

**The relative effect of proprioceptive neuromuscular facilitated stretching
immediately after eccentric exercise Vs proprioceptive neuromuscular
facilitated stretching post delayed onset muscle soreness in healthy,
sedentary male subjects**

By

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*I, Helen Beverleigh Schlebusch, do hereby declare that this dissertation
represents my own work, both in conception and execution.*

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DEDICATION

I would like to dedicate this dissertation to my family, friends and Shaun, for their continuous support and encouragement.

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ABSTRACT

Delayed onset muscle soreness (DOMS) is muscular pain which ranges from mild discomfort to severe debilitating pain, caused by eccentric exercise. It generally sets in 12 – 24 hours after the causative activity and subsides within approximately seven days.

The aim of this study was to determine whether proprioceptive neuromuscular facilitated (PNF) stretching immediately after eccentric exercise was more beneficial than PNF stretching 24 hours after eccentric exercise on the muscle pain experienced in DOMS.

This study was a prospective, randomised clinical trial. Thirty healthy sedentary male participants were randomly selected to participate in the study by advertising in local newspapers and pamphlet distribution in Durban and its surrounding areas. The patients' ages ranged from 20 to 32 years of age. Subjective and objective readings were taken at the beginning and end of each visit, over the three-day study period. This was done with the numerical pain rating scale and the algometer force gauge, respectively. Baseline measurements were taken before any exercise or stretching at the initial visit. All participants then were asked to do squats until fatigue to induce delayed onset muscle soreness.

The participants were divided randomly into two groups, Group A and Group B. The former group underwent PNF stretching immediately after exercise and the latter group underwent PNF stretching twenty four hours after exercise. Both groups were asked to return for two subsequent days following the initial visit and they again underwent PNF stretching at each visit.

Comparison was made between the individual patients' pain perception over time, as well as between each group.

Descriptive analysis was done using frequency tables (reporting counts and percentages) for categorical variables and summary statistics (reporting

mean, standard deviation and range), for quantitative variables. Baseline and demographic characteristics were compared between the two treatment groups using independent t-tests for quantitative variables and Pearson's chi square tests for categorical variables. The treatment effect was assessed using repeated measures ANOVA testing.

Statistical analysis revealed that there was no difference in the improvement of pain experienced between the two groups. However, Group B (PNF stretching 24 hours after exercise) appeared to improve at a greater rate than Group A (PNF stretching immediately after exercise). A larger study needs to be conducted in order to provide statistically relevant results.

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DEFINITIONS

Delayed onset muscle soreness (DOMS): Muscular pain which ranges from mild discomfort to severe debilitating pain caused by eccentric, and less so by concentric exercise. It sets in 12 – 24 hours after the causative activity and subsides within approximately seven days (McArdle *et al.*, 1996; Connolly *et al.*, 2003).

Eccentric exercise: Muscle contractions, which occur when the muscle contracts while lengthening (Albert, 1991; McAtee, 1993).

Proprioceptive Neuromuscular Facilitative (PNF) stretching: A type of stretching in which the muscle being stretched is taken to a point where the initial stretch is felt, the antagonist muscle is then contracted against resistance and this is held for a period of time. The process is then repeated (Anderson *et al.*, 1991).

Static stretching: A type of stretching in which the muscle being stretched is taken to a point at which the stretch is initially felt in the muscle. This is then held for a period of time. Also known as passive stretching (Anderson *et al.*, 1991).

Ballistic stretching: A type of stretching similar to static stretching, yet it incorporates bouncing movements at the initial stretch (Anderson *et al.*, 1991).

Stretch tolerance: the amount of stretch a muscle can perceive permissible, before muscle injury occurs (Ulrike, 2005):

CHAPTER ONE

Introduction

CHAPTER ONE: Introduction

Delayed onset muscle soreness (DOMS) is a common phenomenon in people just beginning an exercise programme, or who change from their regular activities, by increasing their eccentric load (McArdle *et al.*, 1996; Cheung *et al.*, 2003; Connolly *et al.*, 2003). DOMS is muscular pain which varies from mild discomfort to severe debilitating pain (McArdle *et al.*, 1996; Connolly *et al.*, 2003). It sets in 12 – 24 hours after the causative activity and subsides within approximately seven days (McArdle *et al.*, 1996; Connolly *et al.*, 2003). Eccentric exercise is known to induce more muscle soreness than concentric exercise (McArdle *et al.*, 1996; Connolly *et al.*, 2003). As little as 15 repetitions of eccentric muscle contractions, which occur when the muscle contracts while lengthening, seem most often to cause DOMS (Albert, 1991; McAtee, 1993; McArdle *et al.*, 1996). However Cleak and Eston (1992) stated that the amount of tearing, and therefore soreness, depends on the specific activity, as well as the intensity and duration of the activity.

MacIntyre *et al.* (1995) proposed that the large amount of tension in the muscle on one specific eccentric movement may result in myofibril shearing and alterations of temperature and pH of that muscle, leading to muscle soreness. Clarkson and Sayers (1999) suggested that during an eccentric contraction, fewer motor units (and therefore less energy) are recruited for a given work load. Therefore the muscle force is distributed over a smaller cross sectional area of the muscle.

There are several theories that attempt to explain the cause of DOMS (McArdle *et al.*, 1996). These were reviewed by Cheung *et al.* (2003) as the accumulation of lactic acid, muscle spasm, connective tissue damage, muscle damage and inflammation. The lactic acid theory assumes that there is continued production of lactic acid after exercise. This has largely been rejected, as the lactic acid levels return to normal within one hour after exercise (McArdle *et al.*, 1996; Cheung *et al.*, 2003). Theories such as the muscle spasm theory and the connective tissue theory are still unclear (Cheung *et al.*, 2003).

Stauber *et al.* (1990) and McArdle *et al.* (1996) suggested that the tissue swelling and disruption of the extracellular matrix caused by muscle damage may be the cause of pain and inflammation experienced in DOMS.

These theories concur with that of Cleak and Eston (1992), which suggests that there is microscopic tearing of the muscle fibres and muscle protein breakdown, leading to inflammation and swelling of the muscle. This then activates pain receptors in the muscle, causing pain.

Various techniques have been used in the treatment of DOMS. Cheung *et al.* (2003) stated that these included non-steroidal anti-inflammatory drugs (NSAIDS), exercise, stretching techniques and electrical modalities such as ultrasound, interferential current therapy (IFC) and transcutaneous electrical nerve stimulation (TENS). Gulick *et al.* (1996) conducted a study in which they compared the treatment of DOMS with NSAIDS, concentric muscle contractions, ice massage, static stretching, topical arnica ointment and sublingual arnica pillules. This study concluded that none of the treatments was beneficial to treating DOMS. Cheung *et al.* (2003) concluded that NSAIDS are thought to have a prophylactic effect. However they may amplify the symptoms of DOMS if taken in large amounts. They also suggested that cryotherapy, static stretching, homeopathy and electrical modalities have no effect on the symptoms of DOMS. Concentric exercise has been shown to be the most beneficial treatment for the symptoms of DOMS (Cheung *et al.*, 2003).

Stretching has been promoted as an integral part of fitness programmes to decrease the risk of injury, relieve muscle soreness and improve sport performance (Anderson *et al.*, 1991).

The mechanism of action of stretching, leading to a reduction of muscle stiffness, is via increased circulation, passive viscoelastic changes, as well as by reflex inhibition and allowing increased range of motion (Anderson, 1980; Garrett, 1990; Best, 1995). Stretching is also thought to relieve muscle soreness, by increasing "stretch tolerance", that is, a deeper stretch is perceived more permissible (Magnusson, 1996). Increased stretch tolerance allows the patient to

feel less pain for the same force applied to the muscle. This could be due to increased tissue strength, flexibility or analgesia due to increased blood flow (Best, 1995; Magnusson, 1996). The stretch is also thought to disperse oedema and inflammation, leading to decreased pain perception (Bobbert *et al.*, 1986).

There remains a large volume of conflicting evidence surrounding post-exercise stretching. Lund *et al.* (1998) conducted a study in which they used seven healthy, non-trained females and did daily static stretching immediately after eccentric exercise, as well as at 24 hour intervals. This study concluded that there was no significant influence of static stretching on muscle pain. However, Bobbert *et al.* (1986) proposed that static stretching post-exercise helped the dispersion of oedema and hence mediators of pain and inflammation, accumulated due to the muscle damage.

Rodenburg *et al.* (1994) showed that the effect of combined warm-up and stretching before eccentric exercise, and massage after eccentric exercise, on delayed onset muscle soreness decreased the loss of flexibility experienced after a bout of eccentric exercise. Shrier *et al.* (2000) agreed, in his review on the myths and truths of stretching, that warm-up may increase the effectiveness of the stretch applied to the muscle.

Several studies have been conducted to compare the various types of stretching, (Static, Proprioceptive Neuromuscular Facilitative (PNF) and Ballistic) (Cornelius *et al.*, 1992; Shrier *et al.*, 2000; Feland *et al.*, 2001). Shrier *et al.* (2000) showed that PNF stretching resulted in greater increases of range of motion, compared to static or ballistic stretching.

Feland *et al.* (2001) assessed the acute changes in flexibility of the Hamstring muscles after stretching, before exercise. They had 97 participants who were elderly, active individuals. Each participant was allocated to one of three groups, a control group, static stretching group and/or contract-relax PNF (CRPNF) stretching group. All interventions were done before exercise. This study concluded that CRPNF resulted in a greater increase in flexibility than the static stretching group.

Bonnar *et al.* (2004) measured Hamstring flexibility to determine which time-frame of holding contract relax PNF was more beneficial. They concluded that 3 second, 6 second or 10 second holding of the stretch technique produced equal gains.

PNF stretching is proposed to initiate a deeper stretch of the muscle via reciprocal inhibition by contracting the antagonist muscle during the stretch, resulting in greater flexibility and increased range of motion of the joint (Anderson *et al.*, 1991). Ulrike (2005) showed that reciprocal inhibition was not evident during PNF stretching, as the EMG of the antagonist muscle was elevated rather than decreased, showing that there is possible co-contraction. He concluded that the benefit of PNF stretching is possibly from altered stretch perception (a deeper stretch may be perceived as more permissible) and raised pain perception (a greater amount of pain is considered more tolerable).

Jasko' lski *et al.* (2006) conducted a study which concurred with that of Ulrike (2005). They assessed the influence of eccentric contractions on the biceps and triceps brachii muscles during maximal voluntary contraction of elbow flexors using electrical and mechano-myographical activities. They concluded that there were similar changes of the electromyograph (EMG) and mechanomyograph (MMG) in both the agonist and antagonist muscles on contraction. This confirmed that there is possible co-contraction of the agonist and antagonist during forceful contractions. Thus, during antagonist contraction during PNF stretching, there may be some co-contraction of the muscle being stretched, therefore supporting the theory of Ulrike (2005).

Static stretching alone, according to Cheung *et al.* (2003) and Gulick *et al.* (1996), does not have any effect on the pain perceived in DOMS. Yet concentric contractions were shown by Cheung *et al.* (2003) to decrease the symptoms experienced in DOMS. Therefore PNF stretching, which is thought to elicit a deeper stretch (Shrier *et al.*, 2000), as well as incorporate mild concentric contractions of the antagonist muscle, may have a greater effect on the symptoms experienced in DOMS. Results of the present study would contribute to the above, therefore fulfilling the first aim of the study.

Due to the various time periods used in the above studies, and therefore the uncertainty on which time period is more beneficial to apply a stretch to an eccentrically exercised muscle, this study also looked at the difference between PNF stretching immediately after eccentric exercise, compared with PNF stretching 24 hours after eccentric exercise. This fulfilled the second aim of the study.

CHAPTER TWO

Review of the related literature

CHAPTER TWO: Review of the related literature

2.1 Introduction

The human body has three different types of muscle, skeletal muscle, smooth muscle and cardiac muscle (Saurez, 2003). Skeletal muscle is that muscle which is attached to bones and is controlled consciously; this type of muscle causes voluntary movements of the limbs and body (Shier, 1996; Guyton and Hall, 1997; Saurez, 2003). Smooth muscle is an involuntary type of muscle which lines the internal organs and is responsible for bodily functions such as digestion motility and blood vessel constriction (Saurez, 2003). Cardiac muscle is found only in the heart and is involuntary (Shier, 1996; Guyton and Hall, 1997; Saurez, 2003).

