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THE EFFECTS OF A SPECIFIC EXERCISE INTERVENTION ON DELAYED ONSET MUSCLE SORENESS (DOMS) AND NEUROMUSCULAR FUNCTION

By

Mikie Tanya Michelle Mork

A Thesis
Submitted to the Faculty of Graduate Studies
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MASTER OF SCIENCE

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

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MASTER OF SCIENCE

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ABSTRACT

THE EFFECTS OF A SPECIFIC EXERCISE INTERVENTION ON DELAYED ONSET MUSCLE SORENESS (DOMS) AND NEUROMUSCULAR FUNCTION

Mikie Mork, Graduate Student, Faculty of Graduate Studies

Delayed Onset Muscle Soreness (DOMS) is a common phenomenon experienced by individuals who perform unaccustomed exercise that typically involves an eccentric component. Soreness peaks between 24 and 48 hours post-exercise with residual soreness usually remaining beyond that time frame.

Negative implications of DOMS include minimal to severe soreness, the inability to continue safe and effective training or performance, biomechanical alterations predisposing individuals to injury, and decreases in strength and power.

There have been many clinical and therapeutic interventions utilized in an attempt to minimize DOMS and the negative impact on athletic performance. Exercise, therapeutic massage, cryotherapy, ultrasound, and anti-inflammatory drugs have all been tested as methods of determining an effective intervention strategy. The present research attempted to minimize the negative impacts that DOMS has on neuromuscular function by utilizing a specific exercise program as a treatment intervention.

Twenty females between the ages of 19 and 35 participated in the present research. Subjects were free from knee and quadriceps muscle injury and had not participated in specific eccentric training of the lower legs in the six weeks prior to testing. Subjects were equally and randomly divided into a control group and an experimental group. Baseline testing consisted of assessing concentric and eccentric quadriceps peak torque, concentric and eccentric quadriceps angle to peak torque, concentric and eccentric quadriceps average torque, concentric and eccentric quadriceps

relative peak torque, and vertical jump height. Each participant underwent a quadriceps muscle soreness inducing exercise session immediately following baseline assessment. A specific quadriceps muscle exercise intervention was administered to the experimental group 24 hours after the soreness inducing exercise session. The control group received no exercise intervention. Forty-eight hours post-baseline testing, each participant returned to the Biomechanics lab and all variables were re-assessed. In addition, each participant was given a series of visual analog scales to record their muscle soreness levels every 24 hours starting at baseline, for 96 hours.

Repeated measures ANOVA was used to analyze the data. The control group demonstrated significant differences between post-test and baseline assessment times for peak torque, relative peak torque, average torque, and vertical jump height. There were no significant differences between post-test to baseline assessment times for the experimental group. Both groups demonstrated peak soreness between 24 and 48 hours and there were no significant differences between the groups at any of the data points (0, 24, 48, 72, and 96 hours). The experimental group, however did appear to return to near baseline values earlier than the control group.

The data suggests that the specific exercise intervention that was administered in the present research had a protective effect on neuromuscular function.

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"Sometimes you just have to stay up late." MA

To say that I am responsible for the successful completion of this thesis is correct. However, to say that it has been completed with the guidance and support of many others would be more appropriate. I would like to take this opportunity to thank those who contributed in bringing this Masters degree to fruition. You deserve it.

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THE EFFECTS OF A SPECIFIC EXERCISE INTERVENTION ON DELAYED ONSET MUSCLE SORENESS (DOMS) AND NEUROMUSCULAR FUNCTION

CHAPTER 1

INTRODUCTION

Delayed Onset Muscle Soreness (DOMS) is a common phenomenon experienced by individuals who perform unaccustomed exercise that typically involves an eccentric component. The soreness will begin to occur at approximately 8 - 24 hours post-exercise and will peak at approximately 48 hours post exercise. The soreness is most often experienced upon movement (i.e. muscle action) or upon palpation of the muscle. At rest there is usually no perception of soreness (Smith 1992). Perception of soreness is generally reduced at 72 hours with residual soreness remaining beyond that time frame.

DOMS may be experienced by athletes who have not trained for a period of 6-8 weeks, by which time the protective adaptation of a training effect within the muscle has been lost, or who modify their training regime to incorporate new and therefore unaccustomed components to exercise (Donnelly, Clarkson et al. 1992). Individuals who are beginning a training schedule are also at risk for developing DOMS. DOMS may be experienced after performing either aerobic or anaerobic exercise, but generally requires an eccentric component.

Negative implications of DOMS include minimal to severe soreness, the inability to continue safe and effective training or performance, biomechanical alterations

predisposing individuals to injury, decreases in strength and power, interruption of activities of daily living (ADL's) and a decreased motivation and willingness to continue training due to the negative experiences of the soreness (Weber, Servedio et al. 1994). Evidence suggests that a single bout of eccentric exercise will result in some adaptation in the exercised muscle. Eccentric exercise has a protective effect during subsequent bouts of eccentric exercise (Ebbeling and Clarkson 1990; Clarkson, Nosaka et al. 1992; Stauber 1996) in that DOMS and other markers of microscopic muscle damage are significantly reduced (Smith 1992). It is suggested that during the repair process muscle and connective tissue are strengthened and thus more resistant to subsequent microscopic muscle damage (Smith 1992; Kuipers 1994).

There are many theories describing the reason for the onset of delayed muscle soreness. In an attempt to prevent and alleviate DOMS it is important to have an understanding of the underlying mechanisms contributing to DOMS. These mechanisms include damage to the contractile elements of muscle and the associated connective tissue (Hough 1902), as well as the inflammatory process associated with microinjury to both the contractile and noncontractile properties of muscle (Smith 1991).

There have been many clinical and therapeutic interventions used in an attempt to minimize DOMS and its negative impact on performance. Massage, various exercises, cryotherapy, ultrasound and anti-inflammatory drugs have all been used to alleviate symptoms of DOMS. Many of these scientific trials have attempted to provide evidence substantiating the widely accepted theories that they are in fact effective, without success. Use of unproven treatment techniques is common in the field of health care, more specifically Physiotherapy, Athletic Therapy and Massage Therapy (Weber, Servedio et

al. 1994). Intervention effectiveness appears to be based more on prior utilization and acceptance than on scientific evidence.

Although DOMS has been demonstrated by many researchers to cause negative impacts on performance, (Davies and White 1981; Smith 1992; Saxton, Clarkson et al. 1995; MacIntyre, Reid et al. 1996; Paddon-Jones and Quigley 1997), to date there has been inconclusive research in the area of effective treatment interventions or DOMS prevention. In order to minimize negative experiences associated with DOMS and potential detrimental effects on performance, it is necessary to identify a successful treatment intervention. Ideally it would be beneficial to employ a treatment intervention that is readily available to the athlete/participant. In other words, the objective would be to determine a treatment intervention that is simple to use and that does not need to be performed by a qualified therapist while being both cost and time effective. If an efficacious intervention can be developed and the previously mentioned objectives can be met while ensuring minimal risk of causing further injury or pain, then the negative effects of DOMS may be substantially reduced.

DOMS may leave individuals in a condition of mild to extreme soreness depending on the intensity of their activity and their level of fitness. This may discourage the general population from continuing to participate in such activities. DOMS may also decrease the effectiveness of performance for those individuals who participate at high levels of competition. Regardless of the population, it is necessary to determine whether or not there is a method that may be able to reduce DOMS.

Of all the treatment interventions attempted to reduce DOMS that the author has reviewed to date, the single one that best meets the previously outlined objectives is

exercise. Several investigators have been successful in reducing performance deficits on exercise induced damaged muscle using exercise as an intervention. Both Hasson et al. (1989) and Donnelly, Clarkson et al. (1992) using exercise as an intervention, have demonstrated positive effects by reducing perception of pain and reducing performance deficits. Exercise has been accepted by the majority of the athletic community as a temporary or transient relief from DOMS. To date there has been limited research to support the effectiveness of this treatment.

Investigators Tiidus (1995) and Ernst (1998) both concluded that massage was not an effective treatment modality for enhancing restoration of post-exercise muscle strength. Both authors agree that the positive effect of massage on exercise induced damaged muscle has not been demonstrated convincingly.

Using ultrasound as an intervention method has been attempted by Ciccone, Leggin et al. (1991) and Craig, Bradley et al. (1999), and both failed to provide conclusive evidence of beneficial effects.

When investigating the effects of cryotherapy on DOMS most investigators agree that cryotherapy is not effective in reducing the symptoms associated with DOMS (Isabell, Durrant et al. 1992; Gulick, Kimura et al. 1996; Paddon-Jones and Quigley 1997). However, Denegar and Perrin (1992) were able to provide evidence that suggested that ice was in fact effective in treatment of the pain associated with DOMS. Denegar (1992) did not report positive effects of cryotherapy on performance measures.

There is conflicting evidence with regard to the use of non-steroidal anti-inflammatory drugs (NSAIDs) and DOMS. Some success has been reported by Hasson,

Daniels et al. (1993), while other investigators, Donnelly, Maughan et al. (1990) and Bourgeois, MacDougall et al. (1999) reported non-significant findings.

Purpose of the Study

The purpose of the study is to determine whether a specific exercise is a treatment intervention that will be effective in decreasing or minimizing the negative impacts on neuromuscular function and perceived soreness that are associated with Delayed Onset Muscle Soreness.

Hypothesis

The specific exercise intervention administered in the present research will be an effective method of minimizing the negative impacts on perceived soreness and impaired neuromuscular function associated with Delayed Onset Muscle Soreness.

Rationale for the Study

All individuals perform movements on a daily basis that require strong eccentric muscle actions. A wide range of the population experiences the negative effects of Delayed Onset Muscle Soreness. Increasing numbers are participating in athletic activities and are taking a more active approach to achieving health and wellness. This increase in activity exposes individuals to DOMS and the associated negative effects. There is a large variation among subjects in response to exercise that leads to DOMS, some subjects show large biochemical or functional changes (Rodenburg, Steenbeek et al. 1994). As DOMS has been shown to alter biomechanics of movement (Ebbeling and Clarkson 1989) and predispose participants to injury, it is important to determine an

effective treatment intervention that will reduce the negative impacts of DOMS. In addition, some research has indicated that some commonly used methods of treating DOMS by clinical practitioners such as NSAIDs (Evans 1987) and ice application (Isabell, Durrant et al. 1992) may in fact cause further injury or increase the level of perceived soreness.

The specific exercise intervention used in the present study was a leg extension exercise. A maximum of six sets of twelve repetitions using a weight of 50% one repetition maximum of a concentric quadriceps action on the leg extension exercise machine. Quadriceps actions were performed both concentrically and eccentrically at a rate of one second per action type.

The present research is being done on females due to the previous lack of focus of research on this group in the area of sports medicine. Finally, it is the author's hope that the research being done in this study will give rise to additional questions related to DOMS in the area of sports medicine and health care in general.

Limitations and Delimitations

1. All subjects tested in the study will be untrained females, or trained females who have not participated in specific eccentric quadriceps training activity for at least 6 weeks.
2. Soreness will be induced during a heavy exercise bout using both concentric and eccentric actions of knee extension, as performance movements require actions of both types.
3. Soreness will be induced only in the quadriceps muscle group.

Definition of Terms

Average torque The tension produced by the muscle throughout the entire range of motion (Perrin, 1993)

Concentric action Shortening of a muscle under tension (Hall, 1991)

Cryotherapy The application of therapeutic cold agents to living tissue (Starkey, 1993)

Delayed onset muscle soreness (DOMS) Muscle soreness experienced by individuals who perform unaccustomed exercise that involves an eccentric component

Dynamometer A device used for measuring strength that allows isokinetic actions to be made at various preset velocities (MacDougall, Wenger, Green, 1991)

Eccentric action Lengthening of a muscle under tension (Hall, 1991)

Inflammation Local response to injury or infection often characterized by local swelling, pain, heat and redness

Isokinetics The type of muscular action which accompanies a constant angular rate of limb movement

Peak torque The point in the range of motion tested where the greatest torque is produced (Perrin, 1993)

Sarcomere Repeating structural unit of a myofibril; composed of thick and thin filaments; extends between adjacent Z-lines

Torque A rotary force that produces angular acceleration and is the product (F) and the perpendicular distance (d) from the force's line of action to the axis of rotation: $T=Fd_{\perp}$ (Hall, 1991)

CHAPTER 2

REVIEW OF LITERATURE

Introduction

This chapter will include a review of books and articles that are relevant to the mechanisms of Delayed Onset Muscle Soreness, previously employed treatment interventions, physiological adaptation to training and impacts on performance, and soreness inducing exercise. The literature review will contain information on the following topics (1) damage to the sarcomere and connective tissue, swelling and inflammation with an emphasis on the underlying mechanism of DOMS, (2) isokinetic testing, (3) vertical jump performance, (4) eccentric muscle actions, (5) exercise, massage, cryotherapy, ultrasound, and anti-inflammatory drug therapy as methods of treatment intervention, (6) adaptation regarding both the neurological and musculoskeletal systems, (7) performance deficits, (8) soreness inducing exercise, and (9) other relevant material as it is related to the proposed study.

Underlying Mechanisms of DOMS

Damage to the Sarcomere and Connective Tissue

The most supported theory to date describing the cause of DOMS was developed by Hough (1902) in the early 1900's. This theory is based on the supposed structural damage to the sarcomere and surrounding connective tissue during high intensity

eccentric loading of the muscle. The muscle activity which causes the most soreness and damage at the structural level is eccentric activity (MacIntyre, Reid et al. 1995). The initiating event may be related to high specific tension produced by the muscle during eccentric actions which results in shearing of the myofibrils (MacIntyre, Reid et al. 1995). Armstrong (1984), in an earlier study also stated that it seems probable that this increased tension per unit area could cause mechanical disruption of structural elements in the muscle fibres themselves or in the connective tissue that is in series with the contractile elements. One reason eccentric actions cause more damage to muscle than concentric actions is because fewer motor units are recruited during eccentric exercise, and therefore a smaller cross-sectional area of muscle is activated to handle the same load as would be handled in a concentric action (Clarkson and Sayers 1999). Thus, in eccentric actions the force is distributed over a smaller cross-sectional area, therefore, the tension per active cross-sectional area is greater (Armstrong 1984). The reason tissue disruption occurs appears to be related to the fact that fewer motor units are activated during an eccentric, compared to a concentric action for a comparable amount of work. Since the weight is the same, more tension is placed on fewer muscle fibers resulting in disruption of the involved tissue. It has been hypothesized (Clarkson and Sayers 1999) that certain sarcomeres may become overextended and pull apart due to the stress placed on them by the lengthening actions of the muscle. Because some sarcomeres may be stronger than others, weaker sarcomeres are unable to maintain tension as the fiber lengthens, thus passive structures are left to provide support.

A considerable amount of information exists on the underlying mechanisms of DOMS however, the true mechanism underlying this phenomenon remains unclear

(Smith 1991; Kuipers 1994; MacIntyre, Reid et al. 1995). As Hough first described in 1902, "when an untrained muscle makes a series of actions against a strong spring, a soreness frequently results which cannot be regarded as a phenomenon of pure fatigue (Hough 1902)". Hough (1902) then indicated that DOMS has its origin in some sort of rupture within the muscle itself and that this assumption explains other things that may have been observed.

Stauber (1996) suggested that DOMS is due to a complex set of reactions involving disruption of the muscle fiber and connective tissue. There may be two aspects of muscle tissue damage that need to be differentiated from each other: (a) direct myofiber damage, and (b) connective tissue or fascial damage. An example of an intact sarcomere is included in Figure 2-1. Direct myofiber damage occurs during the activity or can be observed immediately after the activity is completed. Connective tissue damage is less well defined but certainly involves collagen and other extracellular matrix components as well as the interconnections between adjacent muscle cells (Stauber 1989). Kuipers (1994) indicated that muscular overuse is associated with structural damage of the contractile elements and is reflected in DOMS. Unaccustomed eccentric exercise has previously been shown to induce disruption within the myofibrillar and connective tissue structures of skeletal muscle (Newham, McPhail et al. 1983; Stauber, Clarkson et al. 1990).

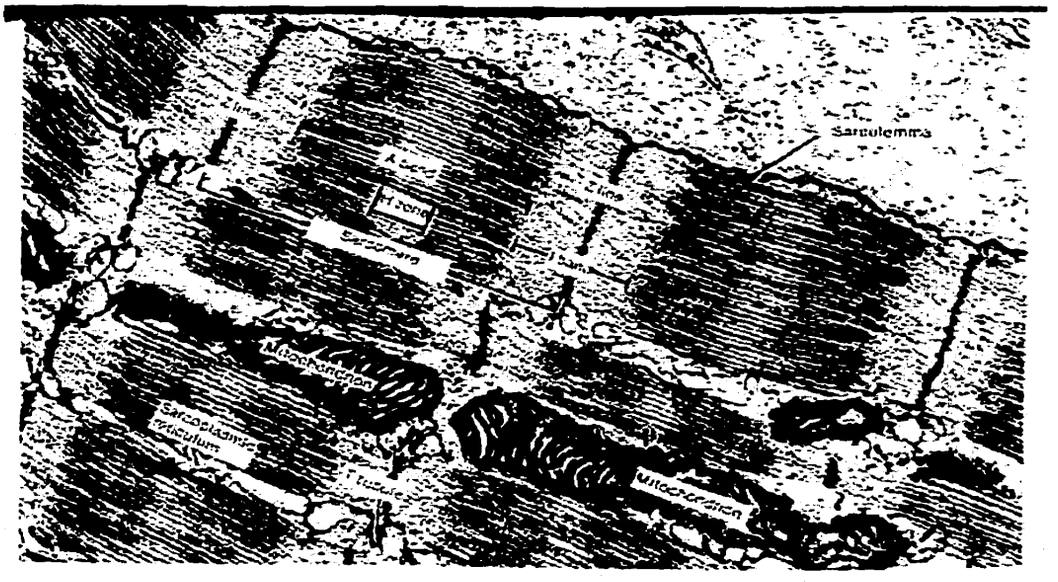

Figure 2-1 Electron micrograph of several sarcomeres at a magnification of 35,000X. (From Tortora & Anagnostakoss, 1990, pg.235)

The mechanical microtrauma after eccentric muscle action results in myofiber damage as well as alterations to the extracellular matrix (Stauber, Clarkson et al. 1990), both of which may lead to inflammation and pain. The theory of intrinsic muscle damage associated with eccentric muscle actions has been supported by many studies using muscle biopsies to document both myofiber damage and connective tissue damage (Newham, McPhail et al. 1983; Stauber, Clarkson et al. 1990). The myofiber damage consisted of hypercontracted sarcomeres, Z line streaming, and refractory fibers that could be observed immediately after exercise when no pain was present (Stauber 1996). The mechanism of injury from eccentric exercise is due to the increased tension per individual cross bridge causing mechanical disruption of the ultrastructural elements within the muscle fibers such as the Z-line and contractile filaments (MacIntyre, Reid et al. 1995). During eccentric activity, the force developed is approximately twice that developed during isometric actions, but the total number of strongly bound cross bridges during eccentric activity is only about 10% greater than during an isometric action.

MacIntyre (1995) suggests that this high tension may result in streaming of the Z-lines. Streaming and smearing of Z-lines, focal loss of Z-lines and extension of the Z-line into the A band have been observed immediately following eccentric exercise (Lieber, Woodburn et al. 1991). Examples of Z-line streaming and smearing are included in Figures 2-2 and 2-3.

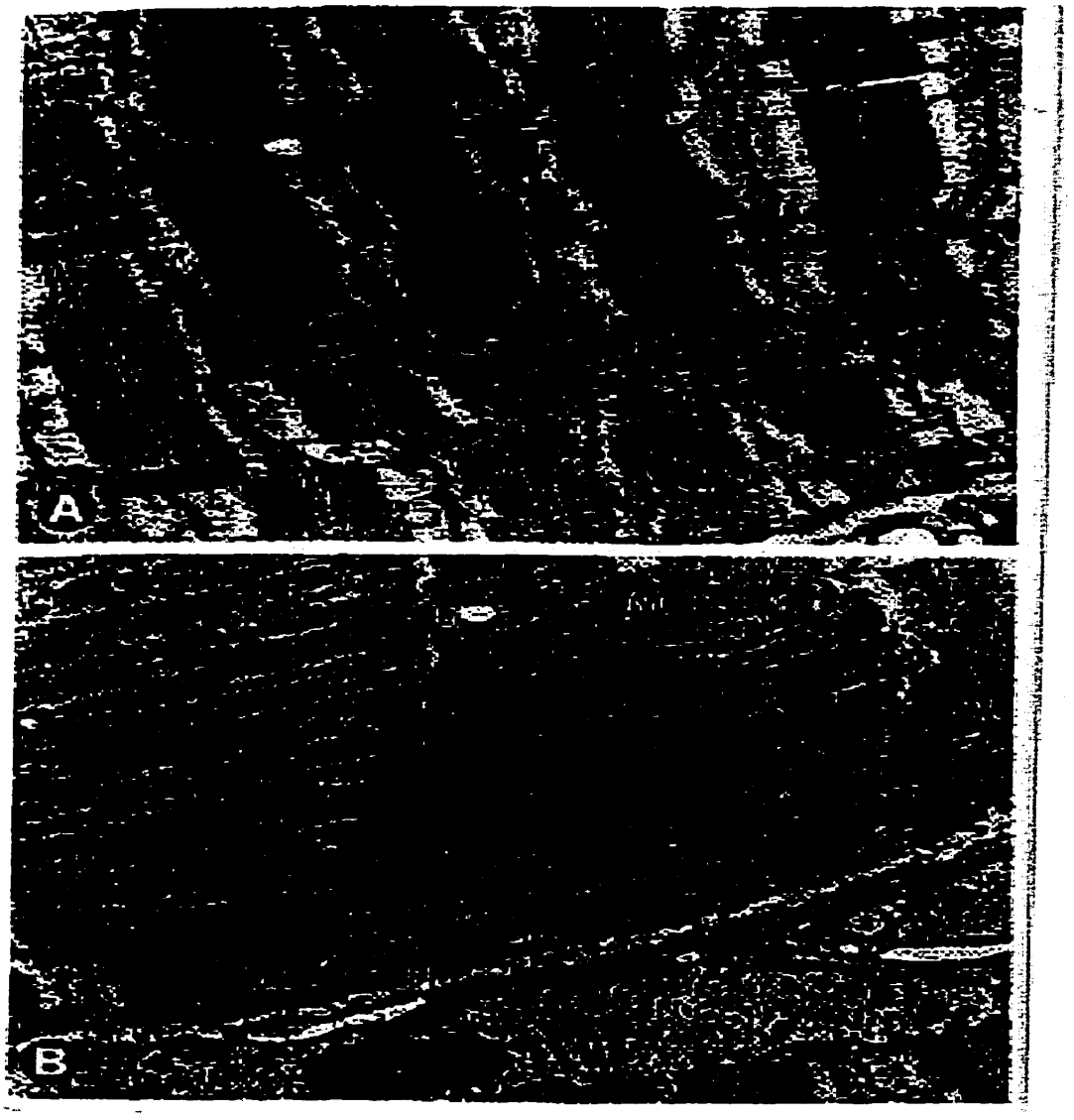

Figure 2-2 Longitudinal electron micrographs of human vastus lateralis muscle following intense eccentric exercise. (A) Focal disruption of the Z-band demonstrating different degrees of streaming.. 1=wavy appearance of the Z-band running a zig-zag course, 2=mild Z-band streaming, 3=more severe Z-band: streaming comprimising the major part of the I-band, 4= dissolution the Z-band and disintegration of the myofibrillar components in the entire sarcomere. (B) More severe Z-band disruption (smearing and focal disruption of the A-band region of the contractile apparatus). (From Friden & Leiber, 1992, pg.523)

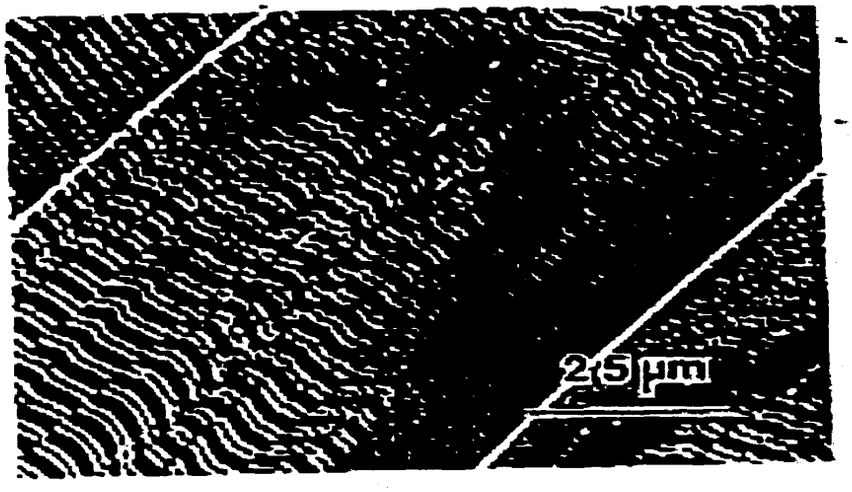

Figure 2-3 Disruption of the contractile material of quadriceps muscle, particularly the myofibrillar Z Band. (Taken from Friden, 1984, pg.60)

The connective tissue involved endomysial separations (Stauber, Clarkson et al. 1990). It has been suggested that eccentric exercise preferentially damages a population of sarcomeres that are nearing the end of the cycle of growth and replacement (Newham, Jones et al. 1987). As these sarcomeres are replaced with newer, stronger fibres, the eventual outcome may be stronger muscle fibres.

The Inflammatory Response

Inflammation is a generalized response of the body to any kind of tissue injury. This injury may be the result of chemical, thermal or mechanical stimuli (Smith 1991). Clinical studies have attempted to find evidence that supports the theory that tissue inflammation is the underlying mechanism of DOMS (Armstrong, Ogilvie et al. 1983; Schwane, Johnson et al. 1983).

The sensation of muscle soreness that is evident between 24 and 48 hours post-exercise can be associated with an acute inflammatory response as suggested by Smith (1991). It is hypothesized that morphological injury occurs after the initial exercise bout. During the first few hours after the onset of injury, white blood cells (WBC), specifically neutrophils are attracted to the injured site (Smith 1991). Similarly, Clarkson (1999) stated that neutrophils are speculated to be the first cells to infiltrate damaged muscle fibers. Damage to muscle fibers results in an inflammatory response that causes a transfer of fluid and cells to the damaged tissue. Increased fluid produces the characteristic swelling after injury (Clarkson and Sayers 1999), however the role of neutrophils in the damage and repair process is unknown (MacIntyre, Reid et al. 1995).

The inflammatory response plays a key role in removal of damaged proteins before regeneration ensues. Following degradative processes, some macrophages may then play a role in muscle repair (Tidball 1995). Macrophages are the predominant type of inflammatory leukocyte at any time after the first 12 hours post-exercise and are the principal removers of cellular debris. Macrophages act as phagocytes and function in the removal of cellular debris in damaged tissue. Macrophages also regulate the consequent repair process and appear when muscle regeneration begins (Tidball 1995). At approximately 8-12 hours after exercise a second shift of WBC (macrophages) begin to infiltrate the damaged area. These cells further penetrate the damaged tissue and also synthesize chemical substances extremely important in the healing process (Smith 1992).

It is believed that one important substance – prostaglandin E – is produced by the macrophage and is central in orchestrating the inflammatory process and is a potent pain-producing agent. Prostaglandin E also plays a major role in healing. The synthesis is

inhibited by aspirin and other nonsteroidal anti-inflammatory drugs, suggesting that the use of these drugs might reduce DOMS. The wide use of anti-inflammatory drugs may actually have an adverse effect on muscle healing (Stauber 1996). Although prostaglandins have been documented to be involved in tissue degradation following injury, they are also involved in tissue growth (Stauber 1996). MacIntyre et al (1996) have demonstrated that there is a greater presence of white blood cells in exercised muscle in the first 24 hours after eccentric exercise, indicating that acute inflammation is one of the underlying reactions of exercise-induced muscle injury. They support the hypothesis that there is more than one mechanism underlying exercise-induced muscle injury, firstly that of mechanical injury and fatigue and then the subsequent events of the inflammatory response (MacIntyre, Reid et al. 1996). It has been shown that exercise and exercise-induced muscle injury can trigger mobilization of some aspects of the inflammatory response but the specific events initiating this are not known.

Different mechanisms have been suggested to be associated with the soreness perception. Since the cellular response does not parallel the symptoms, other factors must contribute to the soreness perception. This may explain the findings that anti-inflammatory drugs fail to alleviate the soreness rating (Kuipers 1994). Friden, Sfakianos et al. (1986) suggested that increased tissue pressure from tissue swelling may be associated with the soreness perception. It is hypothesized that prostaglandins may increase the sensitivity of free nerve endings and that movement causes a sudden increase in the already elevated tissue pressure, leading to pain (Smith 1991).

