day after the exercise intervention, which was followed by a second larger CK response that arose between 4 and 7 days post exercise intervention.

5.1.7 Muscle Soreness and Tenderness

It has been suggested that the presence of soreness and tenderness, which are accepted as indicators of muscle damage, are likely to occur from the inflammatory response of damaged fibres (Proske & Morgan, 2001). In the present study measures of soreness and tenderness were evaluated following the RTI. A general soreness rating was obtained through the use of a linear 0 – 10 scale, with 0 representing no soreness and 10 representing extreme soreness. Tenderness measured the degree of pressure that could be applied to the muscle before the subjects experienced discomfort and pain.

Tenderness measures were taken over a maximum of 12 sites. All subjects had three tenderness sites for the medial and lateral aspects of the musculature, which encompassed a measurement for upper and lower gastrocnemius and one within soleus. Another 5 or 6 sites were examined along the midline of muscles, depending on the length of the subjects' calf. Previous studies have successfully used similar methods in the measurement of soreness (Brown et al., 1997; Clarkson & Tremblay, 1988; McHugh et al., 2000; Smith et al., 1994) and tenderness (Eston et al., 1996; McHugh et al., 2000). In the present study soreness within all testing sessions was significantly different ($p<0.05$) to pre-RTI levels, while significant changes within the tenderness measures were predominantly limited to the medial sites. Therefore hypothesis 6, stating that soreness and tenderness would be significantly elevated for 2 days following the RTI cannot be accepted due to the prolonged soreness experienced for the entirety of the study and varying responses within the areas of tenderness assessment.

In previous studies soreness has been found to be greatest at approximately 2 or 3 days following exercise and is absent or is significantly lower by 5-7 days post exercise (Armstrong, 1984; Clarkson et al., 1992; Clarkson & Tremblay, 1988; Newham et al., 1983). Soreness within the present study increased to a steady level in the testing sessions immediately, 2 hours and 6 hours post RTI. On the second day a large increase occurred that remained at a similar level during the third day. On the last testing day soreness had begun to subside to a level similar to that obtained immediately post-RTI. This pattern of soreness is similar in response to that which has been reported previously in the literature (Clarkson & Tremblay, 1988; Paddon-Jones, 2000; Semark, Noakes, St. Clair Gibson, & Lambert, 1999). The degree of soreness may be of a smaller magnitude in the present study as the RTI employed a 5RM load, which due to the nature of the contraction would be limited by the concentric phase. This would suggest that during the RTI the eccentric component, which is known to induce the greatest degree of damage, was sub-maximal. This could be a possible explanation for why the soreness, although temporally similar to that reported in maximal eccentric studies, was not elevated to the same levels.

The same argument presented above can also be put forward for the tenderness responses. Measures of tenderness in the present study showed that the greatest degree of discomfort was felt on the medial aspects of the plantar flexors. The lateral aspects also had distinct tenderness sensations while the midline had very little development of pain upon palpation. This is a similar response to that reported by Newham et al., (1983) in which tenderness of eccentrically exercised quadriceps was primarily within distal, medial and lateral areas while the central and proximal portions were relatively spared following 20 minutes of box stepping with a constant lead leg. The prevalence of tenderness within the medial and lateral sites of the current study may be explained by the anatomical position of the gastrocnemius. The gastrocnemius is composed of a medial and lateral head, and the medial and lateral tenderness sites were approximated over the muscle bellies of these heads. The midline tenderness sites however were positioned approximately over the line of convergence of the two heads.

Based upon the anatomical location, the pain developed on the medial and lateral aspects was more prominent within the gastrocnemius compared to the soleus muscle. The greater level of pain experienced within the gastrocnemius may be due to the position in which the plantar flexors were trained. As the gastrocnemii muscles cross the knee joint, training the plantar flexors with the knee extended places the muscles in a lengthened position allowing them to generate more force than in a flexed position (Fowles et al., 2000; Kawakami et al., 1998; Sale et al., 1982). Therefore as more force is produced by the gastrocnemii in an extended position the corresponding effects of muscle damage, soreness and tenderness may be more pronounced in this muscle.

The prominence of tenderness within the gastrocnemius may also be associated with the fibre composition of the muscle. The gastrocnemius has a mixed composition of both fast (type II) and slow (type I) twitch fibres while the composition of the soleus is mostly slow twitch fibres (Trappe et al., 2001). During eccentric exercise it has been suggested that type II fibres are selectively damaged (Friden, Sjostrom, & Ekblom, 1983; Jones, Newham, Round, & Tolfree, 1986), possibly as a result of selective

recruitment (Byrne & Eston, 2002b; Enoka, 1996). With the preferential recruitment of these fibres a greater degree of damage and tenderness may be experienced. The existence of fast twitch (type IIb) fibres within the gastrocnemii may be related to the performance decrements observed in the present study and the greater development of tenderness within these muscles compared to the soleus.

The presence of muscle soreness and tenderness may have had an impact on the performance of the criterion measures. The effects of soreness and tenderness may have affected the subjects by preventing them from performing with maximum effort despite the verbal encouragement that was provided. The presence of pain may have inhibited maximal effort due to decreased voluntary drive or through afferent feedback from the muscles in an effort to protect the muscles from further damage. It has, however, been claimed by some researchers that in well-motivated subjects the presence of soreness and discomfort does not seem to inhibit 'full' muscle activation (Margaritis, Tessier, Verdera, Bermon, & Marconnet, 1999; Newham et al., 1987; Newham et al., 1983). Still, others question if 'full' activation can be achieved and sustained during protracted MVCs or during dynamic muscle actions (Byrne & Eston, 2002b).

5.2 Summary and Conclusions

Performance in the days following a heavy resistance training program is an area that has received limited research. Research within this area has practical importance to coaches and to the design of training programs. The current study was implemented to assess the effects of a single resistance training session on physical performance measures within a four day testing period. The results of this study suggest that following a heavy RTI of the plantar flexors performance of MIS, VJ and 10m sprinting ability is impaired for up to 2 days. It is therefore assumed that performance in sports that involve these elements would also be inhibited. This is of importance to coaches, strength and conditioning specialists, and athletes in which slight decreases in ability may be extremely 'costly' to overall performance. Therefore the results of this study have practical importance to designing training programs and within the tapering of training prior to competition.