This review will concentrate on specific aspects of skeletal muscle physiology in relation to delayed onset muscle soreness and eccentric exercise.

2.2 Muscle structure and function

2.2.1 Muscle structure

Skeletal muscle consists of a hierarchy of microscopic muscle fibres, most of which extend the entire length of the muscle. Muscle fibres consist of many myofibrils. The myofibrils are made up of many sarcomeres, which contain two types of proteins, actin and myosin, and which play a fundamental role in the contraction of skeletal muscle. The entire muscle is enclosed by a sheath called the sarcolemma (Shier, 1996; Guyton and Hall, 1997; Travell and Simons 1999; Kinsey *et al.*, 2005).

The arrangement of actin and myosin proteins produces the typical striations seen in skeletal muscle. The actin proteins form the light bands known as I bands. These proteins are held together by Z lines. Where the actin and myosin proteins overlap the dark bands known as the A bands are formed. The section

of myofibril between each Z line is known as the sarcomere (Shier, 1996; Guyton and Hall, 1997; Saurez, 2003).

Myofibrils are surrounded by a cellular matrix called sarcoplasm. This contains large quantities of magnesium, potassium and phosphate. The sarcoplasmic reticulum is a network of membranous channels within the cytoplasm of the muscle fibres. It is responsible for the transport of nutrients and therefore activates muscle contraction when a stimulus is released from the motor nerves (Shier, 1996; Guyton and Hall, 1997; Kinsey *et al.*, 2005).

Motor nerves interact with the muscle fibre through a neuromuscular junction and motor end plate. In this area, the sarcolemma is greatly folded and has abundant mitochondria and vesicles containing neurotransmitter. The muscle fibre and motor end plate are separated by a potential space called the synaptic cleft (Shier, 1996; Guyton and Hall, 1997).

The muscles and tendons contain two types of sensory receptors; these are called the muscle spindle and the Golgi tendon organs. The muscle spindles are found throughout the muscle belly and relay information to the spinal cord regarding the muscle length or the rate of change of the muscle length. The Golgi tendon organs are found in the tendons and relay information regarding the tendon or muscle tension (Shier, 1996; Guyton and Hall, 1997).

2.2.2 Muscle contraction

2.2.2.1 Physiology

Skeletal muscle contraction will only occur if there is a stimulus caused by the release of acetylcholine from the motor nerve fibre. This, in turn, allows shortening of the muscle sarcomeres according to a theory called the sliding filament theory (Shier, 1996; Guyton and Hall, 1997; Saurez, 2003).

When an action potential reaches the end of the motor nerve fibre, the neurotransmitter acetylcholine is released from the vesicles at the axon ending. This substance diffuses across the synaptic cleft and attaches to receptors of the

muscle fibre membrane, initiating a muscle impulse (Shier, 1996; Guyton and Hall, 1997; Kinsey *et al.*, 2005).

The muscle impulse then spreads in all directions across the sarcolemma and deep into the sarcoplasmic reticulum, where a high concentration of calcium ions is stored. The muscle impulse increases permeability of the membranes and calcium ions diffuse into the muscle sarcoplasm (Shier, 1996; Guyton and Hall, 1997; Huxley, 2004).

Once there is a large concentration of calcium ions present in the muscle sarcoplasm, the myosin head attaches and releases intermittently to binding sites along the actin filament causing a "walking action" (Shier, 1996). This action is mainly controlled by an enzyme in the myosin protein called ATPase, which catalyses the break down of ATP (a protein involved in energy metabolism and responsible for driving metabolic reactions in all cells), causing a release of energy and therefore a force to pull the actin protein along (Shier, 1996; Guyton and Hall, 1997). In the transition between rest and exercise, the muscles undergo a large change in the metabolic rate (Saurez, 2003). This is accompanied by an increase in the rate of ATP hydrolysis (Saurez, 2003). The myosin cross bridge is then broken by the binding of another ATP (Shier, 1996; Guyton and Hall, 1997; Huxley, 2004). This cycle causes shortening of the sarcomere and therefore contraction of the muscle (Saurez, 2003). ATP is synthesized at rates that match ATP hydrolysis rates. This allows the maintenance of contractile function (Saurez, 2003).

Every muscle in the human body contains both fast and slow twitch muscle fibres. Some muscles may contain more of one type of fibre, depending on that muscle's action. Fast twitch muscle fibres are specialized for fast, burst type actions such as sprinting and jumping. They are much larger in diameter, contain many enzymes for rapid release of energy and have far fewer mitochondria. On the other hand, slow twitch muscle fibres provide endurance. These fibres are smaller, and contain large numbers of mitochondria and myoglobin for prolonged aerobic energy (Shier, 1996; Guyton and Hall, 1997).

The metabolism of the muscles may vary according to the duration and intensity of exercise (Saurez, 2003; Kinsey *et al.*, 2005). In short bouts of exercise the hydrolysis of ATP is relatively small (Saurez, 2003). Creatine kinase (CK) catalyses the hydrolysis of creatine phosphate (CrP) and the ATP concentration is maintained (Saurez, 2003; Kinsey *et al.*, 2005).

In high-intensity exercise, ATP is derived primarily from glycolysis (the breakdown of glycogen) and formation of lactate (Saurez, 2003; Kinsey *et al.*, 2005). In steady, prolonged exercise the energy is formed by way of mitochondrial oxidative phosphorylation (Suarez, 2003).

A sudden stretch of the muscle excites the muscle spindle. This, in turn, relays signals to the spinal cord of the muscle's action. The spinal cord relays reflex signals to that same muscle, causing it to contract and oppose a further stretch. The immediate stretch reflex is called the dynamic stretch reflex, as it only lasts for the first moment of the stretch. The static stretch reflex continues for some time after the dynamic stretch reflex. This weaker signal is important to maintain contraction of the muscle for the entire time it is being stretched (Guyton and Hall, 1997).

The Golgi tendon organ is responsible for controlling the tension of a muscle. Increased muscle tension excites the Golgi tendon organ to relay messages of the muscle tension to the spinal cord. A reflex signal is then transmitted to the muscle, which prevents the occurrence of high tension in that muscle (Guyton and Hall, 1997).

These stretch reflexes are important to decrease muscle damage during contraction, as well as to stabilize an action or body position (Guyton and Hall, 1997).

2.2.2.2 Types of muscle contraction

Muscle contraction can be divided into two main types of contraction, isotonic and isometric contraction. A contraction is said to be isotonic when the muscle contracts and the tension remains constant; it also shortens. In this type of contraction a load is moved and a greater amount of energy is required by the muscle (McArdle *et al.*, 1996). Isometric contraction is known as contraction of a muscle without shortening of the muscle. This contraction occurs in the postural muscles of the spine and it requires less sliding of the myofibrils among each other (McArdle *et al.*, 1996; Shier, 1996; Guyton and Hall, 1997).

Isotonic muscle contraction is further divided into concentric and eccentric contractions. Concentric contraction is when the muscle shortens while contracting causing the joint to move. This is the most common type of muscle contraction (McArdle *et al.*, 1996; Brockett *et al.*, 1997). Eccentric contraction is when the muscle forcibly lengthens while contracting, due to the external load exceeding the muscle tension (McArdle *et al.*, 1996; Brockett *et al.*, 1997).

Eccentric contraction occurs in activities such as walking downhill, is thought to cause the most damage to muscle and is associated with DOMS (McArdle *et al.*, 1996; Brockett *et al.*, 1997).

McArdle *et al.* (1996) suggested that eccentric exercise may cause a disruption of the sarcolemma, as well as damage to the fast twitch muscle fibres, which are more susceptible to damage due to their low oxidative ability. Clarkson and Sayers (1999) suggest that fewer motor units, and therefore less energy, are recruited for a given work load during eccentric contractions, compared to concentric contractions. Therefore, the muscle force is distributed over a smaller cross-sectional area of the muscle.

Eccentric contractions cause a greater tension per active motor unit, resulting in a large increase of injury risk, as well as shearing of the myofibrils, specifically at the obliquely arranged muscle fibres at the myotendinous junction, as they are less able to withstand high forces (Noonan and Garrett, 1992; MacIntyre *et al.*, 1995). There may also be a metabolic and inflammatory reaction following the

abovementioned muscle damage following eccentric exercise, which may be responsible for the symptoms experience in DOMS (MacIntyre *et al.*, 1995).

2.2.3 Muscle relaxation

Once the nerve impulses stop, acetylcholinesterase rapidly breaks down the acetylcholine in the synaptic cleft and calcium ions are actively transported into the sarcoplasmic reticulum (Kinsey *et al.*, 2005). This prevents a single nerve impulse from continuously stimulating the nerve fibre. The rate of ATP hydrolysis then decreases (Saurez, 2003). The myosin cross bridges are broken by the binding of excess ATP and the muscle returns to its resting state (Shier, 1996; Guyton and Hall, 1997; Huxley, 2004).

2.2.4 Muscle fatigue

When a muscle loses its ability to contract after prolonged strenuous exercise it is said to be fatigued. The physiology of this phenomenon is not clear, but it is thought to result from either an interruption of the muscle's blood supply, inability of the muscle contractile and metabolic process to supply the same continued output, or exhaustion of the motor nerve fibre acetylcholine supply (Shier, 1996; Guyton and Hall, 1997).

Hoskins and Pollard (2005) agree that there are multiple factors associated with muscle fatigue. They state that the central and peripheral nervous systems, as well as local factors, all play a role. With repetitive contraction of the muscle, there may be an exhaustion of the glycogen content of muscle fibres, accompanied by alterations in central nervous system neurotransmitters that alter psychic or perceptual state (Wong *et al.*, 1990).

Endoh *et al.* (2005) assessed the extent to which muscle damage, due to eccentric exercise, affected the time course of central and peripheral fatigue during maximal voluntary contraction. They applied transcranial magnetic stimulation (TMS) to the motor cortex of 10 healthy male participants, to determine voluntary activation and thus the amount of fatigue. The participants performed brief and sustained maximal voluntary contractions. The study

concluded that muscle damage due to repetitive maximal effort eccentric exercise increased both central and peripheral fatigue.

Continuation of exercising a fatigued muscle increases the chance of stretch injury in eccentric contractions, due to the decreased ability to produce force (Hoskins and Pollard, 2005).

Butterfield and Herzog (2005) investigated if the force-length relationship of a muscle could be used as a reliable indicator of muscle damage following eccentric exercise. The study was conducted on six rabbits, which underwent eccentric contractions of the hind limb. They found that eccentric exercise not only causes muscle damage, but also fatigue, both of which alter the force-length relationship of the muscle.

2.3 Hamstring and Quadriceps Femoris muscles

The Hamstring and Quadriceps Femoris muscles are two of the major thigh muscle groups and are responsible for, and play a large role in, the movement of the hip and knee joints (Clemente, 1997; Travell and Simons, 1999; Kinakin, 2004).

2.3.1 Hamstring anatomical attachments

The true Hamstring muscle group consists of three major muscles, the Semitendinosus, Semimembranosus (medial Hamstring) and Biceps Femoris long head (lateral Hamstring) (Clemente, 1997; Travell and Simons, 1999; Kinakin, 2004; Hoskins and Pollard, 2005).

These muscles have a common proximal attachment at the posterior aspect of the ischial tuberosity (Hoskins and Pollard, 2005). The Semitendinosus muscle attaches distally to the tibia after curving around the posteromedial aspect of the medial tibial condyle. The slightly broader Semimembranosus lies deep to the Semitendinosus muscle and attaches distally, just below the joint capsule, to the

posteromedial aspect of the medial tibial condyle. The Biceps Femoris consists of a long and short head, which attach distally together to the posterolateral aspect of the fibula head. The Biceps Femoris short head attaches proximally to the shaft of the femur, along with adductor magnus (Clemente, 1997; Travell and Simons, 1999; Kinakin, 2004; Hoskins and Pollard, 2005).

2.3.2 Hamstring innervation and actions

Branches from the tibial portion of the sciatic nerve supply the Hamstring muscles. These contain fibres from L5 and S1 and S2. The Biceps Femoris has a different innervation; the long head receives fibres from the first three sacral nerves off the tibial portion of the sciatic nerve and the short head receives fibres from the peroneal portion of the sciatic nerve, L5 and S1 and S2 (Clemente, 1997; Travell and Simons, 1999).