In an attempt to explain why DOMS is not experienced during rest but rather in response to movement or palpation, Smith (1990) proposed the following scenario.

Edema associated with DOMS does not produce a significant increase in intramuscular pressure at rest in a compliant compartment. However, movement or palpation may exacerbate even small increases in pressure and thus provides a mechanical stimulus for "pain" receptors already sensitized by prostaglandins. Armstrong (1984), prior to Smith (1990) put forth a similar scenario. Thus, the combination of increased pressure and hypersensitization produces the sensation of DOMS (Smith 1991). Smith (1991) indicated that acute inflammation is the generalized response of the body to acute tissue injury. The main purpose of this response is to promote healing, an event critical to survival (Smith 1991). Since the body responds to all forms of acute tissue injury by activating the inflammatory response, there is no reason to believe that a separate response has evolved to deal with injury incurred during unaccustomed eccentrically based exercise (Smith 1991). However, if inflammation is not present in exercised damaged muscle, then agents and modalities that have been demonstrated to assist in the process of pain reduction and tissue healing in inflammatory conditions might not be effective in the treatment or prevention of DOMS (Stauber, Clarkson et al. 1990). Some evidence supporting the hypothesis of Stauber et al. (1990) exists and is discussed in the following sections.

Isokinetic Testing

It is of importance to be able to objectively characterize human performance in sports and rehabilitation, not only to evaluate patient progress but also to ascertain the efficacy of clinical treatment (Lieber 1992). The accurate assessment of human muscle performance has been the objective of exercise scientists and rehabilitation therapists for many decades. Exercise scientists interested in comparing the effects of various strength and conditioning programs seek to accurately measure muscle force. Clinicians want to document the efficacy of therapeutic exercise in helping patients recovering from injury to the musculoskeletal system regain their strength. Underscoring these objectives is the valid and reliable quantification of the human muscle's capacity to produce force (Perrin 1993). The capacity of muscle to produce force can be assessed through either a static or dynamic action. For the purpose of the present study, the investigator is interested in studying dynamic strength, which Perrin (1993) describes as the application of force through all or part of the joint range of motion. This assessment can be made via both concentric and eccentric modes of actions.

One of the most commonly used tools for musculoskeletal assessment is the isokinetic dynamometer (Lieber 1992), where the term isokinetic means constant velocity. Both concentric and eccentric actions may be isokinetic. An isokinetic dynamometer allows isokinetic actions to be performed at various preset velocities. Typically, the limb or other body part accelerates to engage the resistance mechanism of the dynamometer (MacDougall, Wenger et al. 1991). An isokinetic dynamometer provides resistance by accommodating or precisely matching, the force or torque applied

against the resistance mechanism (typically an electric motor), thereby preventing acceleration beyond the set velocity of movement (MacDougall, Wenger et al. 1991). There are several isokinetic dynamometers available for researchers to test muscle performance. Common isokinetic testing devices include Cybex, Biodex and Kin-Com. The present study will use the Kinetic Communicator (Kin-Com). Use of the Kin-Com allows the investigator to measure concentric and eccentric actions, isometric, isotonic, isokinetic, and passive movements. The present study will investigate both the concentric and eccentric strength of the quadriceps muscle group using the isokinetic mode.

Strength Testing Variables

Interpreting an isokinetic evaluation usually involves careful analysis of the ability of the subject to generate torque, work or power. Torque may be assessed as either a peak or an average value. Peak or average torque values are the isokinetic parameters most frequently used to assess human muscle performance (Perrin 1993). Peak torque is often obtained from the highest point of one of several torque curves (Perrin 1993). Peak torque may be measured as the highest torque value developed during the action (MacDougall, Wenger et al. 1991). If the torque produced by a muscle has been assessed throughout the entire range of motion tested, the measurement may be reported as either a peak or average value. The peak value would be the value from the point in the range of motion tested where the greatest torque was produced. An average value would be calculated from the tension produced by the muscle throughout the entire range of motion tested. In relation to muscle performance, peak torque is a single

maximal torque output at one point in the range of motion, while average torque is the average value over the entire range of motion. Therefore, average torque measures muscle function throughout the entire joint range of motion. Average torque is measured from the complete tracing of one or several consecutive isokinetic curves. Thus, use of average values necessitates careful standardization of the range of motion tested when making pretest, post-test, or bilateral muscle group comparisons (Perrin, 1993). In contrast, peak torque is likely to occur within the midrange of motion assessed. As such, standardization of the range of motion tested for measurement of peak values may not be as essential as when average values are of interest.

The relationship between peak and average torque for a given muscle action is quite high, suggesting that any of these values provide valid assessment of a muscle's ability to generate tension (MacDougal, Wenger et al 1991; Perrin 1993). Both of these measures are likely to provide useful information on the performance of a given muscle group, assuming adherence to consistent test protocols (Perrin 1993).

In addition to peak and average torque values, the interfacing of microprocessors with isokinetic dynamometers enables determination of torque at any point throughout the range of motion. This is called angle specific torque (AST) and enables identification of torque at a predetermined point in the range of motion of a muscle or a certain muscle group's contribution to the torque production tension (MacDougal, Wenger et al 1991; Perrin 1993).

The Kin-Com generates reports indicating the PT and the angle of peak torque (APT). An example of a Kin-Com report displaying PT and APT is included in Appendix D.

Average torque is calculated by dividing angular impulse by time, and is expressed in Newton meter seconds (MacDougal, Wenger et al 1991; Perrin 1993). Torque (T) equals force (F) times the perpendicular distance from the application of force to the axis of rotation ($d\perp$). Therefore, $T=F \times d\perp$. Angular impulse equals torque (T) times time (t). Therefore angular impulse $=T \times t = (F \times d\perp) \times t$. The Kin-Com generates a printout (Appendix E) which reports an average torque value for each repetition at every 7 degrees throughout the testing range of motion. If the averages for each trial are added together and divided by the number of samples, the overall average torque can be calculated.

Examples of peak torque and total work curves are included in Figure 2-4.

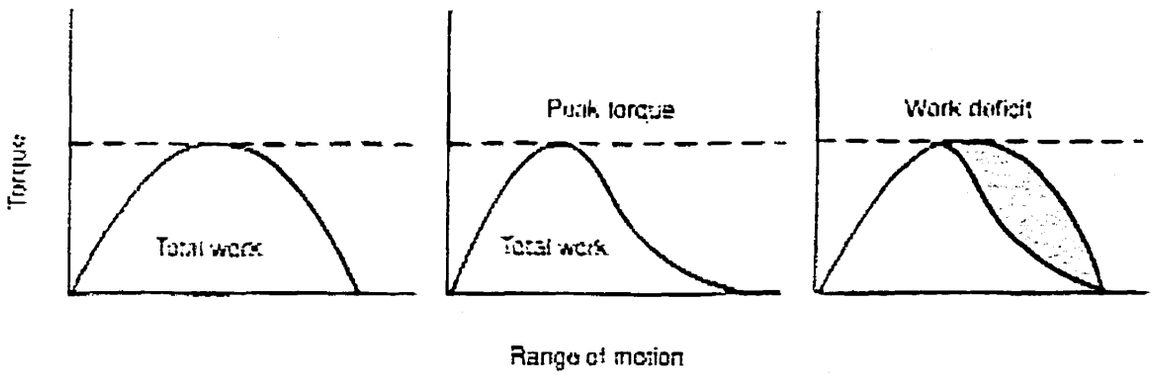

Figure 2-4 Two curves having equal values of peak torque, but an inability to produce a maximal amount of force throughout the full range of motion results in a deficit in total work in the second curve. (From Perrin, 1993, pg. 15)

Subject Positioning

Unwanted variability in strength and power measurements can be reduced by standardizing - and replicating on each test session – the position of subjects and their relationship to the dynamometer. Standardization of subject positioning includes a specified range of movement and a specified position for all body segments (MacDougall, Wenger et al. 1991). Standardization is assisted by the use of straps, pads and supports that stabilize body segments and prevent extraneous movements. It is also important that the relationship between the subject and the dynamometer be standardized, stable and repeatable. The dynamometer and chairs or benches should be well stabilized to prevent extraneous movement. In tests of single joint movements, the axis of the dynamometer should be aligned as closely as possible with the axis of the joint (MacDougall, Wenger et al. 1991). In practice, torque output is greatly affected by the lever arm length, at least in knee extension and flexion. It is recommended that the lever arm length be individually standardized and kept the same for repeated tests (MacDougall, Wenger et al. 1991).

Verbal Encouragement

The presence or absence of verbal encouragement can have a dramatic effect on ability to produce maximum effort. Encouragement is probably more likely to stimulate a maximum effort during any kind of strength assessment or performance. But because encouragement could likely not be consistent among testers or between test sessions, subjects should be instructed before each series of repetitions to produce a maximum effort, and the tester should remain silent during the test (Perrin 1993).

Quadriceps Strength Testing Protocols

One investigator (Hasson, Daniels et al. 1993), used a Lido isokinetic dynamometer to evaluate torque production. The Lido was used to assess concentric and eccentric knee extension peak torque (PT) at 90 degrees/second for five repetitions. The subject was placed in the Lido unit so that the axis of the knee joint was directly in line with the axis of the goniometer. Prior to knee quadriceps muscle testing the subject performed five warm-up repetitions at low resistance. The subject was instructed to give maximum efforts for each of the testing repetitions, and peak torque values were recorded for each subject.

Another investigator used the Cybex Dynamometer to evaluate maximum knee extension PT and total work (TW) (Hasson, Barnes et al. 1989). The dynamometer was set at low velocity/high resistance setting. The subject was placed in the Cybex unit so that the axis of the knee joint was directly in line with the axis of the goniometer. Prior to knee joint muscle testing the subject performed five warm-up repetitions at very low resistance for subject familiarization. Starting knee joint position was 90 degrees of knee flexion for each test. The subject was instructed to give maximum efforts for each repetition and informed to flex and extend the knee through the entire available range as rapidly and as forcefully as possible. Data was collected for PT and TW.

Muscle Soreness and Isokinetic Dynamometers

Isokinetic dynamometers have been used not only to assess muscle strength but also to induce muscle soreness (Tiidus and Shoemaker 1995; MacIntyre, Reid et al. 1996). Tiidus (1995) used the Kin-Com dynamometer to assess dynamic and isometric knee extension peak torques. Prior to testing subjects were allowed an initial familiarization session to become comfortable performing maximum voluntary actions (MVC). The initial MVC was determined as the best value of three trials at each of 0 degrees, 90 degrees and 180 degrees/second. The angular velocities were selected to determine MVC of isometric as well as slow and fast isokinetic speeds that have been popularly employed in studies involving strength testing (Tiidus and Shoemaker 1995). A standard warm-up of five minutes of pedalling a Monark cycle ergometer at 1.5 Kp resistance at 60 rpm preceded the strength measurements.

To induce soreness Tiidus (1995) had the subjects perform eccentric work on the Kin-Com. The eccentric work consisted of seven sets of 20 consecutive quadriceps MVCs at 90 degrees/second with a one-minute rest period between sets. Preliminary testing by the investigator had indicated that subjects preferred performing eccentric work at this angular velocity to higher or lower velocities.

Similar to the above study, MacIntyre, Reid et al. (1996) utilized the Kin-Com to both assess eccentric and concentric torque of the quadriceps and to induce muscle soreness. The subjects were seated on the isokinetic dynamometer, with their hips at 80 degrees, their back supported, and their pelvis stabilized on the bench with strapping. The center of rotation of the Kin-Com was positioned opposite the center of the knee

joint line. The resistance pad was positioned at a point on the lower leg that was 75% of the length of the fibula from the knee joint. The angular velocity was set at 30 degrees/second through a range of 60 degrees. Subjects performed three submaximal and one maximal practice concentric and eccentric action followed by four maximal test actions with a 2-minute rest between the practice and the test actions. To induce muscle soreness, the investigator had the subject perform 10 sets of 10 repetitions of maximal eccentric quadriceps actions at 30 degrees/second. Subjects were verbally encouraged to resist the eccentric movement of the lever arm. Subjects also had continuous feedback of their force from the computer screen to encourage maximal voluntary effort.

Vertical Jump Performance

The vertical jump performance of an athlete is a standardized test used to measure athletic performance. It is not difficult to execute and requires minimal testing equipment, which consist of a tape measure, tape and chalk. The testing protocol that is most commonly used is from The Canadian Physical Activity, Fitness and Lifestyle Appraisal (CPAFLA).

The procedure for measuring vertical jump height is straightforward. Subjects assume a standing position facing sideways to a wall on which a measuring tape has been attached. Standing erect with the feet flat on the floor, they reach as high as possible on the tape with the arm and fingers fully extended and the palm toward the wall. This is recorded as the beginning height. Next the subject should move a safe distance away from the wall (with the hand on the hip, the elbow should barely reach the wall). No run up, step up or pre-jump is permitted. The individual brings the arms downward and

backward while bending the knees to a balanced semi-squat position. The subject then jumps as high as possible with the arms moving forward and upward, touching the tape with the chalk at the peak height of the jump with the arm and fingers fully extended. One then subtracts the beginning height from the peak height to determine the height jumped in centimeters. Record the highest jump from three trials. A rest period of fifteen seconds is recommended between trials (CSEP Members, 1998). Norms and health benefit zones by age groups for females are reported in Table 2-1 (CPAFLA).

Table 2-1

Norms for female vertical jump performance by age groups (cms)

ZONE	15-19 yrs	20-29 yrs	30-39 yrs
Excellent	≥ 37	≥ 40	≥ 32
Very good	29-36	28-39	24-31
Good	22-28	20-27	16-23
Fair	15-21	15-19	11-15
Needs improvement	≤ 14	≤ 14	≤ 10

The only study the author has reviewed to date that assesses vertical jump height performance with regard to DOMS was conducted by Smith and Jackson (1990). It was determined that the loss of strength impacts jumping performance. The authors determined that on days two, three and four after beginning football practice, an inverse relationship existed between the height of a vertical jump and the intensity of DOMS induced through a variety of activities. Smith et al. (1990) suggested that coaches modify

contact drills two to three days after the beginning of practice to minimize the chance of injury.

Eccentric Muscle Action

A muscle's ability to produce tension throughout all or part of a joint's range of motion is known as a dynamic action. A muscle can produce dynamic tension by either shortening or lengthening. If the joint motion is in a direction opposite the normal (gravitational) force and the tension produced by the muscle exceeds the external resistance encountered, the action is shortening (or concentric) in nature. If the joint motion is in the direction of the normal force and the external resistance encountered exceeds the muscle's ability to generate tension, the action is lengthening (or eccentric) in nature (Perrin 1993). Eccentric muscle actions involve the lengthening of a muscle while the muscle produces tension (Smith 1992).

Generally, eccentrics or negatives are involved in lowering, braking and shock absorption movements usually in the direction of gravity (Stauber 1989). When a muscle lengthens as it is being stimulated to develop tension, the action is eccentric. The eccentric tension acts as a braking mechanism. For example, eccentric tension occurs in the elbow flexors during the elbow extension or weight-lowering phase of a curl exercise (see figure 2-5). Without the presence of eccentric tension in the muscles, the weight would drop uncontrolled because of the force of gravity (Hall 1991). Most movements involve a negative component, but it is not always easily identifiable. In fact, there is no standard scientific method for identifying which muscles perform an eccentric action in any given skill. Researchers, therefore, merely examine how the muscle behaves during

a particular movement. Also, it should be noted that in some movements such as landing from a jump, the negative action is more accentuated than in others (Smith 1992).

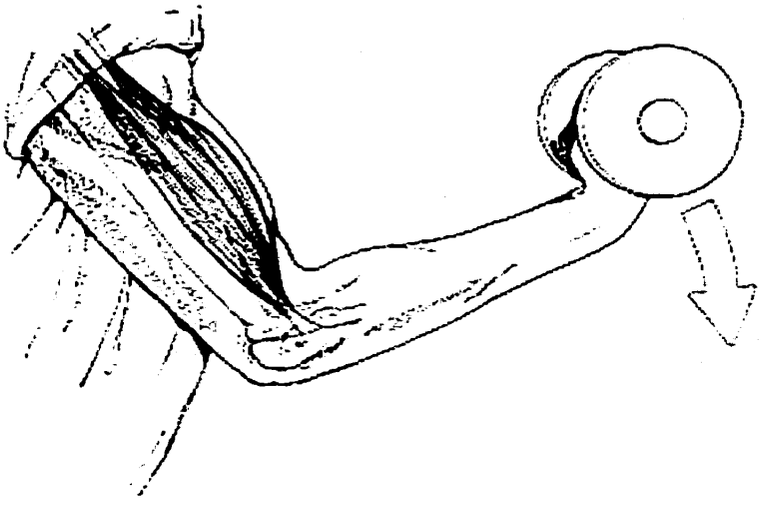

Figure 2-5 The lowering of a weight during a curl exercise involves the presence of eccentric tension in the biceps brachii. (From Hall, 1991, pg.92)

Soreness Inducing Exercise

Many studies have been successful in inducing DOMS using an exercise session consisting of strictly eccentric actions (Hasson, Barnes et al. 1989; Donnelly, Clarkson et al. 1992; Hasson, Daniels et al. 1993; Smith, Keating et al. 1994; Weber, Servedio et al. 1994; Tiidus and Shoemaker 1995; Craig, Cunningham et al. 1996; Giamberardino, Dragani et al. 1996; Gulick, Kimura et al. 1996; Paddon-Jones and Quigley 1997),or a combination of concentric actions and eccentric actions (Donnelly, Maughan et al. 1990; Denegar and Perrin 1992; Isabell, Durrant et al. 1992; Rodenburg, Steenbeek et al. 1994; Bourgeois, MacDougall et al. 1999). These studies support the theory that unaccustomed eccentric exercise if applied at a sufficient intensity will elicit DOMS.

Bench stepping is a popular method of eliciting DOMS. Hasson, Daniels et al. (1993); (Hasson, Barnes et al. 1989); (Giamberardino, Dragani et al. 1996) all utilized similar procedures where subjects were required to step up and down from a step that was 110% of their lower limb length at 15 cycles/minute to the beat of a metronome. Subjects led with the same leg for the duration of the bench stepping sessions, which were 10 minutes and 20 minutes respectively. This ensured that the same leg was performing eccentrically for the entire bench stepping session. Perceived pain was measured at 24 and 48 hours post exercise session and all groups had a significant increase in perceived pain scores at those times when compared to baseline scores (Hasson, Barnes et al. 1989; Hasson, Daniels et al. 1993; Giamberardino, Dragani et al. 1996).

Successful methods to induce DOMS using standard exercise equipment have also been previously reported. Using the weight of a concentric one repetition maximum (1RM), Weber, Servedio et al. (1994) were successful in inducing soreness in the elbow flexors by having the subject perform 10 repetitions of lowering the weight (eccentric action) over a five-second count. The weight was passively returned to the starting (flexed elbow position) by the investigator. Once the subject was no longer able to control the descent of the weight the set was considered finished. If the subject was able to successfully perform the 10 repetitions it was considered a complete set. At this point the weight was lowered by one half of a plate, and the regimen continued (Weber, Servedio et al. 1994). Statistical analyses showed significant increases of perceived soreness when baseline measurements were compared with the 24 and 48 hour measures (Weber, Servedio et al. 1994).

Using a similar protocol, Craig, Cunningham et al. (1996) using each subjects' concentric 1RM exhausted the elbow flexors by three bouts of eccentric exercise to exhaustion. The subjects clearly showed increases in pain levels and tenderness in all groups as a result of DOMS induction (Craig, Cunningham et al. 1996). Using 110% of concentric 1RM, subjects performed 8 sets of 8 eccentric seated dumbbell curl using the elbow flexors (Paddon-Jones and Quigley 1997). Each eccentric action was performed over a 3-second period with an assistant returning the weight to the starting position. Perceived soreness peaked for all subjects at 48 hours and was significantly different than the baseline measures. By 120 hours, no significant soreness remained relative to the pre-test (Paddon-Jones and Quigley 1997). In another study, the exercise session used to induce soreness consisted of 6 sets of 10 repetitions of unilateral knee extension (concentric and eccentric) at an intensity of 80-85% of the baseline concentric 1RM (Bourgeois, MacDougall et al. 1999). Significant DOMS was present at 24 and 48 hours as compared with baseline (Bourgeois, MacDougall et al. 1999).

Isokinetic dynamometers are also a popular method of inducing DOMS. After performing seven sets of 20 consecutive eccentric quadriceps muscle group MVC's at 90 degrees/second, perception of DOMS was assessed on days two through five (Tiidus, 1995). All of the subjects experienced significant DOMS sensation 24-72 hours post-eccentric exercise. By 96 hours post-exercise, most subjects reported little or no residual DOMS sensation (Tiidus, 1995). Smith et al, (1994) was also successful in inducing DOMS in subjects after they performed 4 to 5 sets of eccentric muscle actions at 90% of a previously recorded 1 RM concentric action. There was a significant increase in

soreness demonstrating that the exercise protocol was sufficiently strenuous to induce DOMS (Smith, Keating et al. 1994).

Interventions

Exercise

There have been few studies to date that employ exercise as a possible intervention in an attempt to prevent or delay the negative impacts of DOMS. Gentle exercise involving the affected muscles can be useful as a rehabilitative tool (MacIntyre, Reid et al. 1995). The use of physical activity has long been a standard suggestion to aid in recovery from intense exercise bouts (Weber, Servedio et al. 1994). This recommendation was initially based on observations by Hough (1902), who noted a decrease in soreness with continued actions of the sore muscle. The above statement by Hough (1902) is supported by Hasson (1989) who stated that the success of an exercise intervention was related to a reduction in intramuscular pressure through the muscle pump action. Another possibility that may play a role in the reduction of muscle soreness with exercise, is the endorphin release. These endogenous opiates (endorphins and enkephalins), are secreted by neurons in the brain and spinal cord with the overall effect of inhibiting the transmission of pain (Armstrong 1984; Starkey 1993). It has been suggested that endorphin release is increased during exercise, so exercise-enhanced endorphin secretion could potentially provide an analgesic effect, minimizing the effect of DOMS.

Hasson et al (1989), while examining the effects of a high velocity therapeutic exercise regimen on DOMS and muscular performance found that high speed maximal concentric muscle actions were effective in decreasing muscle soreness and facilitating return of normal muscular performance. The high speed concentric voluntary actions were performed on a dynamometer 24 hours post muscle soreness exercise bout at 300 degrees/second for 6 sets of 20 repetitions for a total of 120. Dependent variables (performance measures) included Maximum Voluntary Action (MVC) by the quadriceps, Peak Torque (PT) by the quadriceps at high resistance, and Total Work (TW) by the quadriceps. These variables had significantly less decrease from baseline for the experimental group when compared to the control group. Following therapeutic intervention (TE), the TE group was significantly higher than the control group for all muscle performance variables measured at 48 hours (Hasson, Barnes et al. 1989). At 48 hours post muscle soreness exercise bout, the Soreness perception index (SPI) of quadriceps was also significantly less for the experimental versus control. These results suggest that high-speed voluntary muscle actions are effective in decreasing DOMS and facilitating return of normal muscle performance. Factors affecting DOMS are presently believed to be related to the processes of inflammation and muscle edema, which follow tissue injury. The tissue disruption caused by eccentric lengthening actions cannot be reversed instantaneously, but the production of prostaglandins can be affected (Hasson, Barnes et al. 1989). This is the strategy utilized when patients are given nonsteroidal anti-inflammatory agents.

If prostaglandin production is retarded prior to large amounts of fluid accumulation in the injured area, muscle soreness should be minimal (Hasson, Barnes et

al. 1989). According to Hasson (1989) it is believed that the end process of tissue damage is inflammation and fluid accumulation, which are the major causes of the development of the soreness. Research has demonstrated (Friden, Sfakianos et al. 1986) that concentric actions resulted in much lower intramuscular pressures than eccentric actions. The mechanism for decreasing muscle soreness following high speed muscle actions has been proposed to be related to decreased inflammation, or decreased fluid compartmental pressures, or both (Hasson, Barnes et al. 1989). Further research to examine the effects of high speed voluntary muscle actions on the inflammatory process and intramuscular compartmental fluid pressures after a bout of eccentric exercise is recommended (Hasson, Barnes et al. 1989).

Isabell et al. (1992) indicated that the pattern of change for the exercise group appeared favorable with respect to soreness levels as compared to the control group. The patterns of change that their subjects demonstrated somewhat support the argument of exercise as an effective method of reducing DOMS. The exercise group had the smallest decreases in ROM and strength and the smallest increases in soreness and Creatine Kinase (CK) levels. The individuals in the exercise group performed mild full ROM elbow flexion and extension exercises, with only the gravitational pull on the hand and arm providing resistance. The repetitions were performed continuously during a 20-second period and then rested for 40 seconds. This exercise/rest interval was continued for a total treatment time of 15 minutes. Treatment was applied at 0, 2, 4, 6, 24, 72, and 96 hours post-exercise.

In contrast to Hasson et al. (1989), Donnelly et al. (1992) and Weber et al. (1994), both conducted studies that found that after a heavy bout of unaccustomed eccentric

exercise, exercise employed immediately and 24 hours after, did not significantly reduce/alter muscle soreness, strength or force generation. After inducing soreness of the nondominant elbow flexors, upper body ergometry was performed at 60 rpm for a workload of 400 kg.m/min in a counterclockwise direction using the right upper extremity as the point of reference (Weber, Servedio et al. 1994). Although the intervention did not produce any statistically significant differences between groups, the author did indicate that having an athlete perform light concentric actions post eccentric exercise bout may prove to be the most effective method of diminishing the effects of DOMS (Weber, Servedio et al. 1994).

The exercise intervention that was employed by Donnelly et al. (1992) was at 50% of the maximum torque produced during the initial heavy eccentric bout. The exercise intervention was performed on a Biodex isokinetic dynamometer and was set to cease movement if the torque exceeded the 50% pre set point so it was clearly sub-maximal in nature. The exercise intervention was employed 24 hours after the initial heavy eccentric bout. The intervention did not appear to alter muscle soreness strength or flexibility (Donnelly, Clarkson et al. 1992). Using exercise as an effective treatment intervention appears to be effective for minimizing the negative effects of DOMS. Alternatively, rest would appear to be less effective. As there is no soreness involved with rest, this is what most people are going to choose to do, allowing the DOMS to produce maximum effects on performance.

Massage

Another treatment intervention that has been studied in an attempt to decrease the negative effects of DOMS is therapeutic massage. Massage has been used to assist recovery from muscle fatigue in the sports medicine field for many years but uncertainty exists about its effectiveness (Callaghan 1993; Smith, Keating et al. 1994; Tiidus 1997). The mechanisms suggested for the apparent efficacy of massage include increase in circulation and lymph flow and decrease in muscle tension (Smith, Keating et al. 1994). Deep friction or vigorous massage can evoke vascular changes similar to those of inflammation. The treated area is marked by increased blood flow, histamine release and an increased temperature. When performed properly, massage can increase venous and lymphatic flow that assists in the removal of edema (Starkey 1993). Massage increases lymphatic flow and movement of fluid depends on forces outside of the system. Such factors as gravity, muscle action and massage can affect the flow of lymph which assists in the reduction of edema (Prentice 1994). If edema, swelling and inflammation are significant factors in muscle soreness sensation, massage may be able to affect soreness by reducing their presence in affected muscles (Tiidus 1997). It is not immediately apparent how massage may be able to physiologically affect the time course or severity of the post-exercise muscle damage/repair process.

In a study conducted by Tiidus et al. (1995), subjects, one hour after undergoing a heavy eccentric bout of exercise, had one leg manually massaged for 10 minutes by a Registered Massage Therapist (RMT). The RMT used both superficial and deep effleurage strokes beginning at the knee and moving proximally covering approximately

75% of the thigh area of the treatment leg. This treatment was repeated at 24 and 72 hours post heavy eccentric bout. The perceived level of soreness tended to be reduced in the massaged leg 48-96 hours post-exercise although it was not significant. However, it was concluded that massage was not an effective treatment modality for enhancing long term restoration of post-exercise muscle strength and its use for this purpose in athletic settings should be questioned Tiidus (1995).

A systematic review conducted by Ernst (1998) found that many studies conducted with respect to DOMS and manual massage formed positive associations and suggested that post-exercise massage may alleviate symptoms of DOMS. Ernst (1998) suggested that massage therapy may be a promising treatment for DOMS and that definitive studies are warranted. He also stated that most of the trials were burdened with serious flaws, and their results are far from uniform (Ernst 1998). Although massage may be a promising intervention for the reduction of DOMS, its effectiveness has not been demonstrated convincingly.