The impairment of performance observed within this study was attributed to the effects of muscle fatigue and exercise-induced muscle damage. The contribution of these effects is difficult to distinguish within the current study due to the limitation of measures performed and to the cross over effects of muscle fatigue and exercise-induced muscle damage. It is however believed that exercise-induced muscle damage played a greater role in the declines in performance observed. This is based upon there being very little improvement in MIS performance following the periods of rest within the first testing day and further declines during test 1 of day 2 following overnight recovery. Although plasma CK concentration 3 days following the RTI was not significantly different to the pre-RTI level, other indicators of exercise-induced muscle damage such as force loss and the presence of soreness and tenderness allude to the existence of some degree of muscle damage.

The study also showed significant improvement in performance of the SBJ and the Illinois agility run within the testing period. These results were unexpected and were attributed to learning and practice effects that occurred from repeated performance. The

effects of muscle fatigue and exercise-induced muscle damage may have impacted on performance of the criterion measures however these may have been masked by the greater influence of learning and practice effects. This is an area in which the current study could be improved upon by including more familiarisation sessions to reduce the effects of learning and practice. Other areas of improvement include using a simpler agility test, which could be measured through the use of a timing gate system. An eating checklist could also be included to gain indications of impairments in performance due to diet and to act as a reminder to consume food immediately following each testing session.

Recommendations for future research in this area include:

1. The effects of a heavy RTI on larger muscle groups (eg quadriceps) and/or incorporating multiple muscle groups in the RTI. This would be more specific to strength and conditioning programs undertaken in sport.
2. Include female subjects to investigate any gender differences in acute responses and recovery.
3. Incorporate resistance trained subjects or subjects that have a resistance training history to examine the recovery process in relation to resistance training status.

CHAPTER 6

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APPENDICES

Appendix A

Physical Activity and Medical Questionnaire

Physical Activity and Medical Questionnaire

Name: _____ Age:_____

Height: _____cm Weight:_____kg

Current Physical Activity:_____

How many hours per week do you perform physical activity? _____

Are you currently performing any specific resistance training? Yes No

Have you ever been involved in any resistance training? Yes No

If yes, when and how long for?

_____

_____

_____

Have you had any joint injuries to the lower leg? Yes No

If yes what, when, and how did the injury occur?

_____

_____

_____

Do you have any current muscular strains? Yes No

If yes, where and when did the injury occur.

_____

_____

Please circle the correct answer to any of the following medical conditions

1. Do you suffer from high or abnormal blood pressure? Yes No
2. Any known abnormal heart conditions? Yes No

3. Do you suffer from Asthma? Yes No
4. Do you have Diabetes? Yes No
5. Are you on any medications/drugs? Yes No
6. Is there any condition that is not mentioned that may affect your ability to participate in this study? Yes No

If you answered Yes to any of the above questions, please provide more detail in the space provided.

_____

_____

_____

_____

_____

Appendix B

Informed Consent Form

Information and Consent Form

The effect of a heavy resistance training intervention on the performance measures of strength, power, acceleration and agility.

Thank you for your interest in my research topic of investigating changes in performance measures following a heavy resistance training intervention. The following information is provided to fully inform you about the nature of the study.

Purpose of the Study

The purpose of this study is to investigate the effects of a single session of heavy resistance training of the calves on measures of strength, power, acceleration and agility.

Exercise and Measurements

If you agree to participate in this study you will be asked to attend the laboratory on 11 occasions. The first two occasions will be for familiarisation sessions in which you will be introduced to the training apparatus and the testing measures that will be used. The first familiarisation session will be used to determine the correct weight to be used in the resistance training session. Following these familiarisation sessions there will be a minimum of three days before training and testing will begin. On the first day you will be required to attend the laboratory on 3 occasions. During the first occasion you will be required to perform a series of tests known as criterion measures (see below) which will be used as baseline data throughout the study. Following the series of tests you will be asked to complete a resistance training session where you will perform 10 sets of 5 repetitions of standing calf raises with the weight identified during the familiarisation session, on a customised standing calf raise machine. Immediately following the resistance training session you will again be asked to complete the same criterion measures as performed before the resistance training session. You will then rest for a period one-hour before returning to have the criterion measures tested for the third time. The final (4^{th}) testing session for the first day will occur 3 hours after the third testing. On each of the following 3 days you will be asked to attend the laboratory for testing twice per day, once in the morning and then again in the afternoon. Each testing session

is expected to be completed in one hour and the resistance training session should take a maximum of 30 minutes. Both the intervention and testing sessions will occur in a sports science laboratory located at the Joondalup campus of Edith Cowan University.

Criterion Measurements

The following measurements will be made during each testing session.

Maximum Voluntary Isometric Strength

You will be required to perform a standing calf raise against the immovable shoulder pads of a standing calf raise machine. During performance of this task you will be verbally encouraged to produce maximum force. The force exerted on the machine will be measured by strain gauges and displayed on a computer terminal.

Vertical Jump Test

The vertical jump test requires you to jump maximally in a vertical direction with your hands on you hips. Jump height will be calculated from the flight time of the jump, which will be recorded, by timing pads.

Standing Broad Jump

The standing broad jump requires you to jump as far as you can in a forward horizontal movement. The length of the jump will be measured from the level of your feet at the start to the point to where your feet land.

10 m Sprint

The 10m-sprint test will occur indoors and requires you to sprint as fast as you can for 10 metres. The sprint will be measured by way of timing gates situated at 0, 5 and 10 metres.

Illinios Agility Run

The Illinios agility run is a general test of agility. It involves you sprinting while weaving around a course marked by plastic cones in the shortest period of time.

Risks and Ethical Considerations

You may experience some muscular soreness and slight swelling in the calves due to the effects of the resistance intervention in the calf musculature. These symptoms are normal affects of unaccustomed physical exertion and will improve over subsequent days.

All personal information and test results will remain confidential and will only be used for the current study. Any data published from this study will not contain your name or any personal information that would identify you specifically as a subject. You are free to withdraw from the study at any time and for any reason without prejudice.

Requirements

During the testing and training period you will be requested not to perform any physical activity, other than that required for the study, but otherwise to keep your daily life style as you normally would. As the study involves a resistance training intervention you will be asked to complete a physical and medical questionnaire prior to the commencement of testing.

Should you have any questions or require further information please feel free to contact me.

Yours Sincerely,

Naomi Forrest (Masters Candidate)
School of Biomedical and Sports Science, Edith Cowan University
100 Joondalup Drive, Joondalup WA 6027
Phone: 9400 5097 E-mail: n.forrest@ecu.edu.au

Declaration

I, _____ have read and understood the information provided to me regarding the requirements and the risks of being a subject in this study. I have completed the medical and physical activity questionnaire to the best of my knowledge.

I agree to participate in this study realising that I am free to withdraw from the study at any point without prejudice.

I am aware that the research data obtained in this study may be published and that I will not be identifiable in any way.