The Semitendinosus, Semimembranosus and Biceps Femoris extend the thigh at the hip joint and therefore control flexion of the hip during forward flexion and standing and indirectly keep the trunk erect during walking. These hip extensors also flex the leg at the knee joint. Individually, the Biceps Femoris rotates the tibia laterally and the Semitendinosus and Semimembranosus rotate the tibia medially (Clemente, 1997; Travell and Simons, 1999; Hoskins and Pollard, 2005).

2.3.3 Quadriceps Femoris anatomical attachments

The Quadriceps Femoris muscle group consists of four muscles, Rectus Femoris, Vastus Medialis, Vastus Intermedius and Vastus Lateralis (Kinakin, 2004).

The Rectus Femoris is the only muscle of the Quadriceps Femoris group which spans two joints, the hip and the knee. This muscle attaches proximally by two separate tendons, the straight head attaches to the anterior inferior iliac spine and the reflected head attaches to the posterior brim of the acetabulum. Distally, the Rectus Femoris attaches with the other Quadriceps Femoris muscles to the

proximal pole of the patella by the patella ligament, as well as to the tibial tuberosity (Clemente, 1997; Travell and Simons, 1999; Kinakin, 2004).

The Vastus Medialis attaches to the posteromedial aspect of the entire length of the femur shaft to the intertrochanteric line and the medial lip of the linea aspera. This muscle not only attaches distally to the patella tendon, but by a slip of muscle to the medial patella retinaculum (Clemente, 1997; Travell and Simons, 1999; Kinakin, 2004).

The Vastus Intermedius lies deep to the Rectus Femoris and attaches proximally to the anterolateral aspect of the shaft of the femur (Clemente, 1997; Travell and Simons, 1999; Kinakin, 2004).

The Vastus Lateralis is the biggest muscle of the Quadriceps Femoris group and attaches proximally to the greater trochanter of the femur, the lateral lip of the linea aspera and the posterolateral aspect of the femur shaft. Distally, this muscle attaches with the other Quadriceps Femoris muscles to the patella tendon, as well as to the lateral patella retinaculum (Clemente, 1997; Travell and Simons, 1999; Kinakin, 2004).

2.3.4 Quadriceps Femoris innervation and actions

All four of the Quadriceps Femoris muscles are innervated by branches of the femoral nerve, fibres from L2, L3, L4 (Clemente, 1997; Travell and Simons, 1999).

The entire Quadriceps Femoris group extends the leg at the knee joint and controls movements of squatting and sitting down from a standing position. The Rectus femoris flexes the thigh at the hip joint (Clemente, 1997; Travell and Simons, 1999).

2.4 Delayed onset muscle soreness

2.4.1 Definition

Delayed onset muscle soreness (DOMS) is commonly known as muscle stiffness and soreness experienced 12 to 24 hours after unaccustomed exercise (McArdle *et al.*, 1996). DOMS is thought to be a grade 1 muscle strain (Close *et al.*, 2005). The pathology associated with DOMS is sub-clinical or without clinical manifestations, but the symptoms of DOMS may vary from mild muscle stiffness that resolves within a few hours to debilitating pain and restricted movement (Gulick *et al.*, 1996). Eccentric exercise, in which there is contraction of a lengthening muscle, is thought to induce DOMS to a greater extent, as the actin myosin cross bridges must be separated with greater force, causing greater tension per motor unit and therefore greater risk of injury (Cheng *et al.*, 1993; Brockett *et al.*, 1997).

The musculotendinous junction has been shown to be the most painful and tender site of the muscle initially, and approximately 24 – 48 hours later - the muscle belly itself becomes the most painful and tender area (MacIntyre *et al.*, 1995; Nie *et al.*, 2005).

Jasko' lski *et al.* (2006) studied the influence of eccentric contractions on the biceps and triceps brachii muscles during maximal voluntary contraction of elbow flexors, using electrical and mechano-myographical activities. They concluded that there were similar changes of the electromyograph (EMG) and mechanomyograph (MMG) in both the agonist and antagonist muscles. This confirmed that there is a great link to the agonist and antagonist muscles' motorneuron pool, allowing for co-contraction of the agonist and antagonist during forceful contractions. This is thought to provide increased support for the joint being moved, as well as increased strength (Jasko' lski *et al.*, 2006).

Dannecker *et al.* (2003) induced DOMS and assessed pain response 48 hours later among males and females. It was concluded that females reported lower

muscle pain intensity than males. However, no pressure threshold difference was found between the sexes. This showed that both sexes perceived an equal amount of pain for a similar force applied to the muscle. Nie *et al.* (2005) concluded that there were no gender differences in pain perception of DOMS. They felt that many more studies need to be performed to draw definitive results.

2.4.2 Mechanism

Numerous proposed theories attempt to describe the mechanism of DOMS, demonstrating that the mechanism of DOMS is still not clear. These theories were reviewed by Cheung *et al.* (2003) as the accumulation of lactic acid, muscle spasm, connective tissue damage, muscle damage and inflammation. The lactic acid theory has largely been rejected, as DOMS is not associated with concentric exercise and lactic acid levels return to pre-exercise levels approximately one hour post exercise (Gulick *et al.*, 1996).

The muscle spasm theory is described by Cheung *et al.* (2003) as an increased resting muscle activity leading to localized motor unit spasm after an eccentric exercise bout. This muscle spasm was thought to cause vessel constriction, leading to ischemia and pain substance collection. Bajaj *et al.* (2003) investigated whether prophylactic muscle relaxant use decreased the pain felt in DOMS, based on the muscle spasm theory. They gave 20 male subjects a course of either a placebo or tolperisone (a centrally acting muscle relaxant) three times a day for eight days. The participants underwent several exercise bouts over this same eight-day period. Pressure pain threshold, range of limb abduction, isometric force and EMG were taken immediately after exercise, 24 hours and 48 hours after exercise. Results showed no difference between placebo and tolperisone groups and therefore showing no effect of tolperisone.

The connective tissue damage theory states that the fast twitch muscle fibres (responsible for quick bouts or high-intensity exercise) are less robust than slow twitch muscle fibres (responsible for prolonged, low-intensity exercise), are more susceptible to stretch-induced injury and therefore, with excessive strain of eccentric exercise, DOMS may occur (Cheung *et al.*, 2003).

This connective tissue damage theory was assessed in the Paschalis *et al.* (2005) study. They examined the difference in muscle damage and performance in the same volumes of high and low intensity eccentric exercise. Twelve healthy men underwent one bout of high-intensity eccentric exercise and two weeks later all participants underwent a bout of low-intensity exercise. Muscle damage (measured by serum creatine kinase levels), range of motion and DOMS were assessed before exercise, as well as at various time intervals post exercise. They concluded that high- and low-intensity eccentric exercise has similar effects on muscle damage, but muscle performance was more greatly affected by high-intensity eccentric exercise. Chapman *et al.* (2006) later conducted a similar study, in which they also used 12 untrained participants. These participants did low intensity eccentric exercise with one arm and then two weeks later did high intensity eccentric exercise with the opposite arm. The same measurements were taken as in the Paschalis *et al.* (2005) study. Chapman *et al.* (2006) concluded that high-intensity eccentric exercise caused greater muscle damage than low-intensity eccentric exercise.

Stauber *et al.* (1990) and Cleak *et al.* (1992) suggested that there is microscopic tearing of the muscle fibres and muscle protein breakdown, particularly at the z line, leading to inflammation and swelling of the muscle. This activates the pain receptors in the muscle, causing the perception of pain. The amount of tearing, and therefore soreness, depends on the specific activity, as well as the intensity and duration of the activity (Cleak *et al.*, 1992). Close *et al.* (2005) and Peake *et al.* (2005) agreed that the mechanism of DOMS may well be mechanical, as opposed to metabolic.

Miliadis *et al.* (2005) conducted a study in which they assessed the relationship between platelet activating factor (PAF) (an inflammatory mediator) and muscle damage caused by eccentric exercise. Venous blood samples were taken from 13 healthy male participants immediately before and at various time intervals after eccentric exercise. They concluded that there was a definite inverse relationship between the PAF levels and joint range of motion. Further studies need to be conducted to draw definitive results.

Paschalis *et al.* (2006) stated that eccentric muscle contractions may cause an altered gait, caused by an increased amount of activity of muscle specific serum enzymes. This leads to decreased afferent inputs from the muscle spindle, Golgi tendon organ and afferent nerve endings. Due to the altered nerve receptors, there is a substantial decrease in the stretch reflex sensitivity, reduction of the muscle and joint stiffness regulation and reduced muscle performance.

2.4.3 Treatment and management

Various treatment modalities have been assessed to relieve the symptoms of DOMS, or to reduce the magnitude of the initial injury (Cheung *et al.*, 2003; Gulick *et al.*, 1996).

2.4.3.1 Cryotherapy

Common indications for cryotherapy are muscle spasm, injury-causing pain, and to reduce bleeding and swelling (Kitchen and Bazin, 1996).

Application of cold to an injured area causes decreased local metabolism, as well as immediate vasoconstriction and therefore decreased circulation, leading to reduced extravasation of fluid and therefore reduced oedema and swelling and decreased agitation of the pain receptors. The local decrease in temperature leads to an elevation of pain threshold (Kitchen and Bazin, 1996).

Gulick *et al.* (1996) compared various treatment techniques for the recovery of DOMS. They concluded that ice massage provided relief in the acute stages of DOMS, due to its analgesic effect. This treatment was not effective in relieving any of the other symptoms of DOMS, such as muscle stiffness. This theory was later supported by Cheung *et al.* (2003) who emphasised that cryotherapy is not effective in the prevention and treatment of DOMS, but only provides an analgesic effect.

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2.4.3.2 Anti-inflammatory drugs

One of the mechanisms of DOMS is associated with the inflammatory process and accumulation of oedema. This begins within several hours of tissue damage and therefore anti-inflammatory drugs have been researched for the prevention and management of DOMS (Connolly *et al.*, 2003; Cheung *et al.*, 2003).

NSAIDs, as well as analgesic drugs, taken prophylactically before the onset of DOMS symptoms, have proven to be beneficial (Cheung *et al.*, 2003; Gulick *et al.*, 1996). However, great doses of NSAIDs may impair the muscle recovery (Gulick *et al.*, 1996). Almekinders (1999) agreed that anti-inflammatory drugs are beneficial in the treatment of DOMS, to a small degree. Further studies are required to be able to draw conclusive results.

2.4.3.3 Homeopathy

Arnica is the preferred homeopathic remedy for muscle soreness, due to its analgesic, antibiotic and anti-inflammatory properties (Cheung *et al.*, 2003).

Vickers *et al.* (1997) assessed whether homeopathic medicine was superior to placebo for the treatment of DOMS. They concluded that the homeopathic remedy was not beneficial. However they did admit that their method of stepping may not have been sufficient to induce DOMS.

Gulick *et al.* (1996) compared homeopathic treatment with NSAIDs, static stretching, ice massage and concentric muscle activity. They concluded, with regards to homeopathy, that the effect of Arnica on DOMS was insignificant. Dean (1998) later agreed that many more studies need to be conducted regarding homeopathy and the treatment of DOMS, as well as to clarify the difference between homeopathy and placebo.

2.4.3.4 Massage

The increase in local blood flow associated with vigorous massage of damaged muscles increases the oxygenation as well as decreases inflammation, which, in turn, should decrease the symptoms of DOMS (Kitchen and Bazin, 1996). There

have been conflicting results from various studies that have assessed the effectiveness of massage. Hart *et al.* (2005) determined the effect of sports massage on the pain response to eccentric exercise. They induced DOMS in the calf muscles of 19 healthy subjects and carried out sports massage on one leg over three consecutive days. They concluded that sports massage did not result in pain reduction.

Rodenburg *et al.* (1994) found that there were small reductions in muscle soreness following eccentric exercise, warm up, stretching and massage. It is not clear which management technique was most beneficial. A study done by Gulick *et al.* (1996) found no significant difference with warm up, stretching and massage. These conflicting results may be due to the inconsistency in timing of the massage after exercise, as well as the differences among the techniques of therapists (Cheung *et al.*, 2003).

Dannecker *et al.* (2004) revised two studies on self-care behavior for musculoskeletal pain. Both studies showed that massage was one of the main therapies employed for musculoskeletal pain.