Rodenburg et al. (1994) attempted to combine three interventions to study the effects on subjective DOMS pain scores. After participating in a 15-minute warm-up and a stretching session subjects underwent an eccentric exercise session. Fifteen minutes following the exercise session, the intervention group underwent a massage that was performed by a physiotherapist. This combination did prove to reduce some of the negative effects of eccentric exercise. However, the subjective scores in the treatment group were lower than the control group. The treatments used in this study may be useful to reduce DOMS and functional restrictions due to sports activities, but also may be useful during normal daily activities in which performance may be hindered by DOMS

and large decreases in maximal force and range of motion after exercise. However, since the effects are only small, it has to be questioned how much effort should be taken to do a warm-up, stretching exercises and massage, to reduce DOMS (Rodenburg, Steenbeek et al. 1994).

There is currently very little evidence that manual massage has any significant impact on the recovery of muscle function following exercise or on any of the physiological factors associated with the recovery process. In addition, the types and durations of massage employed by therapists varies based on athlete and therapist preference and not on scientific data (Tiidus 1997). Tiidus (1997) stated that the time and money spent by sports teams on the provision of sports massage may be misplaced. Because little evidence exists which supports manual massage as an effective therapeutic modality in affecting recovery of muscle strength and performance following damage and DOMS reduction, the use of massage for these purposes should be questioned (Tiidus 1997). The time and money spent by sports teams and individuals on the provision of sports massage may be misplaced if the primary purpose is to reduce DOMS. However, another purpose is to assist with the removal of lactic acid and other waste products from the tissues. It has been postulated that various forms of massage may enhance blood flow. Increasing blood flow could increase oxygen delivery to injured tissue and thereby, theoretically, enhance the healing/return to homeostasis process (Tiidus 1997).

Ultrasound

The effectiveness of electrotherapeutic modalities has been investigated as an effective treatment intervention to decrease the negative symptoms associated with DOMS. Ultrasound is an electrotherapeutic modality that has been used to decrease the

symptoms of inflammation, pain and edema, and to increase the rate of healing of damaged tissues. A localized warming of the tissues may occur that can lead to an increase in the extensibility of tissues such as scar tissue (Starkey 1993; Prentice 1994). These effects may contribute to the reported analgesic action of ultrasound and the reduction of edema (Craig, Bradley et al. 1999). Craig (1999) also stated that ultrasound might be expected to accelerate the inflammation and healing processes while reducing the pain associated with DOMS. Little conclusive evidence supporting the positive effects of ultrasound has been reported.

Subjects in a study conducted by Craig, Bradley et al. (1999) were randomly divided into four separate treatment groups: control, placebo, low-dosage pulsed ultrasound, or high-dosage pulsed ultrasound. DOMS was induced in the elbow flexors through repeated eccentric exercise until exhaustion (Craig, Bradley et al. 1999). There were no significant differences in the groups when compared for elbow flexion strength and resting angles or pain. The study provided no convincing evidence to support the use of pulsed ultrasound therapy in the management of DOMS within the parameters of this study. Ultrasound demonstrated no significant benefits in terms of subjective pain relief or range of movement.

Similarly, (Ciccone, Leggin et al. 1991) attempted to determine the effect of salicylate phonophoresis as compared with ultrasound used alone on DOMS. Phonophoresis is a technique in which ultrasound is used to drive a topical application of a selected medication into the tissues (Prentice 1994). Medications commonly applied through phonophoresis most often are either anti-inflammatories or anagelsics. This comparison was conducted so that any ultrasound effects could be distinguished from the

pharmacologic effects of trolamine salicylate (an anti-inflammatory-analgesic cream) when both are used together in the form of salicylate phonophoresis. Salicylates are compounds that evoke a number of pharmacologic effects, including analgesia and decreased inflammation caused by a reduction in prostaglandins (Prentice 1994). In a group of 10 subjects, findings suggested that the use of ultrasound alone increased the symptoms associated with DOMS. When ultrasound was applied to a group of 10 subjects with the trolamine salicylate, the same increases were not observed. These results suggest that the ability of ultrasound to increase the mechanisms underlying the DOMS may be offset by the pharmacologic activity of the trolamine salicylate (Ciccone, Leggin et al. 1991).

Cryotherapy

Cryotherapy, the application of a cold modality to the human body (Starkey 1993), is widely regarded as an effective, easy to use, and inexpensive treatment modality for traumatic soft-tissue injury (Paddon-Jones and Quigley 1997). If one considered the body's inflammatory response to tissue injury, it may be expected that the use of cryotherapy would be effective in decreasing the symptoms associated with DOMS. The local effects of cold application include vasoconstriction and a decrease in metabolic rate and pain transmission (Starkey 1993). The most beneficial effect of cold application during an acute injury is to decrease the need for oxygen in the area being treated. A cold environment decreases cellular metabolic rate, consequently decreasing the amount of oxygen required by the cells to survive. By reducing the number of cells killed by a lack of oxygen, the degree of secondary hypoxic injury is limited. Since fewer cells are

damaged from secondary hypoxic injury, smaller amounts of inflammatory substances are released into the area (Starkey 1993; Prentice 1994).

Several investigators (Isabell, Durrant et al. 1992; Gulick, Kimura et al. 1996; Paddon-Jones and Quigley 1997) have provided evidence to support the theory that cryotherapy is not effective in reducing the symptoms associated with DOMS.

During one such study, after muscle soreness was induced, the subject using an ice ball applied ice massage. An ice ball is formed by freezing water in a plastic or styrofoam cup. During application of the ice ball, the ice melts and the edges of the cup can be peeled away to expose more ice. This application process allows the therapist/subject to massage the body part with the ice while holding the bottom of the cup. Subjects massaged the entire length of their biceps using circular and stroking motions. The treatment was applied at 0, 2, 4, 6, 24, 72, and 96 hours post-exercise. Each treatment continued for 15 minutes (Isabell, Durrant et al. 1992). The therapeutic use of ice was not effective in reducing the symptoms of DOMS. Though not statistically significant, the author suggested that the patterns in the data may indicate that ice application may be contraindicated in the treatment of DOMS. They noted that the ice group had the highest peak soreness at rest scores, the highest serum CK levels, and the lowest low peak total ROM of all the groups (Isabell, Durrant et al. 1992).

Similar to the previous study described, results from a study performed by Paddon-Jones and Quigley (1997) indicate that cryotherapy does not facilitate recovery of strength or reduce the severity of DOMS following eccentric exercise. Following the eccentric exercise protocol, subjects had the eccentrically exercised arm placed in an ice-water immersion bath. A total of five, 20-minute immersions were performed; each

separated by 60-minute rest intervals. The first ice-water immersion occurred immediately following the completion of the eccentric exercise session. It was concluded that muscular soreness and strength loss occur in spite of attempts to use cryotherapy.

Gulick, Kimura et al. (1996), employed a treatment intervention of ice massage following the soreness inducing exercise session. They received an ice massage for 20 minutes. The ice cup was moved in circular motions along the length of the exercised muscle group. The ice group generated less isometric force after treatment and provided transient relief from acute muscle soreness but was not successful in abating DOMS (Gulick, Kimura et al. 1996). It was concluded that ice massage was not effective in abating signs and symptoms of DOMS.

In contrast to the above-mentioned studies with regard to cryotherapy as an intervention method, Denegar and Perrin (1992) produced positive results. Forty-eight hours post exercise bout, subjects underwent a 20-minute ice application using a plastic bag filled with crushed ice. Immediately following the ice application perceived pain scores and concentric and eccentric average torques were recorded. These values were compared to the baseline values taken 48 hours earlier and to values taken immediately prior to the ice application. Results indicated that ice was effective in treatment of the pain associated with DOMS (Denegar and Perrin 1992). Although these results appear favorable, it would be expected that perceived soreness would decrease immediately following an application of ice over a 20-minute period. The analgesic effect of the ice application disappears within hours (Starkey 1993), and after this time the soreness returns. The effectiveness of the ice therapy should have been tested 3-4 hours after the cryotherapy to determine the long-term effect.

NSAIDs (non-steroidal anti-inflammatory drugs)

Anti-inflammatory drugs have been studied as a possible successful treatment intervention with regard to DOMS. Ibuprofen and Naproxen are two anti-inflammatory drugs commonly used in the treatment of soft-tissue injuries (Donnelly, Maughan et al. 1990). One study appears to have been successful in using these NSAIDs (Hasson, Daniels et al. 1993) while others (Donnelly, Maughan et al. 1990);Bourgeois, MacDougall et al. (1999) were not.

Results from a study conducted by Donnelly, Maughan et al. (1990) suggest that ibuprofen is not an appropriate treatment for delayed onset muscle soreness. and. A specified dosage was administered to the participants 30 minutes prior to the exercise bout of downhill running and every 6 hours up to 72 hours post-exercise. There were no significant differences between the drug group and the placebo group with respect to subjective soreness or isometric strength.

Using similar outcome measures Bourgeois et al, (1999) indicates that NSAID administration did not alter muscle force deficit, nor perceived muscle pain post-exercise. Naproxen was administered at a specified dose both before and after resistance exercise yielding no significant results.

In contrast to the above, Hasson et al, (1993) conducted a study which considered the effect of ibuprofen on muscle soreness, damage, and performance. Ibuprofen was once again administered prophylactically and therapeutically at specified dosages. Outcome measures were taken at 24 hours and 48 hours and compared to baseline. Results from the study indicate that a prophylactic dosage of ibuprofen does decrease

muscle soreness perception and may assist in restoring muscle function (Hasson, Daniels et al. 1993).

Hasson, Daniels et al. (1993) were able to find positive results within their study while Donnelly, Maughan et al (1990) were not. This may be due to differences in methodology. A ten-minute bench stepping session was performed by Hasson, Daniels et al. (1993) and a 45 minute downhill treadmill run was performed by Donnelly, Maughan et al (1990). Ibuprofen dosages also differed between the two studies. The soreness inducing exercise session was more intense for the subjects who performed the downhill run. The difference in exercise intensity between the two groups may be the reason for the different results.

Adaptation

It has been well documented that after one bout of eccentric exercise the muscle becomes more resistant to damage for a time period of up to six weeks (Ebbeling and Clarkson 1990; Clarkson, Nosaka et al. 1992; Stauber 1996). It should be emphasized that the best prevention for DOMS is regular exercise. It is recognized that repetition of an activity that includes eccentric muscle actions leads to protection from repeated injury (Ebbeling and Clarkson 1990; Stauber, Clarkson et al. 1990). Eccentric effort is known to produce rapid training effects on muscles which last for a long time, 4-6 weeks even after a single exercise (Giamberardino, Dragani et al. 1996).

In a study conducted by Newham, Jones et al. (1987), the authors state that one interesting feature is the rapidity with which the pain and muscle damage are reduced or abolished with repeated exercise. In their previous work, release of creatine kinase (CK),

an indirect marker of muscle damage, and muscle tenderness were measured after one bout of exercise involving actions at 50% maximum force. When the exercise was repeated one week later both pain and CK release were much reduced. This training effect was found to last approximately six weeks, indicating a considerable and long-lasting adaptation of the muscles to eccentric exercise (Newham, Jones et al. 1987).

It is widely accepted that DOMS will only occur after the first few bouts of an exercise program and therefore training acts in a preventive fashion to reduce muscle damage and soreness (MacIntyre, Reid et al. 1995). It has been shown (Friden, Seger et al. 1983), that there is less muscle fiber damage after training implying that there is a protective effect associated with regular physical exercise. There is evidence that the pain and stiffness experienced after eccentric actions are a consequence of shortening of the noncontractile material that is arranged in parallel with the contractile material. This may be a response to some form of damage to the connective tissue, and if so the training could have caused some adaptation of this tissue (Newham, Jones et al. 1987). It is suggested that during the healing process muscle and connective tissue are strengthened and thus more resistant to subsequent damage (Smith 1992).

Possible explanations for the adaptation may include that there may be a change in the pattern of motor unit recruitment. Training, and thus, adaptation may cause a change in the order of motor unit recruitment such that either susceptible fibers are spared on the second and subsequent occasions or more fibers are recruited and the force-fiber ratio is reduced (Newham, Jones et al. 1987). There may also be some adaptation in the muscle fibers such that they become more resistant to the fatiguing and damaging effects of eccentric exercise. This might be seen as a change in the strength and contractile

properties of the muscle (Newham, Jones et al. 1987). Kuipers (1994) is in agreement and stated that the adaptation can probably be attributed to a change in recruitment as well as to an increase in connective tissue thickness and strength.

Ebbeling et al, (1990) demonstrated that an adaptation response had taken place within the affected muscle prior to full recovery and restoration of muscle function following the initial eccentric exercise bout. It can be concluded that complete recovery and restoration of muscle function is not a prerequisite for adaptation following eccentric exercise (Ebbeling and Clarkson 1990). Further research in this area is required to provide more conclusive evidence regarding the mechanisms of adaptation.

Muscle Soreness Perception-Visual Analog Scale (VAS)

An investigator needs to score one or more aspects (features) of pain in order to construct a profile of a pain state. The simplest and most common approach is to collapse all of the dimensions of pain into a single measure that one obtains from the patient's subjective report. The VAS is perhaps the most familiar approach (Turk and Melzack 1992). VAS are primarily used to gather information about internal feelings, perceptions, or sensations that are difficult to measure on scales with predetermined intervals (Lee and Kieckhefer 1989). Their use is common in determining perceived pain levels of individuals experiencing pain related to DOMS. The VAS that most clearly delineate extremes (i.e., the worst imaginable pain, the most intense pain imaginable) are 10-15 cm in length, and have been shown to have the greatest sensitivity and are the least vulnerable to distortions or biases in rating (Turk and Melzack 1992). End anchors need to allow for the entire range of sensations regarding the phenomenon being studied, so

that limits of responses are not externally constrained. Examples include best to worst (Lee and Kieckhefer 1989). The VAS also has a high number of response categories. Because they are usually measured in millimeters, the scale can be considered as having 101 points. This high number of response categories makes the VAS potentially more sensitive to changes in pain intensity than measures with limited numbers of response categories (Turk and Melzack 1992). Another advantage of VAS is the potential increase in sensitivity of subject responses. Since respondents are not restricted to arbitrary, previously quantified intervals, they may make as fine a discrimination as they wish. This also has the potential for enhancing respondent satisfaction (Lee and Kieckhefer 1989).

The VAS provides a simple, efficient and minimally intrusive measure of pain intensity that has been used widely in clinical and research settings where a quick index of pain is required and to which a numerical value can be assessed (Turk and Melzack 1992). The VAS are relatively simple so that the majority of patients as well as experimental subjects can easily respond to these scales (Price, McGrath et al. 1983). Since VAS is devoid of numerical labels, this bias is minimized (Lee and Kieckhefer 1989). The VAS consists of a 10-cm line with the two endpoints labeled with verbal descriptors. The patient is required to place a mark on the 10 cm line at a point that corresponds to the level of pain intensity he or she presently feels (Turk and Melzack 1992). Lee et al (1989) agrees that a typical scale is composed of a horizontal line with end anchor. For ease of calculation, 100-mm lines are most common. Horizontal lines are less subject to respondent error attributable to the angle at which the scale is viewed (Lee and Kieckhefer 1989). The length of the line must be verified on all VAS to be

administered (Lee and Kieckhefer 1989). The distance in centimeters from the low end of the VAS to the patients mark is used as a numerical index of the severity of pain (Turk and Melzack 1992) pg.153. VAS in which line length is the response continuum, have been reported as valid and reliable measures for the intensity of pain (Price, McGrath et al. 1983). Also, the verbal anchor points on VAS can be modified to delineate the different dimensions of pain so that although subjects use the same type of scale, they could respond differentially to multiple dimensions of the pain (Price, McGrath et al. 1983).

There is much evidence supporting the validity of the VAS for pain intensity. Such scales demonstrate possible relations to other self-report measures of pain intensity. They are sensitive to treatment effects and are distinct from measures of other subjective components of pain (Turk and Melzack 1992). The lack of bias or distortion in VAS ratings may be partly the result of the fact that, in the studies described, subjects were instructed carefully about how to use the VAS and the entire range of stimulus intensities to be used was gradually presented beforehand (Turk and Melzack 1992). Directions to subjects should be clear, concise, and specific. Directions should be followed immediately with an example of how to use VAS, so that misunderstandings can be promptly identified and corrected (Lee and Kieckhefer 1989). Price et al (1983) indicates that their study demonstrates that the VAS can be used as a valid and reliable measure for both the intensity and unpleasantness of human pain. Also, these VAS can be used to measure either experimentally induced pain or chronic clinical pain (Price, McGrath et al. 1983).

The visual analog scale (VAS) has been used successfully by several investigators to assess DOMS. It is a commonly used assessment tool when pain levels are reported.

Gulick, Kimura et al. (1996), used a VAS that consisted of a 10 cm line with descriptors at each end. At the left end there was the number zero with the descriptor "no soreness at all", and at the right end there was the number ten with the descriptor "soreness as bad as it could be". Each subject placed an x along a 10 cm line to describe the amount of muscle soreness he/she was presently experiencing (Gulick, Kimura et al. 1996). Data was collected pre induced DOMS, 24, 48, and 72 hours after treatment. Peak soreness at 48 hours was reported with a mean value of approximately 3.5 cms. By day 6 minimal soreness means were reported at approximately 0.6 cms. The present study is similar to Gulick, Kimura et al. (1996), with the exception of an added assessment time of 96 hours post DOMS induction.

Similar to the above study (Bourgeois, MacDougall et al. 1999) used a 100 mm VAS using descriptor terms of "no discomfort whatsoever" (0 mm) to "maximal discomfor"t (100 mm). The VAS was given to each of the subjects at 24 and 48 hours postexercise. This scale was used to determine the degree of discomfort in the quadriceps muscle group after the exercise stimulus (Bourgeois, MacDougall et al. 1999).

Another study which used the VAS to assess DOMS was performed by (Ciccone, Leggin et al. 1991). The VAS consisted of a continuous horizontal line 150 mm in length, with anchor points of "no soreness" and "worst possible soreness" at the left and right ends respectively. Subjects indicated the amount of soreness by placing a slash somewhere along the VAS. Relative soreness was then calculated by measuring the distance of the slash from the left end of the VAS (Ciccone, Leggin et al. 1991).

Although the length of the line used was 150 mm, as opposed to the 100 mm lines in the above studies, the descriptors remain similar. Soreness increased from negligible levels on day one to appreciable levels by day two. Groups reported peak levels of soreness between days two and three, reaching levels that ranged between 29% and 45% of the maximum possible rating (150 mm). Soreness began to decline toward baseline values (0 mm) by day four of the study.

Using similar descriptors as the above studies, Nosaka and Clarkson (1995) represented the left end of the VAS with, "no soreness" and right end of the VAS with "very, very sore". The horizontal line used by Nosaka (1995) was 50 mm in length. Mean VAS values for the 12 subjects were reported as peaking to 30 mm at 24 hours with minimal values around 0.05 mm at 96 hours.

Craig, Cunningham et al. (1996) employed a computerized VAS for daily pain assessment. Subjects rated their pain using simple mouse control prior to induction of DOMS and at 24, 48, and 72 hours post DOMS induction. The end descriptors or the length of the horizontal line used by Craig (1996) were not reported. Mean VAS values for the 12 subjects were reported as peaking to 2.5 mm at 24 hours with minimal values at 0 mm at 96 hours.

Performance Deficits

The functional outcome of DOMS, as demonstrated by Hough (1902) was a reduction in muscular force output immediately after the exercise and lasting several days. The performance deficit preceded the onset of muscle soreness, which began the day after the exercise session. The decrease in muscle performance is due to a reduction

in the muscle's intrinsic ability to produce force (Stauber 1996). Researchers have shown that performance deficits can last for more than 5 days following a bout of eccentric exercise (Howell, Chleboun et al. 1993). Muscular performance impairment has previously been described in terms of loss of maximum voluntary force production (Newham, Jones et al. 1987). Indirect evidence of exercise-induced muscle damage is associated with the development of muscle soreness and a prolonged loss of strength and range of motion (Saxton, Clarkson et al. 1995).

Assessing the relationship between development of soreness and the loss of muscle strength suggests that there is little or no relationship between the two (Ebbeling and Clarkson 1989). Exercised muscles exhibited a dramatic 35 % loss of strength, on the day following the exercise (Howell, Chleboun et al. 1993). Even on the tenth post-exercise day the muscles had recovered only to about 70% of their control strength. At this time, soreness had fully disappeared for most of the subjects, confirming our impressions that the decrease in contractile strength was not simply an artifact of pain limited effort by the subjects during the force measurements (Howell, Chleboun et al. 1993). It has taken as long as a week for eccentric torque at high velocities to recover (MacIntyre, Reid et al. 1995). After fatiguing eccentric exercise, there is a decrease in maximal force production observed as early as one hour after the exercise (MacIntyre, Reid et al. 1996). As the loss of force production of muscles is observed almost immediately following an eccentric exercise session, the onset of perceived soreness would appear to have little effect on this performance deficit as it is not normally observed until 24 to 48 hour post-exercise session.

Individuals who experience severe DOMS after performing unaccustomed eccentric exercise show significant reductions in eccentric strength, as well as concentric and isometric strength (Ebbeling and Clarkson 1989; Smith 1992). This reduction in strength is most pronounced immediately after exercise, with little restoration at 24 and 48 hours and recovery may be slow, lasting from eight to ten days (Ebbeling and Clarkson 1989). The loss of strength/power impacts performance. On days two, three and four after beginning football practice, an inverse relationship exists between the height of a vertical jump and the intensity of DOMS induced through a variety of activities (Smith 1992). Interestingly, this was the only piece of literature that the author has located to date that has incorporated the use of the vertical jump as a performance measure in regard to assessing the impact that DOMS has on athletic performance.

CHAPTER 3

METHODS

Introduction

The purpose of the study was to determine whether a specific exercise would be an effective intervention in decreasing or minimizing the negative impacts on performance and perceived soreness that are associated with Delayed Onset Muscle Soreness. The specific exercise used in the present study was a leg extension exercise, using a maximum of six sets of twelve repetitions using a weight of 50% of one repetition maximum of a concentric quadriceps action on the leg extension exercise machine. Quadriceps actions were performed both concentrically and eccentrically at a rate of one second per action type.

The hypothesis was that there would be differences in both perceived pain and performance means between the two groups, experimental and control.

Subjects

Subjects consisted of 20 healthy females between the ages of 19-35. They were recruited by posters, which were posted in various locations at The University of Manitoba, as well as by personal communication with the researcher. Subjects were equally and randomly divided into an experimental and a control group of 10 subjects each. The experimental group received an exercise treatment and the control group did not. They had not participated in any specific eccentric training for a six-week period

preceding the testing sessions. Eccentric training included any downhill running, lower body resistance training, or stair training. All subjects had also not experienced any DOMS in the previous 6 weeks. Any such training or soreness would have reduced the likelihood of responses or symptoms of muscle microinjury resulting from the experimental exercise. Participants were free from any hip or knee injuries and had not used NSAID's for 48 hours prior to the SIES. Use of Tylenol was not included. Participants gave written informed consent prior to testing (Appendix B). Participants were instructed to refrain from participating in any activities outside of their ADL'S for the duration of the testing period. They were instructed not to take any anti-inflammatory or pain medications and not to apply any thermotherapy, cryotherapy, or any other therapeutic modality or topical analgesics to the affected quadriceps muscles. The height and weight of the subjects were recorded with all other testing information at the baseline assessment (Appendix A).

Testing Protocol

Each subject performed a 5-minute warm-up on a Monark stationary cycle to prepare the body for testing. They were then positioned on the Kin-Com and all dynamometer measurements were recorded and stored in the computer. Subjects were seated with the trunk/hip angle positioned at 90 degrees and the knee of the testing leg hanging comfortably over the edge of the seat. The backrest was then adjusted appropriately to ensure that the hip/trunk angle was at 90 degrees. The dynamometer head was positioned at the level of the knee joint line. The lever arm was adjusted to the length of the lower leg with the resistance pad positioned so the bottom of the pad was in

line with the top of the medial malleolus of the testing leg. The subject had straps placed around the hips/ waist, chest, and thigh just proximal to the knee joint. This ensured that the trunk remained stationary during the testing procedure. Subjects were asked to fold their arms across their chest during testing. An example of a standard position for testing is included in Figure 2-6. The resistance pad attached to the lever arm was securely attached to the distal lower leg. All positioning measurements were recorded.

Figure 2-6 Classic seated knee test position with body stabilized by straps around thigh, waist, and chest, and with arms folded across chest. (From Perrin, 1993, pg.36)

Isokinetic resistance testing is a relatively recent development. Reliable and valid assessment can only be obtained with adequate patient education and familiarization with the isokinetic concept of exercise. Individuals were instructed on the operation of the Kin Com and were given clear instructions for the testing protocol. Subjects were

advised that an isokinetic dynamometer was set at a predetermined velocity and that resistance would be encountered only when the subject attempted to move the body segment at an equal or greater velocity. Instructions to the subject by the Investigator should include "push and pull as hard and as fast as you can" (Perrin 1993). Subjects should be informed that the instrument will attempt to "push or pull" their limb, and that they should resist the movement of the lever arm. The subject must be told to contract as hard and as fast as possible during test actions (MacDougall, Wenger et al. 1991).

In the case of both concentric and eccentric actions, an adequate familiarization period should be provided for each subject in the form of warm-up repetitions prior to assessment and should consist of first submaximal and then maximal efforts. In general, three submaximal and five maximal repetitions are adequate to obtain reliable measurements of isokinetic peak torque and average torque (Perrin 1993). Subjects performed both concentric and eccentric quadriceps actions with one leg that was randomly selected. Prior to testing and after the warm-up subjects performed 3 trials to familiarize themselves with the Kin-Com. These trials were sub-maximal. An example of a flow chart that was used is included in Figure 2-7.

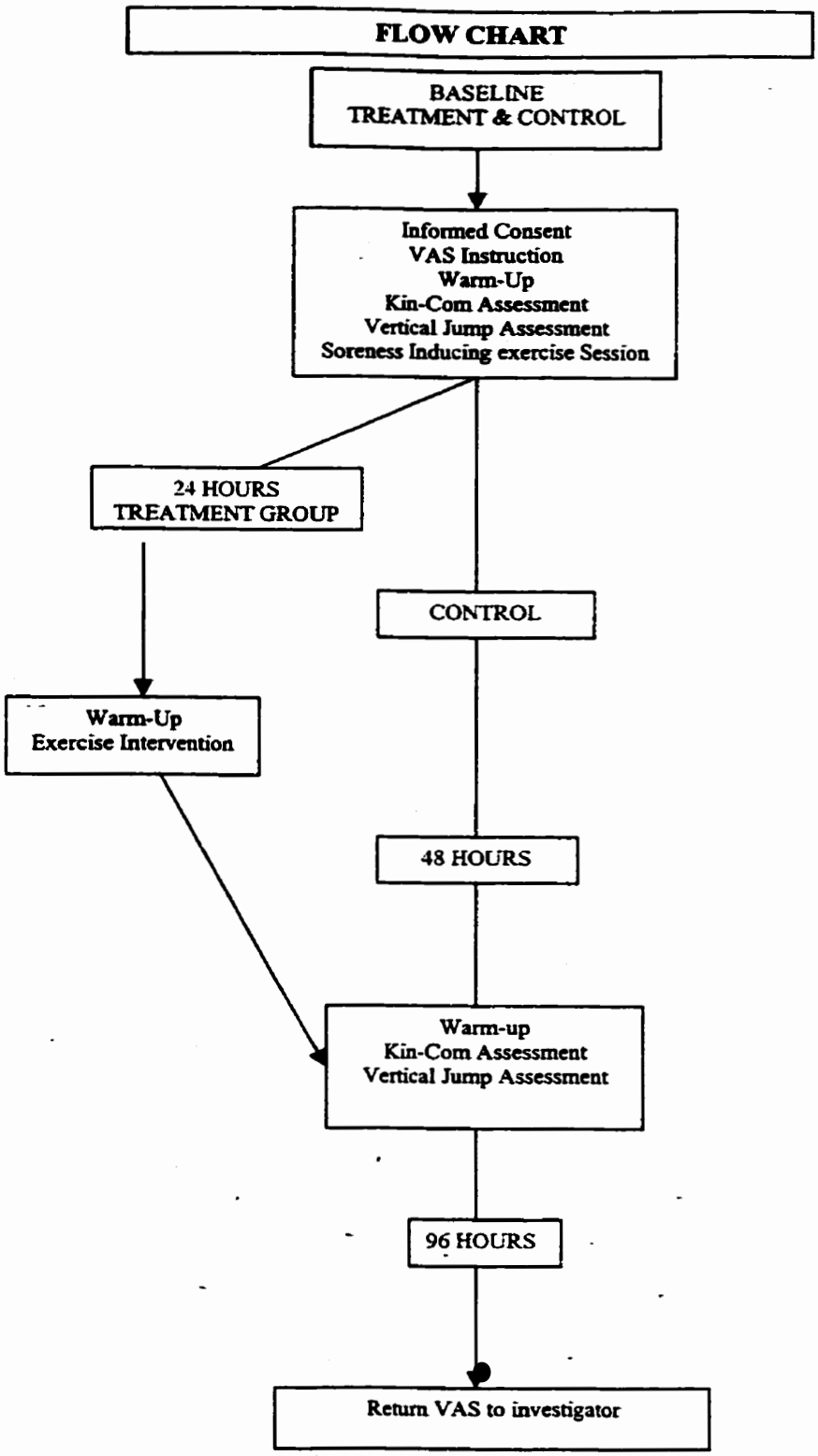

Figure 3-7 Flow chart to ensure consistency of protocol.