Participant_____ Date_____

Investigator_____ Date_____

Appendix C

Raw Data Results

MVC (kg)

Subject	Pre	Imm Post	2hrs Post	6hrs Post	Day 2 Test 1	Day 2 Test 2	Day 3 Test 1	Day 3 Test 2	Day 4 Test 1	Day 4 Test 2
1	367.00	377.50	379.50	350.50	307.00	296.50	314.50	330.00	374.50	343.00
2	674.00	513.00	478.50	527.00	422.50	415.50	379.00	438.50	607.50	631.50
3	534.00	482.50	483.75	493.50	522.00	484.50	492.50	494.00	500.25	495.50
4	462.25	407.25	400.50	427.00	399.75	418.75	419.50	394.75	392.25	462.00
5	482.25	474.50	444.75	479.00	445.25	459.50	481.25	453.00	434.75	466.00
6	645.00	598.00	594.75	579.25	560.25	516.25	686.50	615.00	666.00	635.25
7	670.25	612.00	687.25	552.50	621.50	604.00	615.00	622.00	635.50	628.00
8	541.75	541.75	540.75	543.00	509.25	498.00	530.25	535.00	519.25	552.25
9	563.25	462.50	516.75	516.00	538.75	505.25	573.00	567.50	573.00	569.25
10	680.50	649.00	649.25	673.50	652.00	691.50	668.25	742.00	709.75	726.75
11	516.50	516.50	503.00	508.25	525.75	512.25	568.00	510.50	590.00	578.50
12	*	*	*	*	*	*	*	*	*	*
13	558.00	516.25	445.00	403.00	535.50	510.50	579.00	442.50	404.75	448.75
14	726.50	715.25	753.75	765.25	755.00	784.25	800.75	770.75	803.00	666.00
Mean	**570.87**	**528.15**	**529.04**	**524.44**	**522.65**	**515.13**	**546.73**	**531.96**	**554.65**	**554.06**
SEM	**28.74**	**26.41**	**31.31**	**30.19**	**32.04**	**34.24**	**36.81**	**35.98**	**36.60**	**29.58**

Note: * Denotes data unmeasured due to subject discomfort

Vertical Jump Height (cm)

Subject	Pre	Imm Post	2hrs Post	6hrs Post	Day 2 Test 1	Day 2 Test 2	Day 3 Test 1	Day 3 Test 2	Day 4 Test 1	Day 4 Test 2
1	48.00	46.50	44.67	45.00	44.33	42.33	42.00	43.33	44.33	49.33
2	36.00	34.00	34.00	34.33	34.33	38.33	31.67	34.33	36.00	39.33
3	28.33	24.67	24.00	23.33	23.67	23.00	24.00	25.00	23.67	27.33
4	37.33	34.33	35.00	35.67	35.00	34.33	31.67	34.00	33.00	35.67
5	31.00	30.33	29.00	29.33	31.33	30.33	30.33	31.33	32.67	33.67
6	34.67	31.33	32.33	33.00	33.33	34.33	33.33	34.33	37.67	37.67
7	42.00	41.33	41.33	37.33	41.33	39.67	41.00	40.33	41.00	45.67
8	35.89	34.33	34.22	33.22	35.33	34.78	34.89	35.33	37.11	39.00
9	42.00	40.33	41.67	42.67	38.33	39.33	40.33	42.67	41.00	41.00
10	39.00	40.00	39.33	38.67	43.00	43.33	43.33	42.00	42.33	41.33
11	28.33	29.00	28.67	26.67	28.00	27.33	28.67	30.67	28.67	28.00
12	28.67	29.67	30.33	29.67	30.00	27.67	31.33	29.00	29.67	31.67
13	33.33	32.33	32.67	33.67	33.67	31.67	33.00	33.00	33.33	33.67
14	42.00	38.00	39.33	41.67	41.33	43.33	39.00	40.00	42.67	44.00
Mean	**36.18**	**34.73**	**34.75**	**34.59**	**35.21**	**34.98**	**34.61**	**35.38**	**35.94**	**37.67**
SEM	**1.60**	**1.57**	**1.57**	**1.65**	**1.59**	**1.71**	**1.52**	**1.49**	**1.63**	**1.72**

Standing Broad Jump (cm)

Subject	Pre	Imm Post	2hrs Post	6hrs Post	Day 2 Test 1	Day 2 Test 2	Day 3 Test 1	Day 3 Test 2	Day 4 Test 1	Day 4 Test 2
1	212.00	211.00	208.00	212.67	215.00	208.33	212.00	210.33	218.67	213.67
2	177.67	168.33	168.33	169.67	153.67	166.33	154.67	161.50	183.00	192.67
3	199.33	200.00	198.00	190.67	194.67	201.00	200.00	203.67	202.33	206.00
4	197.00	192.33	200.00	198.00	187.67	193.67	187.33	195.33	188.33	195.67
5	187.33	194.67	197.00	197.33	195.33	198.00	192.67	202.33	191.33	205.00
6	173.33	171.33	190.67	187.67	183.33	192.00	197.00	195.00	196.33	202.00
7	208.33	210.67	215.00	210.33	207.33	208.00	209.67	207.67	209.33	212.67
8	174.33	183.00	184.33	176.00	178.33	190.00	180.67	180.67	187.33	191.67
9	181.00	182.00	179.33	187.00	188.33	187.00	196.33	196.67	196.67	207.67
10	205.33	203.00	211.00	205.67	211.67	212.67	218.33	223.67	221.33	221.33
11	169.67	171.00	172.67	168.67	165.67	162.67	169.67	171.00	165.00	165.00
12	178.67	181.00	179.00	180.00	179.67	176.00	182.33	181.50	184.00	189.00
13	181.00	174.67	179.33	181.67	182.67	186.67	180.00	190.00	191.33	194.00
14	214.67	217.67	211.33	218.67	218.67	217.00	212.67	216.33	215.00	223.00
Mean	**189.98**	**190.05**	**192.43**	**191.72**	**190.14**	**192.81**	**192.38**	**195.41**	**196.43**	**201.38**
SEM	**4.18**	**4.41**	**4.14**	**4.27**	**4.99**	**4.40**	**4.81**	**4.64**	**4.18**	**4.03**

10m Sprint (sec)