2.4.3.5 Electrical modalities

Transcutaneous electrical nerve stimulation (TENS) and interferential current (IFC) therapy are thought to be the most beneficial electrical modalities for the management of DOMS, due to their muscle stimulating and analgesic qualities. Further research on these modalities is required (Cheung *et al.*, 2003).

Craig *et al.* (1999) investigated the therapeutic effect of ultrasound on DOMS. They used 48 participants, of whom half were male and half were female, and induced DOMS in the non-dominant arm. The subjects were then randomly allocated to one of four treatment groups: control, placebo, low-dosage pulsed ultrasound and high-dosage pulsed ultrasound. They concluded that there was no significant evidence in the results to support ultrasound as a therapy for DOMS.

2.4.3.6 Exercise

Cleary *et al.* (2002) assessed if the temporal pattern of repeated eccentric exercise bouts would decrease the pain perceived, as well as the muscle tenderness that followed eccentric exercise. In their study, 31 healthy individuals performed eccentric exercise bouts over four different time periods. The authors concluded that carrying out several small bouts of similar eccentric exercise before beginning an intensive eccentric exercise training programme tends to decrease the amount of muscle soreness experienced with the onset of DOMS.

According to Gulick *et al.* (1996) and Cheung *et al.* (2003), concentric exercise (that exercise in which the muscle shortens while contracting) is the most beneficial of all management techniques for the relief of DOMS. The mechanism is thought to be due to breakdown of adhesions formed during muscle repair, or to the release of endorphins, which decrease the sensation of pain.

Zaiduddin *et al.* (2006) questioned whether a bout of concentric exercise would alleviate DOMS, as well as enhance the recovery of the muscle. They concluded that light concentric exercise has a temporary analgesic effect on DOMS, but does not speed up muscle damage recovery.

2.4.3.7 Stretching

The mechanism of action of stretching, leading to a reduction of muscle stiffness, is by way of increased circulation, passive viscoelastic changes, and by reflex inhibition and allowing increased range of motion (Anderson, 1980; Garrett, 1990; Best, 1995). In addition, stretching is thought to relieve muscle soreness by increasing "stretch tolerance", that is, a deeper stretch is perceived more permissible (Magnusson *et al.*, 1996). Increased stretch tolerance allows the patient to feel less pain for the same force applied to the muscle. This could be due to increased tissue strength, flexibility or analgesia due to increased blood flow (Best, 1995; Magnusson *et al.*, 1996). The stretch is also thought to disperse oedema and inflammation, leading to decreased pain perception (Bobbert *et al.*, 1986).

There are three common types of stretching, static stretching, ballistic stretching and PNF stretching (Anderson *et al.*, 1991). In static stretching, the muscle is lengthened until a mild stretch is felt. This is held for 10 – 30 seconds and then released.

Ballistic stretching consists of regular bouncing movements while the muscle is on a stretch. In PNF stretching, the muscle is lengthened to the stretch, the antagonist muscle is contracted and held for 10 – 30 seconds, then released. Stretches are generally repeated three times for each muscle (Anderson *et al.*, 1991).

Smith *et al.* (1993) compared the extent of DOMS caused by static and ballistic stretching. The effect of these stretches on serum creatine kinase was also assessed. Twenty male subjects, all unaccustomed to stretching, underwent either static (sustained stretch) or ballistic stretching (bouncing movements whilst stretching). The stretching was performed in three sets of 17 stretches, each held for 60 seconds. The NRS was used to subjectively interpret the pain experienced and serum creatine kinase levels were assessed as an objective measure before stretching, and every 24 hours thereafter, for five days. Results showed that DOMS was greater for static stretching than for ballistic stretching and the serum creatine kinase was increased at 24 hours.

Reisman *et al.* (2005) investigated if warm-up static stretching decreases the muscle pain and stiffness experienced in DOMS. Participants eccentrically exercised the elbow flexors of one arm and used the other arm as a control. Resting elbow angle and muscle soreness were measured before and after exercise, as well as at 24 hours after the exercise. There was a decreased resting elbow angle and increased pain sensation after the exercise, both of which returned to near control levels over the following four days. This study concluded that the warm-up static stretching decreased muscle tension and pain experienced after eccentric exercise.

2.5 Proprioceptive neuromuscular stretching

PNF stretching is thought to achieve greater gains than from static or ballistic stretching alone, due to employing an isometric contraction prior to the stretch (McAtee, 1993; Feland *et al.*, 2001; Bonnar *et al.*, 2004).

PNF refers to any of several stretching techniques in which a muscle group is passively stretched, then contracted isometrically against resistance while in the stretched position, followed by passive stretching again through the resulting increased range of motion (Ferber *et al.*, 2002; Bonnar *et al.*, 2004).

PNF stretching techniques may employ isometric agonist contraction and relaxation, where the stretched muscles are contracted isometrically and then relaxed, or the antagonist muscles of the stretched muscles may be contracted (Feland *et al.*, 2001; Bonnar *et al.*, 2004).

The most common PNF stretching techniques are known as the contract-relax technique and the contract-relax-antagonist-contract (CRAC) technique. The former technique is conducted by assuming an initial passive stretch, the muscle being stretched is isometrically contracted, the muscle is briefly relaxed and immediately subjected to a passive stretch which stretches the muscle even further than the initial passive stretch. This final passive stretch is held. The muscle is then relaxed (McAtee, 1993; Ferber *et al.*, 2002).

The CRAC technique involves performing two isometric contractions: first of the agonists, then of the antagonists. After assuming an initial passive stretch, the stretched muscle is isometrically contracted. The muscle is relaxed while its antagonist immediately performs an isometric contraction that is held. The muscles are then relaxed (McAtee, 1993; Ferber *et al.*, 2002). The antagonist-contraction in this technique serves, via reciprocal inhibition, to relax and further stretch the muscle that was subjected to the initial passive stretch (McAtee, 1993; Feland *et al.*, 2001; Ferber *et al.*, 2002; Bonnar *et al.*, 2004).

PNF stretching is proposed to initiate a deeper stretch of the muscle via reciprocal inhibition due to the antagonist muscle contraction, resulting in greater flexibility and increased range of motion of the joint (Anderson *et al.*, 1991).

Ulrike (2005) found that reciprocal inhibition was not evident during PNF stretching, as the EMG of the antagonist muscle was elevated rather than

decreased. He concluded that the benefit of PNF stretching is possibly from altered stretch perception and raised pain perception.

In a study by MacDougall (1999), static stretching was compared to PNF stretching in the treatment of active myofascial trigger points. This study concluded that there was a significant difference in pain perception levels of the two groups, the PNF group showing lower pain perception.

The time period for holding a stretch has been the subject of much debate. Brandy and Irion (1994) used subjects between the ages of 20 and 40 years with greater than 30 degrees loss of knee extension resembling tight Hamstring muscles. The subjects were divided into four groups and each group had static stretching for different time intervals. It was concluded that stretching for periods between 30 and 60 seconds was more effective for increasing muscle flexibility than stretching for 15 seconds, or no stretching at all. Gaines (2004) tested the relative effectiveness and correct sequencing of PNF and active rocker-board exercises in the rehabilitation of chronic ankle sprains. She used PNF stretching for a maximum of 15 seconds. It was concluded that both PNF and active rocker-board exercises were beneficial, in chronic ankle sprain rehabilitation.

2.6 Conclusion

DOMS is a frequent phenomenon in people doing unaccustomed eccentric exercise. The mechanisms are not clearly understood, but evidence shows that muscle damage and inflammation are the underlying mechanisms to the muscle pain and stiffness experienced 24 hours after the initiating eccentric exercise bout. There are various known treatment methods for DOMS, such as cryotherapy, anti-inflammatory drugs, massage and stretching. However, it is not clear as to the most beneficial management technique or the timing of applying these techniques. Studies have been conducted assessing whether prophylactic treatment before the initial exercise is more beneficial than directly after initial exercise, or management only once the pain and stiffness of DOMS has set in 24 hours later.

Stretching is thought to provide relief for DOMS by increasing reflex inhibition, circulation and dispersion of oedema. There have been various conflicting results with regard to stretching and DOMS. Static stretching, regardless of whether applied to the muscle before or after exercise, has had no beneficial effect on DOMS. PNF stretching has been shown to have a greater effect on reducing muscle stiffness and soreness than static or ballistic stretching. Little is known about the effect of PNF stretching directly after exercise, compared to PNF stretching only once the muscle pain post-eccentric exercise is experienced.

CHAPTER THREE

Methodology

CHAPTER THREE: Methodology

3.1 Introduction

Chapter three outlines the materials, methods and procedures that were used in the present study. A detailed description of the study design, study protocol, inclusion and exclusion criteria and measurements is given.

3.2 Study design

This study is a prospective, randomised, controlled clinical trial.

Objective 1: To determine the relative effectiveness of proprioceptive neuromuscular facilitated stretching in terms of subjective and objective findings on delayed onset muscle soreness associated with unaccustomed post-eccentric exercise in healthy, sedentary male individuals.

Objective 2: To determine the relative effectiveness of proprioceptive neuromuscular facilitated stretching immediately after exercise compared to proprioceptive neuromuscular facilitated stretching once DOMS symptoms are present, in terms of subjective and objective findings on delayed onset muscle soreness associated with unaccustomed post-eccentric exercise in healthy sedentary male individuals.

3.3 Patient selection

Thirty healthy sedentary male participants took part in this study. They were drawn from Durban and its surrounding areas and were informed of the study by means of pamphlets and advertising in local newspapers (Appendix H). Convenience sampling was used. Patients that fitted into the study criteria were used.

3.4 Inclusion Criteria

1. Patients used in this study were required not to have been doing any form of exercise for the duration of the study.
2. Patients were required to be asymptomatic and not be suffering from back pain, or any other musculoskeletal or systemic problems (osteoarthritis, cardiovascular disease, etc.).
3. Patients may not have been taking any medication or anti-inflammatories (for epilepsy or musculoskeletal problems).
4. Patients between the ages of 20 to 40 years. With increased homogeneity, factors related to health and age influenced the study less.
5. Only male patients were included in this study (homogeneity).
6. Patients who had signed an informed consent form.

3.5 Exclusion Criteria

1. Patients who were symptomatic for any condition.
2. Patients that were manual labourers were not used in this study.
3. Patients could not be receiving other treatment for the duration of this study.
4. Patients who filled in the informed consent forms incorrectly.
5. Patients who had not signed informed consent forms were excluded from this study.
6. Patients who did not conform to research protocol were excluded from this study.
7. Patients could not start an exercise routine for the duration of this study.
8. Patients with hyper-flexibility (gymnasts), or connective tissue disorders (Marfans Syndrome), were not used in this study.
9. Patients who had undergone any form of surgery of the lower extremities or back were excluded from this study.
10. Patients who did not complete their NRS pain diary.

3.6 Procedure

A screening interview (telephonically or at the clinic) was used to determine prospective participants:

1. Was the individual between the ages of 20 and 40 years of age?
2. Did the individual do any form of exercise or sport?
3. What was their occupation?
4. Did the individual have any medical complaints?
5. Was the individual on any medication?

The participant was booked in for an appointment at the chiropractic clinic and a full medical and family history (Appendix C) was taken and a shortened physical examination (Appendix D) was carried out. An explanation of the study was given and, if the patient was still interested in taking part in the study, they were given a patient information sheet (Appendix A) and the informed consent form (Appendix B) was signed.

The participants were informed that all data would be captured in confidence, no names would be divulged, their file number would be used as identity and that only the researcher and her supervisor would have access to the data.

3.7 The sample group

The 30 participants were divided randomly, by asking each participant to draw a letter, A or B, out of a hat, thereby showing which group the participant would fall into, leaving two groups of 15 participants each. Each patients' file number was used as identity throughout the research process, in order to maintain confidentiality.

3.8 Measurements

3.8.1 Measurement tools

3.8.1.1 Numerical Pain Rating Scale (NRS): (Appendix E)

To gather subjective information from the patient about the pain experienced in DOMS (Jensen *et al.*, 1986), each participant was asked to rate any muscle pain experienced in the Quadriceps Femoris and Hamstring muscles at that moment, on a scale from zero to 100, zero being the absence of pain and 100 being pain at its worst. This was asked at the beginning of each visit and at the end of each visit, over a period of three days.