Kin-Com Pre-Testing (Baseline)

Prior to the soreness inducing exercise session (SIES) subjects were required to perform five maximal voluntary eccentric actions and five maximal voluntary concentric actions using the knee extensors on the Kin-Com. Peak Torque (PT), Average Torque (AT) and Angle of Peak Torque (APT) were recorded. No verbal encouragement was given to any of the subjects to ensure consistency between subjects. Subjects were asked to exert maximal effort with each action. There was a five-second rest between action types. The rest allowed each subject to focus on each upcoming action type. The Kin-Com was set at an angular velocity of 90 degrees per second. Knee extension occured through an 80-degree range of motion where full extension was described as 15 degrees from the horizontal and knee flexion was described as 95 degrees from the horizontal. This range of motion was set automatically by the Investigator. The range of motion tested was comfortable and standardized between subjects. Prior testing indicated that a range of motion of 80 degrees was comfortable for each subject and did not put the knee joint in a position of hyperextension.

Vertical Jump

Immediately following the warm-up, subjects had a five-minute rest period in order to allow the body to recover. At this point the subjects were ready to perform the vertical jump test.

Reach height was determined by the subject standing at a 90-degree angle to the wall with their right arm extended to a vertical position above their head. A tape measure

was taped to the wall and the measurement recorded was to the tip of their middle finger. Each subject performed three countermovement vertical jumps with an arm swing and a fifteen second rest between jumps. The vertical jump began from a standing, stationary position. During the descent of the countermovement, the hips, the knees, and the ankles are flexed into positions which stretch the muscles that will later act to extend that same joint (Vint and Hinrichs 1996). It has been hypothesized that as well as improving the force-producing capacities of the muscle itself, the countermovement utilizes some of the elastic properties of the muscles and tendons. This movement increases the distance over which force can be exerted, thereby prolonging the upward propulsion phase and taking up some of the muscular slack that is associated with the initial stages of the development of muscular tension (Vint and Hinrichs 1996). The height for each jump was recorded and the standing height value was subtracted. The jump with the highest value was recorded as the baseline measurement.

Soreness Inducing Exercise Session (SIES)

This exercise session was performed to induce DOMS in all the subjects. Subjects were taken to a leg extension machine at the athletic facility in The Frank Kennedy Centre. Initially, 1RM concentric MVC of the quadriceps was determined and recorded. Subjects were familiarized with the leg extension machine and were asked to perform one repetition at 50 (22.7 kg) pounds. The investigator determined if the repetition at 50 pounds (22.7 kg) was performed successfully by the subjects. If it was performed successfully, then the weight was increased by 10 to 20 (4.5 to 9.0 kg)pounds depending on the level of ease, until the subject could no longer complete one repetition.

If the repetition at 50 pounds (22.7 kg) was not performed successfully the weight was decreased by 10 to 20 (4.5 to 9.0 kg) pounds until the subject could successfully complete one repetition. The leg extension machine was chosen as it was safe for the participants and it isolated the quadriceps muscle group. Individuals performed subsequent sets of 12 repetitions each at 80% concentric MVC. Once the subject could no longer control the movement of the weight the set was considered complete. The subjects were then required to continue, performing as many controlled repetitions per set as possible until they were no longer able to continue. They performed the repetitions on a six count, 3 seconds up (concentric) and 3 seconds down (eccentric). Subjects had a one-minute rest between sets. A maximum of seven sets were performed. Both legs were used during the SIES. An example of the leg extension machine and the leg extension exercise are included in Figures 2-8 and 2-9.

Figure 2-8 Starting position for seated leg extensions. Primary muscles worked are quadriceps. (From Bompa & Cornacchia, 1998, pg.172)

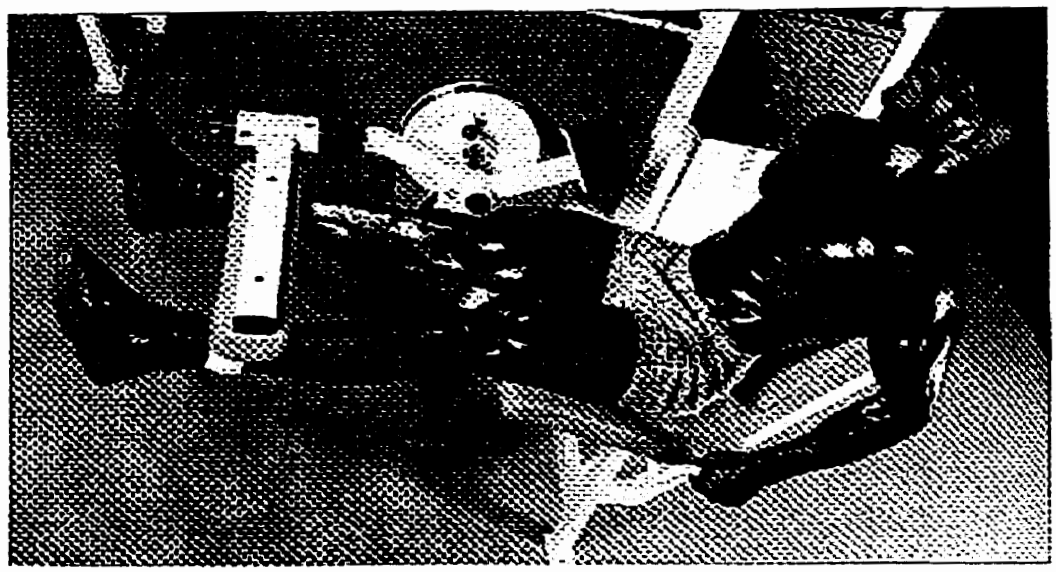

Figure 2-9 End position for seated leg extensions. Primary muscles worked are quadriceps. (From Bompa & Cornacchia, 1998, pg.172)

Exercise Intervention

This exercise session was performed to determine the effect on performance of vertical jump height and maximal quadriceps actions. Twenty-four hours post baseline testing, the experimental group underwent an exercise intervention. This experimental group consisted of 10 subjects randomly chosen from the 20 subjects who participated in the pretest. Individuals performed an exercise session on the leg extension machine, the same machine that was used to perform the SIES. Prior to the exercise intervention, subjects performed a five-minute warm up consisting of two sets of knee extension exercises, one at 25% MVC and one at 40% MVC. Subjects performed both concentric and eccentric actions of the quadriceps using a load of 50% concentric MVC of the quadriceps. The MVC was determined during the baseline testing. The actions were performed at a rate of one second per action type with no rest between actions. Subjects performed 6 sets of 12 repetitions with a one-minute rest in-between sets.

Post-Test

Forty-eight hours post baseline testing, each subject returned to the Biomechanics Lab for the post-test which was identical to the baseline testing protocols and procedures. Following a warm-up peak torque, average torque and angle of peak torque were determined using the Kin-Com along with the maximum vertical jump height.

Soreness Perception

Prior to the warm up and baseline testing subjects were given a VAS to determine the baseline soreness level in the quadriceps. An example of the VAS used is included is Appendix C. They were given clear and precise instructions as to how they should record their perceived level of pain of the quadriceps muscles. Subjects were required to record their perceived level of pain prior to testing and every 24 hours post testing for the following 4 days. The VAS consisted of three separate scales each being 10 cm in length. Subjects were provided with an addressed stamped envelope in which to put their five VAS sheets. They were to be returned to the investigator immediately after completion either in person or by mail.

Statistical Analyses

Statistical analyses was performed using repeated measures analyses of variance (ANOVA) with factors being time and treatment. An ANOVA baseline between group comparison was done on subject characteristics age, height and weight. Mean and variance values are reported in appropriate tables. All statistical analyses were performed on an IBM computer using Statistical Package for the Social Sciences (SPSS) version 7.5. Significance levels were set at $p<0.05$.

All dependent variables within the present study can be analyzed using ANOVA as the scores fulfill the two fundamental assumptions of parametric statistical tests (Hassard 1991). The first is that the researcher can meaningfully and sensibly calculate some basic descriptions of the data set, such as mean and standard deviation (SD)

(Hassard 1991). This implies that our data is measured on a ratio scale. A measurement scale with a constant interval and a true zero point is accurately described as a ratio scale because it can be legitimately used for "ratio" statements such as "twice as big" (Hassard 1991). The second is that the data will follow a normal distribution pattern (Hassard 1991). All variables were tested for normality and were found to follow a normal distribution with the exception of visual analog scale values at 0, 72 and 96 hours where the values were low (close to zero). Subjects will be randomly assigned to either the treatment or control groups using random allocation. The only way to remove the possibility of bias in treatment allocation is to remove allocation entirely from subjective human decision making (Hassard 1991). Random allocation will be performed using a random number table, which Hassard (1991) describes as a convenient method of random allocation. Randomization is a flexible and easy–to-use approach for treatment allocation.

For each of the outcome measures, the ANOVA compared the differences between the mean scores of the two groups at baseline and at post-test, and compared the differences between the baseline assessment time and the post-test assessment time for both the control and the experimental group.

For each of the outcomes, total variation was divided into:

A) Is there a difference between control measures and treatment measures without looking at time? This is the between group, within time variation.

B) Is there a difference between baseline measures and post-test measures regardless of group? This is the within person, between time variation.

C) Does the within person difference depend on which group the subjects were in? In other words, is there an interaction between A and B?

Outcome Measures:

1. Perceived Soreness.
2. Performance

Dependent Variables:

1. Concentric and Eccentric Peak Torque (objective)
2. Concentric and Eccentric Average Torque (objective)
3. Concentric and Eccentric Angle of Peak Torque (objective)
4. Concentric and Eccentric Relative Peak Torque (objective)
5. Vertical Jump Height (objective)
6. Perceived Soreness (subjective)

Independent Variables:

1. Exercise Intervention
2. Time

PILOT STUDY

METHODS

A pilot study had been performed prior to data collection for the present study. The goal of the pilot study was to: (1) to collect data that will provide the investigator with an opportunity to gain some practical experience in carrying out the proposed protocol, (2) ensure that instructions to subjects are clear and concise, and make modifications where necessary, (3) determine whether or not the soreness inducing exercise session would elicit the expected level of perceived soreness, (4) collect and analyze preliminary data. The investigator recruited 3 subjects for the pilot study.

Pilot study data was obtained in the Biomechanics Lab at the University of Manitoba. On the initial visit to the lab, the subjects' height and weight were determined and recorded. Subject characteristics are reported in Table 3-1. They were then asked to read and sign an Adult Informed Consent, which was then signed and dated by the Investigator and a witness. Subjects were then given a VAS scale with specific instructions on how to record information regarding their level of soreness every 24 hours for the following 96 hours. Subjects then performed a 5-minute warm-up session according to the previously outlined warm-up protocol.

Table 3-1

Subject Characteristics

Subject	Age (yrs)	Height (cms)	Weight (kg)
#1	35	168	73
#2	24	160	51
#3	22	159	57

Following the warm-up the standing reach height of the subject was taken and recorded. Subjects then performed three vertical jumps according to the CPAFLA guidelines outlined earlier. All three jump scores were recorded and subtracted from the standing reach height. The largest (best) score was used as the baseline vertical jump height.

Subjects were then positioned on the Kin-Com and were given clear instructions describing the testing procedures. Lever arm length and seat back positioning were recorded for replication purposes. The Kin-Com computer was turned on and the angular velocity was set to 90 degrees and all information was entered into the computer for storage purposes. Subjects were then given three submaximal familiarization trials. Following the familiarization period, subjects performed five maximal concentric and eccentric quadriceps actions. The data was recorded and stored in the computer for further analysis of PT, AT and APT.

Subjects were then taken to Frank Kennedy Centre to perform the soreness inducing exercise session. Subjects were seated on the leg extension machine and their quadriceps concentric 1RM was determined. Subjects were familiarized with the leg

extension machine and were asked to perform one repetition at 50 pounds. The investigator determined whether the repetition at 50 pounds was performed successfully by each subject. If it was performed successfully, then the weight was increased by 10 to 20 pounds depending on the level of ease, until the subject could no longer complete one repetition. If the repetition at 50 pounds was not performed successfully the weight was decreased by 10 to 20 pounds until the subject successfully completed one repetition. Eighty percent of the 1RM was determined and recorded. Twelve repetitions were considered a complete set. Once the subject could no longer perform a complete set, they were asked to perform as many repetitions as possible within the set, until they could no longer control the movement of the weight. A maximum of seven sets were performed. At this point the set was considered complete by the investigator. Subjects were asked to perform each repetition on a six count, three seconds on the way up and three seconds on the way down, with no rest between repetitions. Subjects had a one-minute rest between sets. The investigator recorded the weight used, number of sets and repetitions per set.

Subjects returned to the Biomechanics Lab 48 hours after the initial (baseline) test session. After performing a 5-minute warm up session, vertical jump and Kin-Com assessments were performed using the same protocol that was used to determine baseline data. At 96 hours following baseline testing all VASs were returned to investigator for analysis.

RESULTS

Graphs reporting pilot study data are displayed in Figures 3-1 to 3-8.

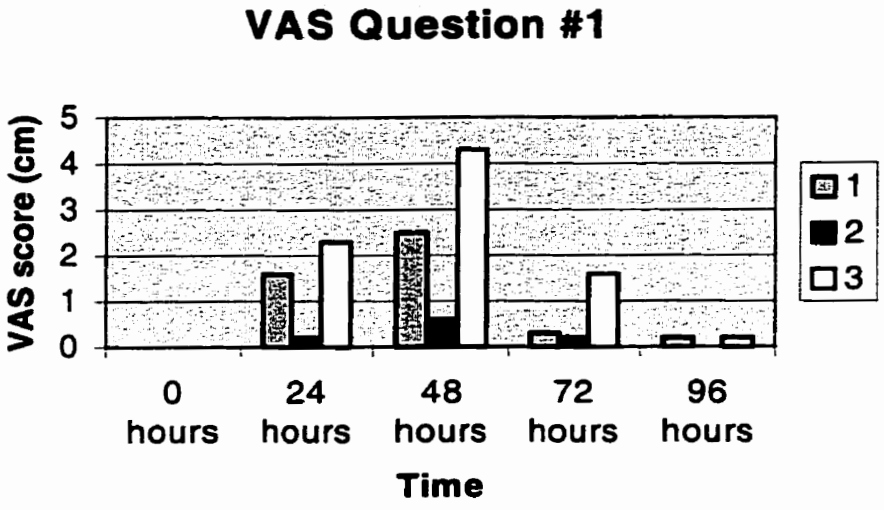

Figure 3-1 What is the current level of pain you are experiencing?

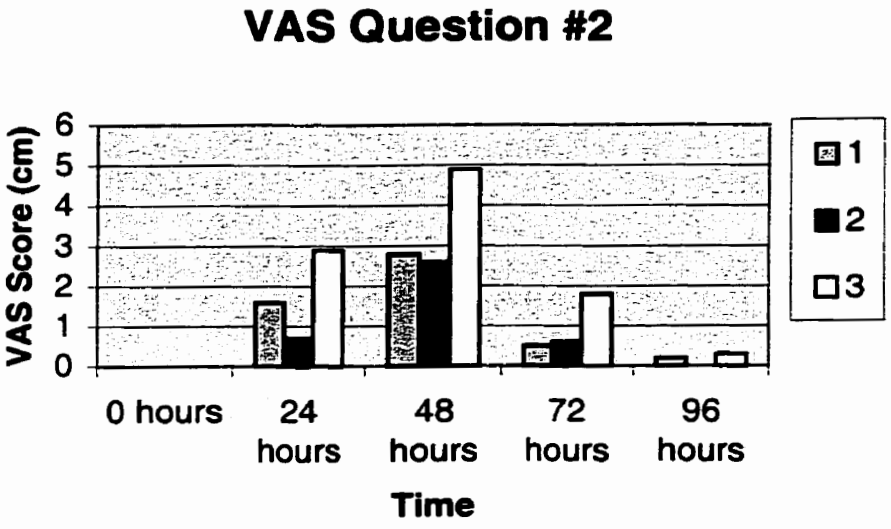

Figure 3-2 What is the level of pain associated with the movement?

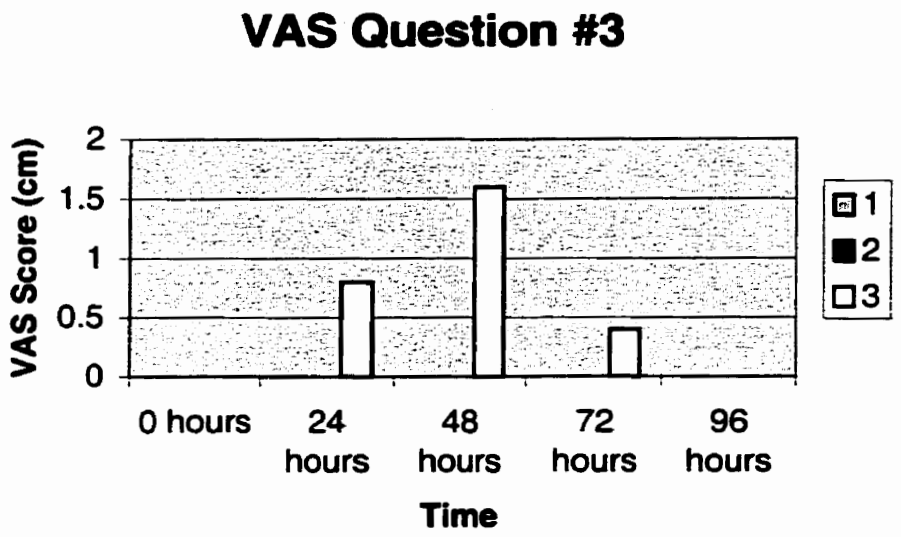

Figure 3-3 To what extent does this pain limit your ability to function?

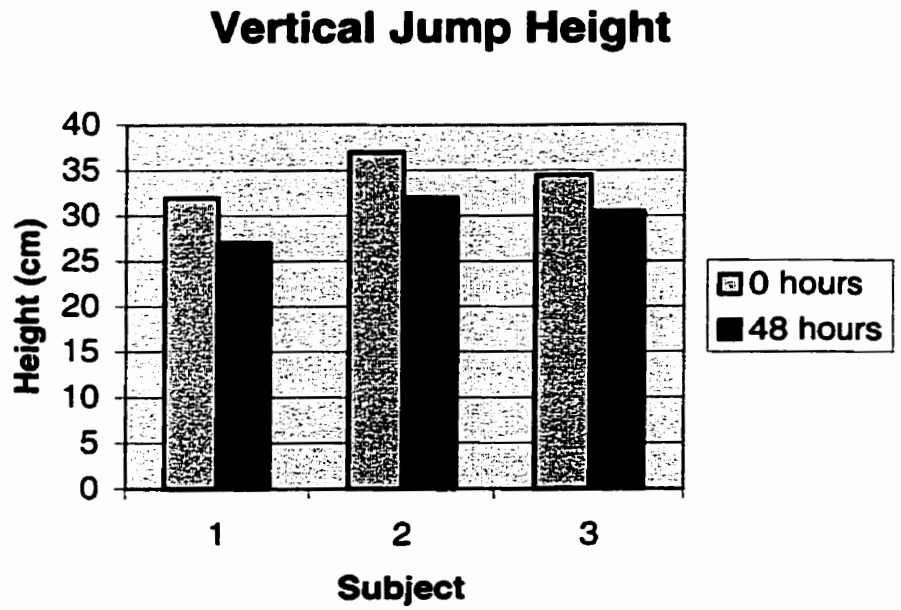

Figure 3-4 Vertical jump height.

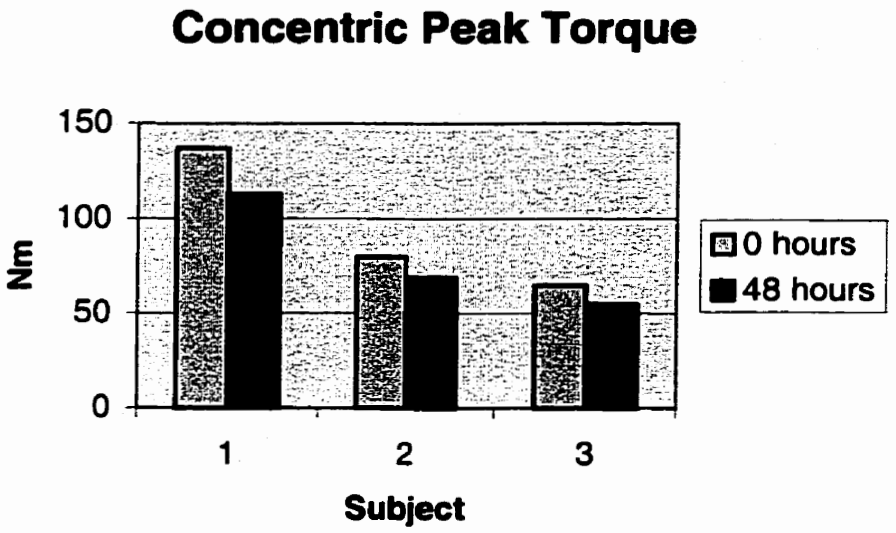

Figure 3-5 Quadriceps concentric peak torque.

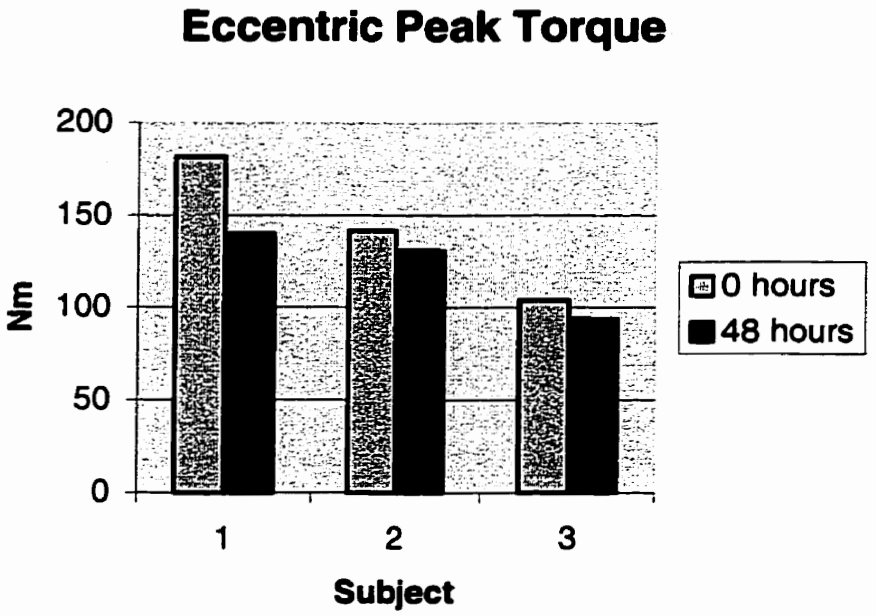

Figure 3-6 Quadriceps eccentric peak torque.

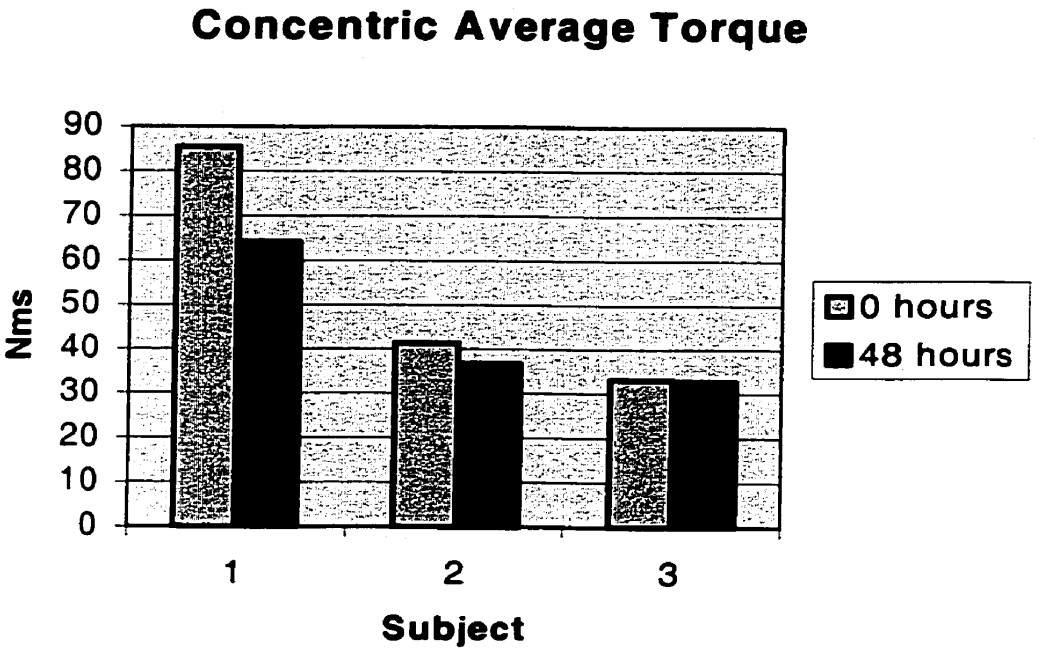

Figure 3-7 Quadriceps concentric average torque.

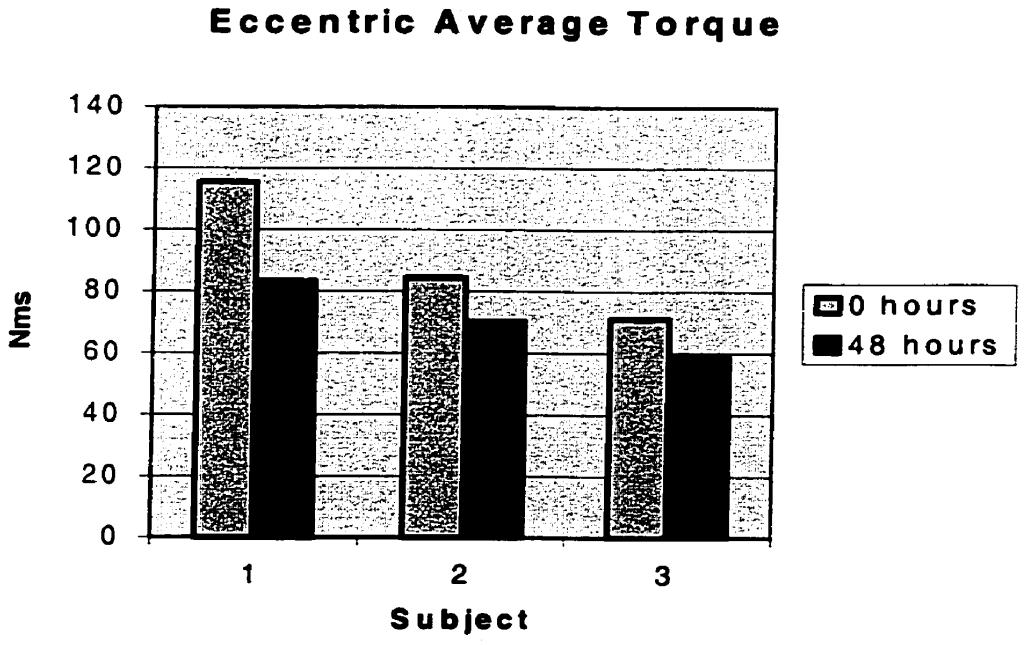

Figure 3-8 Quadriceps eccentric average torque.

DISCUSSION

Due to the limited number of subjects used in the pilot study, statistical significance cannot be determined. Based on the results of the pilot study, no conclusions can be made due to lack of sample size. However, at the 48-hour re-evaluation test session, when compared to baseline measurements all three subjects displayed increases in muscle soreness, decreases in vertical jump height and decreases in both concentric and eccentric peak torque and average torque values. This suggests that the soreness inducing exercise session was sufficient to produce soreness and decrease performance.