Subject	Pre	Imm Post	2hrs Post	6hrs Post	Day 2 Test 1	Day 2 Test 2	Day 3 Test 1	Day 3 Test 2	Day 4 Test 1	Day 4 Test 2
1	1.94	1.94	1.97	1.97	1.96	1.99	2.01	1.98	2.01	1.98
2	1.92	2.05	2.07	1.97	2.03	2.04	2.08	2.01	1.98	1.94
3	1.92	1.99	1.98	2.01	1.98	1.97	2.04	1.97	1.97	1.95
4	2.03	2.09	2.03	2.08	2.01	2.07	2.10	2.06	2.04	1.92
5	1.95	2.05	2.09	2.05	2.12	2.07	2.19	1.97	2.04	2.00
6	1.92	1.98	2.03	1.98	1.99	1.99	1.96	2.03	1.97	1.90
7	1.85	1.88	1.86	1.86	1.82	1.85	1.85	1.82	1.88	1.87
8	2.00	2.07	1.94	2.13	2.14	2.06	2.10	2.07	2.07	2.07
9	1.87	1.85	1.85	1.83	1.87	1.82	1.88	1.88	1.83	1.82
10	1.84	1.84	1.84	1.82	1.82	1.81	1.80	1.77	1.86	1.81
11	2.11	2.16	2.17	2.19	2.20	2.19	2.10	2.10	2.11	2.08
12	1.92	1.98	1.89	1.89	1.97	1.90	1.87	1.95	1.83	1.86
13	2.06	2.08	2.11	2.06	2.05	2.12	2.12	2.09	2.07	1.95
14	1.81	1.85	1.82	1.81	1.85	1.83	1.76	1.77	1.76	1.75
Mean	**1.94**	**1.99**	**1.98**	**1.98**	**1.99**	**1.98**	**1.99**	**1.96**	**1.96**	**1.92**
SEM	**0.02**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.04**	**0.03**	**0.03**	**0.03**

Illinois Agility Run (sec)

Subject	Pre	Imm Post	2hrs Post	6hrs Post	Day 2 Test 1	Day 2 Test 2	Day 3 Test 1	Day 3 Test 2	Day 4 Test 1	Day 4 Test 2
1	16.53	16.92	16.85	16.48	16.50	16.62	16.73	16.47	16.33	16.16
2	16.42	17.00	16.81	16.49	16.80	16.46	17.73	16.76	16.16	15.93
3	16.58	16.64	16.34	16.20	16.56	16.13	15.91	16.24	15.98	15.87
4	17.00	16.96	17.16	17.23	16.83	16.90	16.50	16.30	16.79	16.38
5	17.23	17.36	17.56	17.56	17.06	16.86	16.76	16.69	17.02	16.63
6	16.70	16.45	16.13	16.44	16.22	15.86	15.90	16.11	15.75	15.48
7	14.89	14.71	14.90	14.58	14.89	14.77	14.60	14.68	14.73	14.51
8	16.18	16.33	16.76	16.97	16.42	16.23	16.72	16.64	16.71	16.22
9	15.17	15.64	15.66	15.65	15.52	14.96	15.09	15.64	15.14	15.38
10	15.43	15.36	14.79	14.63	14.40	14.69	14.48	14.24	14.84	14.49
11	18.34	18.68	18.07	18.15	18.00	18.08	17.15	16.94	17.47	17.06
12	16.39	16.06	15.96	15.83	16.02	15.93	15.93	15.58	15.38	15.34
13	18.01	17.88	17.90	17.71	17.73	17.57	17.79	17.50	17.12	17.30
14	15.78	15.83	15.48	15.40	15.68	15.17	14.91	15.13	14.90	14.85
Mean	**16.48**	**16.25**	**16.46**	**16.38**	**16.33**	**16.16**	**16.16**	**16.07**	**16.02**	**15.83**
SEM	**0.26**	**0.28**	**0.28**	**0.29**	**0.27**	**0.27**	**0.29**	**0.24**	**0.25**	**0.23**

Soreness (VAS 0-10)

Subject	Pre	Imm Post	2hrs Post	6hrs Post	Day 2 Test 1	Day 2 Test 2	Day 3 Test 1	Day 3 Test 2	Day 4 Test 1	Day 4 Test 2
1	0	2	2	2	2	2	1	1	0	0
2	0	2	3	3	5	5	5	3.5	2	1
3	0	1	1	1	3	2	2	2	2	1.5
4	0	3	3	3	5	4	5	6	5	4
5	0	4	3	3	5	5	6	5	4	3
6	0	2	2	4	7	8	6	3	1	1
7	0	1	1	1	2	2	1	1	0	0
8	0	0	0	0	1	1	1	1	0	0
9	0	0	2	2	2	2	1	1	1	1
10	0	2	2	2	2	2	4	5	4	5
11	0	0	0	0	0	0	3	3	2	1
12	0	0	0	0	1	1	0	0	0	0
13	0	1	0	0	0	0	0	0	0	0
14	0	0	0	0	6	6	4	3	2	1
Mean	**0**	**1.29**	**1.36**	**1.50**	**2.93**	**2.86**	**2.79**	**2.46**	**1.64**	**1.32**
SEM	**0**	**0.34**	**0.32**	**0.37**	**0.61**	**0.64**	**0.59**	**0.51**	**0.45**	**0.42**

Tenderness Right Leg Immediately Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	100	100	100	100	100	^	100	100	100	100	100	100
2	65	100	65	80	80	95	55	100	100	90	70	80
3	100	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	^	45	100	100	100	70	100
5	100	100	100	100	100	100	95	95	100	100	80	100
6	70	100	100	100	100	100	60	95	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	95	100	100	100	100	100
10	100	100	100	100	100	100	70	100	100	100	100	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	100	100	100	100	100	100	75	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ Denotes subjects in which site was not measured due to length of legs

Tenderness Right Leg 2 hours Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	100	100	100	100	85	^	50	90	100	100	100	100
2	35	55	50	50	50	70	30	45	70	40	45	80
3	100	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	85	^	100	100	100	100	35	100
5	100	100	100	100	100	100	80	100	100	100	100	100
6	100	100	100	100	100	100	75	85	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	10	100	100	95	100	100
10	100	100	100	100	100	100	85	100	100	65	100	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	90	75	95	100	100	100	70	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length

Tenderness Right Leg 6 hours Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	90	90	100	100	100	^	30	90	100	90	100	100
2	30	30	40	55	50	50	25	80	75	30	30	40
3	100	100	100	100	100	100	100	100	100	100	100	100
4	90	90	100	100	100	^	35	100	100	100	100	100
5	100	100	100	100	100	100	90	100	100	100	100	100
6	60	100	100	100	100	100	65	100	100	100	100	100
7	95	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	80	100	100	100	100	^	10	100	100	100	100	100
10	100	100	100	100	100	100	65	75	100	90	100	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	75	90	100	100	100	100	45	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length