3.8.1.2 Algometer: (Appendix F)

Objective information was gathered, in kilograms per centimetre squared, of the muscle sensitivity (pain pressure threshold) due to DOMS (Fischer, 1987).

These readings were taken at the beginning of each visit and directly after the intervention, over a three-day period. The location of each reading was marked, using Henna dye, at the initial consultation. The middle of the Quadriceps Femoris muscle belly was found at the mid-point between the greater trochanter and the superior pole of the patella. The Hamstring muscle belly was found at the mid-point between the ischial tuberosity and the popliteal fossa.

The footplate of the algometer was placed over the marked spot on the muscle and a pressure was applied at approximately 1kg per centimetre squared per second, in an anterior to posterior direction.

When the participants first felt pain, they were requested to say "yes".

At that point the algometer was removed and a reading in kg/cm squared was taken.

3.8.1.3 NRS Diary: (Appendix G)

A NRS diary was given to each participant to take home. They were asked to fill it in, using the same concept as the NRS filled out at the visits, at eight-hour intervals (or before going to sleep and on waking). This was used to gather further subjective information from the patient.

3.8.2 Measurement frequency

Subjective and objective information was gathered at four intervals. At the initial consultation, before exercise (Measurement 1), as well as after exercise, Group A after stretching and Group B after exercise (Measurement 2). Again at 24 hours after exercise (Measurement 3), before and after stretching and 48 hours after exercise (Measurement 4), before and after stretching.

The participants were asked to keep an NRS diary every eight-hours, between each consultation (or before going to sleep and on waking).

3.9 Intervention

All participants performed the same type of eccentric exercise, in the form of squats, until fatigue set in, to induce delayed onset muscle soreness. There was no pre-exercise warm-up period.

The researcher explained and demonstrated a simple squat: standing with feet hip-width apart, back straight and eyes looking forward. The knees were then bent to 90 degrees, keeping feet flat on the floor, back straight and eyes looking straight ahead. The knees were extended again to bring the body to the starting position.

Group A participants underwent PNF stretching. The participant was supine for the Hamstring stretch. The researcher took the muscle to a point where the participant first felt the stretch in the muscle by flexing the hip and keeping the knee straight. The participant was then asked to contract the antagonist muscle (the Quadriceps Femoris) by pushing against the researcher in the opposite direction to the original stretch. This was held for 30 seconds, then released and

repeated three times. The Quadriceps Femoris muscle was stretched, with the participant prone. The examiner extended the hip until the initial stretch of the muscle was felt. The participant was then asked to contract the antagonist muscle (Hamstring) by pushing against the researcher in the opposite direction to the original stretch. This was held for 30 seconds, then released and repeated three times. These procedures were repeated: three sets of 30 seconds immediately after the exercise, 24 hours after exercise and 48 hours after exercise.

Group B underwent PNF stretching (as explained for Group A) of the Quadriceps Femoris and Hamstring muscles for three sets of 30 seconds, once the symptoms of DOMS set in (24 hours after exercise) and 48 hours after exercise.

The participants that did not experience symptoms of DOMS 24 hours after exercise were excluded from the study and given one free treatment for any musculoskeletal problem within one month of participating in the study.

3.10 Ethical considerations

The rights and welfare of all the participants were protected as follows:

1. The participant was not forced or coerced into taking part in the study.
2. Participation was voluntary and did not involve any financial benefit.
3. Information was given to the participant in an understandable language.
4. Informed consent was obtained.
5. The participant was free to withdraw from the study at any stage.
6. Confidentiality was maintained at all times.

3.11 Statistical procedures

3.11.1 Treatment of the data

Data were captured in an MS Excel Spreadsheet and imported into SPSS version 13 (SPSS Inc., Chicago, Illinois, USA) for analysis. A p value of <0.05 was considered statistically significant.

3.11.2 Methods of data analysis

Descriptive analysis was carried out using frequency tables (reporting counts and percentages) for categorical variables and summary statistics (reporting mean, standard deviation and range) for quantitative variables. Baseline and demographic characteristics were compared between the two treatment groups, using independent t-tests for quantitative variables and Pearson's chi square tests for categorical variables. The treatment effect was assessed using repeated measures ANOVA testing. This process tests three null hypotheses simultaneously:

1. There is no time effect. There is no change of subjective and objective readings, NRS and algometer, respectively, over time for either group, Group A or Group B. Therefore neither intervention, PNF stretching immediately after exercise, or PNF stretching 24 hour after exercise, is beneficial for decreasing the pain experienced in DOMS, over time.
2. There is no group effect. There is no change of subjective or objective readings, NRS and algometer readings, respectively, in either group, Group A or Group B.
3. There is no time by group interaction (treatment effect). There is no effect of either intervention, PNF stretching immediately after exercise, or PNF stretching 24 hour after exercise, in either group, Group A or Group B, on decreasing the pain experienced in DOMS.

In the presence of a significant time by group interaction, a treatment effect is declared. Therefore, if the subjective and objective readings improve over the three-day study period, NRS decreasing and algometer readings increasing, then the treatment, PNF stretching immediately after exercise (Group A) or PNF stretching 24 hours after exercise (Group B), is considered to have been beneficial in relieving the pain experienced in DOMS. In this case, any significant main effects (time or group effects) cannot be interpreted.

Profile plots were done to assess the direction or trend in the treatment effect.

3.11.3 Parametric tests

3.11.3.1 Independent t-test

Independent t-tests determine the difference between two means (HyperStat Online Statistics Textbook, 2006).

The null hypothesis (H_0) states that there is no difference between the two groups with respect to the variable of interest. The hypothesis (H_a) states that there is a difference between the two groups with respect to the variable of interest.

H_0 : There is no difference between Group A (PNF stretching immediately after exercise) and Group B (PNF stretching 24 hours after exercise) with respect to muscle pain perceived.

H_a : There is a difference between Group A (PNF stretching immediately after exercise) and Group B (PNF stretching 24 hours after exercise) with respect to muscle pain perceived.

If $p < \alpha$ (0.05), reject H_0 .

Where p is the reported p-value.

3.11.3.2 Pearson's chi square test

Pearson's chi square test assesses whether or not an observed frequency distribution differs from a theoretical distribution, as well as whether or not paired observations on two variables are independent of each other (HyperStat Online Statistics Textbook, 2006).

The null hypothesis (H_0) states that the two variables are independent from each other and no association exists. The hypothesis (H_a) states that the two variables are associated with each other.

H_0 : Variables A and B are independent and no association exists. Muscle pain and study group A or B are independent and no association exists.

Ha: Variables A and B are associated with each other. Muscle pain and study group A or B are associated with each other.

If $p < \alpha$ (0.05), reject H_0 .

Where p is the reported p-value.

3.11.3.3 Repeated measures ANOVA test

Repeated measures analysis of variance test assesses hypotheses about differences between two or more means. This enables the researcher to assess the same measurement done on a participant several times during the study, for example NRS. This test decreases Type 1 error rate, which occurs when using independent t-tests repeatedly to form the same results (HyperStat Online Statistics Textbook, 2006).

Results from repeated measures ANOVA tests are interpreted with Wilk's lambda, a number between 0 and 1, with values close to 0 showing differences in group means and close to 1 showing no differences. The F value is calculated during the between-subjects repeated measures ANOVA test.

The null hypothesis (H_0) states that there is no difference between the two groups with respect to the variable of interest. The hypothesis (H_a) states that there is a difference between the two groups with respect to the variable of interest.

H_0 : There is no difference between Group A (PNF stretching immediately after exercise) and Group B (PNF stretching 24 hours after exercise), with respect to muscle pain perceived over time.

H_a : There is a difference between Group A (PNF stretching immediately after exercise) and Group B (PNF stretching 24 hours after exercise), with respect to muscle pain perceived over time.

If $p < \alpha$ (0.05), reject H_0 .
Where p is the reported p-value.

CHAPTER FOUR

Results

CHAPTER FOUR: Results

4.1 Introduction

Chapter four presents the results obtained after statistical analysis of the data collected in the study. It contains demographic data and subjective and objective data, namely numerical pain rating scales and algometer readings.

The results have been tabulated and, where appropriate, presented as graphs.

4.2 Results

4.2.1 Demographics

Thirty participants were enrolled in the trial and randomized into two treatment groups, A and B. The demographics were compared between the treatment groups to ensure randomization was complete.

Table 1: T-test to compare mean age of participants between treatment groups

	group	N	Mean	Std. Deviation	Std. Error Mean	t statistic	p value
age	A	15	25.80	4.709	1.216	-0.728	0.473
	B	15	27.00	4.309	1.113		

Table 1 shows that there was no difference in mean age of participants between treatment groups ($p=0.473$). The mean age of Group B (27.00) was slightly older than Group A (25.80), but this difference was not significant.

Table 2: Cross-tabulation of race and treatment group

			Group		Total
			A	B	
Race	Black	Count	2	5	7
		% within Race	28.6%	71.4%	100.0%
	Indian and Coloured	Count	3	1	4
		% within Race	75.0%	25.0%	100.0%
	White	Count	10	9	19
		% within Race	52.6%	47.4%	100.0%
Total		Count	15	15	30
		% within Race	50.0%	50.0%	100.0%

Pearson's chi square 2.338, $p=0.311$

Table 2 shows that there was no statistically significant difference in proportions of race groups between the treatment groups ($p=0.311$). The majority of participants were white (19) and the number of white participants was almost equal between the two groups, ten in Group A and nine in Group B. It appeared that group B had more black (5) participants than group A (2) and *vice versa* for Indian and coloured participants, three in Group A and one in Group B. This slight difference was not statistically significant.

4.2.2 Baseline outcome measurements

It is important that the baseline outcome measurements, numerical pain rating scale (NRS) and algometer readings, were equivalent between treatment groups, otherwise differences after follow-up could be incorrectly attributed to treatment.

Table 3: T-test to compare mean baseline outcomes between treatment groups

	Group	N	Mean	Std. Deviation	Std. Error Mean	t statistic	p value
Initial NRS pre	A	15	1.00	2.803	0.724	-0.603	0.551
	B	15	2.67	10.328	2.667		
Initial Hamstring left algometer	A	15	8.333	2.1057	0.5437	-0.799	0.431
	B	15	8.833	1.2016	0.3102		
Initial Hamstring right algometer	A	15	8.847	1.8574	0.4796	0.066	0.948
	B	15	8.807	1.4139	0.3651		
Initial Quadriceps Femoris left algometer	A	15	7.880	1.8241	0.4710	0.186	0.854
	B	15	7.753	1.9082	0.4927		
Initial Quadriceps Femoris right algometer	A	15	8.540	1.5361	0.3966	0.903	0.374
	B	15	7.993	1.7714	0.4574		

Table 3 shows that there were no significant differences at baseline between the treatment groups for any of the outcomes.

4.2.3 Analysis of the treatment effect

4.2.3.1 Numerical pain rating scale (NRS)

For NRS, the starting time point chosen was eight hours post-exercise at Visit 1. The reason for not using the initial NRS score was that the majority of participants had a zero value, as stiffness had not yet been induced. The reason for not using the immediately post-exercise score was that, for some participants, the NRS score was still zero, as stiffness may have taken a while to induce. Thus, by eight hours post-exercise, all participants had experienced some degree of stiffness. This was thus their baseline score.

Table 4: Within-subjects and between-subjects effects for NRS

Effect	Statistic	p value
Time	Wilk's lambda=0.534	0.007
Group	F = 0.717	0.404
Time*group	Wilk's lambda=0.720	0.138

Table 4 shows that there was a significant time effect ($p=0.007$), which means that NRS values changed significantly over time, regardless of treatment group, as the p value for the intervention effect, time by group, was not significant ($p=0.138$). Thus, for NRS, there was no evidence of a differential treatment effect between Group A (PNF stretching immediately post-exercise) or Group B (PNF stretching 24 hours post-exercise). Therefore, for NRS readings, PNF stretching directly after exercise was not more beneficial than PNF stretching 24 hours after exercise, according to the subjective measurement of pain. This confirms the null hypothesis (H_0).