CHAPTER 4

RESULTS

Subjects

The subjects who participated in the present study were females between the ages of 19 and 35. They had not participated in any specific eccentric training for six weeks prior to the testing sessions. Specific eccentric training included, for example, downhill running, lower body resistance training or stair training. In the six weeks prior to testing, participants had also not experienced any DOMS. Any such previous training or soreness would have reduced the likelihood of responses or symptoms of muscle injury resulting from the soreness inducing exercise session or experimental exercise. The mean subject characteristics for the control group and the experimental group are presented in Table 4-1.

An ANOVA was done to analyze the subject characteristics. There were no significant differences between the control and experimental group means with respect to age, height or weight, although age almost reached significance. Individual subject characteristics are included in Appendix F. A t-test was performed to determine if there was a significant difference between the number of repetitions performed by the control and experimental groups during the soreness inducing exercise session. The control group averaged 59.7 repetitions and the experimental group averaged 53.5 repetitions. This was not a significant difference.

Table 4-1 Anthropometric variables for experimental and control groups (mean ±SD)

Variable	Control N=10	Experimental N=10	F ratio	p value
Age (yr)	25.5 ±5.25	21.7 ±2.21	4.079	.059
Height (cm)	168.8 ±3.99	169.2 ±5.7	.033	.858
Weight (kg)	75.83 ±13.09	67.3 ±10.16	2.647	.121

Comparison of groups at baseline

There were no significant differences between the control group and the experimental group in any of the variables tested at baseline testing, so both groups were similar at the outset. A summary of repeated measures ANOVA findings by dependent variables average torque, peak torque, angle to peak torque, relative peak torque, and vertical jump are located in Table 4-3. There was a significant time effect but not a significant group effect. A decision was made a priori to test for simple effects within group by time regardless of the significance of the group by time interaction. Individual subject results are included in Appendix F.

Average Torque

The mean results for baseline quadriceps concentric and eccentric average torque produced by the control and experimental groups are presented in Table 4-2, Figure 4-1 and Figure 4-2 respectively. There were no significant differences between the experimental and control groups in average torque at baseline testing.

Peak Torque

Mean scores for baseline quadriceps concentric and eccentric peak torque produced by the control and experimental groups are presented in Table 4-2, Figure 4-3

and Figure 4-4 respectively. The difference between the mean peak torque for the two groups at baseline was not significant.

Angle to Peak Torque

The mean results for baseline quadriceps concentric and eccentric angle to peak torque demonstrated by the control and experimental groups are presented in Table 4-2, Figure 4-5 and Figure 4-6 respectively. There were no significant differences between the two groups in angle to peak torque at baseline.

Relative Peak Torque

Mean results for baseline quadriceps concentric and eccentric relative peak torque attained by the control and the experimental groups are presented in Table 4-2, Figure 4-7 and Figure 4-8 respectively. The baseline comparison between the two groups revealed no significant results for either concentric or eccentric actions.

Vertical Jump

The mean results for vertical jump attained by the control and experimental groups are presented in Table 4-2 and Figure 4-9. There were no significant differences between the control and experimental group means at the baseline assessment.

Comparison of groups at post-test

There were no significant differences between the control group and the experimental group in any of the variables tested at the post-test assessment time. A summary of repeated measures ANOVA findings by dependent variables average torque, peak torque, angle to peak torque, relative peak torque, and vertical jump are located in Table 4-3. There was a significant time effect but not a significant group effect. A decision was made a priori to test for simple effects within group by time regardless of

the significance of the group by time interaction. Individual subject results are included in Appendix F.

Average Torque

The mean results for post-test quadriceps concentric and eccentric average torque produced by the control and experimental groups are presented in Table 4-2, Figure 4-1 and Figure 4-2 respectively. There were no significant differences between the experimental group and the control group at post-test.

Peak Torque

The mean scores for post-test quadriceps concentric and eccentric peak torque produced by the control and experimental groups are presented in Table 4-2, Figure 4-3 and Figure 4-4 respectively. The difference between the two groups at post-test was not significant.

Angle to Peak Torque

The mean scores for post-test quadriceps concentric and eccentric angle to peak torque produced by the control and experimental groups are presented in Table 4-2, Figure 4-5 and Figure 4-6 respectively. The difference between the two groups at post-test was not significant.

Relative Peak Torque

The mean scores for post-test quadriceps concentric and eccentric relative peak torque produced by the control and experimental groups are presented in Table 4-2, Figure 4-7 and Figure 4-8 respectively. The difference between the two groups at post-test was not significant.

Vertical Jump

The mean results for vertical jump attained by the control and experimental groups are presented in Table 4-2 and Figure 4-9. There were no significant differences between the control and experimental group means at the post-test assessment time.

Intervention results for the control group

With the exception of concentric and eccentric angle to peak torque, significant differences were found between baseline and post-test mean scores for the remainder of the variables: average torque, peak torque, relative peak torque, and vertical jump for the control group. A summary of repeated measures ANOVA findings by dependent variables average torque, peak torque, angle to peak torque, relative peak torque, and vertical jump are located in Table 4-3. There was a significant time effect but not a significant group effect. A decision was made a priori to test for simple effects within group by time regardless of the significance of the group by time interaction. Simple effects testing within group by time findings by dependent variables average torque, peak torque, angle to peak torque, relative peak torque, and vertical jump are included in Table 4-4. Individual subject results are included in Appendix F.

Average Torque

The baseline and post-test results for the control group are presented in Table 4-2. A significant difference ($p<0.05$) was found when the average concentric torque post-test value was compared to the average concentric torque baseline value. A significant difference ($p<0.01$) was found when comparing the average eccentric torque post-test value to the average eccentric torque baseline value.

Peak Torque

Baseline and post-test results for the control group are presented in Table 4-2. A significant difference ($p<0.01$) was found when the post-test concentric peak torque was compared to the baseline concentric peak torque. A significant difference ($p<0.01$) was shown for the post-test to baseline eccentric peak torque comparison for the control group.

Angle to Peak Torque

Control group angle to peak torque comparison results are presented in Table 4-2. The concentric angle to peak torque baseline value was 25 degrees (± 4.5 degrees) and the concentric post-test value was 25.4 degrees (± 4.8 degrees). The total difference between the two concentric test-times was 0.8 degrees. The eccentric baseline value was 20 degrees (± 4.7 degrees) and the eccentric post-test value was 21.4 degrees (± 6.8 degrees). The total difference between the two eccentric test times was 1.4 degrees. There were no significant differences between baseline and post-test comparisons for either concentric or eccentric muscle actions.

Relative Peak Torque

Control group relative peak torque comparison results are presented in Table 4-2. When the control group baseline concentric value was compared to the post-test concentric value, means were statistically different ($p<0.01$). Control group eccentric mean comparisons were also significantly different ($p<0.01$).

Vertical Jump

Vertical jump baseline and post-test mean values for the control group are presented in Table 4-2. The post-test mean value of the control group decreased to 25.82

cm from a baseline mean value of 30.12 cm for a total decrease of 4.3 cm. There was a significant difference between baseline and post-test vertical jump scores ($p<0.01$).

Intervention results for the experimental group

The experimental group attained no significant differences between baseline and post-test measurements for peak torque, average torque, relative peak torque, or vertical jump. A summary of repeated measures ANOVA findings by dependent variables average torque, peak torque, angle to peak torque, relative peak torque, and vertical jump are located in Table 4-3. There was a significant time effect but not a significant group effect. A decision was made a priori to test for simple effects within group by time regardless of the significance of the group by time interaction. Simple effects testing within group by time findings by dependent variables average torque, peak torque, angle to peak torque, relative peak torque, and vertical jump are included in Table 4-4. Individual subject results are included in Appendix F.

Average Torque

The baseline and post-test mean results for the experimental group are presented in Table 4-2. The experimental group displayed no significant differences when the post-test and the baseline average torque values were compared for either the concentric or eccentric muscle actions.

Peak Torque

The experimental group comparison results are presented in Table 4-2. No significant differences were found between the baseline and post-test means for the experimental group with respect to peak torque.

Angle to Peak Torque

The experimental group comparison results are presented in Table 4-2. The concentric baseline value was 27.2 degrees (± 5.01 degrees) and the concentric post-test value was 27.1 degrees (± 4.9 degrees). The total difference between the two was 0.1 degrees. The eccentric baseline value was 25.8 degrees (± 8.54 degrees) and the eccentric post-test value was 23.7 degrees (± 9.63 degrees). The total difference between the baseline value and the post-test value was 2.1 degrees. Differences between the baseline and post-test assessment times for the experimental group were not found to be statistically significant.

Relative Peak Torque

The experimental group comparison results are presented in Table 4-2. Comparison of the experimental group from baseline to post-test for both concentric and eccentric actions revealed no significant differences with respect to relative peak torque.

Vertical Jump

The experimental group comparison results are presented in Table 4-2. With respect to the experimental group, the post-test mean value decreased to 26.4 cm from a baseline mean value of 27.6 cm for a total decrease of 1.2 cm. There was not a significant difference between the baseline and post-test assessment times for the experimental group.

Table 4-2 Mean ± standard deviation for dependent variables average torque, peak torque, angle to peak torque, relative peak torque, and vertical jump by group and time.

	Group			
	Control		Experimental	
Dependent Variable	**Baseline Mean±SD**	**Post-test Mean±SD**	**Baseline Mean±SD**	**Post-test Mean±SD**
Average torque concentric (Nm)	83.09 ±17.95	71.58 ±20.34	84.32 ±14.85	81.34 ±14.07
Average torque eccentric (Nm)	126.69 ±29.45	107.5 ±29.44	114.49 ±29.46	111.18 ±26.24
Peak torque concentric (Nm)	151.4 ±32.17	129.7 ±31.4	142.4 ±18.28	140.5 ±24.92
Peak torque eccentric (Nm)	233 ±63.11	200.4 ±51.87	202.5 ±44.14	198.1 ±43.97
Angle to peak torque concentric (Nm)	25 ±4.5	25.4 ±4.8	27.0 ±5.01	27.1 ±4.9
Angle to peak torque eccentric (Nm)	20 ±4.7	21.4 ±6.8	25.8 ±8.54	23.7 ±9.63
Relative peak torque concentric (Nm/kg)	2.02 ±.4384	1.744 ±.4229	2.132 ±.211	2.096 ±.2901
Relative peak torque eccentric (Nm/kg)	3.061 ±.6181	2.64 ±.5068	3.016 ±.509	2.953 ±.5268
Vertical jump (cm)	30.12 ±10.56	25.82 ±8.14	27.6 ±3.08	26.4 ±3.28

Table 4-3 Summary of Repeated Measures ANOVA findings by dependent variables average torque, peak torque, angle to peak torque, relative peak torque, and vertical jump.

	Source		
Measure	**Group F (df,df)**	**Time F (df,df)**	**Group x Time F(df,df)**
Concentric average torque (Nm)	0.63(1,18)	5.42(1,18)**	1.87(1,18)
Eccentric average torque (Nm)	0.13(1,18)	5.76(1,18)**	2.87(1,18)*
Concentric peak torque (Nm)	0.01(1,18)	5.45(1,18)**	3.84(1,18)*
Eccentric peak torque (Nm)	0.56(1,18)	6.90(1,18)**	4.01(1,18)*
Concentric angle to peak torque (Nm)	0.93(1,18)	0.01(1,18)	.00(1,18)
Eccentric angle to peak torque (Nm)	1.64(1,18)	0.08(1,18)	1.45(1,18)
Concentric relative peak torque (Nm/kg)	2.63(1,18)	5.36(1,18)**	3.17(1,18)*
Eccentric relative peak torque (Nm/kg)	0.37(1,18)	5.83(1,18)**	3.19(1,18)*
Vertical jump (cm)	0.10(1,18)	11.29(1,18)***	3.59(1,18)*

*p<0.10
**p<0.05
***p<0.01

Table 4-4 Simple effects testing within group by time findings by dependent variables average torque, peak torque, angle to peak torque, relative peak torque, and vertical jump.

Dependent Variable	Control (F, sig of F)	Experimental (F, sig of F)
Average torque concentric (Nm)	6.83, .018**	.46, .506
Average torque eccentric (Nm)	8.28, .01***	.25, .623
Peak torque concentric (Nm)	9.22, .007***	.07, .793
Peak torque eccentric (Nm)	10.72, .004***	.20, .664
Angle to peak torque concentric (Nm)	.00, .955	.00, .955
Angle to peak torque eccentric (Nm)	.42, .523	1.11, .307
Relative peak torque concentric (Nm/kg)	8.39, .01***	.14, .71
Relative peak torque eccentric (Nm/kg)	8.82, .008***	.20, .662
Vertical jump (cm)	13.80, .002***	1.07, .314

*p<0.10
**p<0.05
***p<0.01

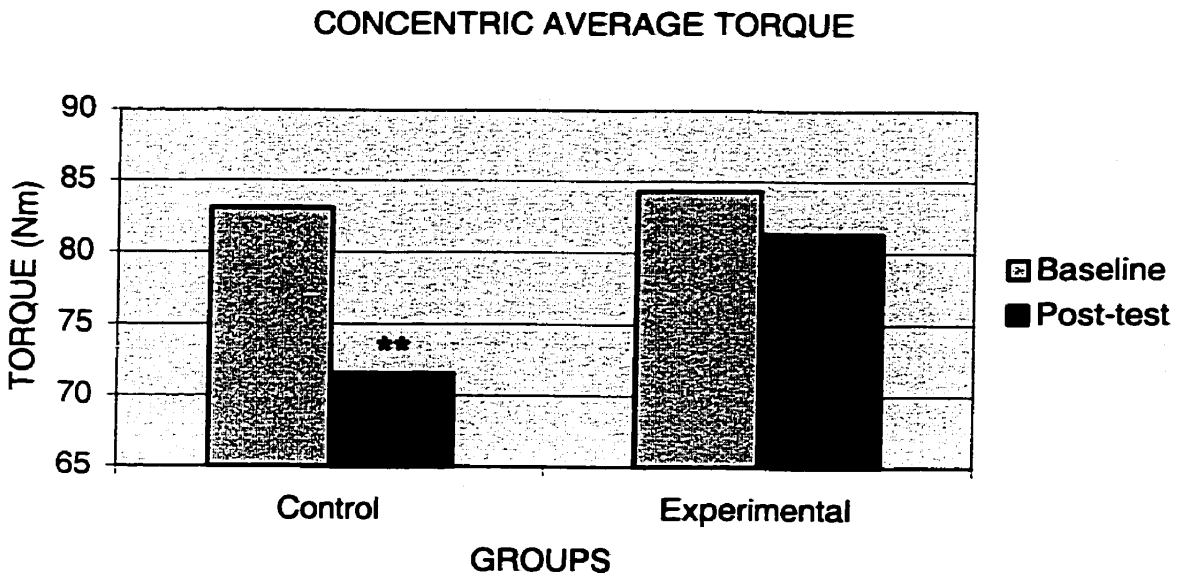

Figure 4-1 Baseline and post-test concentric average torque mean values for both the control and the experimental groups. **p<0.05 significantly different from baseline value

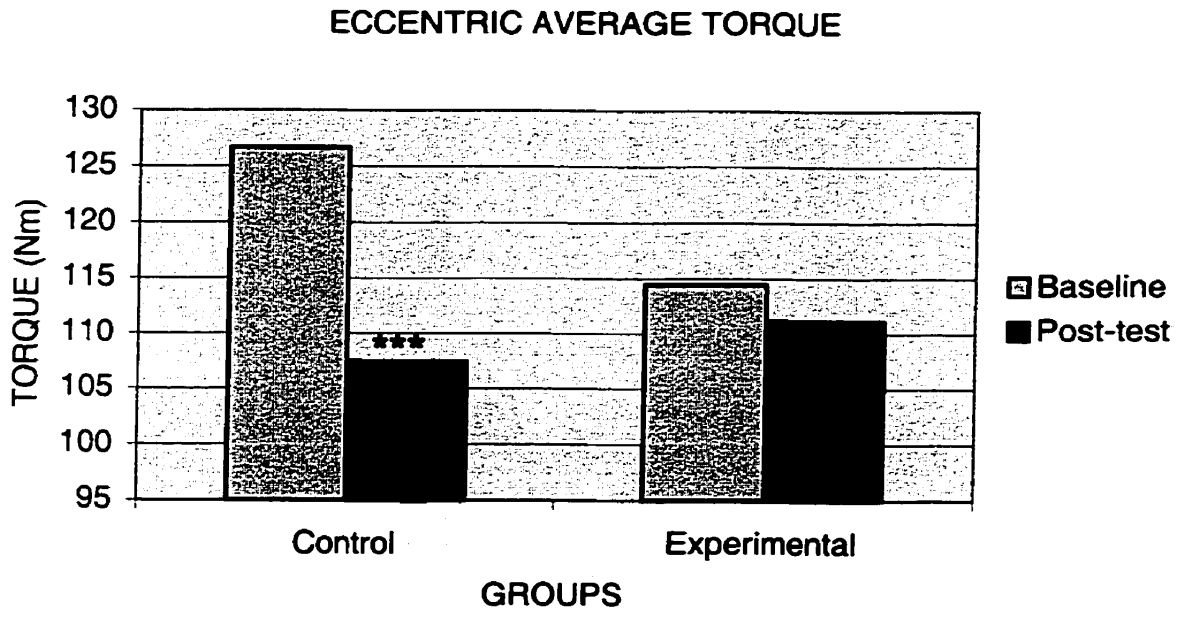

Figure 4-2 Baseline and post-test eccentric average torque mean values for both the control and the experimental groups. ***p<0.01 significantly different from baseline value

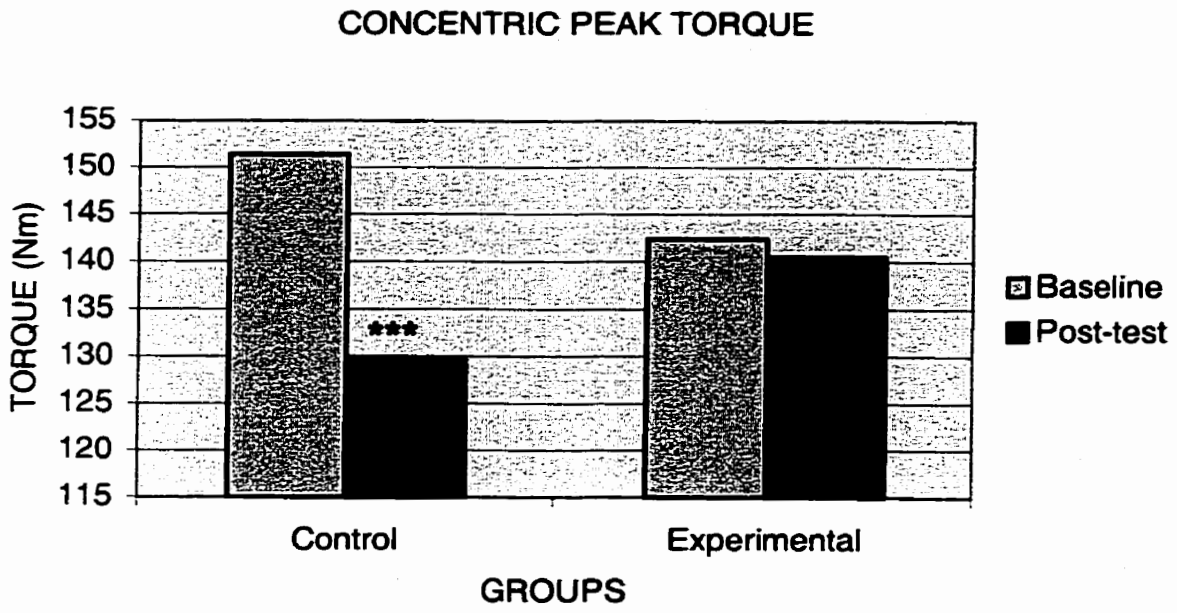

Figure 4-3 Baseline and post-test concentric peak torque mean values for both the control and the experimental groups. ***p<0.01 significantly different from baseline value

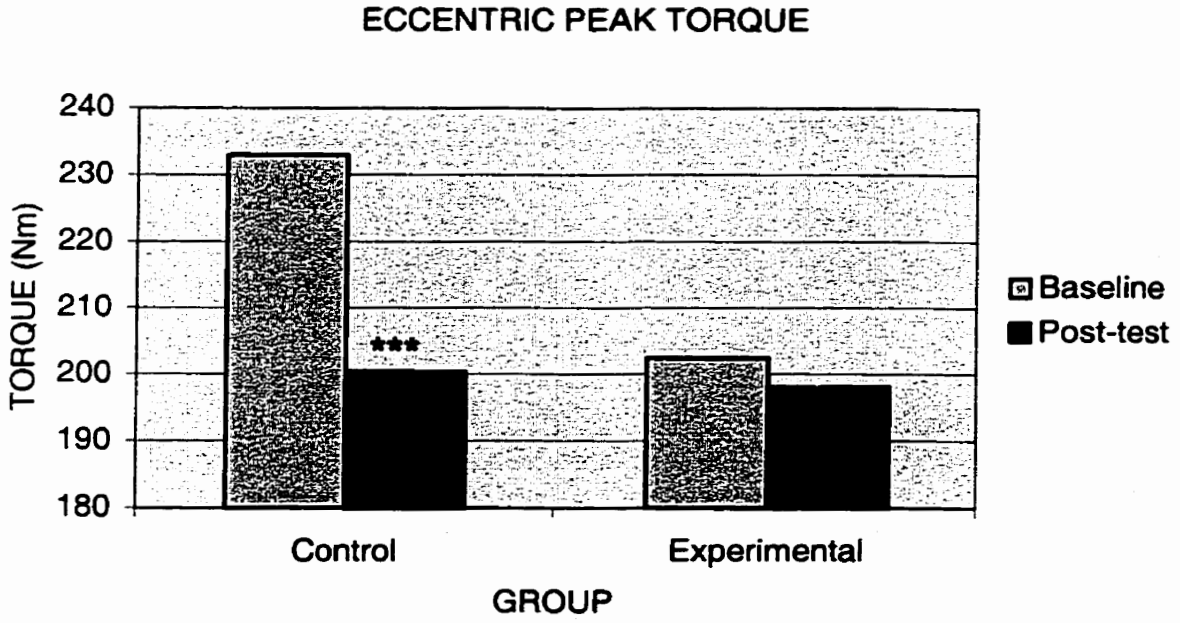

Figure 4-4 Baseline and post-test eccentric peak torque mean values for both the control and the experimental groups. ***p<0.01 significantly different from baseline value

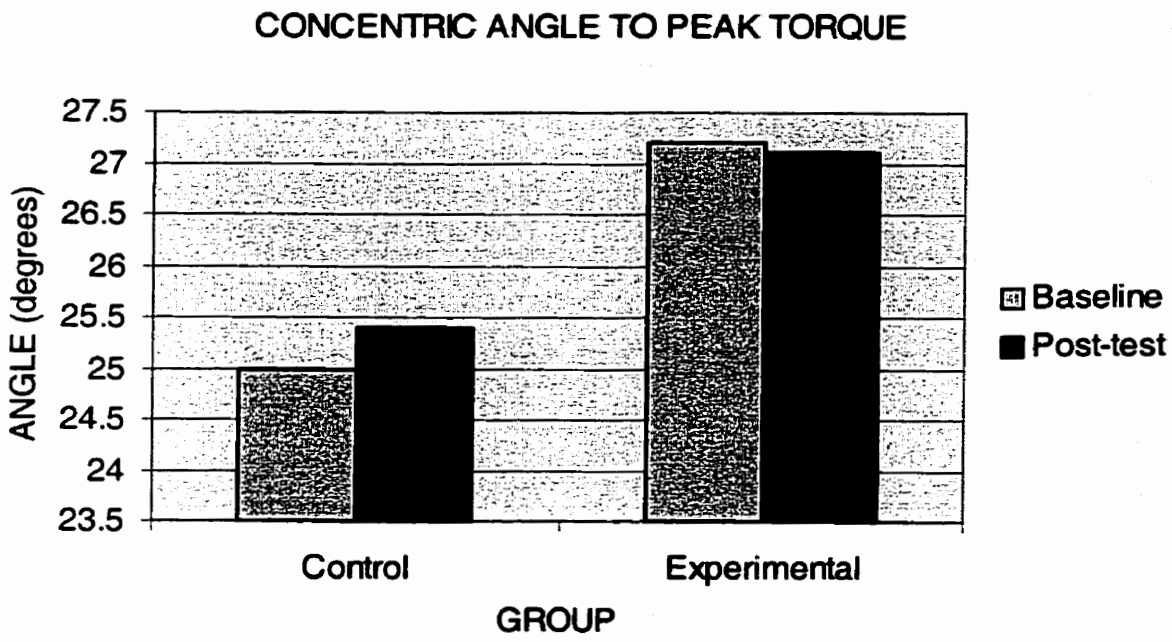

Figure 4-5 Baseline and post-test concentric angle to peak torque mean values for both the control and the experimental groups.

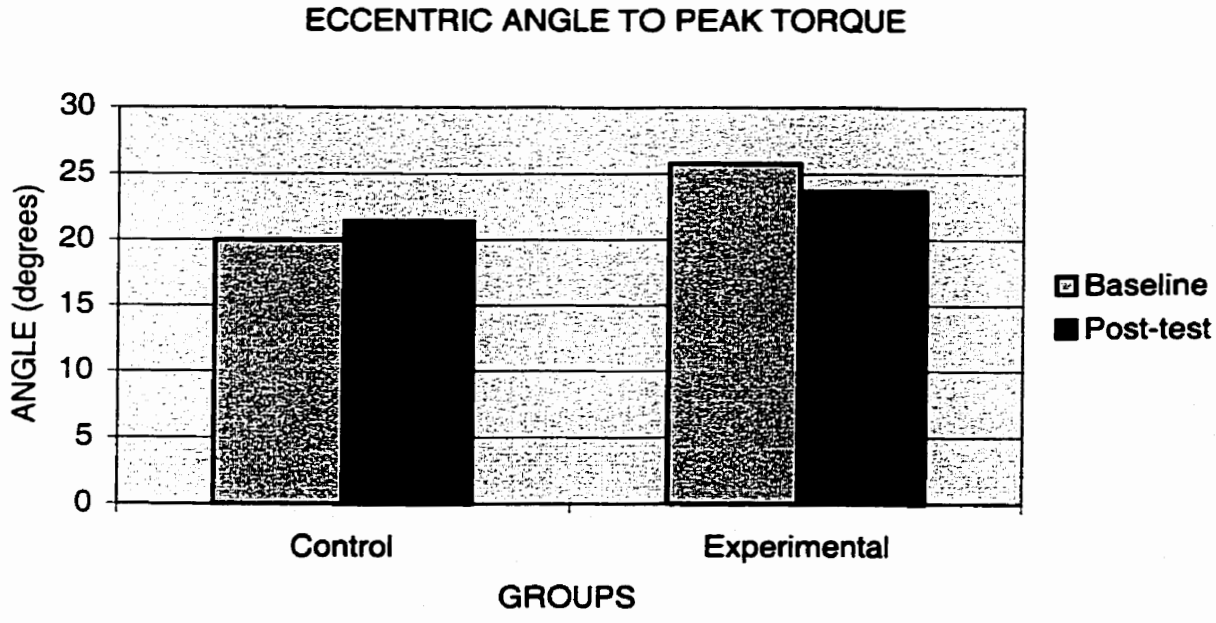

Figure 4-6 Baseline and post-test eccentric angle to peak torque mean values for both the control and the experimental groups.