Tenderness Right Leg Day 2 Test 1 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	100	100	100	100	100	^	55	95	100	90	95	100
2	15	90	15	65	70	80	20	95	100	20	0	45
3	100	100	100	100	100	100	90	60	100	100	100	100
4	85	100	100	100	100	^	25	100	100	15	55	100
5	100	100	100	100	100	100	100	100	100	100	100	100
6	60	75	95	100	100	100	35	75	100	80	100	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	0	95	100	75	100	100
10	100	100	100	100	100	100	65	65	100	90	95	100
11	100	100	100	100	100	100	75	85	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	15	90	100	100	100	100	35	80	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length

Tenderness Right Leg Day 2 Test 2 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	100	100	100	100	90	^	55	55	100	80	80	90
2	15	100	0	30	70	80	10	80	100	0	0	85
3	100	100	100	100	100	100	100	100	100	100	100	90
4	100	100	100	100	90	^	25	70	60	30	45	100
5	100	100	100	100	100	100	45	90	100	100	100	100
6	85	100	100	100	100	100	80	55	100	90	90	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	40	100	100	95	100	100
10	100	100	100	100	100	100	70	75	100	45	75	100
11	100	100	100	100	100	100	40	85	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	100	100	100	100	100	100	85	100	100	50	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length

Tenderness Right Leg Day 3 Test 1 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	100	100	100	100	100	^	25	80	100	100	90	100
2	40	95	70	60	60	100	0	70	95	0	5	85
3	100	100	100	100	100	100	100	90	100	100	100	100
4	100	100	100	100	100	^	0	90	55	5	60	100
5	95	95	100	100	100	100	55	60	100	100	70	100
6	100	100	100	100	100	100	35	100	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	95	100	100	100	100	100
9	100	100	100	100	100	^	65	100	100	90	100	100
10	100	100	100	100	100	100	65	80	100	100	100	100
11	100	100	100	100	100	100	70	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	75	100	100	100	100	100	50	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length

Tenderness Right Leg Day 3 Test 2 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	100	100	100	100	100	^	100	65	100	70	100	100
2	50	85	70	50	65	100	10	80	85	15	10	60
3	100	100	100	100	100	100	100	90	100	100	100	100
4	100	100	100	100	100	^	10	90	100	10	55	100
5	95	95	90	100	100	100	85	100	100	100	80	100
6	70	100	100	100	100	100	45	45	100	90	100	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	50	100	100	100	100	100
10	100	100	100	100	100	100	50	70	100	70	90	100
11	100	100	100	100	100	100	80	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	50	85	100	100	100	100	50	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length

Tenderness Right Leg Day 4 Test 1 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	100	100	100	100	100	^	75	100	100	85	90	100
2	60	100	70	100	95	100	55	100	100	100	20	95
3	100	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	^	5	80	100	10	45	100
5	100	100	100	100	100	75	85	90	100	85	100	100
6	100	100	100	100	100	100	35	80	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	70	100	100	100	100	100
10	100	100	100	100	100	100	70	75	100	100	100	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	70	100	100	100	100	100	25	100	100	95	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length

Tenderness Left Leg Immediately Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	#	#	#	#	#	^	#	#	#	#	#	#
2	#	#	#	#	#	#	#	#	#	#	#	#
3	100	100	100	100	100	100	100	100	100	100	100	100
4	#	#	#	#	#	^	#	#	#	#	#	#
5	100	100	100	100	100	100	100	100	100	100	80	100
6	75	95	95	100	100	100	70	80	100	100	100	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	95	100	100	100	100	100
10	100	100	100	100	100	100	100	100	100	100	100	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	95	100	100	100	100	100	75	90	95	100	100	100
14	100	100	100	100	100	100	80	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length, # denotes sites unmeasured due to assumption of equality within legs.

Tenderness Left Leg 2 hours Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	#	#	#	#	#	^	#	#	#	#	#	#
2	#	#	#	#	#	#	#	#	#	#	#	#
3	100	100	100	100	100	100	100	100	100	100	100	100
4	#	#	#	#	#	^	#	#	#	#	#	#
5	100	100	100	100	100	100	100	95	100	100	100	100
6	55	75	85	100	100	100	60	80	100	100	95	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	50	100	100	100	100	100
10	100	100	100	100	100	100	95	100	100	100	95	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	80	100	100	100	100	100	75	95	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length, # denotes sites unmeasured due to assumption of equality within legs.

Tenderness Left Leg 6 hours Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	#	#	#	#	#	^	#	#	#	#	#	#
2	#	#	#	#	#	#	#	#	#	#	#	#
3	100	100	100	100	100	100	100	100	100	100	100	100
4	#	#	#	#	#	^	#	#	#	#	#	#
5	100	100	100	100	100	100	100	100	100	100	100	100
6	80	80	100	100	95	100	35	85	100	85	95	100
7	100	100	100	100	100	100	90	100	100	95	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	20	100	100	100	100	100
10	100	100	100	100	100	100	60	100	100	100	95	100
11	100	100	100	100	100	100	60	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	50	90	100	100	100	100	55	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	90	100

Note: ^ denotes subjects in which site was not measured due to leg length, # denotes sites unmeasured due to assumption of equality within legs.

Tenderness Left Leg Day 2 Test 1 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	#	#	#	#	#	^	#	#	#	#	#	#
2	10	5	0	100	70	85	70	60	85	10	0	65
3	100	100	100	100	100	100	90	100	100	100	100	100
4	100	100	95	100	100	^	20	70	100	20	60	95
5	100	100	100	100	100	100	100	100	80	100	100	100
6	55	55	80	95	100	100	55	55	90	85	95	100
7	100	100	100	100	100	100	100	80	100	100	100	100
8	100	100	100	100	100	^	80	100	100	100	100	100
9	100	100	100	100	100	^	40	100	100	100	100	100
10	100	100	100	100	100	100	75	95	100	100	100	100
11	100	100	100	100	100	100	90	90	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	45	90	100	100	100	100	70	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length, # denotes sites unmeasured due to assumption of equality within legs.

Tenderness Left Leg Day 2 Test 2 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	10	5	0	25	100	60	65	40	65	0	0	20
2	100	100	100	100	100	100	80	100	100	100	100	90
3	80	100	100	100	100	^	0	45	50	25	100	100
4	100	100	100	100	100	100	45	90	70	95	100	100
5	65	100	100	100	100	100	0	45	100	100	85	100
6	100	100	100	100	100	100	100	80	100	100	100	100
7	100	100	100	100	100	^	65	100	100	100	100	100
8	100	100	100	100	100	^	80	100	100	100	100	100
9	100	100	100	100	100	100	70	100	100	100	100	100
10	100	100	100	100	100	100	100	80	100	100	100	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	100	100	100	100	100	100	100	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length, # denotes sites unmeasured due to assumption of equality within legs.