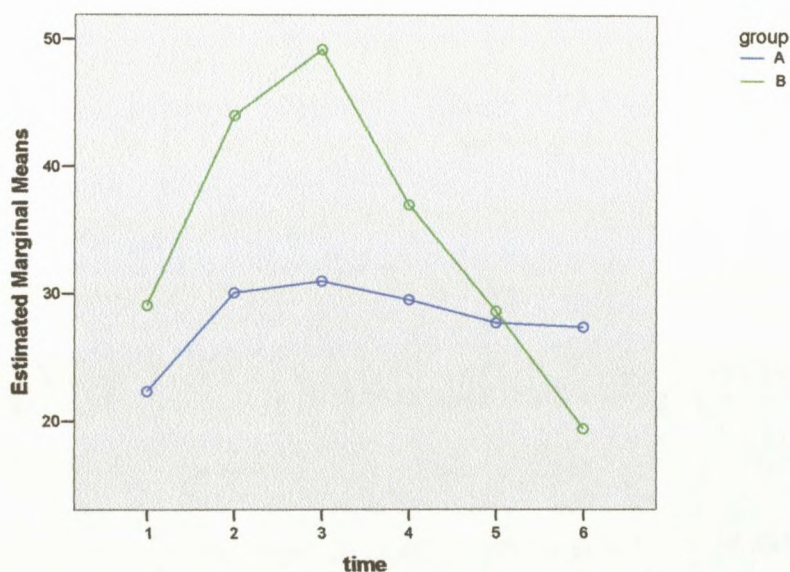


Figure 1: Profile plot of mean NRS over time by treatment group

Figure 1 shows the profile plot of mean NRS over time by treatment Group A (PNF stretching immediately post-exercise) and Group B (PNF stretching 24 hours post-exercise). Although the p value for the interaction between treatment

and group was not significant, there appears to be the trend of an interaction (non parallel profiles or crossing over of profiles) at Time 5. Group B (PNF stretching 24 hours after exercise) appears to decrease NRS score at a faster rate than Group A (PNF stretching immediately post-exercise). Group B (PNF stretching 24 hours post-exercise) returns to lower than their baseline at Time 6, while Group A (PNF stretching immediately post-exercise) remained higher than their baseline score at the end. Therefore Group B (PNF stretching 24 hours post-exercise), showed a faster decrease in pain experienced due to DOMS than Group A (PNF stretching immediately post-exercise) from day 2 of the study. Group B (PNF stretching 24 hours post-exercise) also had a larger decrease in pain experienced than Group A (PNF stretching immediately post-exercise), to less than baseline NRS measurements. However, this effect was not statistically significant at the 0.05 level and could be related to lack of statistical power, with only 15 samples per group.

4.2.3.2 Algometer readings

4.2.3.2.1 Left Hamstring algometer readings

For algometer measurements, four time point measurements were compared, using repeated measures ANOVA. The baseline measurement for algometer readings was taken as visit 2, since stiffness was induced at visit 1 and maximum pain was felt on day 2.

Table 5: Within-subjects and between-subjects effects for algometer – left Hamstring

Effect	Statistic	p value
Time	Wilk's lambda=0.638	0.008
Group	F = 0.027	0.872
Time*group	Wilk's lambda=0.887	0.367

Table 5 shows that, for the left Hamstring, there was a significant time effect ($p=0.008$). There was a change in algometer readings over time, regardless of the group. No group effect ($p=0.872$) was shown and no difference between

Group A (PNF stretching immediately post-exercise) and Group B ((PNF stretching 24 hours post-exercise) was shown. There was also no evidence of a treatment effect ($p=0.367$), no difference between groups A (PNF stretching immediately post-exercise) and B (PNF stretching 24 hours post-exercise) over time, once again confirming the null hypothesis (H_0).

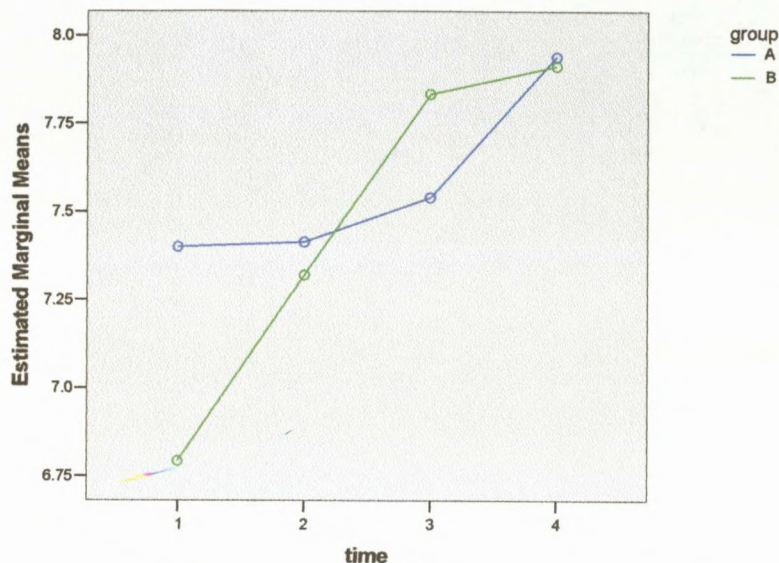


Figure 2: Profile plot of mean algometer – left Hamstring over time by treatment group

Figure 2 shows that both treatment groups A (PNF stretching immediately post-exercise) and B (PNF stretching 24 hours post-exercise) showed a mean increase in algometer measurements over time, indicating that there was decreased muscle pain experienced in the left Hamstring muscle over time. There was the suggestion that Group B (PNF stretching 24 hours post-exercise) improved at a faster rate than Group A (PNF stretching immediately post-exercise), but this was not statistically significant ($p=0.367$).

4.2.3.2.2 Right Hamstring algometer readings

Table 6: Within-subjects and between-subjects effects for algometer – right Hamstring

Effect	Statistic	p value
Time	Wilk's lambda=0.558	0.001
Group	F = 0.038	0.847
Time*group	Wilk's lambda=0.960	0.779

For the right Hamstring muscle, Table 6 shows that there was a highly significant time effect ($p=0.001$) and no treatment effect ($p=0.779$), meaning that both Groups A (PNF stretching immediately post-exercise) and B (PNF stretching 24 hours post-exercise) showed improvement in algometer readings for the right Hamstring muscle over time. This improvement was not, however, different between the treatment groups. This confirms the null hypothesis (H_0), by showing that the pain experienced in DOMS improved at approximately the same rate, whether PNF stretching was done immediately or 24 hours after exercise.

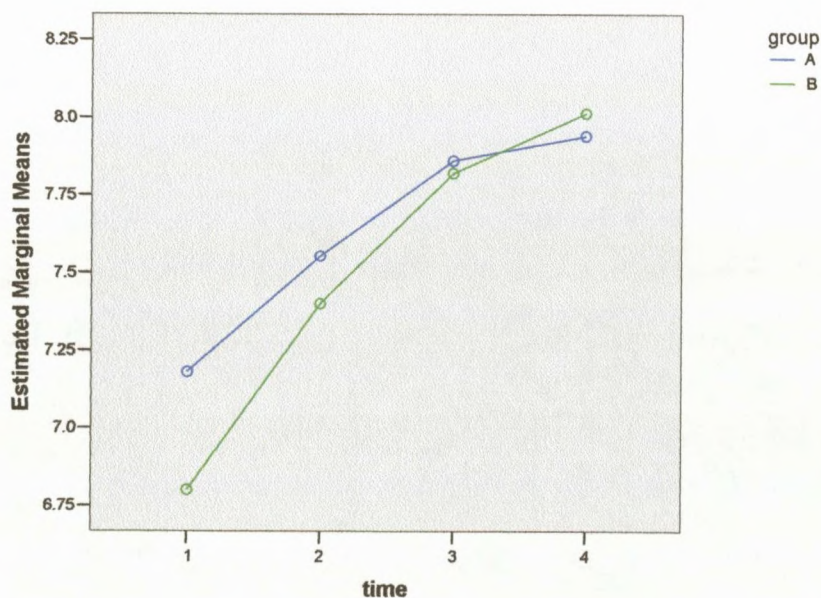


Figure 3: Profile plot of mean algometer – right Hamstring over time by treatment group

Figure 3 shows that both Groups A (PNF stretching immediately post-exercise) and B (PNF stretching 24 hours post-exercise) improved over time with regard to algometer measurements of the right Hamstring, but that the rate of improvement was similar in both groups. There was a slight crossing over of profiles at time 3, where the rate of improvement in Group B (PNF stretching 24 hours post exercise), overtook that of Group A (PNF stretching immediately post exercise). This shows that PNF stretching 24 hours after exercise may improve the pain experienced in DOMS quicker than PNF stretching immediately after exercise.

4.2.3.2.3 Left Quadriceps Femoris algometer readings

Table 7: Within-subjects and between-subjects effects for algometer – left Quadriceps Femoris

Effect	Statistic	p value
Time	Wilk's lambda=0.471	<0.001
Group	F = 0.251	0.620
Time*group	Wilk's lambda=0.867	0.286

Table 7 shows that there was a highly significant time effect ($p < 0.001$) without a treatment effect ($p = 0.286$), indicating that both groups A (PNF stretching immediately post-exercise) and B (PNF stretching 24 hours post-exercise) had improvement of pain perception for the left Quadriceps Femoris muscle algometer readings at the same rate, thus confirming the null hypothesis (H_0).

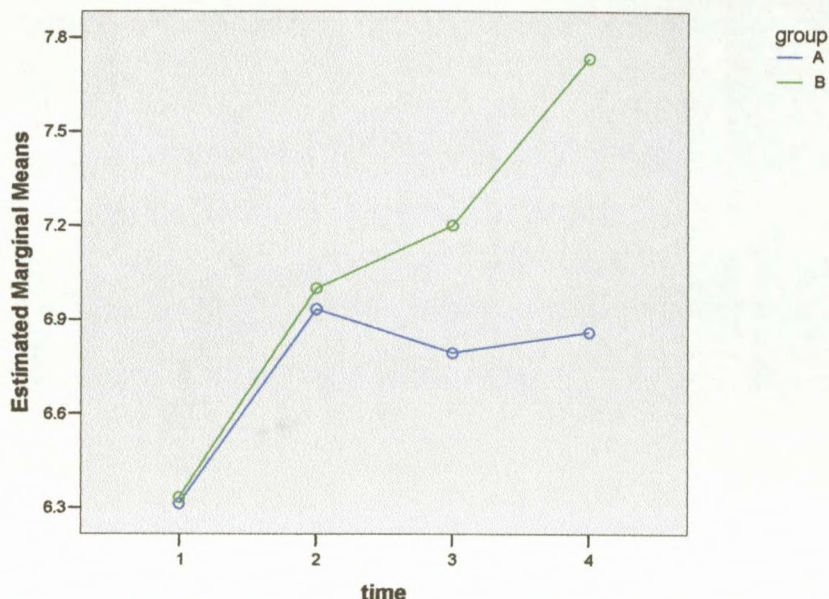


Figure 4: Profile plot of mean algometer – left Quadriceps Femoris over time by treatment group

With respect to the results in Table 7, Figure 4 shows that the rate of improvement was the same up to time 2, whereafter Group B (PNF stretching 24 hours post-exercise) continued to show improvement, while Group A (PNF stretching immediately post-exercise) levelled off their algometer measurements. There is thus a trend towards a more beneficial effect of Group B (PNF stretching 24 hours post-exercise), but there is insufficient statistical evidence. With a larger sample size, this time by group treatment effect may have been significant. The present study appears to have been underpowered, with a sample size of only 30.

4.2.3.2.4 Right Quadriceps Femoris algometer readings

Table 8: Within-subjects and between-subjects effects for algometer – right Quadriceps Femoris

Effect	Statistic	p value
Time	Wilk's lambda=0.530	0.001
Group	F = 0.060	0.809
Time*group	Wilk's lambda=0.870	0.298

Table 8 shows that there was a highly significant time effect ($p=0.001$) without a treatment effect ($p=0.298$), indicating that both groups A (PNF stretching immediately post exercise) and B (PNF stretching 24 hours post exercise) improved at the same rate, but there were no differences between the two groups, thus confirming the null hypothesis (H_0).