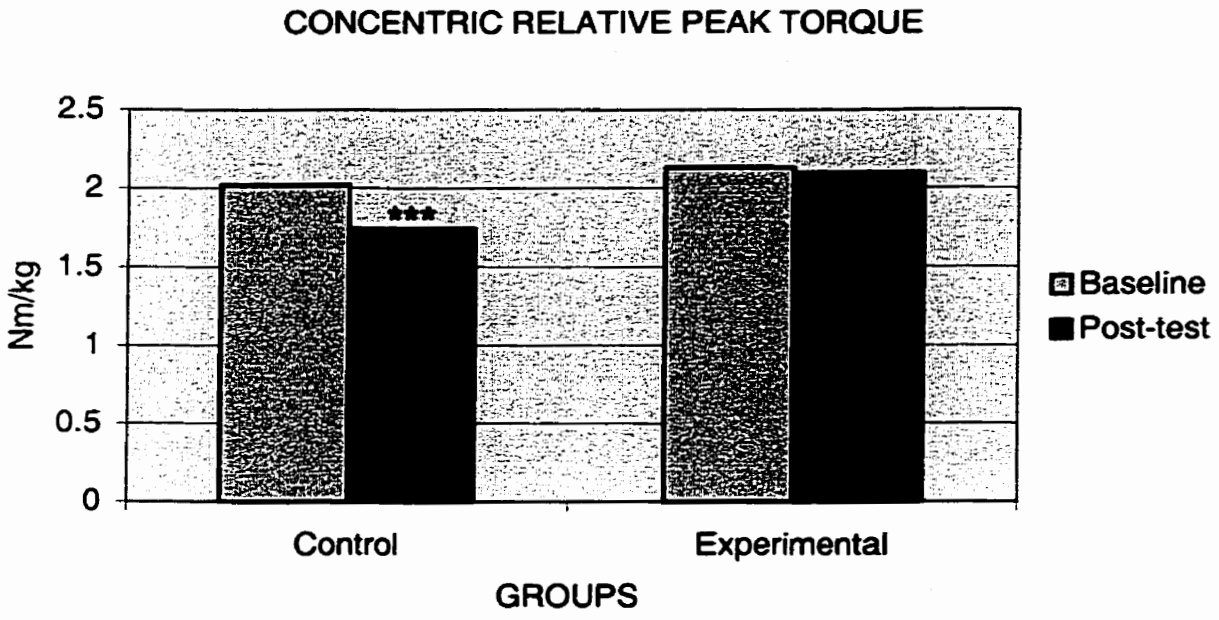

Figure 4-7 Baseline and post-test relative concentric peak torque mean values for both the control group and the experimental group ***p<0.01 significantly different from baseline value

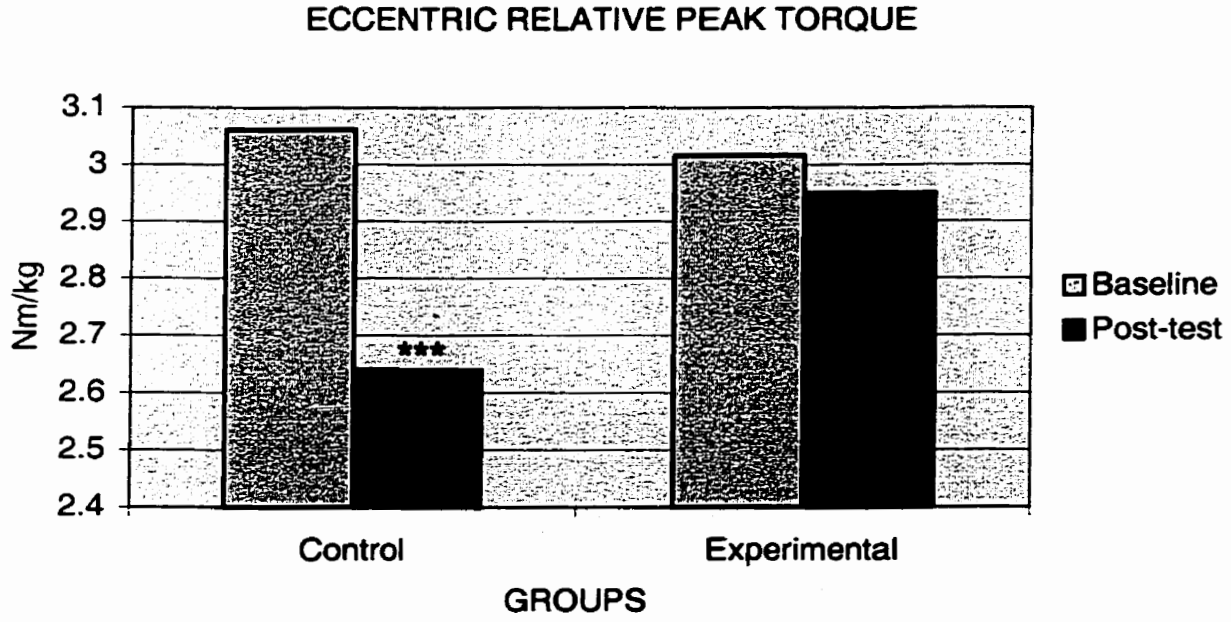

Figure 4-8 Baseline and post-test relative eccentric peak torque mean values for both the control group and the experimental group, ***p<0.01 significantly different from baseline value

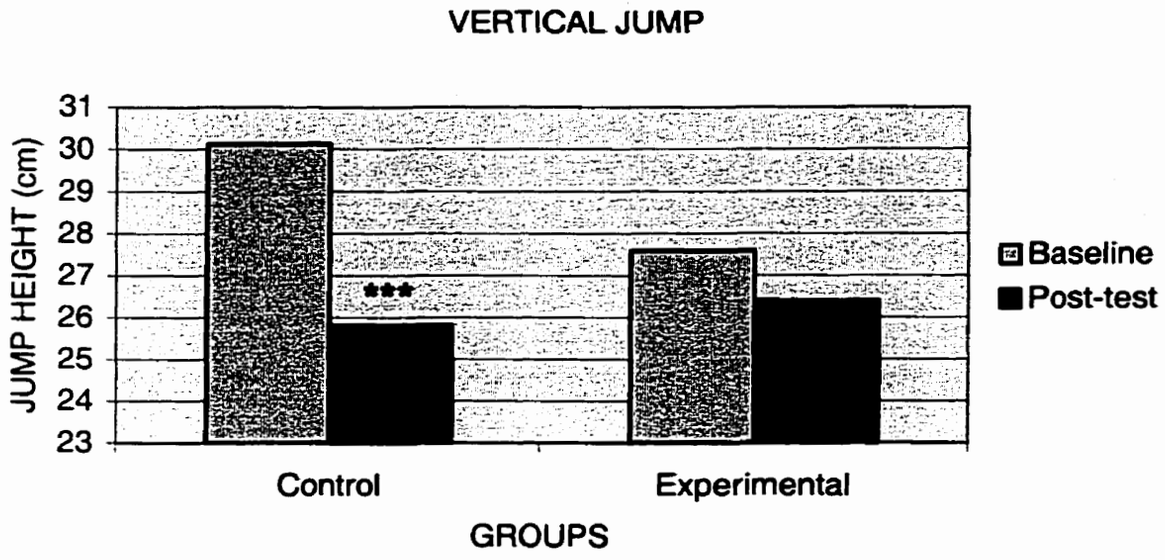

Figure 4-9 Baseline and post-test vertical jump mean values for both the control and the experimental groups ***p<0.01 significantly different from baseline value

Visual Analog Scales

With regard to visual analog scale questions one, two and three at 0 hours, the group means were all equal to 0. There was no variance within groups, control or experimental, therefore statistics cannot be computed for these three data sets. The visual analog scales are scored on a ten-centimeter scale, where 0 indicates "no pain" and 10 indicates "worst imaginable pain". Therefore higher values indicate greater pain scores.

Visual Analog Scale Question #1:

What is the level of pain you are currently experiencing?

The mean results for the visual analog scale question number one "What is the current level of pain you are experiencing?" reported by the control and the experimental groups are presented in Table 4-6 and Figure 4-10. The mean values for visual analog scale question number one at 0 hours (Q1VAS0), at 24 hours (Q1VAS24), at 48 hours (Q1VAS48), at 72 hours (Q1VAS72), and at 96 hours (Q1VAS96) are expressed in centimeters from zero. There were no significant differences between the control and experimental group means at 0, 24, 48, 72, and 96 hours. Individual subject results are included in Appendix F.

Table 4-5. Visual analog scale question number one (Q1VAS) " What is the level of pain you are currently experiencing?" comparison of scores at 0, 24, 48, 72, and 96 hours for experimental and control groups (mean ± SD)

Variable	Control N=10	Experimental N=10	F ratio	p value
Q1VAS0 (cm)	0	0	0	0
Q1VAS24 (cm)	2.61 ±2.6	3.03 ±2.07	.159	.694
Q1VAS48 (cm)	2.76 ±1.83	2.32 ±1.93	.272	.608
Q1VAS72 (cm)	1.49 ±1.52	1.4 ±1.78	.015	.905
Q1VAS96 (cm)	.58 ±.85	.74 ±1.35	.1	.756

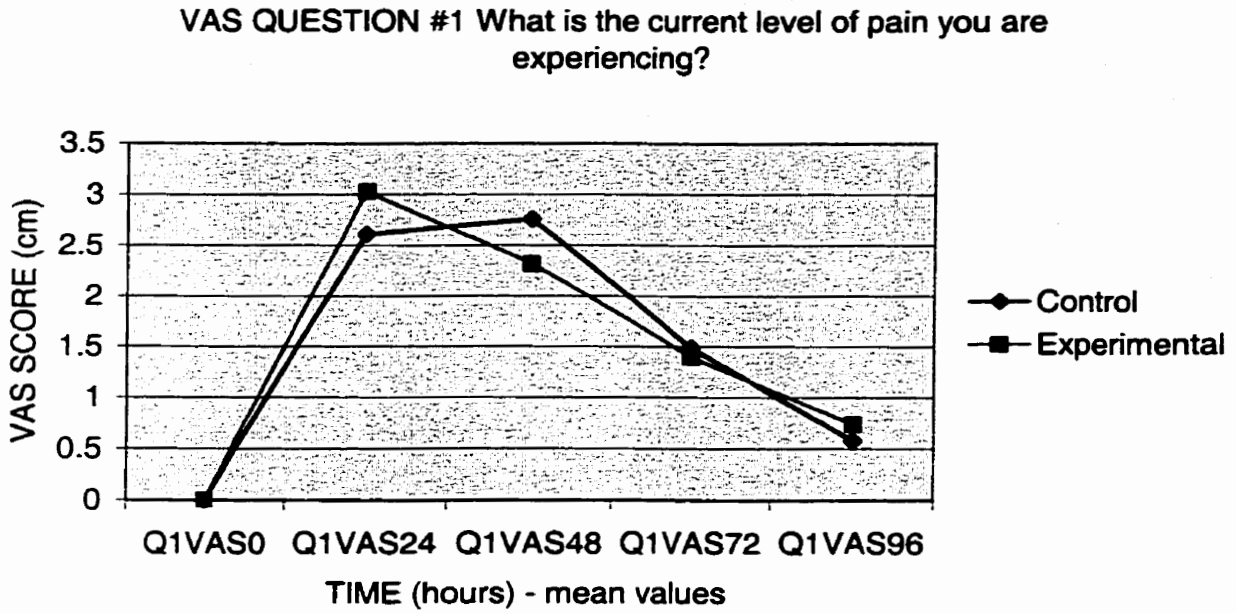

Figure 4-10 Visual analog scale question one "What is the current level of pain you are experiencing?" mean values for both the control and the experimental groups at 0, 24, 48, 72, and 96 hours.

Visual Analog Scale Question #2:

What is the level of pain associated with the movement?

The mean results for the visual analog scale question number two "What is the level of pain associated with the movement?" reported by the control and the experimental groups are presented in Table 4-7 and Figure 4-11. The mean values for visual analog scale question number two at 0 hours (Q2VAS0), at 24 hours (Q2VAS24), at 48 hours (Q2VAS48), at 72 hours (Q2VAS72), and at 96 hours (Q2VAS96) are expressed in centimeters. There were no significant differences between the control and experimental group means at 0, 24, 48, 72, and 96 hours. Individual subject results are included in Appendix F.

Table 4-6. Visual analog scale question number two (Q2VAS) " What is the level of pain associated with the movement?" comparison of scores at 0, 24, 48, 72, and 96 hours for experimental and control groups (mean ± SD)

Variable	Control N=10	Experimental N=10	F ratio	p value
Q2VAS0 (cm)	0	0	0	0
Q2VAS24 (cm)	3.7 ±2.74	3.94 ±2.42	.043	.838
Q2VAS48 (cm)	3.9 ±2.4	3.66 ±3.08	.071	.793
Q2VAS72 (cm)	2 ±1.9	2.09 ±2.46	.008	.928
Q2VAS96 (cm)	.77 ±1.02	.63 ±1.01	.094	.763

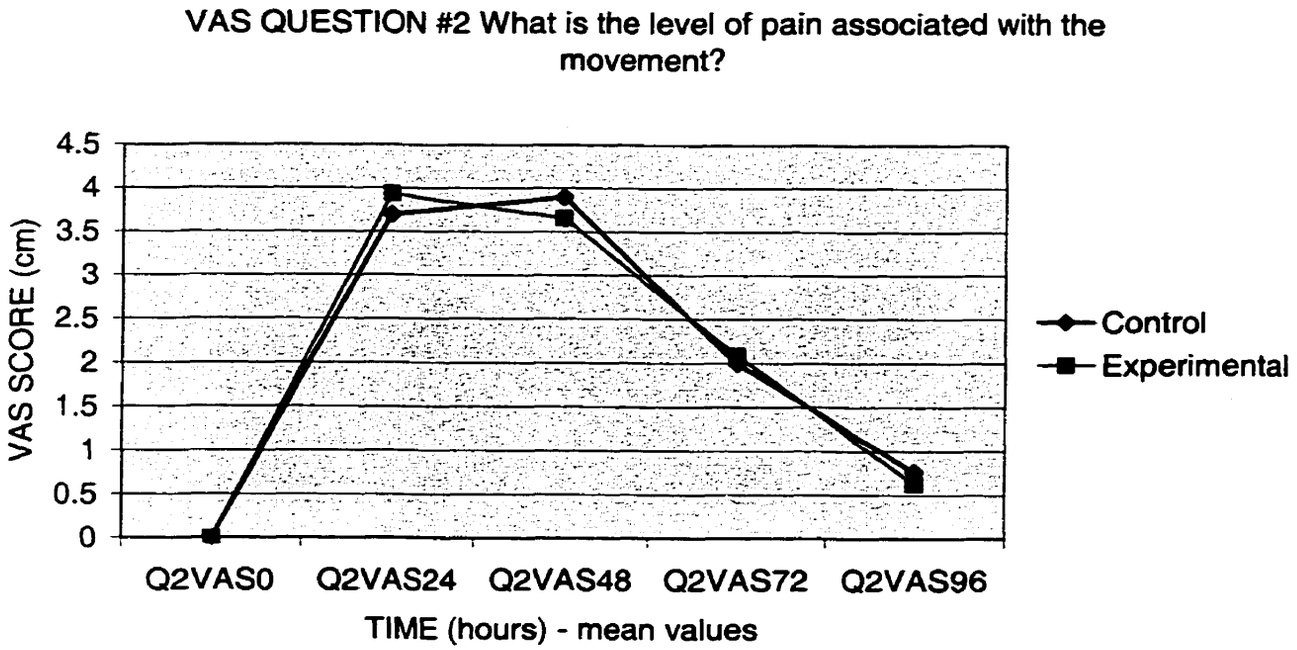

Figure 4-11 Visual analog scale question two "What is the level of pain associated with the movement?" mean values for both the control and the experimental groups at 0, 24, 48, 72, and 96 hours.

Visual Analog Scale Question #3:

To what extent does this pain limit your ability to function?

The mean results for the visual analog scale question number three "To what extent does this pain limit your ability to function?" reported by the control and the experimental groups are presented in Table 4-8 and Figure 4-12. The mean values for visual analog scale question number three at 0 hours (Q3VAS0), at 24 hours (Q3VAS24),

at 48 hours (Q3VAS48), at 72 hours (Q3VAS72), and at 96 hours (Q3VAS96) are expressed in centimeters. There were no significant differences between the control and experimental group means at 0, 24, 48, 72, and 96 hours. Individual subject results are included in Appendix F.

Table 4-7. Visual analog scale question number three (Q3VAS) " To what extent does this pain limit your ability to function?" comparison of scores at 0, 24, 48, 72, and 96 hours for experimental and control groups (mean ± SD)

Variable	Control N=10	Experimental N=10	F ratio	p value
Q3VAS0 (cm)	0	0	0	0
Q3VAS24 (cm)	2.42 ±2.34	2.15 ±2.32	.067	.799
Q3VAS48 (cm)	2.78 ±2.2	2.28 ±2.54	.221	.644
Q3VAS72 (cm)	1.19 ±1.66	1.09 ±1.73	.017	.897
Q3VAS96 (cm)	.23 ±.52	.31 ±.55	.110	.744

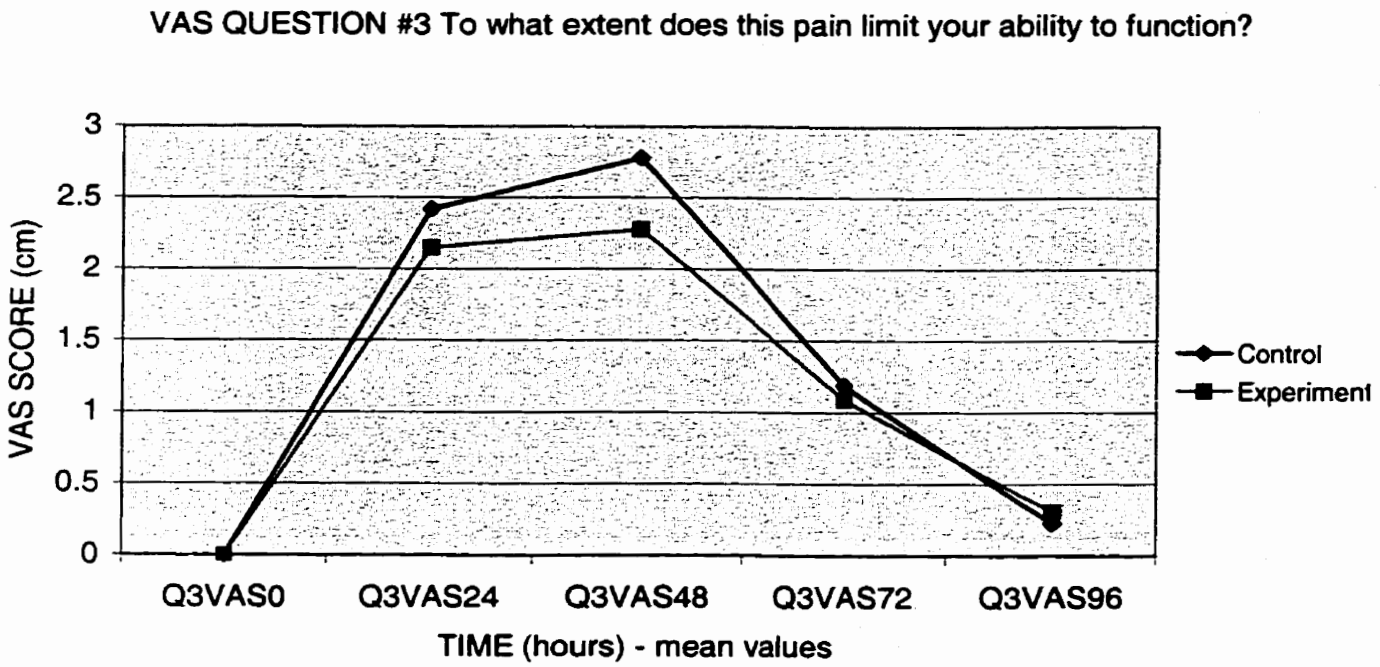

Figure 4-12 Visual analog scale question three "To what extent does this pain limit your ability to function?" mean values for both the control and the experimental groups at 0, 24, 48, 72, and 96 hours.

Pairwise comparisons: Visual Analog Scales - Differences between times.

Control group, N=10

Visual analog scale question #1 (Q1)

Q1	Dependent Variable
1	Q1VAS0
2	Q1VAS24
3	Q1VAS48
4	Q1VAS72
5	Q1VAS96

Control group - VAS #1

Control group mean results for visual analog scale question number one at 0, 24, 48, 72, and 96 hours are presented in Table 4-9.

Pairwise comparisons indicate that with respect to visual analog scale question one at 0 hours, the mean differences were significant at the .05 level when compared to visual analog scale question one at 24, 48, and 72 hours, but not at 96 hours.

When visual analog scale question one at 24 hours was compared to visual analog scale question one at 0 and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question one at 48 and 72 hours the mean differences were non-significant.

When visual analog scale question one at 48 hours was compared to visual analog scale question one at 0, 72, and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question one at 24 hours the mean difference was non-significant.

With respect to visual analog scale question one at 72 hours, the mean differences were significant at the .05 level when compared to visual analog scale question one at 0, 48, and 96 hours, but not at 24 hours.

With respect to visual analog scale question one at 96 hours, the mean differences were significant at the .05 level when compared to visual analog scale question one at 24, 48, and 72 hours, but not when compared to baseline (i.e. 0 hours).

Table 4-8. VAS question #1 Differences between times at 0, 24, 48, 72 and 96 hours for the control group N=10.

Variable	Mean ±SD	Mean Difference
Q1VAS0 (cm)	0	
2		**-2.61***
3		**-2.76***
4		**-1.49***
5		**-0.58**
Q1VAS24 (cm)	2.61 ±2.6	
1		**2.61***
3		**-0.15**
4		**1.12**
5		**2.03***
Q1VAS48 (cm)	2.76 ±1.83	
1		**2.76***
2		**0.15**
4		**1.27***
5		**2.18***
Q1VAS72 (cm)	1.49 ±1.52	
1		**1.49***
2		**-1.12**
3		**-1.27***
5		**0.91***
Q1VAS96 (cm)	.58 ±.85	
1		**0.58**
2		**-2.03***
3		**-2.18***
4		**-0.91***

*p<0.05.

Visual analog scale question #2 (Q2)

Q2	Dependent Variable
1	Q2VAS0
2	Q2VAS24
3	Q2VAS48
4	Q2VAS72
5	Q2VAS96

Control group - VAS #2

Control group mean results for visual analog scale question number two at 0, 24, 48, 72, and 96 hours are presented in Table 4-10.

Pairwise comparisons indicate that with respect to visual analog scale question two at 0 hours, the mean differences were significant at the .05 level when compared to visual analog scale question two at 24, 48, 72, and 96 hours.

When visual analog scale question two at 24 hours was compared to visual analog scale question two at 0, 72, and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question two at 48 hours the mean difference was non-significant.

When visual analog scale question two at 48 hours was compared to visual analog scale question two at 0, 72, and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question two at 24 hours the mean difference was non-significant.

With respect to visual analog scale question two at 72 hours, the mean differences were significant at the .05 level when compared to visual analog scale question two at 0, 24, 48, and 96 hours.

With respect to visual analog scale question two at 96 hours, the mean differences were significant at the .05 level when compared to visual analog scale question two at 0, 24, 48, and 72 hours.

Table 4-9. VAS question #2 Differences between times at 0, 24, 48, 72 and 96 hours for the control group N=10.

Variable	Mean ±SD	Mean Difference
Q2VAS0 (cm)	0	
2		**-3.70***
3		**-3.99***
4		**-2.0***
5		**-0.77***
Q2VAS24 (cm)	3.7 ±2.74	
1		**3.70***
3		**-0.29**
4		**1.70***
5		**2.93***
Q2VAS48 (cm)	3.9 ±2.4	
1		**3.99***
2		**0.29**
4		**1.99***
5		**3.22***
Q2VAS72 (cm)	2 ±1.9	
1		**2.0***
2		**-1.70***
3		**-1.99***
5		**1.23***
Q2VAS96 (cm)	.77 ±1.02	
1		**0.77***
2		**-2.93***
3		**-3.22***
4		**-1.23***

*p<0.05 level.

Visual analog scale question #3 (Q3)

Q3	Dependent Variable
1	Q3VAS0
2	Q3VAS24
3	Q3VAS48
4	Q3VAS72
5	Q3VAS96

Control group - VAS #3

Control group mean results for visual analog scale question number three at 0, 24, 48, 72, and 96 hours are presented in Table 4-11.

Pairwise comparisons indicate that with respect to visual analog scale question three at 0 hours, the mean differences were significant at the .05 level when compared to visual analog scale question three at 24 and 48 hours, but not at 72 or 96 hours.

When visual analog scale question three at 24 hours was compared to visual analog scale question three at 0 and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question three at 48 and 72 hours the mean differences were non-significant.

When visual analog scale question three at 48 hours was compared to visual analog scale question three at 0, 72, and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question three at 24 hours the mean difference was non-significant.

With respect to visual analog scale question three at 72 hours, the mean differences were significant at the .05 level when compared to visual analog scale question three at 48 and 96 hours, but not at 0 or 24 hours.

With respect to visual analog scale question three at 96 hours, the mean differences were significant at the .05 level when compared to visual analog scale question three at 24, 48, and 72 hours, but like visual analog scale question one, non significant differences were found when compared to the baseline mean.

Table 4-10. VAS question #3 Differences between times at 0, 24, 48, 72 and 96 hours for the control group N=10.

Variable	Mean ±SD	Mean Difference
Q3VAS0 (cm)	0	
2		**-2.42***
3		**-2.78***
4		**-1.19**
5		**-0.23**
Q3VAS24 (cm)	2.42 ±2.34	
1		**2.42***
3		**-0.36**
4		**1.23**
5		**2.19***
Q3VAS48 (cm)	2.78 ±2.2	
1		**2.78***
2		**0.36**
4		**1.59***
5		**2.55***
Q3VAS72 (cm)	1.19 ±1.66	
1		**1.19**
2		**-1.23**
3		**-1.59***
5		**0.96***
Q3VAS96 (cm)	.23 ±.52	
1		**0.23**
2		**-2.19***
3		**-2.55***
4		**-0.96***

* $p<0.05$ level.

Experimental group, N=10

Visual analog scale question #1 (Q1)

Q1	Dependent Variable
1	Q1VAS0
2	Q1VAS24
3	Q1VAS48
4	Q1VAS72
5	Q1VAS96

Experimental group - VAS #1

Experimental group mean results for visual analog scale question number one at 0, 24, 48, 72, and 96 hours are presented in Table 4-12.

Pairwise comparisons indicate that with respect to visual analog scale question one at 0 hours, the mean differences were significant at the .05 level when compared to visual analog scale question one at 24, 48, and 72 hours, but not at 96 hours.

When visual analog scale question one at 24 hours was compared to visual analog scale question one at 0 72, and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question one at 48 hours the mean difference was non-significant.

When visual analog scale question one at 48 hours was compared to visual analog scale question one at 0, 72, and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question one at 24 hours the mean difference was non-significant.

With respect to visual analog scale question one at 72 hours, the mean differences were significant at the .05 level when compared to visual analog scale question one at 0, 24, 48, and 96 hours.

With respect to visual analog scale question one at 96 hours, the mean differences were significant at the .05 level when compared to visual analog scale question one at 24, 48, and 72 hours, but not when compared to baseline.

Table 4-11. VAS question #1 Differences between times at 0, 24, 48, 72 and 96 hours for the experimental group N=10.

Variable	Mean ±SD	Mean Difference
Q1VAS0 (cm)	0	
2		**-3.03***
3		**-2.32***
4		**-1.4***
5		**-0.74**
Q1VAS24 (cm)	3.03 ±2.07	
1		**3.03***
3		**0.71**
4		**1.63***
5		**2.29***
Q1VAS48 (cm)	2.32 ±1.93	
1		**2.32***
2		**-0.71**
4		**0.92***
5		**1.58***
Q1VAS72 (cm)	1.4 ±1.78	
1		**1.4***
2		**-1.63***
3		**-0.92***
5		**0.66***
Q1VAS96 (cm)	.74 ±1.35	
1		**0.74**
2		**-2.29***
3		**-1.58***
4		**-0.66***

* $p<0.05$ level.

Visual analog scale question #2 (Q2)

Q2	Dependent Variable
1	Q2VAS0
2	Q2VAS24
3	QVAS48
4	Q2VAS72
5	Q2VAS96

Experimental group - VAS #2

Experimental group mean results for visual analog scale question number two at 0, 24, 48, 72, and 96 hours are presented in Table 4-13.

Pairwise comparisons indicate that with respect to visual analog scale question two at 0 hours, the mean differences were significant at the .05 level when compared to visual analog scale question two at 24, 48, and 72 hours, but not at 96 hours.

When visual analog scale question two at 24 hours was compared to visual analog scale question two at 0, 72, and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question two at 48 hours the mean difference was non-significant.

When visual analog scale question two at 48 hours was compared to visual analog scale question two at 0, 72, and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question two at 24 hours the mean difference was non-significant.

With respect to visual analog scale question two at 72 hours, the mean differences were significant at the .05 level when compared to visual analog scale question two at 0, 24, 48, and 96 hours.

With respect to visual analog scale question two at 96 hours, the mean differences were significant at the .05 level when compared to visual analog scale question two at 24, 48, and 72 hours, but not when compared to baseline.

Table 4-12. VAS question #2 Differences between times at 0, 24, 48, 72 and 96 hours for the experimental group N=10.

Variable	Mean ±SD	Mean Difference
Q2VAS0 (cm)	0	
2		**-3.94***
3		**-3.66***
4		**-2.09***
5		**-0.63**
Q2VAS24 (cm)	3.94 ±2.42	
1		**3.94***
3		**0.28**
4		**1.85***
5		**3.31***
Q2VAS48 (cm)	3.66 ±3.08	
1		**3.66***
2		**-0.28**
4		**1.57***
5		**3.03***
Q2VAS72 (cm)	2.09 ±2.46	
1		**2.09***
2		**-1.85***
3		**-1.57***
5		**1.46***
Q2VAS96 (cm)	.63 ±1.01	
1		**0.63**
2		**-3.31***
3		**-3.03***
4		**-1.46***

* $p<0.05$ level.