Tenderness Left Leg Day 3 Test 1 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	#	#	#	#	#	^	#	#	#	#	#	#
2	10	0	0	40	50	60	65	65	50	0	0	20
3	100	100	100	100	100	100	80	85	100	100	100	100
4	90	90	100	100	100	^	10	15	100	25	45	100
5	100	100	100	100	100	100	55	65	65	95	50	100
6	65	90	100	100	100	100	25	60	100	100	90	100
7	100	100	100	100	100	100	100	80	100	100	100	100
8	100	100	100	100	100	^	65	100	100	100	100	100
9	100	100	100	100	100	^	80	100	100	100	100	100
10	100	100	100	100	100	100	75	75	100	100	100	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	75	100	100	100	100	100	100	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length, # denotes sites unmeasured due to assumption of equality within legs.

Tenderness Left Leg Day 3 Test 2 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	#	#	#	#	#	^	#	#	#	#	#	#
2	70	30	0	55	65	65	60	100	70	0	0	50
3	100	100	100	100	100	100	70	60	100	100	100	100
4	100	50	100	100	100	^	10	70	100	0	95	100
5	95	100	100	100	100	100	55	60	100	100	100	100
6	95	90	100	100	100	100	40	75	100	100	95	100
7	100	100	100	100	100	100	100	90	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	80	100	100	100	100	100
10	100	100	100	100	100	100	65	90	100	100	100	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	45	95	100	100	100	100	70	100	100	70	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length, # denotes sites unmeasured due to assumption of equality within legs.

Tenderness Left Leg Day 4 Test 1 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	#	#	#	#	#	^	#	#	#	#	#	#
2	95	25	20	100	100	60	100	85	85	0	10	45
3	100	100	100	100	100	100	100	100	100	100	100	100
4	100	75	90	100	100	^	50	65	65	0	85	100
5	100	100	100	100	100	100	90	100	75	90	80	100
6	100	100	100	100	100	100	70	90	100	100	55	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	90	100	100	100	100	100
10	100	100	100	100	100	100	75	90	100	90	90	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	70	100	100	100	100	100	50	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length, # denotes sites unmeasured due to assumption of equality within legs.

Tenderness Left Leg Day 4 Test 2 Post RTI (kPa)

	Midline Sites						Medial Sites			Lateral Sites		
Subject	5	10	15	20	25	30	5	15	25	5	15	25
1	#	#	#	#	#	^	#	#	#	#	#	#
2	70	80	55	100	100	65	100	85	100	10	25	100
3	100	100	100	100	100	100	100	55	100	100	100	100
4	100	100	100	100	100	^	15	70	75	0	95	100
5	100	100	100	100	100	100	95	100	90	100	90	100
6	95	90	100	100	100	100	45	95	100	85	100	100
7	100	100	100	100	100	100	100	100	100	100	100	100
8	100	100	100	100	100	^	100	100	100	100	100	100
9	100	100	100	100	100	^	90	100	100	100	100	100
10	100	100	100	100	100	100	60	95	100	95	95	100
11	100	100	100	100	100	100	100	100	100	100	100	100
12	100	100	100	100	100	100	100	100	100	100	100	100
13	50	100	100	100	100	100	50	100	100	100	100	100
14	100	100	100	100	100	100	100	100	100	100	100	100

Note: ^ denotes subjects in which site was not measured due to leg length, # denotes sites unmeasured due to assumption of equality within legs.

CK

Subject	Pre-RTI	Day 4 Test 1
1	93.5	94
2	90.9	144
3	114	142
4	24.4	86.3
5	72.1	275
6	88.3	173
7	205	254
8	113	100
9	421	518
10	127	404
11	584	1940
12	36.6	117
13	128	100
14	898	626
Mean	**213.99**	**355.24**
SEM	**66.95**	**130.12**

Appendix D

Statistical Output

One Way ANOVA's with Simple Contrasts

MIS

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TEST	Type III Sum of Squares	df	Mean Square	F	Sig.
TEST	Level 2 vs. Level 1	591.224	1	591.224	9.326	.011
	Level 3 vs. Level 1	447.619	1	447.619	5.408	.040
	Level 4 vs. Level 1	473.889	1	473.889	7.981	.017
	Level 5 vs. Level 1	942.350	1	942.350	8.097	.016
	Level 6 vs. Level 1	1208.615	1	1208.615	8.513	.014
	Level 7 vs. Level 1	349.596	1	349.596	1.748	.213
	Level 8 vs. Level 1	361.352	1	361.352	2.682	.130
	Level 9 vs. Level 1	17.328	1	17.328	.227	.643
	Level 10 vs. Level 1	26.433	1	26.433	.683	.426
Error(TEST)	Level 2 vs. Level 1	697.371	11	63.397		
	Level 3 vs. Level 1	910.494	11	82.772		
	Level 4 vs. Level 1	653.175	11	59.380		
	Level 5 vs. Level 1	1280.252	11	116.387		
	Level 6 vs. Level 1	1561.782	11	141.980		
	Level 7 vs. Level 1	2200.055	11	200.005		
	Level 8 vs. Level 1	1482.263	11	134.751		
	Level 9 vs. Level 1	839.974	11	76.361		
	Level 10 vs. Level 1	426.006	11	38.728		

VJ

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TEST	Type III Sum of Squares	df	Mean Square	F	Sig.
TEST	Level 2 vs. Level 1	218.764	1	218.764	9.130	.010
	Level 3 vs. Level 1	213.529	1	213.529	8.409	.012
	Level 4 vs. Level 1	284.054	1	284.054	9.460	.009
	Level 5 vs. Level 1	94.649	1	94.649	2.346	.150
	Level 6 vs. Level 1	164.216	1	164.216	3.029	.105
	Level 7 vs. Level 1	228.785	1	228.785	3.505	.084
	Level 8 vs. Level 1	53.750	1	53.750	1.536	.237
	Level 9 vs. Level 1	4.749	1	4.749	.091	.767
	Level 10 vs. Level 1	235.592	1	235.592	8.352	.013
Error(TEST)	Level 2 vs. Level 1	311.497	13	23.961		
	Level 3 vs. Level 1	330.091	13	25.392		
	Level 4 vs. Level 1	390.359	13	30.028		
	Level 5 vs. Level 1	524.458	13	40.343		
	Level 6 vs. Level 1	704.740	13	54.211		
	Level 7 vs. Level 1	848.457	13	65.266		
	Level 8 vs. Level 1	454.905	13	34.993		
	Level 9 vs. Level 1	675.472	13	51.959		
	Level 10 vs. Level 1	366.702	13	28.208		