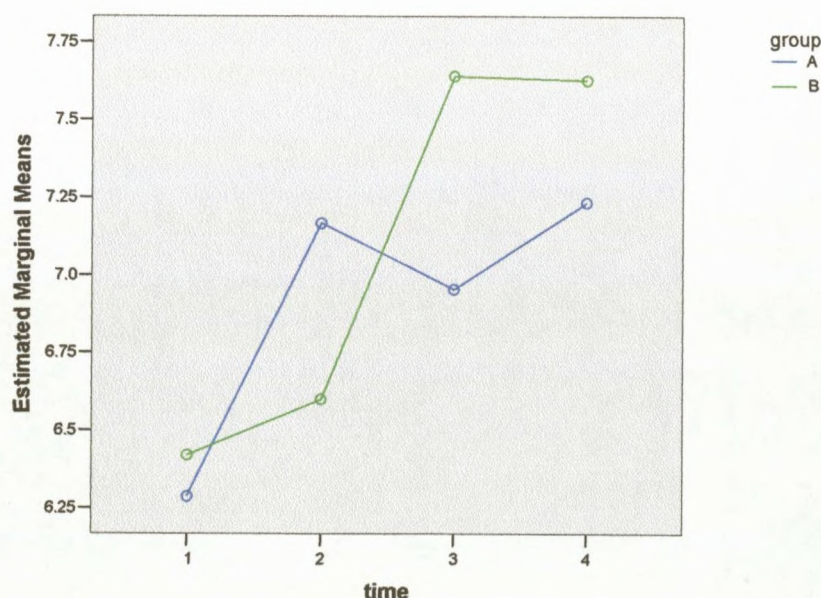


Figure 5: Profile plot of mean algometer – right Quadriceps Femoris over time by treatment group

Figure 5 shows, however, that the rate of improvement in Group B (PNF stretching 24 hours post-exercise) was higher than in Group A (PNF stretching immediately post-exercise). There is thus a trend towards a more beneficial effect of Group B (PNF stretching 24 hours post-exercise), but there is insufficient statistical evidence. Once again underpowering was a problem, as clinical significance without statistical significance was achieved.

4.3 Summary and conclusion

This study has failed to demonstrate a statistically significant difference between PNF stretching immediately after exercise and PNF stretching 24 hours after exercise. However, both groups showed significant improvements according to all outcomes measured over time, a significant decrease in NRS readings and an increase in algometer readings over time, regardless of the group. Thus, both PNF stretching immediately after exercise and PNF stretching 24 hours after exercise results in significant improvements over time, thus confirming the null hypothesis (H_0), that there is no difference between the Groups A and B over time. Trends showed that Group B (PNF stretching 24 hours after exercise) was perhaps more beneficial than immediate PNF stretching, for all the outcomes measured. This cannot be concluded with any statistical certainty, since no statistically significant treatment effects were observed for any outcomes. This may have been due to an underpowered study because of a low sample size. Further studies, with larger samples, should be undertaken to confirm these findings.

CHAPTER FIVE

Discussion

CHAPTER FIVE: Discussion

5.1 Introduction

The results that were presented in chapter four will be discussed in this chapter. The demographics will be discussed, followed by the baseline outcomes measurements. The results of this study will be compared with available literature on the subject, to determine how the results of this study compare to other studies.

5.2 Demographic data

The average age of the participants between the two treatment groups was compared in Table 1. The results show that there was no difference in average age of participants between treatment groups and there was a relatively even age spread between the two groups.

The participants ranged from 20 to 32 years of age. The average age of group B was slightly higher (27) than Group A (25.8), but this difference was not significant, with $p = 0.473$. In a similar study, Lund *et al.* (1993) used healthy, untrained women with higher ages of 28 to 46. These participants underwent eccentric exercise of the right Quadriceps Femoris until exhaustion, as well as daily static stretching.

Gulick *et al.* (1996) investigated which of the known treatment techniques used for relief of DOMS were most effective, such as NSAIDS, concentric muscle contractions, ice massage, static stretching and Arnica ointment. They used participants between the ages of 21 and 40 and had similar results within this age group. In subsequent studies, the researchers used similar age groups; Bonnar *et al.* (2004) used active participants between the ages of 18 and 29 and Ulrike (2005) used participants between the ages of 17 and 44. Feland *et al.* (2001) assessed the acute changes in flexibility of Hamstring muscles from static and PNF stretching before activity, in 55- to 79-year-old athletes. They found that

the results differed between participants that were younger than 65 years of age and the participants that were older than 65 years of age.

There seems to be a trend showing that homogeneity occurs in age groups ranging from 18 to approximately 45. This could possibly be due to the connective tissue change observed with increasing age (Feland *et al.*, 2001).

Table 2 compared the race distribution among the treatment groups. Results show that there was no statistically significant difference in proportions of the race group between the treatment groups, with the p value = 0.311. The majority of participants were white (19 participants) and the number of white participants was almost equal between the two groups, ten in Group A and nine in Group B. Group B had more black participants, five in total, than Group A, two in total, and *vice versa* for Indian and coloured participants, one in Group B and three in Group A. This slight difference was not statistically significant. There were no comparisons made according to race in other similar published articles. According to the present study, no statistically relevant results were found according to race, as the p value = 0.113.

5.3 Baseline outcomes measurements

Table 3 assesses the average baseline outcomes, Numerical Pain Rating Scale (NRS) and algometer readings, between treatment groups. All baseline measurements were taken before any exercise or stretching was done, at Visit 1. No significant differences were found at baseline between the treatment groups for any of the outcomes. All the participants in either group had similar NRS and algometer readings to begin with, the average initial NRS reading for Group A was 1 and Group B was 2.67. The average algometer readings were as follows: for the left Hamstring both Group A and Group B averaged 8.333 force/kg, for the right Hamstring algometer readings, Group A averaged 8.847 force/kg, and Group B averaged 8.807 force/kg. Similar results were found with the Quadriceps Femoris averages. For the left Quadriceps Femoris averages, Group A showed 7.880 force/kg and Group B showed 7.753 force/kg. Right Quadriceps Femoris Group A showed an average of 8.540 force/kg and Group B showed an average

of 7.993 force/kg. These similar results at baseline allow increased reliability of the subsequent results for comparison. Gulick *et al.* (1996) used similar measurement tools to interpret muscle pain, namely the visual analogue scale and algometer. Baseline measurements were equal or similar in all participants used in Gulick *et al.* (1996) study.

5.4 Analysis of the treatment effect

5.4.1 Numerical Pain Rating Scale (NRS)

Table 4 shows that the NRS values for both the treatment groups changed significantly over time ($p = 0.007$). Thus for NRS, there was no evidence of a differential treatment effect, even though there was a significant change over time for all participants' pain perception and there was no significant difference between the two Groups A and B ($p = 0.404$).

Figure 1 shows the profile plot of average NRS over time by treatment group. At Time 5 (day 2 of the study, 24 hours after exercise), Group B appears to decrease NRS score at a faster rate than Group A. Group B returned to lower than their baseline at Time 6, while Group A remained higher than their baseline score at the end, showing that PNF stretching 24 hours after exercise had a greater effect on the pain experienced in DOMS. This effect was not statistically significant at the 0.05 level and this could be due to lack of statistical power with only 15 participants per group. The sample size used in the present study is prominent in the majority of previous studies conducted on DOMS (Gulick *et al.*, 1996; Ulrike *et al.*, 2005). Lund *et al.* (1998) used only seven participants in their study, where they assessed the effects of daily passive stretching on DOMS. It appears that several studies conducted on the effects of a treatment modality on DOMS were underpowered statistically.

5.4.2 Algometer readings

For algometer measurements, four time points' measurements were compared, using repeated measures ANOVA. The baseline measurement for algometer readings was taken as visit 2, since stiffness was induced at visit 1 and maximum pain was felt on day 2 (24 hours post-exercise). This does not concur with the findings of Lund *et al.* (1998), in which they found muscle soreness to peak 48 hours after exercise. The differences between the two studies may contribute to this finding. Lund *et al.* (1998) conducted their study on healthy, untrained females and the current study was conducted on healthy, untrained males. The former study assessed the effect of static stretching on DOMS and the latter study assessed the effect of PNF stretching on the pain perceived in DOMS. Dannecker *et al.* (2003) showed that females reported lower muscle pain than males when pain response was measured 48 hours after eccentric exercise between males and females. Several other researchers have shown peak soreness to vary between 24 and 48 hours after eccentric exercise (MacIntyre *et al.*, 1995; McArdle *et al.*, 1996; Nie *et al.*, 2005).

The muscles measured, left and right Hamstrings and left and right Quadriceps, were statistically tested separately. There were therefore four separate analyses for algometer readings.

The Hamstring muscles both had a significant time effect, according to the repeated measures ANOVA statistical test for algometer readings. This is shown in Table 5 (left Hamstring) as $p=0.008$ and Table 6 (right Hamstring) as $p = 0.001$. There was a change over time for all participants, regardless of the group. No group effect was found for either the left ($p=0.872$) or the right ($p=0.847$) Hamstrings, indicating no difference between Groups A and B. There was no evidence of a treatment effect for left ($p=0.367$) and right ($p=0.779$) Hamstrings. This shows that both treatments, PNF stretching immediately after exercise and PNF stretching 24 hour after exercise, were both as beneficial as each other.

Figures 2 and 3 show that both the treatment groups, for the left and right Hamstring muscles respectively, had an average increase in algometer

measurements and therefore increased pressure threshold and decreased pain, over time. There was also the suggestion that Group B improved at a faster rate than Group A, for both Hamstring muscles.

The Quadriceps Femoris muscles' algometer readings demonstrated in Table 7 (left) and Table 8 (right) show that there was a highly significant time effect for the left ($p < 0.001$) and right Quadriceps Femoris muscles ($p = 0.001$), without a treatment effect for left ($p = 0.286$) and right ($p = 0.298$) Quadriceps Femoris muscles, indicating that both groups A and B improved at the same rate for both left and right Quadriceps Femoris muscles. Figures 4 and 5 show that the rate of improvement was the same up to Time 2, whereafter Group B continued to show improvement, while Group A reached a plateau. There is thus a trend towards a more beneficial effect of Group B, but there is insufficient statistical evidence. With a greater sample size, this time by group treatment effect may have been significant.

Feland *et al.* (2001) compared static stretching to PNF stretching in elderly active participants by assessing Hamstring flexibility only. They stretched the participants prior to the exercise and concluded that both treatment groups had increased flexibility, the PNF group having a greater increase.

5.5 Summary

Both groups showed significant improvements with respect to all outcomes, measured over time. Either modality of treatment results in significant improvement over time. But trends showed that Group B (PNF stretching 24 hours after exercise) was perhaps more beneficial than stretching directly after exercise, for all the outcomes measured (NRS and algometer readings). This cannot be concluded with any statistical certainty, since no statistically significant treatment effects were observed for any outcomes. This may have been due to an underpowered study due to low sample size. Larger studies should be undertaken in the future to confirm these findings.

CHAPTER SIX

Conclusions and recommendations

CHAPTER SIX: Conclusions and Recommendations

6.1 Introduction

The study had two primary aims. Chapter six will discuss these aims and whether or not they were achieved. The limitations experienced over the duration of this study will be analyzed and recommendations for further studies will be made.

6.2 Aim 1

To determine the relative effectiveness of proprioceptive neuromuscular facilitated stretching in terms of subjective and objective findings on delayed onset muscle soreness associated with unaccustomed post-eccentric exercise in healthy, sedentary male individuals.

Subjective data were gathered via a NRS scale reading at eight hour intervals over the three-day study period. These were statistically analysed and showed that Group B (PNF stretching 24 hours after exercise) decreased NRS score at a faster rate than Group A (PNF stretching immediately after exercise). The participants that had PNF stretching 24 hours after exercise (Group B) returned to lower than their baseline at Time 6 (day 3 of the study, 48 hours after exercise), while the participants that had PNF stretching immediately after exercise (Group A) remained higher than their baseline score at the end of the three-day study. The subjective NRS readings show that there was a perceived decrease in pain over time, regardless of the treatment group, but the PNF stretching 24 hours after exercise group appeared to have a greater recovery rate. DOMS has a natural decrease in perceived muscle soreness over time (Gulick *et al.*, 1996). Peak soreness is at approximately 24 – 48 hours after exercise and a decrease in pain is experienced thereafter (Close *et al.*, 2005). In the present study, peak soreness was recorded at 24 hours after exercise and there was decreased perceived pain from 48 hours onwards.

Objective data were gathered via algometer readings taken on the Quadriceps Femoris and Hamstring muscles at six intervals over the three-day study period. These were statistically analysed by repeated measures ANOVA, showing significant time effect, no group effect and no evidence of a treatment effect for all muscles measured, left and right Hamstrings and left and right Quadriceps Femoris muscles. Both the treatment Groups A and B, for all muscles, had an average increase in algometer measurements and therefore increased pressure threshold and decreased pain, over time.