Visual analog scale question #3 (Q3)

Q3	Dependent Variable
1	Q3VAS0
2	Q3VAS24
3	Q3VAS48
4	Q3VAS72
5	Q3VAS96

Experimental group - VAS #3

Experimental group mean results for visual analog scale question number three at 0, 24, 48, 72, and 96 hours are presented in Table 4-13.

Pairwise comparisons indicate that with respect to visual analog scale question three at 0 hours, the mean differences were significant at the .05 level when compared to visual analog scale question three at 24 and 48 hours, but not at 72 or 96 hours.

When visual analog scale question three at 24 hours was compared to visual analog scale question three at 0 and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question three at 48 and 72 hours the mean difference was non-significant.

When visual analog scale question three at 48 hours was compared to visual analog scale question three at 0 and 96 hours the mean differences were significant at the .05 level. However when compared to visual analog scale question three at 24 and 72 hours the mean differences were non-significant.

With respect to visual analog scale question three at 72 hours, the mean differences were not significant at the .05 level when compared to visual analog scale question three at any other data point.

With respect to visual analog scale question three at 96 hours, the mean differences were significant at the .05 level when compared to visual analog scale question three at 24 and 48 hours, but not at baseline or 72 hours.

Table 4-13. VAS question #3 Differences between times at 0, 24, 48, 72 and 96 hours for the experimental group N=10.

Variable	Mean ±SD	Mean Difference
Q3VAS0 (cm)	0	
2		**-2.15***
3		**-2.28***
4		**-1.09**
5		**-0.31**
Q3VAS24 (cm)	2.15 ±2.32	
1		**2.15***
3		**-0.13**
4		**1.06**
5		**1.84***
Q3VAS48 (cm)	2.28 ±2.54	
1		**2.28***
2		**0.13**
4		**1.19**
5		**1.97***
Q3VAS72 (cm)	1.09 ±1.73	
1		**1.09**
2		**-1.06**
3		**-1.19**
5		**0.78**
Q3VAS96 (cm)	.31 ±.55	
1		**0.31**
2		**-1.84***
3		**-1.97***
4		**-0.78**

*$p<0.05$ level.

CHAPTER 5

DISCUSSION

Overview

The purpose of this study was to determine the effects of a specific exercise intervention on delayed onset muscle soreness (DOMS) and neuromuscular function; and to determine the validity of some present research which suggests that a specific exercise intervention can decrease the muscle soreness and performance deficits associated with DOMS (Hasson et al., 1989). Three other investigations using exercise as an intervention for DOMS did not find any reduction in muscle soreness and performance deficits (Hasson et al., 1989; Donnelly et al., 1992; Isabell et al., 1992; Weber et al., 1994).

The experimental group performed the specific exercise intervention utilized in this study twenty-four hours post baseline testing and the soreness inducing exercise. The experimental group consisted of 10 subjects randomly chosen from the 20 subjects who participated in the study. Individuals performed an exercise session on the leg extension machine that consisted of both concentric and eccentric actions of the quadriceps using a load of 50% 1RM concentric quadriceps, which was determined during the baseline testing. Prior to the exercise intervention, subjects performed a five-minute warm-up consisting of 2 sets of knee extension exercises, the first at 25% 1RM and the second at 40% 1RM. The actions were performed at a rate of one second per action type with no rest between actions. Subjects performed 6 sets of 12 repetitions with a one-minute rest in between sets. This study had five phases: the pre-exercise

measurements (baseline), the induction of DOMS, the exercise intervention for the experimental group, the post -test measurements 48 hours after baseline testing, and the visual analog scale ratings taken every 24 hours from baseline to 96 hours.

When the post-test means of the control group were compared to the baseline means of all dependent variables with the exception of angle to peak torque, statistically significant differences were found. For the experimental group, there were no significant differences between post-test and baseline measures for any dependent variable. The performance of the control group was negatively affected by the soreness inducing exercise session with the presumptive diagnosis of DOMS. It appears that the soreness inducing exercise session used in the present study was sufficient to induce DOMS and negatively affect muscular performance. Also the data suggests that the exercise intervention was successful in minimizing neuromuscular functional deficits associated with DOMS.

Torque Comparisons

In the present study, the control group produced significant differences between baseline and post-test mean values for both the concentric and eccentric actions with respect to peak torque and average torque of the quadriceps. The experimental group displayed no significant differences from baseline to post-test. The control group quadriceps concentric peak torque underwent a decrease of 21.7 Nm while the experimental group underwent a decrease of only 1.9 Nm. The control group quadriceps eccentric peak torque underwent a decrease of 32.6 Nm while the experimental group underwent a decrease of only 4.4 Nm. The data suggests that performance decreases less

when the specific exercise intervention used in this study was implemented. The results for quadriceps peak torque appear to favor the experimental group, as this group displayed less of a decrease in peak torque values. This lowered decrease in peak torque values was likely due to the exercise intervention.

Concentric and eccentric peak torque values were compared to non-gravity corrected normative values of knee extension peak torque reported by Hanten and Ramberg (1988). He reported that nondisabled females aged 25 attained a concentric peak torque of 154.74 Nm and an eccentric peak torque of 235.63 Nm. These values are based on the isokinetic dynamometer being set at 90 degrees per second, which was the angular velocity used in this research. Baseline concentric peak torque for the control group in the present study was 151.4 Nm and the eccentric peak torque was 233 Nm. The concentric and eccentric baseline peak torques for the experimental group was 142.4 Nm and 202.5 Nm respectively. The mean age for the control group was 25.5 years and the experimental group was 21.7 years. In comparison to normative data, the control group was very similar with a difference of 3.3 Nm concentric peak torque and a difference of 2.63 Nm eccentric peak torque. The experimental group had greater differences when compared to normative data than the control group with a concentric peak torque difference of 12.34 Nm and an eccentric peak torque difference of 33.13 Nm. This comparison suggests that the baseline peak torque strength of the control group was very close to the normative data and the experimental group baseline peak torque strength was lower than the normative data.

A later study conducted by Colliander and Tesch (1989), reported that physically active nondisabled females aged 27 had a quadriceps concentric peak torque value of 227

Nm compared to 151.4 Nm (control) and 142.4 Nm (experimental) in the present study. Colliander and Tesch (1989) reported a quadriceps eccentric peak torque value of 394 Nm compared to 233 Nm (control) and 202.5 Nm (experimental) in the present study. The dynamometer angular velocity for both the present study and the study by Colliander and Tesch (1989) was set at 90 degrees per second. The concentric and eccentric quadriceps actions were performed bilaterally in the Colliander and Tesch (1989) study, compared to unilateral quadriceps actions performed in this study, which may account for the differences in concentric and eccentric peak torque values.

A recent study by Porter et al. (1995) reported concentric and eccentric quadriceps peak torque values demonstrated by participants with similar characteristics to those in the present study. Subjects consisted of females aged 20-29 years with a mean height of 167 cm and a mean weight of 58.9 kg. Approximate values taken from a figure reported by Porter et al. (1995) indicate a concentric peak torque value of 125 Nm and an eccentric peak torque of 160 Nm. Compared to the concentric peak torque value (146.9 Nm) of the entire sample in the present study, the value differed by 21.9 Nm. The eccentric peak torque comparison of the value reported by Porter et al. (1995) and the eccentric peak torque value (217.75 Nm) of the present study differed by 57.75 Nm.

Porter et al. (1995) and the present researcher both used a Kin-Com isokinetic dynamometer set at an angular velocity of 90 degrees per second. To determine peak torque, Porter et al. (1995) averaged the two (of the three) maximal muscle action cycles with the highest peak torque attained. This value was reported as concentric or eccentric peak torque. In the present study the highest torque attained over five maximal actions was reported as peak torque.

When quadriceps relative peak torque (Nm/kg) values of subjects in the present study were compared to normative values reported by Colliander and Tesch (1989), the normative relative peak torque values were higher. Colliander and Tesch (1989), reported that physically active nondisabled females aged 27 had a normative concentric relative peak torque value of 4.03 Nm/kg and a normative relative eccentric peak torque value of 7.02 Nm/kg. This is based on an isokinetic dynamometer knee extension exercise set at 90 degrees per second, which was the speed of the dynamometer used in the present research. The present study reported baseline concentric and eccentric relative peak torque values for the control group to be 2.02 Nm/kg and 3.06 Nm/kg respectively. The baseline concentric and eccentric relative peak torque values for the experimental group were reported at 2.132 Nm/kg and 3.01 Nm/kg respectively.

The present study reported the mean age of female participants in the control group to be 25.5 years and the mean age of the female participants in the experimental group to be 21.7 years. These subjects are younger than the females described in the normative data by Colliander and Tesch (1989), which was a mean age of 27 years. The present study reported no significant difference between the control and experimental group with respect to age. The normative body weight for females reported by Colliander and Tesch (1989) was 57 kg. The mean body weight for the control and experimental groups in the present study was 75.83 kg and 67.3 kg respectively. The higher concentric and eccentric peak torque values and lower body weight values reported by Colliander and Tesch (1989), when compared to the present study, may account for the higher relative peak torque values.

A 1988 study by Highgenboten et al. reported quadriceps relative peak torque data collected using a Kin-Com set at an angular velocity of 50 degrees per second through an 80 degree range of motion, similar to the present study. Subjects were females between the ages of 15-34 years with a mean age of 23.55 years and a mean weight of 57.10 kg. Concentric relative peak torque was reported as 2.12 Nm/kg. This value is marginally higher than the concentric relative peak torque of 2.08 Nm/kg reported in the present study. Eccentric relative peak torque reported by Highgenboten (1988) was 2.36 Nm/kg, slightly lower than the eccentric relative peak torque value of 3.03 Nm/kg reported in the present study.

Effect of Exercise Intervention on Torque

The present study produced results similar to Hasson et al. (1989), who reported significant differences between the control and experimental groups with respect to quadriceps peak torque when an exercise intervention was introduced. Hasson et al. (1989) evaluated muscle performance and muscle soreness at 0 hours (baseline), 24 hours and 48 hours after a 10-minute session of bench stepping to induce DOMS. The exercise intervention consisted of 120 high-speed (300-degrees/second) voluntary maximum concentric quadriceps actions administered at 24 hours post baseline testing using a dynamometer. Concentric peak torque percent decrease from baseline were significantly less ($p<0.05$) for the experimental group than the control group at 48 hours post baseline testing; 3.8% versus 12.1% respectively. The present study showed that the concentric peak torque percent decrease from baseline was significantly less ($p<0.05$) for the experimental group than the for control group at 48 hours; 1.33% versus 14.33%

respectively. The eccentric peak torque percent decrease from baseline was also significantly ($p<0.01$) less for the experimental group than the control group; 2.17% versus 13.99% respectively.

The inflammatory response is believed to begin as rapidly as a few hours after tissue injury and lasts from 24-48 hours (Hasson et al., 1993). In conjunction with tissue injury is an influx of fluid into the muscle resulting in an elevation of intramuscular pressure (Friden et al., 1986) and an increase in limb circumference (Friden et al., 1986; Nosaka and Clarkson., 1996). Progression of muscle edema and increased intramuscular pressure may be related to the delayed onset response of muscle soreness perception. Friden et al., (1986) identified an increase in pressure and volume between 24 and 48 hours in the anterior compartment of the lower limb along with an increase in discomfort. In addition, he also demonstrated individual muscle fiber swelling and an inflammatory response following eccentric exercise. Friden et al., (1986) stated that increased tissue fluid pressure after eccentric exercise is due to the swelling of the compartment. Quadriceps swelling however was not assessed in the present research. In further work, this could be assessed using methods such as measurements of limb circumference or water displacement.

The mechanism for decreasing muscle soreness and performance deficits following high-speed voluntary muscle actions has been proposed to be related to decreased inflammation, or decreased fluid compartmental pressure or both (Hasson et al., 1989). It is postulated that the success of this exercise intervention was related to a reduction in intramuscular pressure through the muscle pump action. If swelling is a contributing factor to perception of pain and neuromuscular function deficits, then

exercise, which promotes fluid movement through the lymphatic system away from the damaged muscle would be expected to result in decreased soreness and have protective effects on neuromuscular deficits (Stauber, 1996). Exercise would be expected to move fluid out of the muscle and reduce swelling. However, this has yet to be proven and was not directly addressed in this investigation.

The present study and the study conducted by Hasson et al. (1989) differed in the equipment used to administer the soreness inducing exercise session, the exercise intervention, the action types and speed of the exercise intervention, and the number of actions involved in the intervention. Despite these differences, the findings of both studies indicate that high-speed voluntary actions are effective in decreasing DOMS and facilitating return of normal muscle performance.

Three other investigations using exercise as a treatment did not find any reduction in DOMS signs and symptoms (Donnelly et al., 1992; Isabell et al., 1992; Weber et al., 1994). The investigation conducted by Isabell et al., (1992) had a mixed gender group of twenty-two subjects, 11 males and 11 females from a group of volunteers participating in a basketball activity class. They investigated the effects of exercise, ice massage with exercise and ice massage, on the prevention and treatment of DOMS. Baseline measures were recorded for biceps flexion (concentric) strength and perceived soreness. Elbow flexion peak torque was assessed using a dynamometer set at 60 degrees/second. Subjects performed 8-10 maximal actions and the average of the three highest peak scores was recorded as peak torque. To induce muscle soreness, subjects performed up to 300 concentric/eccentric actions of the elbow flexors with 90% of their 10 repetition maximum. Dependent variables were assessed at 2, 4, 6, 24, 48, 72, and 96 hours post-

exercise. The exercise intervention consisted of elbow flexion and extension exercise with gravity as the only resistance, administered at 0, 2, 4, 6, 24, 48, 72, and 96 hours post DOMS inducement. Subjects performed continuous repetitions during a 20-second period, then rested their arms for 40 seconds. This exercise/rest regimen was repeated for 15 minutes.

Isabell et al., (1992) demonstrated significant differences that occurred in all variables with respect to time ($p,<0.05$), however no significant mode of treatment/assessment time interaction was present. Similar to the present study, decreases in concentric peak torque corresponded with increases in perceived soreness. According to Isabell et al. (1992), the non-significant mode of treatment/assessment time interaction suggests that the use of ice massage, ice massage with exercise, or exercise alone is not effective in significantly reducing the symptoms of DOMS. Although not statistically significant, the pattern of change appeared to favor the exercise group with respect to peak torque and soreness levels when compared to the control group. The peak torque for the control group decreased 20.69% and peak torque for the exercise group decreased 9.5%. Perceived soreness was assessed using the Talag scale where (1) = No Pain and (7) = Unbearable Pain. All groups had a rating of 0 indicating no pain at the pre-test measurement time. Soreness peaked at 48 hours for all groups. However the exercise group had the lowest score at 48 hours of approximately 2.75, considerably lower than the control group which produced a score of approximately 3.75 at 48 hours.

The obvious difference between the study conducted by Isabell (1992) and the present study was the exercise intervention itself. In the Isabell (1992) study, no external load was used while the present study used 50% of the 1RM. Isabell (1992) also

employed the intervention at 8 separate times over the course of the 5 day study compared to the one time intervention at 24 hours in the present study. However, the repetitive movement patterns for both the soreness inducing exercise session and the exercise intervention were the same in both studies, consisting of both concentric and eccentric muscle actions. Other similarities include the method and the load used to induce soreness. The present study utilized a load of 80 percent 1RM using a leg extension exercise and Isabell (1992) utilized a load of 90 percent 1RM using an elbow flexion exercise. For both studies, each set was separated by a 1-minute rest period and consisted of both concentric and eccentric actions. The absence of a load during the exercise intervention Isabell (1992) used was most likely the reason that, when compared to the present study, the findings were different.

Weber et al. (1994) determined that exercise, specifically upper body ergometry was not an effective intervention to reduce or alleviate soreness and force deficits associated with DOMS. Weber (1994) used 40 healthy, untrained volunteer female subjects between the ages of 18 and 35 from the local community and university as participants. The subject population, similar to the present study, limited subject population to females in order to maintain more homogeneous groups; in particular, to limit any gender-related variability in muscle mass and its impact on the force data and the potential response to DOMS. All subjects were instructed to refrain from physical activity, medication, or any other therapeutic intervention for the 48-hour testing period. Baseline peak torque and soreness levels were recorded using a dynamometer and a Talag scale respectively. The soreness inducing exercise was introduced. This consisted of high intensity eccentric exercise of the elbow flexors using an arm curl weight

machine. One repetition maximum was determined and subjects were required to lower the weight (eccentric action) over a five-second count. The investigator, without assistance from the subject, then returned the weight to the starting position. This was repeated for a maximum of 10 repetitions or until the subject could no longer control the lowering of the weight. At the end of each set, after a one-minute rest, the weight was decreased by one-half of a plate and the regimen continued until the subject could no longer complete 10 repetitions in one set with the lowest plate.

The exercise intervention was administered immediately following the soreness inducing exercise session and again at 24 hours after peak torque and soreness ratings were recorded. The intervention consisted of eight minutes of concentric upper body ergometry with the ergometer set at 60 repetitions per minute. Peak torque and soreness ratings were recorded for the final time at 48-hours post baseline testing.

Similar to the present study, there was no significant difference between groups at baseline for peak torque. However, Weber noted a significant decrease in peak torque for the control group and the experimental group between 0 and 48 hours. The present study found a significant difference between 0 and 48 hours for the control group only, suggesting that the exercise intervention had a protective effect on neuromuscular function for the experimental group. According to Weber (1994), exercise in the form of upper body ergometry was not effective in reducing soreness or toque deficits, as there were no differences in the soreness ratings or torque deficits measured in the subjects in the experimental group compared with those in the control group.

In a similar study conducted by Donnelly et al. (1992), the effects of light eccentric exercise on damaged muscle was investigated. An experimental and a control

group, both consisting of nine subjects performed two heavy bouts (HB) of eccentric exercise, HB1 and HB2, 14 days apart, using the elbow flexor muscles of the non-dominant arm. The experimental group performed an additional light bout (LB) on the day following HB1. All exercise sessions were performed on a dynamometer set at 105 degrees per second. The HBs consisted of 70 maximal eccentric muscle actions. The LB of 25 such cycles was performed with all parameters identical to those in HB1 and HB2, except the dynamometer was set to cease movement if the torque produced exceeded 50 percent of the maximum torque produced during HB1.

Maximal voluntary isometric muscle action (MVC) strength and muscle soreness were recorded before HB1 and HB2, and at 24-hour intervals for five days after each HB. Muscle soreness was rated on a similar scale to that used in the present study, which was a scale from 1 (normal) to 10 (very sore). Results indicated that the LB did not alter muscle soreness or strength when compared to the control group. Muscle soreness developed in the biceps and peaked for both groups at 48 hours after HB1, and declined thereafter with soreness levels reaching baseline levels at five days post HB, which correspond to the results in the present study.

The study conducted by Donnelly (1992) and the present study differed in several aspects. Firstly the soreness inducing exercise session and the exercise intervention were performed on a dynamometer compared to resistance training apparatus. Secondly, the biceps actions, for both the HB and the LB consisted only of eccentric actions compared to concentric and eccentric action of the quadriceps used in the present research. The difference in results may be explained by the fact that concentric muscle actions at submaximal levels do not produce tissue damage and therefore do not elicit an

inflammatory response. Additionally, concentric muscle actions are associated with much lower intramuscular pressure and muscle edema, possibly due to the muscle pump effect. Donnelly (1992), excluded concentric actions from the soreness inducing exercise and from the exercise intervention.

There were no other published studies located that examined the impact of exercise on DOMS. A number of differences exist between the protocols used in the studies previously described and the present study, including the type and intensity of the soreness inducing exercise, the type and intensity of the exercise intervention, the muscle groups involved, and the time at which the exercise intervention was administered. All or several of these differences may have contributed to the difference in the success of the exercise intervention. It is the opinion of the researcher that the different protocols are the key reasons for differences in the outcomes of the studies. As mentioned earlier, these studies differed somewhat in terms of both participant group and testing protocols, therefore, the comparisons should be viewed with caution.

Effects of Exercise Intervention on Vertical Jump

The vertical jump values displayed non-significant differences between the control and experimental groups at baseline and post-test. From baseline to post-test the decreases in vertical jump height were 4.3 cm for the control group and 1.2 cm for the experimental group. There was a significant difference from baseline to post-test for the control group ($p<0.05$) but not for the experimental group. These results indicate that there was less of a decrease in vertical jump height for the experimental group. This

finding suggests that the exercise intervention may have had a protective effect on vertical jump performance.

Compared to norms reported by CSEP (1998), average females 20-29 years of age, which have a vertical jump height between 28 and 39 cm are in the "Very Good" zone. Both the control and the experimental groups fall into this range with baseline mean scores of 30.12 cm and 27.6 cm respectively.

Visual Analog Scale

With respect to the visual analog scale questions, there were significant differences between testing times for both the control and experimental groups, which concur with previous research using pain scales while determining DOMS pain levels (Hasson et al., 1989; Ciccone et al., 1991; Weber et al., 1994; Nosaka, Clarkson, 1995; Craig et al., 1996; Giamberardino et al., 1996; Gulick et al., 1996; Bourgeois et al., 1999). It appears that the soreness inducing exercise session used in the present research was sufficient in inducing muscular soreness. However, there were no significant differences in muscle soreness between groups within any time period as measured by the VAS.

Time Differences Between Groups

Although the control and experimental groups behaved similarly over time with respect to all three of the VAS questions, there were differences between the two groups.

With respect to question number one, "What is the current level of pain you are experiencing?" the experimental group demonstrated a significant difference between 24

hours and 48 hours where the control group did not. When compared to the control group at 24 hours, the experimental group had a higher score of 0.42 cm but this was not significant. When compared to the control group at 48 hours the experimental group demonstrated a lower score by 0.44 cm. By the 72-hour assessment time, both groups dropped to within 0.09 cm of each other. The pattern of this data suggests that the control groups' soreness peaked at 48 hours and the experimental groups' soreness peaked at 24 hours. Both groups had mean scores of 0 at the baseline assessment time, therefore, the difference in peak soreness between the control and the experimental group is likely due to the exercise intervention that was administered to the experimental group.

The "movement" referred to in visual analog scale question number two "What is the level of pain associated with the movement?" is movement in relation to the quadriceps. For example, this could refer to walking, ascending or descending stairs, or rising from or sitting down in a chair. The control and experimental groups behaved similarly with the exception of the baseline to 96 hour assessment time comparison. The control group demonstrated a significant difference between these two assessment times, where the experimental group did not. The VAS score for the control group at 96 hours was 0.14 cm higher than the experimental group VAS score at the same time. This suggests that although both groups were nearing baseline levels by the 96-hour assessment time, the control group was not as close to the baseline value as the experimental group was. It is possible that this very small difference may be due to recorder error, or, more likely, the exercise intervention.

Visual analog scale question number three "To what extent does this pain limit your ability to function?" revealed two time periods where the control group significantly

differed from assessment times when the experimental group did not; between the 48 hour and the 72 hour assessment times and the 72 hour and the 96 hour assessment times. The control group demonstrated a peak VAS score at 48 hours, as did the experimental group. The peak VAS score for the control group at the 48-hour assessment time was 0.50 cm higher than the peak VAS score of the experimental group at the same assessment time. The difference between the two groups at 72 hours was 0.10 cm. The control group had a larger decrease in VAS score from 48 hours to 72 hours than the experimental group did. Similar to VAS question number two, both groups were near baseline values at the 96 hour assessment time with the difference between the two groups being 0.08 cm.

This VAS data subjectively demonstrates that by 96 hours after the soreness inducing exercise session, participants were experiencing only residual soreness and that their ability to function normally had returned almost completely to pre-soreness levels.

Effect of DOMS on Visual Analog Scale Scores

Using a soreness inducing protocol similar to the present study, Bourgeois (1999) induced soreness of the quadriceps. The exercise consisted of six sets of 10 repetitions of a knee extension exercise (concentric and eccentric phases) using standard weight training equipment, at an intensity of 80-85% of the baseline concentric 1RM. The reasons for using this method of soreness inducement was similar to the reasons for the similar method implemented in this study. The researcher purposefully chose a concentric/eccentric exercise testing protocol because this is the usual exercise mode

encountered. Purely eccentrically based exercise is rarely encountered in sports or activities of daily living.

A 100-mm (10 cm) visual analog pain scale with descriptor terms of "no discomfort" (0 mm) to "maximal discomfort" (100 mm) was administered to each of the subjects at 24 hours and 48 hours post-exercise. This scale was used to determine the degree of discomfort in the quadriceps muscle group after the exercise. The results were significant DOMS at 24 hours and at 48 hours as compared to baseline values. Similar results were demonstrated by both the control and the experimental group in the present study. VAS values in this study were within close range of those reported by Bourgeois (1999). VAS values were not recorded beyond 48 hours by Bourgeois (1999) therefore it is unknown whether or not the VAS scores would have returned to near baseline values by 96 hours post soreness inducing exercise session, as they did in this study.

The purpose of a study by Gulick et al., (1996) was to identify a treatment method which could assist in the recovery of DOMS. Using the wrist extensors to induce DOMS, Gulick et al. (1996) had participants perform 15 sets of 15 eccentric wrist actions using a dynamometer set at 30 degrees per second. Immediately following the eccentric exercise session, participants performed 10 minutes on an upper body ergometer with no resistance followed by 10 minutes of rest. Muscle soreness was assessed using a 10-cm visual analog pain scale with the descriptor "no soreness at all" at one end and "soreness as bad as it could be" at the other. Each subject placed a line through the 10-cm VAS line to describe the amount of muscle soreness that was presently perceived. Measurements were taken at baseline, 24, 48, and 72 hours after the eccentric exercise bout. Similar to the Bourgeois (1999) study previously described, and the present study,

peak soreness values occured at 48 hours. By 72 hours, soreness had decreased to near baseline measures. The upper body ergometer exercise intervention was not successful in alleviating DOMS.

Contrary to the present study, Hasson (1989) demonstrated significant differences between the control and the experimental group using exercise as an intervention at 24-hours. The method of assessing quadriceps muscle soreness differed when compared to the present research. Hasson (1989) used a metal probe attached to a load cell. At grid intercepts of 2 cm apart over the quadriceps musculature, a gradually increasing force was applied up to a maximum of 50 newtons. The subject was asked to verbally indicate when the sensation of pressure changed to one of discomfort. The amount of force was then recorded. Muscle soreness was assessed at baseline, 24 and 48 hours post soreness inducing exercise. At 48 hours, when DOMS typically peaks, the soreness was significantly less in the experimental group than the control group ($p<0.05$). In the present study no significant differences between the control and experimental groups were found.

In summary, the VAS provided a useful tool to assess muscle soreness. The VAS was able to provide the information necessary to determine baseline soreness levels, time of peak soreness and the time at which soreness levels returned to near baseline levels. To provide even more information the VAS scores could have been recorded at twelve-hour time intervals as opposed to 24-hour intervals, and assessment times could have also been extended beyond the 96-hour time period. The extension in time would likely not reveal any additional information due to the fact that both the experimental group and the control group had returned to near baseline VAS values by that time.

There was a difference between muscle soreness and muscle function in the present research. There was no significant difference between the two groups at any data collection point for the Visual Analog Scales, however the control group demonstrated a significant difference between baseline and post-test for all performance variables with the exception of angle of peak torque. The exercise intervention had a protective effect on performance for the experimental group as there were no significant differences between baseline and post-test for any of the performance variables. Because the control group and the experimental group behaved similarly with respect to soreness scores but differently with respect to performance, the perceived soreness appeared not to have a significant effect on performance for the experimental group. The exercise intervention received by the experimental group may have caused tissue fluid changes within the quadriceps muscle compartment due to the muscle pump action thereby decreasing the neuromuscular function deficits. Based on this research, there appears to be a difference between the pain mechanism and the mechanism for neuromuscular function.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the effects of a specific exercise intervention on Delayed Onset Muscle Soreness (DOMS) and neuromuscular function. This was done to assess the accuracy of the present belief of the active population that "working it out" through strenuous exercise is beneficial in reducing the negative strength deficits and muscle soreness associated with DOMS. The hypothesis of this study was that a specific exercise intervention would be an effective method of decreasing or minimizing the negative strength deficits and muscle soreness associated with DOMS.

The data was collected on 20 female subjects between the ages of 19-35. Subjects were randomly placed into two groups of ten, the control and the experimental groups. Subjects had not participated in any specific eccentric training or experienced any DOMS for a six-week period preceding the testing sessions and had not used non-steroidal anti-inflammatory drugs for 48 hours prior to the soreness inducing exercise session. Dependent variables included peak torque and average torque, which were assessed using the Kin-Com isokinetic dynamometer set at an angular velocity of 90 degrees/second, vertical jump height, and perceived quadriceps muscle soreness using a visual analog scale. Data was collected at baseline (0 hours) and 48 hours for the performance variables, and at baseline, 24, 48 72, and 96 hours for the perceived soreness scale variables.