SBJ

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	SESSION	Type III Sum of Squares	df	Mean Square	F	Sig.
SESSION	Level 2 vs. Level 1	1.646E-02	1	1.646E-02	.002	.963
	Level 3 vs. Level 1	26.194	1	26.194	1.769	.206
	Level 4 vs. Level 1	12.711	1	12.711	1.170	.299
	Level 5 vs. Level 1	4.571E-02	1	4.571E-02	.002	.965
	Level 6 vs. Level 1	34.008	1	34.008	1.491	.244
	Level 7 vs. Level 1	24.818	1	24.818	.655	.433
	Level 8 vs. Level 1	119.954	1	119.954	4.043	.066
	Level 9 vs. Level 1	172.692	1	172.692	7.766	.015
	Level 10 vs. Level 1	534.817	1	534.817	17.388	.001
Error(SESSION)	Level 2 vs. Level 1	94.589	13	7.276		
	Level 3 vs. Level 1	192.473	13	14.806		
	Level 4 vs. Level 1	141.231	13	10.864		
	Level 5 vs. Level 1	305.466	13	23.497		
	Level 6 vs. Level 1	296.593	13	22.815		
	Level 7 vs. Level 1	492.600	13	37.892		
	Level 8 vs. Level 1	385.717	13	29.671		
	Level 9 vs. Level 1	289.094	13	22.238		
	Level 10 vs. Level 1	399.847	13	30.757		

10m Sprint

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	TEST	Type III Sum of Squares	df	Mean Square	F	Sig.
TEST	Level 2 vs. Level 1	87.100	1	87.100	19.524	.001
	Level 3 vs. Level 1	52.923	1	52.923	4.873	.046
	Level 4 vs. Level 1	49.821	1	49.821	7.109	.019
	Level 5 vs. Level 1	86.106	1	86.106	8.405	.012
	Level 6 vs. Level 1	60.071	1	60.071	8.136	.014
	Level 7 vs. Level 1	99.644	1	99.644	5.214	.040
	Level 8 vs. Level 1	19.024	1	19.024	2.802	.118
	Level 9 vs. Level 1	14.997	1	14.997	2.049	.176
	Level 10 vs. Level 1	4.571	1	4.571	.680	.424
Error(TEST)	Level 2 vs. Level 1	57.996	13	4.461		
	Level 3 vs. Level 1	141.192	13	10.861		
	Level 4 vs. Level 1	91.102	13	7.008		
	Level 5 vs. Level 1	133.176	13	10.244		
	Level 6 vs. Level 1	95.979	13	7.383		
	Level 7 vs. Level 1	248.424	13	19.110		
	Level 8 vs. Level 1	88.264	13	6.790		
	Level 9 vs. Level 1	95.149	13	7.319		
	Level 10 vs. Level 1	87.373	13	6.721		

Soreness

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	SESSION	Type III Sum of Squares	df	Mean Square	F	Sig.
SESSION	Level 2 vs. Level 1	23.143	1	23.143	14.425	.002
	Level 3 vs. Level 1	25.786	1	25.786	17.446	.001
	Level 4 vs. Level 1	31.500	1	31.500	16.059	.001
	Level 5 vs. Level 1	120.071	1	120.071	23.322	.000
	Level 6 vs. Level 1	114.286	1	114.286	20.155	.001
	Level 7 vs. Level 1	108.643	1	108.643	22.649	.000
	Level 8 vs. Level 1	85.018	1	85.018	22.915	.000
	Level 9 vs. Level 1	37.786	1	37.786	13.200	.003
	Level 10 vs. Level 1	24.446	1	24.446	9.688	.008
Error(SESSION)	Level 2 vs. Level 1	20.857	13	1.604		
	Level 3 vs. Level 1	19.214	13	1.478		
	Level 4 vs. Level 1	25.500	13	1.962		
	Level 5 vs. Level 1	66.929	13	5.148		
	Level 6 vs. Level 1	73.714	13	5.670		
	Level 7 vs. Level 1	62.357	13	4.797		
	Level 8 vs. Level 1	48.232	13	3.710		
	Level 9 vs. Level 1	37.214	13	2.863		
	Level 10 vs. Level 1	32.804	13	2.523		

Tenderness
Right Leg - Medial Sites

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	SESSION	Type III Sum of Squares	df	Mean Square	F	Sig.
SESSION	Level 2 vs. Level 1	229.311	1	229.311	5.789	.032
	Level 3 vs. Level 1	1334.192	1	1334.192	5.815	.031
	Level 4 vs. Level 1	2105.042	1	2105.042	11.128	.005
	Level 5 vs. Level 1	3352.968	1	3352.968	19.118	.001
	Level 6 vs. Level 1	3669.949	1	3669.949	14.745	.002
	Level 7 vs. Level 1	4114.629	1	4114.629	14.382	.002
	Level 8 vs. Level 1	2810.194	1	2810.194	12.749	.003
	Level 9 vs. Level 1	1642.694	1	1642.694	10.398	.007
	Level 10 vs. Level 1	1146.092	1	1146.092	13.229	.003
Error(SESSION)	Level 2 vs. Level 1	514.944	13	39.611		
	Level 3 vs. Level 1	2982.775	13	229.444		
	Level 4 vs. Level 1	2459.102	13	189.162		
	Level 5 vs. Level 1	2279.965	13	175.382		
	Level 6 vs. Level 1	3235.695	13	248.900		
	Level 7 vs. Level 1	3719.272	13	286.098		
	Level 8 vs. Level 1	2865.606	13	220.431		
	Level 9 vs. Level 1	2053.850	13	157.988		
	Level 10 vs. Level 1	1126.252	13	86.635		

Tenderness
Right Leg - Midline Sites

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	SESSION	Type III Sum of Squares	df	Mean Square	F	Sig.
SESSION	Level 2 vs. Level 1	1.786	1	1.786	1.000	.336
	Level 3 vs. Level 1	298.729	1	298.729	1.574	.232
	Level 4 vs. Level 1	507.968	1	507.968	2.130	.168
	Level 5 vs. Level 1	451.446	1	451.446	2.502	.138
	Level 6 vs. Level 1	288.018	1	288.018	1.258	.282
	Level 7 vs. Level 1	119.136	1	119.136	1.375	.262
	Level 8 vs. Level 1	217.330	1	217.330	2.293	.154
	Level 9 vs. Level 1	41.728	1	41.728	2.404	.145
	Level 10 vs. Level 1	20.643	1	20.643	1.809	.202
Error(SESSION)	Level 2 vs. Level 1	23.214	13	1.786		
	Level 3 vs. Level 1	2467.760	13	189.828		
	Level 4 vs. Level 1	3100.199	13	238.477		
	Level 5 vs. Level 1	2345.331	13	180.410		
	Level 6 vs. Level 1	2975.232	13	228.864		
	Level 7 vs. Level 1	1126.042	13	86.619		
	Level 8 vs. Level 1	1232.047	13	94.773		
	Level 9 vs. Level 1	225.661	13	17.359		
	Level 10 vs. Level 1	148.357	13	11.412		

Tenderness
Right Leg - Lateral Sites

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	SESSION	Type III Sum of Squares	df	Mean Square	F	Sig.
SESSION	Level 2 vs. Level 1	19.849	1	19.849	2.070	.174
	Level 3 vs. Level 1	457.257	1	457.257	2.731	.122
	Level 4 vs. Level 1	384.092	1	384.092	1.223	.289
	Level 5 vs. Level 1	1536.368	1	1536.368	3.008	.107
	Level 6 vs. Level 1	2445.171	1	2445.171	5.525	.035
	Level 7 vs. Level 1	1238.168	1	1238.168	2.771	.120
	Level 8 vs. Level 1	1607.143	1	1607.143	3.549	.082
	Level 9 vs. Level 1	600.111	1	600.111	2.960	.109
	Level 10 vs. Level 1	317.492	1	317.492	3.150	.099
Error(SESSION)	Level 2 vs. Level 1	124.640	13	9.588		
	Level 3 vs. Level 1	2176.310	13	167.408		
	Level 4 vs. Level 1	4082.975	13	314.075		
	Level 5 vs. Level 1	6640.587	13	510.814		
	Level 6 vs. Level 1	5753.240	13	442.557		
	Level 7 vs. Level 1	5809.010	13	446.847		
	Level 8 vs. Level 1	5887.713	13	452.901		
	Level 9 vs. Level 1	2635.444	13	202.726		
	Level 10 vs. Level 1	1310.397	13	100.800		

Tenderness
Left Leg - Medial Sites

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	SESSION	Type III Sum of Squares	df	Mean Square	F	Sig.
SESSION	Level 2 vs. Level 1	118.539	1	118.539	3.297	.099
	Level 3 vs. Level 1	258.651	1	258.651	4.826	.053
	Level 4 vs. Level 1	970.644	1	970.644	9.085	.013
	Level 5 vs. Level 1	1034.408	1	1034.408	11.800	.006
	Level 6 vs. Level 1	1853.804	1	1853.804	8.024	.018
	Level 7 vs. Level 1	1536.600	1	1536.600	7.529	.021
	Level 8 vs. Level 1	1272.693	1	1272.693	10.034	.010
	Level 9 vs. Level 1	352.052	1	352.052	8.424	.016
	Level 10 vs. Level 1	589.992	1	589.992	9.754	.011
Error(SESSION)	Level 2 vs. Level 1	359.541	10	35.954		
	Level 3 vs. Level 1	535.905	10	53.591		
	Level 4 vs. Level 1	1068.400	10	106.840		
	Level 5 vs. Level 1	876.614	10	87.661		
	Level 6 vs. Level 1	2310.236	10	231.024		
	Level 7 vs. Level 1	2041.022	10	204.102		
	Level 8 vs. Level 1	1268.440	10	126.844		
	Level 9 vs. Level 1	417.906	10	41.791		
	Level 10 vs. Level 1	604.899	10	60.490		

Tenderness
Left Leg - Midline Sites

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	SESSION	Type III Sum of Squares	df	Mean Square	F	Sig.
SESSION	Level 2 vs. Level 1	5.717	1	5.717	1.906	.197
	Level 3 vs. Level 1	39.369	1	39.369	2.200	.169
	Level 4 vs. Level 1	38.653	1	38.653	3.151	.106
	Level 5 vs. Level 1	114.762	1	114.762	2.976	.115
	Level 6 vs. Level 1	25.293	1	25.293	3.106	.108
	Level 7 vs. Level 1	17.363	1	17.363	2.961	.116
	Level 8 vs. Level 1	22.266	1	22.266	2.528	.143
	Level 9 vs. Level 1	4.416	1	4.416	1.961	.192
	Level 10 vs. Level 1	14.686	1	14.686	2.321	.159
Error(SESSION)	Level 2 vs. Level 1	29.992	10	2.999		
	Level 3 vs. Level 1	178.981	10	17.898		
	Level 4 vs. Level 1	122.656	10	12.266		
	Level 5 vs. Level 1	385.668	10	38.567		
	Level 6 vs. Level 1	81.428	10	8.143		
	Level 7 vs. Level 1	58.648	10	5.865		
	Level 8 vs. Level 1	88.084	10	8.808		
	Level 9 vs. Level 1	22.524	10	2.252		
	Level 10 vs. Level 1	63.261	10	6.326		

Tenderness
Left Leg - Lateral Sites

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	SESSION	Type III Sum of Squares	df	Mean Square	F	Sig.
SESSION	Level 2 vs. Level 1	4.044	1	4.044	1.000	.341
	Level 3 vs. Level 1	1.014	1	1.014	2.222	.167
	Level 4 vs. Level 1	9.109	1	9.109	2.224	.167
	Level 5 vs. Level 1	4.044	1	4.044	1.000	.341
	Level 6 vs. Level 1	9.091	1	9.091	3.052	.111
	Level 7 vs. Level 1	42.651	1	42.651	1.401	.264
	Level 8 vs. Level 1	.254	1	.254	1.000	.341
	Level 9 vs. Level 1	91.181	1	91.181	3.276	.100
	Level 10 vs. Level 1	12.360	1	12.360	3.550	.089
Error(SESSION)	Level 2 vs. Level 1	40.444	10	4.044		
	Level 3 vs. Level 1	4.564	10	.456		
	Level 4 vs. Level 1	40.958	10	4.096		
	Level 5 vs. Level 1	40.444	10	4.044		
	Level 6 vs. Level 1	29.787	10	2.979		
	Level 7 vs. Level 1	304.427	10	30.443		
	Level 8 vs. Level 1	2.535	10	.254		
	Level 9 vs. Level 1	278.308	10	27.831		
	Level 10 vs. Level 1	34.818	10	3.482		

Paired Samples T-Test

Plasma CK Concentration

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	CKPRE - CKPOST	-141.2500	370.5643	99.0375	-355.2074	72.7074	-1.426	13	.177