A strenuous quadriceps exercise session was introduced to each subject immediately after baseline testing. This soreness inducing exercise session consisted of seven sets of a maximum of 12 repetitions of a bilateral quadriceps extension exercise using the quadriceps extension weight machine. The weight used was 80% of 1RM concentric quadriceps contraction determined prior to data collection. Both concentric and eccentric contractions were performed with a contraction rate of three seconds per contraction type (i.e. three seconds concentric quadriceps contraction, three seconds eccentric quadriceps contraction) with a one-minute rest in between sets.

An exercise intervention was introduced to the experimental group 24-hours following the soreness inducing exercise session. The exercise intervention consisted of six sets of 12 repetitions of a quadriceps extension exercise, using a weight of 50% 1RM. The control group received no exercise intervention.

In comparing the peak torque data, it was noted that the mean values for both the control and the experimental groups were close to the normalized data for females similar in age and physical condition. There were no significant differences between the two groups at either baseline or post-test times. There was however, a significant difference between the two data collection time points for the control group but not for the experimental group, which indicates that the exercise intervention that was received by the experimental group had a positive effect on peak torque scores when compared to the control group.

When relative peak torque was calculated by dividing peak torque (Nm) by body weight (kg), the results were the same as for peak torque. There were significant differences between the baseline and post-test means for the control group and there were

no significant differences between the baseline and the post-test means for the experimental group. This data suggests that the exercise intervention significantly decreased torque output for the control group when compared to the experimental group.

Mean values for average torque between groups demonstrated no significant differences. However, there were significant differences between baseline and post-test mean values for the control group, but not for the experimental group. Again, this data supports the hypothesis, which stated that the exercise intervention would help reduce performance deficits for the experimental group when compared to the control group.

Vertical jump comparisons between groups demonstrated no significant differences at either baseline or post-test measures. The control group showed a significant difference between the baseline and post-test measures, and the experimental group also demonstrated a significant difference between times. The exercise intervention did not have a similar effect on vertical jump as was seen for torque values.

The three visual analog scale questions revealed no significant differences between groups at any of the five data collection points. Within group comparisons showed significant differences between times for both the control and the experimental groups, which indicate that the intensity of the soreness inducing exercise session was sufficient in inducing DOMS. All subjects indicated "no pain" at baseline testing and each group indicated a mean peak soreness and quadriceps functional impairment between 24 and 48 hours post soreness inducing exercise.

Conclusions

Based on the results of the present study, the following conclusions appear justified:

1. The exercise intervention was successful in significantly limiting the amount of decrease in quadriceps concentric peak torque following the soreness inducing exercise session for the experimental group when compared to the control group.
2. The exercise intervention was successful in significantly limiting the amount of decrease in quadriceps eccentric peak torque following the soreness inducing exercise session for the experimental group when compared to the control group.
3. The exercise intervention was successful in significantly limiting the amount of decrease in quadriceps concentric average torque following the soreness inducing exercise session for the experimental group when compared to the control group.
4. The exercise intervention was successful in significantly limiting the amount of decrease in quadriceps eccentric average torque following the soreness inducing exercise session for the experimental group when compared to the control group.
5. Following the soreness inducing exercise session, the concentric angle to peak torque for the control group did not change significantly.
6. Following the soreness inducing exercise session, the eccentric angle to peak torque for the control group did not change significantly.
7. The exercise intervention demonstrated no significant effect in altering the concentric angle to peak torque following the soreness inducing exercise session for the experimental group.

8. The exercise intervention demonstrated no significant effect in altering the eccentric angle to peak torque following the soreness inducing exercise session for the experimental group.
9. Vertical jump scores decreased significantly for the control group following the soreness inducing exercise session.
10. Vertical jump scores did not decrease significantly for the experimental group following the soreness inducing exercise session and the exercise intervention.
11. The exercise intervention did not produce significant differences between groups with respect to time for any of the three visual analog scales.
12. The soreness inducing exercise session produced significant results within groups with respect to time for the control group for all of the three visual analog scales.
13. The soreness inducing exercise session produced significant results within groups with respect to time for the experimental group for all of the three visual analog scales.

Recommendations

Based on the present study, the following recommendations are made for future studies that intend on using a similar methodology:

1. The Kin-Com dynamometer angular velocity that was used in the present study (90 degrees per second) could be combined with both slower and faster angular velocities. The slower and faster angular velocities may be useful in providing information with respect to quadriceps peak torque, angle to peak torque and

average peak torque at both slower and faster speeds after the induction of DOMS.

2. More data collection points with respect to all performance variables could be recorded, such as every 24 hours following baseline assessment. This information may be useful in determining the length of time required for performance values to return to baseline levels.

3. Different intervention methods that were mentioned in the literature review such as the use of NSAIDs, could be combined with exercise or used alone to determine the effects of other modalities on neuromuscular function and perceived soreness.

4. A different type of exercise intervention varying the equipment used or the intensity or type of contraction could be explored.

5. The exercise intervention could be administered at several different time points after the soreness inducing exercise session. This would help provide information regarding the optimal time to implement exercise as an intervention.

6. The age group or gender of subjects could be modified to cover a broader range of individuals. This would help in determining intervention strategies across a more general population.

7. From a clinical perspective there should be more data collection points to indicate the time of onset of muscle soreness using the Visual Analog Scales.

8. From a clinical perspective physical signs of DOMS such as muscle swelling and muscle tenderness should also be evaluated by the therapist or physician.

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Appendix A

Example of the Subject Information Sheet that was used

Subject Information Sheet

Name:_____ **Age:**_____

Address:_____

Phone Number:_____

Intervention Group:_____ Control Group:_____

MEASUREMENTS:

Height (cms): _____

Mass (kg): _____

BASELINE VERTICAL JUMP HEIGHT (cms):

Standing Reach Height:_____

Trial #1: _____

Trial #2: _____

Trial #3: _____

Best jump height value: _____

MAXIMAL VOLUNTARY CONCENTRIC ACTION (lbs):

MVC: _____

80% MVC: _____

SORENESS INDUCING EXERCISE SESSION:

Repetitions performed per set (indicated by a √).

	SET #1	SET #2	SET #3	SET #4	SET #5	SET #6	SET #7
Repetition 1							
Repetition 2							
Repetition 3							
Repetition 4							
Repetition 5							
Repetition 6							
Repetition 7							
Repetition 8							
Repetition 9							
Repetition 10							
Repetition 11							
Repetition 12							

EXERCISE INTERVENTION:

50% MVC: _____

Repetitions performed per set (indicated by a √).

	SET #1	SET #2	SET #3	SET #4	SET #5	SET #6
Repetition 1						
Repetition 2						
Repetition 3						
Repetition 4						
Repetition 5						
Repetition 6						
Repetition 7						
Repetition 8						
Repetition 9						
Repetition 10						
Repetition 11						
Repetition 12						

POST-TEST VERTICAL JUMP HEIGHT (cms):

Trial #1: _____
Trial #2: _____
Trial #3: _____
Best jump height value: _____

Date of Session #1: _____
Date of Session #2: _____
Date of Session #3: _____

Length of Lever Arm:_____
Seat Back Position:_____
File name baseline:_____ File name 48 hours:_____
Subject #:_____

Appendix B

Example of the Adult Informed Consent that was used

Adult Informed Consent

You have volunteered to participate in a study entitled "The Effects of a Specific Exercise Intervention on Delayed Onset Muscle Soreness (DOMS) And Neuromuscular Function". This study is a topic of a master's thesis being completed by the Investigator, Mikie Mork, a graduate student in the Faculty of Physical Education and Recreation Studies.

The only requirements are that you are female between the age of 18 and 35, have not participated in downhill running, lower body resistance training, stair training, or aerobics classes in the previous 6 weeks. You agree to refrain from participating in any activities outside of your activities of daily living for the duration of the testing period. You will not take any anti-inflammatory or pain medications and will not apply any heat, ice, any other therapeutic modality or topical analgesics to your thigh muscles. In addition, you are presently free from knee or thigh muscle injury and know of no medical reason, which would indicate that participating in this research would be of any risk.

In the present study you, being classified as a healthy female, will be randomly placed into one of two study groups at the time of your initial visit to the Biomechanics Lab at the University of Manitoba. Your height and weight will be recorded. You will be required to perform a 5-minute warm-up on a stationary cycle. Strength of the thigh muscles will be assessed using the KIN-COM isokinetic dynamometer. This strength assessment consists of performing a resistance exercise with a computer to measure the force that you are applying. Next, your maximum vertical jump height will be assessed. Following these assessments, you will be required to perform maximal thigh contractions on a leg extension machine. You will be likely to experience some soreness in the thigh muscles following this exercise. This initial session should take approximately one hour.

Depending on which group you have been assigned to, you may or may not be required to return to the Biomechanics Lab 24 hours after the initial test session. If you are required to return at this time, you will be required to perform some light thigh contractions on the same leg extension machine used the day before. This session should take approximately 30 minutes.

You will be required to return to the Biomechanics Lab 48 hours after the initial test session. At this time you will be required to perform a warm-up on a stationary cycle. Strength of the thigh muscles will be assessed using the KIN-COM isokinetic dynamometer. Next, your maximum vertical jump height will be assessed. This last session should take approximately 30 minutes

In addition, you will be required to fill out a visual analog scale (a self report of your pain level) every 24 hours for the following 4 days starting at the time of your initial test session. You will be asked to mail or deliver (whichever is more convenient for you) the completed scales to the investigator after the 4 days of recording is finished. You will be provided with a stamped envelope for your convenience.

Your participation is completely voluntary and you are free to stop your participation at any time without any type of penalty. You are free to ask any questions of the investigator at any time and will receive a clear and honest response. The investigator will record all information, however, your data will remain confidential and will be stored in a locked environment at the University of Manitoba. The recorded data will not be redistributed or used for any purpose other than the present study. Your identity will not be revealed at any time without your written consent.

Do you have any questions?
Should you have questions at a later date, please contact us at any time.

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Health, Leisure and Human Performance Research Institute
The University of Manitoba
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Health, Leisure and Human Performance Research Institute
The University of Manitoba
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The Education/Nursing Research Ethics Board has approved this study. Any questions or concerns regarding a procedure may be reported to the Human Ethics Secretariat at 474-7122 or to Dr. Jennifer Mactavish, Head of the researcher's department at 474-8627.

I _____, have read the above information and understand the testing procedures, the risks involved, and I agree to participate. I acknowledge that I may experience muscle soreness and that the testing procedures are within my capability. I also understand that I have the right to withdraw at any time with no repercussions. I also have the right to ask for and receive feedback and summary information in regards to this study. In case of injury, I relieve the University of Manitoba and the Investigator of any liability that may arise as the result of my participation.

_____ _____
Signature of Investigator Date

_____ _____
Signature of Participant Date

_____ _____
Signature of Witness Date

Appendix C

Example of the Visual Analogue Scales that were used

Visual Analog Scale

What is the current level of pain you are experiencing?

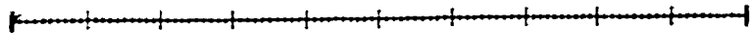
No Pain |——————————————————————————————| Worst Imaginable Pain

What is the level of pain associated with the movement?

No Pain |——————————————————————————————| Worst Imaginable Pain

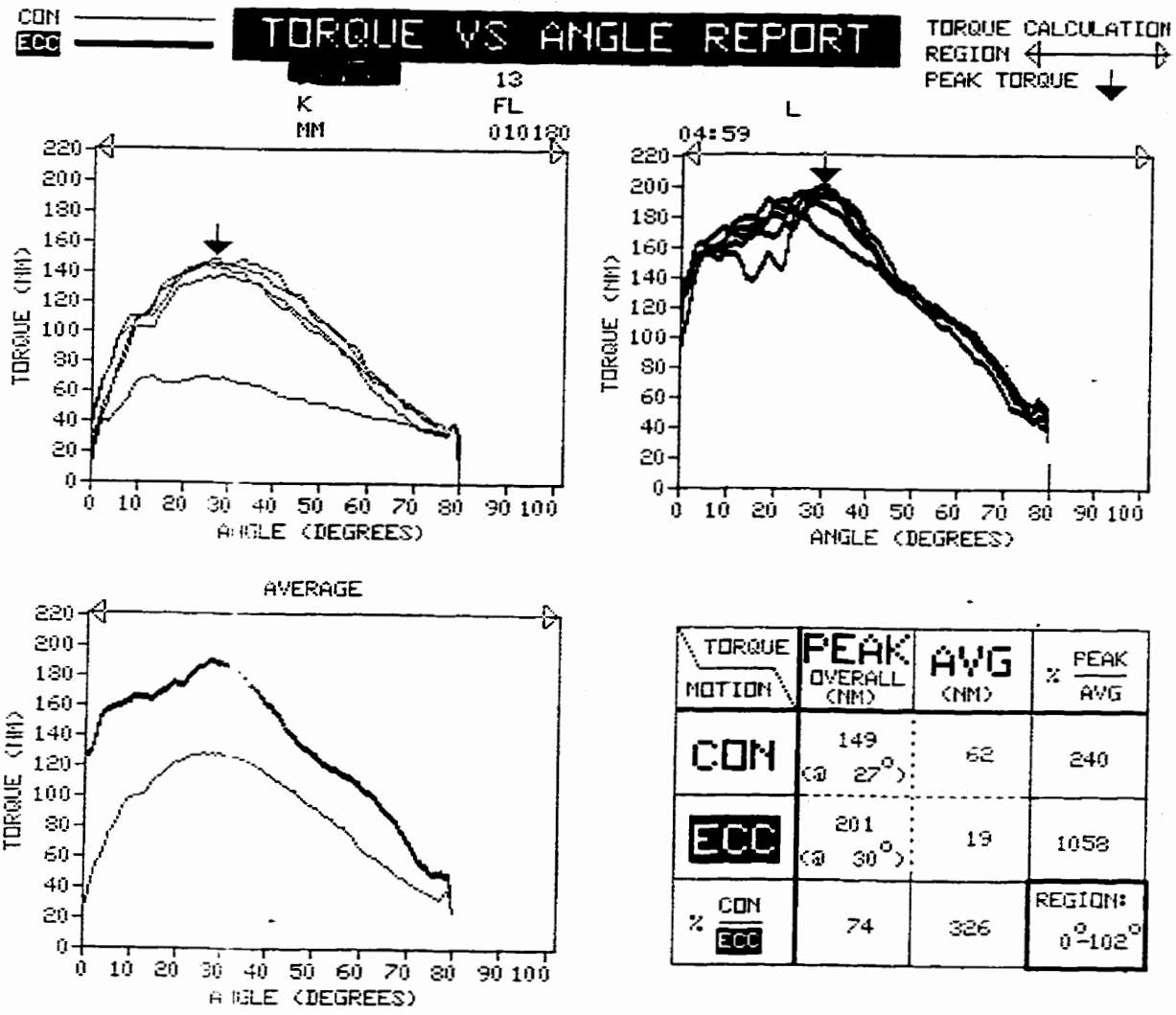
To what extent does this pain limit your ability to function?

No effect |——————————————————————————————| Incapacitated



Appendix D

Example of Kin-Com generated report displaying Peak Torque and Angle of Peak Torque

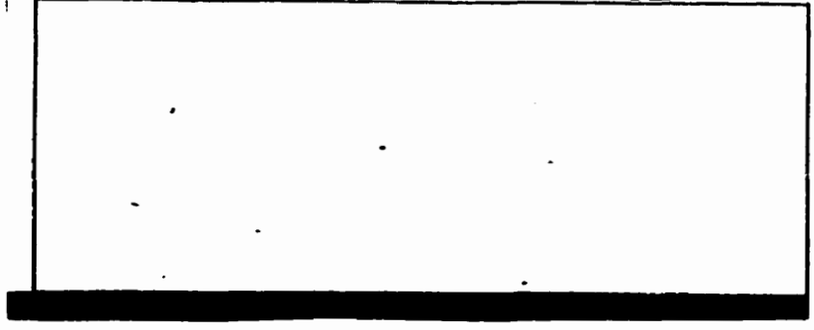

CON
ECC
TORQUE VS ANGLE REPORT
TORQUE CALCULATION
REGION
PEAK TORQUE
13
K
FL
MM
010180
L
04:59
TORQUE (NM)
ANGLE (DEGREES)
AVERAGE
TORQUE | PEAK OVERALL (NM) | AVG (NM) | % PEAK/AVG
MOTION
CON | 149 (@ 27°) | 62 | 240
ECC | 201 (@ 30°) | 19 | 1058
% CON/ECC | 74 | 326 | REGION: 0°-102°

Appendix E

Example of Kin-Com generated report displaying Average Torque

ANGLE	TORQUE		
	MIN	AVG	MAX
CONCENTRIC			
-8	-48.9	-88.5	-109.9
-16	-66.3	-113.1	-135.7
-24	-70.5	-128.9	-147.9
-32	-67.5	-128.2	-149.4
-40	-60.5	-117.0	-143.0
-48	-53.9	-101.1	-122.0
-56	-48.8	-82.4	-96.5
-64	-42.9	-60.0	-72.0
-72	-35.7	-43.2	-50.1
-80	0.3	-15.5	-33.3
ECCENTRIC			
80	0.3	8.5	-26.7
72	-48.0	-57.1	-65.7
64	-81.6	-91.0	-98.4
56	-106.8	-114.3	-119.3
48	-126.0	-131.2	-135.9
40	-147.0	-158.3	-168.9
32	-160.5	-185.2	-195.9
24	-179.2	-187.6	-197.8
16	-145.7	-173.2	-193.5
8	-154.8	-164.4	-174.4

ANATOMICAL REFERENCE



Appendix F

Individual Subject Results

C = Conrol group
E = Experimental group

Table F-1 Control group subject characteristics

Subject	Group	Age (yr)	Height (cm)	Mass (kg)
1	C	20	170	77
3	C	21	174	66.3
7	C	30	164	100
10	C	20	170.5	68
11	C	28	166	78
12	C	24	171	64
14	C	19	173.5	84
16	C	27	168	75
19	C	31	161.5	56
20	C	35	169.5	90

Table F-2 Experimental group subject characteristics

Subject	Group	Age (yr)	Height (cm)	Mass (kg)
2	E	19	160.5	70.5
4	E	23	173.5	83.5
5	E	20	167	63.5
6	E	22	173.5	71
8	E	21	168.5	70.5
9	E	19	181.5	75.5
13	E	22	166	60.5
15	E	24	168	62.5
17	E	26	166.5	45.5
18	E	21	167	70

Table F-3 Control group baseline and post-test average concentric and eccentric average torque values

Subject	Group	Baseline concentric average torque	Baseline eccentric average torque	Post-test concentric average torque	Post-test eccentric average torque
1	C	101.8	187.14	106.15	171.29
3	C	93.26	131.11	68.17	97.52
7	C	72.97	126.31	49.06	138.79
10	C	107.85	137.14	77.6	87.81
11	C	62.58	118.19	83.15	121.75
12	C	77.81	93.59	72.58	81.58
14	C	77.82	123.65	56.24	97.44
16	C	59.17	132.77	43.83	95.57
19	C	71.26	75.73	60.71	73.66
20	C	106.39	141.28	98.37	109.64

Table F-4 Experimental group baseline and post-test concentric and eccentric average torque values.

Subject	Group	Baseline concentric average torque	Baseline eccentric average torque	Post-test concentric average torque	Post-test eccentric average torque
2	E	72.15	83.22	70.99	105.87
4	E	92.52	136	98.91	105.03
5	E	69.32	99.53	71.19	97.01
6	E	80.16	149.87	97.65	164.12
8	E	103.83	148.45	73.81	104.39
9	E	97.71	130.54	89.07	126.81
13	E	87.23	125.97	87.79	127.08
15	E	72.99	67.4	70.63	91.98
17	E	63.31	81.71	58.21	65.78
18	E	104.05	122.29	95.15	123.78

Table F-5 Control group baseline and post-test concentric and eccentric peak torque values

Subject	Group	Baseline concentric peak torque	Baseline eccentric peak torque	Post-test concentric peak torque	Post-test eccentric peak torque
1	C	189	342	164	289
3	C	192	225	136	196
7	C	155	260	105	231
10	C	164	217	129	155
11	C	138	203	156	225
12	C	118	176	126	158
14	C	161	232	103	180
16	C	113	215	86	163
19	C	103	134	106	136
20	C	181	326	186	271

Table F-6 Control group baseline and post-test concentric and eccentric angle to peak torque values

Subject	Group	Baseline concentric angle to peak torque	Baseline eccentric angle to peak torque	Post-test concentric angle to peak torque	Post-test eccentric angle to peak torque
1	C	26	16	24	24
3	C	22	18	18	16
7	C	20	19	33	29
10	C	31	23	24	32
11	C	31	23	29	24
12	C	22	20	28	23
14	C	30	26	31	21
16	C	27	25	19	20
19	C	27	21	24	17
20	C	19	10	24	8

Table F-7 Experimental group baseline and post-test concentric and eccentric peak torque values.

Subject	Group	Baseline concentric peak torque	Baseline eccentric peak torque	Post-test concentric peak torque	Post-test eccentric peak torque
2	E	128	171	111	171
4	E	149	223	164	177
5	E	137	194	136	197
6	E	138	252	148	284
8	E	153	251	118	187
9	E	170	241	173	248
13	E	145	193	149	201
15	E	142	123	142	177
17	E	103	150	98	124
18	E	159	227	166	215

Table F-8 Experimental group baseline and post-test concentric and eccentric angle to peak torque values.

Subject	Group	Baseline concentric angle to peak torque	Baseline eccentric angle to peak torque	Post-test concentric angle to peak torque	Post-test eccentric angle to peak torque
2	E	21	32	22	27
4	E	37	38	37	33
5	E	26	11	24	10
6	E	27	24	34	28
8	E	29	24	22	13
9	E	20	15	27	9
13	E	28	22	27	30
15	E	28	36	27	27
17	E	32	28	27	24
18	E	24	28	24	36

Table F-9 Control group baseline and post-test concentric and eccentric relative peak torque values.

Subject	Group	Baseline concentric relative peak torque	Baseline eccentric relative peak torque	Post-test concentric relative peak torque	Post-test eccentric relative peak torque
1	C	2.45	4.44	2.13	3.75
3	C	2.90	3.39	2.05	2.96
7	C	1.55	2.60	1.05	2.31
10	C	2.41	3.19	1.90	2.28
11	C	1.77	2.60	2.00	2.88
12	C	1.84	2.75	1.97	2.47
14	C	1.92	2.76	1.23	2.14
16	C	1.51	2.87	1.15	2.17
19	C	1.84	2.39	1.89	2.43
20	C	2.01	3.62	2.07	3.01

Table F-10 Control group baseline and post-test concentric and eccentric relative peak torque values.

Subject	Group	Baseline concentric relative peak torque	Baseline eccentric relative peak torque	Post-test concentric relative peak torque	Post-test eccentric relative peak torque
2	E	1.82	2.43	1.57	2.43
4	E	10.78	2.67	1.96	2.12
5	E	2.16	3.06	2.14	3.10
6	E	1.94	3.55	2.08	4.00
8	E	2.17	3.56	1.67	2.65
9	E	2.25	3.19	2.29	3.28
13	E	2.40	3.19	2.46	3.32
15	E	2.27	1.97	2.27	2.83
17	E	2.26	3.30	2.15	2.73
18	E	2.27	3.24	2.37	3.07

Table F-11 Control group baseline and post-test vertical jump values.

Subject	Group	Baseline vertical jump	Post-test vertical jump
1	C	32.5	32
3	C	36	30
7	C	16	13.5
10	C	49	33
11	C	39.5	34.5
12	C	25	21
14	C	30.5	23.5
16	C	13.5	11.5
19	C	26.7	29.7
20	C	32.5	29.5

Table F-12 Experimental group baseline and post-test vertical jump values.

Subject	Group	Baseline vertical jump	Post-test vertical jump
2	E	28	25
4	E	22.5	20
5	E	29	26
6	E	26.5	27.5
8	E	29.5	28
9	E	27.5	27.5
13	E	31	30
15	E	27	26.5
17	E	23	22.5
18	E	32	31

Table F-13 Control group values for VAS question number one " What is the level of pain you are currently experiencing?" at 0, 24, 48, 72, and 96 hours.

Subject	Group	Q1VAS0	Q1VAS24	Q1VAS48	Q1VAS72	Q1VAS96
1	C	0	0.3	0.2	0	0
3	C	0	0.5	3.8	1.8	0.5
7	C	0	7	5	3.1	1.5
10	C	0	3.1	3.5	2.4	0.7
11	C	0	2.3	1.9	0.1	0
12	C	0	0.6	1	0	0
14	C	0	5.1	4.2	1.1	0.2
16	C	0	6.1	5.3	4.5	2.6
19	C	0	1.1	0.7	0.2	0
20	C	0	0	2	1.7	0.3

Table F-14 Experimental group values for VAS question number one " What is the level of pain you are currently experiencing?" at 0, 24, 48, 72, and 96 hours.

Subject	Group	Q1VAS0	Q1VAS24	Q1VAS48	Q1VAS72	Q1VAS96
2	E	0	0.5	0.1	0	0
4	E	0	3.9	0.8	0.4	0
5	E	0	2.2	4.2	1.6	0.3
6	E	0	1.1	0.2	0	0
8	E	0	1.6	3.4	1.4	0.1
9	E	0	6.3	2.9	1.5	0.4
13	E	0	6	4.9	3.3	3.4
15	E	0	2.8	2	0.3	0
17	E	0	1.3	0.1	0	0
18	E	0	4.6	4.6	5.5	3.2

Table F-15 Control group values for VAS question number two "What is the level of pain associated with the movement?" at 0, 24, 48, 72, and 96 hours.

Subject	Group	Q2VAS0	Q2VAS24	Q2VAS48	Q2VAS72	Q2VAS96
1	C	0	2.5	2.1	0.2	0.1
3	C	0	0.7	3.8	1.6	0.3
7	C	0	8	8.3	4.8	2
10	C	0	5.2	5	4.6	2.1
11	C	0	3.5	2.8	0.1	0
12	C	0	1.7	0.9	0.2	0
14	C	0	6.7	6.7	1.7	0.2
16	C	0	6.5	5.9	4.3	2.6
19	C	0	2.2	1.7	0.5	0.2
20	C	0	0	2.7	2	0.2

Table F-16 Experimental group values for VAS question number two "What is the level of pain associated with the movement?" at 0, 24, 48, 72, and 96 hours.

Subject	Group	Q2VAS0	Q2VAS24	Q2VAS48	Q2VAS72	Q2VAS96
2	E	0	0.6	0.1	0	0
4	E	0	5.8	4.3	0.8	0
5	E	0	2.8	5.2	1.9	0.5
6	E	0	1.3	0.2	0.1	0
8	E	0	3.9	6.6	6.4	2.2
9	E	0	6.5	2.3	1.3	0.3
13	E	0	8	8.9	4.6	0.5
15	E	0	3.5	2.5	0.3	0
17	E	0	1.7	0.2	0	0
18	E	0	5.3	6.3	5.5	2.8

Table F-17 Control group values for VAS question number three "To what extent does this pain limit your ability to function?" at 0, 24, 48, 72, and 96 hours.

Subject	Group	Q3VAS0	Q3VAS24	Q3VAS48	Q3VAS72	Q3VAS96
1	C	0	0.2	0.3	0	0
3	C	0	0.2	3.2	0.9	0.1
7	C	0	4.6	6.5	3.8	0
10	C	0	0.9	1.6	0.6	0.2
11	C	0	2.4	1.6	0	0
12	C	0	2.7	1	0	0
14	C	0	4.8	3.6	0.2	0
16	C	0	6.9	6.6	4.6	1.7
19	C	0	1.5	1.7	0.3	0
20	C	0	0	1.7	1.5	0.3

Table F-18 Experimental group values for VAS question number three "To what extent does this pain limit your ability to function?" at 0, 24, 48, 72, and 96 hours.

Subject	Group	Q3VAS0	Q3VAS24	Q3VAS48	Q3VAS72	Q3VAS96
2	E	0	0.1	0	0	0
4	E	0	1.7	0.4	0	0
5	E	0	0.5	2.6	0.3	0
6	E	0	0.1	0.1	0	0
8	E	0	0.6	3.1	2.5	1.1
9	E	0	6.5	1.3	1.5	0
13	E	0	4.1	7	1.1	0.5
15	E	0	3.2	2.1	0.1	0
17	E	0	0	0	0	0
18	E	0	4.7	6.2	5.4	1.5