6.3 Aim 2

To determine the relative effectiveness of proprioceptive neuromuscular facilitated stretching immediately after exercise versus proprioceptive neuromuscular facilitated stretching once DOMS symptoms are present in terms of subjective and objective findings on delayed onset muscle soreness associated with unaccustomed post eccentric exercise in healthy, sedentary male individuals.

Subjective data were gathered over the three-day study period by means of NRS readings. These data were analysed statistically and conclusions were drawn. PNF stretching 24 hour after exercise (Group B) appeared to decrease NRS score at a faster rate than PNF stretching immediately after exercise (Group A). Group B returned to lower than their baseline, while Group A remained higher than their baseline score at the end of the study. Therefore group B had a greater decrease in pain perception than group A. This suggests that PNF stretching 24 hours after exercise is more beneficial than PNF stretching directly after exercise.

Objective data were gathered by means of algometer readings taken on the Quadriceps Femoris and Hamstring muscles at six intervals over the three-day study period. These were statistically analysed with repeated measures ANOVA showing that the rate of improvement in Group B (PNF stretching 24 hour after exercise) was higher than in Group A (PNF stretching immediately after exercise). There is thus a trend towards a more beneficial effect in PNF stretching 24 hours after the initiating eccentric exercise.

There was insufficient statistical evidence to draw conclusive results, as the sample size was small, consisting of only 15 participants per treatment group. The statistical analysis done on this study alludes to the following: that if the same study were to be conducted on a much larger scale, the trends noticed may show a largely significant treatment effect and therefore demonstrate that PNF stretching 24 hours after exercise would be beneficial to relieve the pain perceived in DOMS. This needs to be confirmed.

6.4 Final conclusion

The purpose of this study was to determine the most favourable time period in which to apply PNF stretching to eccentrically exercised muscles, directly after exercise or 24 hours later, in order to decrease the pain experienced in DOMS. The results tend to favour PNF stretching 24 hours after the eccentric exercise over PNF stretching immediately after eccentric exercise.

Statistical analysis showed a significant difference between Group A and Group B, for both NRS scores and algometer readings. This indicates that PNF stretching 24 hours after the initiating eccentric exercise is more beneficial than PNF stretching immediately after eccentric exercise in relieving the muscle soreness experienced in DOMS.

It is the researcher's opinion that, as PNF stretching employs a contraction of the antagonist muscle while eliciting the stretch, there is increased work done on those muscles in the stretch directly after eccentric exercise and therefore increased muscle damage. This study used both Hamstring and Quadriceps Femoris muscles for readings and therefore assessed the antagonist work. In agreement with Gulick *et al.* (1996), bouts of concentric exercise after the initiating eccentric exercise may decrease the symptoms of DOMS experienced. Therefore PNF stretching 24 hours later employs a stretch as well as a bout of concentric exercise of the antagonist muscle.

6.5 Limitations and further recommendations

6.5.1 Sample size

Due to financial and time constraints, the sample size for this study was small and therefore this study had statistically underpowered results.

A longer time period may be necessary to conduct a larger study and increase the reliability of the study.

6.5.2 Variables

The term "sedentary" may be interpreted in many different ways. Incorporating a specific means of calculating the participants' fitness levels in future studies may increase the reliability of the study.

Patients may interpret pain to varying degrees; the NRS is not reliable as the sole baseline measurement. Future studies should use more objective measurements, such as the goniometer, to measure muscle flexibility as an indicator to muscle damage. This may provide results to show a greater correlation between PNF stretching and the time period at which it is applied after exercise.

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APPENDIX A

PATIENT INFORMATION LETTER

Dear participant

Thank you for taking the time to consider participation in my research study.

TITLE OF RESEARCH:

The relative effect of proprioceptive neuromuscular facilitated stretching immediately after eccentric exercise Vs proprioceptive neuromuscular facilitated stretching post delayed onset muscle soreness in healthy sedentary male subjects.

PRINCIPAL INVESTIGATORS:

Helen Schlebusch

Dr A Docrat

M. Tech: Chiropractic CCFC

INTRODUCTION:

The commonly experienced pain and stiffness in muscles 24 to 48 hours after beginning an exercise programme is known as delayed onset muscle soreness, which is thought to be due to muscle fibre damage and inflammation. There are several proposed treatments for this phenomenon, but most of the literature around these treatment modalities reveals conflicting data.

Stretching, in general, is thought to reduce muscle stiffness via increased circulation, allowing increased range of motion. Proprioceptive neuromuscular facilitation stretching has been shown to have a greater effect than static stretching in pain perception of myofascial trigger points, but little research has been done on the effects on delayed onset muscle soreness.

PURPOSE OF THE STUDY:

To assess if PNF stretching immediately after exercise is more beneficial than PNF stretching once the discomfort of DOMS has set in.

PROCEDURES:

This study will include 60 healthy, sedentary, male participants, divided randomly into 2 groups. At the first visit, information of all the groups' muscle sensitivity to pain, of the Quadriceps Femoris and Hamstring muscles, will be assessed using the algometer and numerical pain rating scale. All the groups will then do eccentric exercise in the form of squats, until fatigue. Each participant will then undergo stretching, beginning either immediately after exercise (Group A) or 24 hours later (Group B). You will be required to return for stretching and readings for 2 consecutive days after the initial appointment.

RISKS/ DISCOMFORTS:

Delayed onset muscle soreness will be experienced as a mild discomfort of the muscles for no longer than 1 week duration.

Cramping or muscle spasm may occur during eccentric exercise, if this does occur, the exercise will be immediately stopped and appropriate treatment will be given.

No other risks are associated with this study.

BENEFITS:

The intervention is thought to ease the discomfort felt due to DOMS.

You will be given 1 free treatment for any musculoskeletal complaint within one month of participating in this study.

NEW FINDINGS:

I am aiming to distinguish if PNF stretching immediately after exercise is more beneficial than PNF stretching only once the discomfort of DOMS is experienced.

REASON WHY YOU MAY BE WITHDRAWN FROM THIS STUDY WITHOUT YOUR CONSENT:

1. If you do not arrive for any one of the 3 consecutive appointments,
2. Begin an exercise regimen during the study.
3. Begin taking any anti-inflammatory drugs during the study
4. If you do not experience the symptoms of DOMS after 24h and are in group B.
5. If you fail to fill in your pain rating diary at 8 hour intervals.

REMUNERATION:

This study is entirely voluntary, and therefore no remuneration will be given.

COSTS OF THE STUDY:

There will be no cost to the volunteer for the duration of this study.

CONFIDENTIALITY:

All volunteer information is confidential, only the researcher, supervisor and relative authorities will have access to it.

RESEARCH – RELATED INJURY:

There is no known research related injury for this study.

PERSONS TO CONTACT FOR PROBLEMS OR QUESTIONS:

Helen Schlebusch – 082 851 7355

Dr A. Docrat – 031 2042589

M. Tech: Chiropractic CCFC

Please don't hesitate to ask questions on any aspects of this study. If you have any queries or complaints please feel free to contact me or my supervisor.

Yours sincerely,
Helen Schlebusch (Chiropractic intern)

APPENDIX B
INFORMED CONSENT FORM

TITLE OF RESEARCH:

The relative effect of proprioceptive neuromuscular facilitated stretching immediately after eccentric exercise Vs proprioceptive neuromuscular facilitated stretching post delayed onset muscle soreness in healthy sedentary male subjects.

SUPERVISOR:

Dr A Docrat

M. Tech: Chiropractic CCFC

031 2042589

RESEARCH STUDENT:

Helen Schlebusch

082 851 7355

Please circle the appropriate answer:

- | | | |
|--|-----|----|
| 1. Have you read the research information letter? | Yes | No |
| 2. Have you had an opportunity to ask questions regarding this study? | Yes | No |
| 3. Have you received satisfactory answers to your questions? | Yes | No |
| 4. Have you had an opportunity to discuss this study? | Yes | No |
| 5. Have you received enough information about this study? | Yes | No |
| 6. Do you understand the implications of your involvement in this study? | Yes | No |
| 7. Do you understand that you are free to withdraw from this study? | Yes | No |

At any time

Without having to give any reason for withdrawing, and

Without affecting your future health care.

- | | | |
|---|-----|----|
| 8. Do you agree to voluntarily participate in this study? | Yes | No |
| 9. Who have you spoken to? _____ | | |

Please ensure that the researcher completes each section with you.

If you have answered NO to any of the above, please obtain the necessary information before signing.

Please print in block letters:

Patient / volunteer Name: _____ Sign: _____

Witness Name: _____ Sign: _____

Intern Name: _____ Sign: _____

APPENDIX C:
PATIENT HISTORY

DURBAN UNIVERSITY OF TECHNOLOGY
CHIROPRACTIC DAY CLINIC
CASE HISTORY

Patient: _____ Date: _____
File #: _____ Age: _____
Sex: _____ Occupation: _____
Intern: _____ Signature: _____

FOR CLINICIANS USE ONLY:

Initial visit

Clinician: _____ Signature: _____

Case History:

Examination:

Previous:

Current:

X-Ray Studies:

Previous:

Current:

Clinical Path. Lab:

Previous:

Current:

CASE STATUS:

PTT:	Signature:	Date:
------	------------	-------

CONDITIONAL:

Reason for Conditional:

Signature:

Date:

Conditions met in Visit No:

Signed into PTT:

Date:

Case Summary signed off:

Date:

Intern's Case History:

1. Source of History:

2. Chief Complaint: (patient's own words):

3. Present Illness:

	Complaint 1	Complaint 2
<ul style="list-style-type: none">◦ Location◦ Onset: Initial: Recent:◦ Cause:◦ Duration:◦ Frequency:◦ Pain (character):◦ Progression:◦ Aggravating Factors:◦ Relieving Factors:◦ Associated S & S:◦ Previous Occurrences:◦ Past Treatment:◦ Outcome:		

4. Other Complaints:

5. Past Medical History:

- General Health Status:
- Childhood Illnesses:
- Adult Illnesses:
- Psychiatric Illnesses:
- Accidents/Injuries:
- Surgery:
- Hospitalizations:

6. Current health status and life-style:

- Allergies
- Immunizations
- Screening Tests incl. xrays

- Environmental Hazards (Home, School, Work)
- Exercise and Leisure
- Sleep Patterns
- Diet
- Current Medication
- Analgesics/Week:
- Tobacco
- Alcohol
- Social Drugs

7. Immediate Family Medical History:

- Age
- Health
- Cause of Death
- DM
- Heart Disease
- TB
- Stroke
- Kidney Disease
- CA
- Arthritis
- Anaemia
- Headaches
- Thyroid Disease
- Epilepsy
- Mental Illness
- Alcoholism
- Drug Addiction
- Other

8. Psychosocial history:

- Home Situation and daily life
- Important experiences
- Religious Beliefs

9. Review of Systems:

- General
- Skin
- Head
- Eyes
- Ears
- Nose/Sinuses
- Mouth/Throat
- Neck
- Breasts
- Respiratory
- Cardiac
- Gastro-intestinal
- Urinary
- Genital
- Vascular
- Musculoskeletal
- Neurologic
- Haematologic
- Endocrine
- Psychiatric

APPENDIX D
PHYSICAL EXAMINATION

Durban University of Technology
PHYSICAL EXAMINATION: SENIOR

Patient Name: _____				File No: _____		Date: _____	
Student: _____				Signature: _____			
VITALS:							
Pulse rate:				Respiratory rate:			
Blood Pressure:		R	L	Medication if hypertensive:			
Temperature:				Height			
Weight:		Any recent change?		If yes: How much gain/loss		Over what period	
GENERAL EXAMINATION:							
General Impression							
Skin							
Jaundice							
Pallor							
Clubbing							
Cyanosis (Central/Peripheral)							
Oedema							
Lymph nodes		Head and Neck					
		Axillary					
		Epitrochlear					
		Inguinal					
Pulses							
Urinalysis							
SYSTEM SPECIFIC EXAMINATION:							
CARDIOVASCULAR EXAMINATION							
RESPIRATORY EXAMINATION							
ABDOMINAL EXAMINATION							
NEUROLOGICAL EXAMINATION							
COMMENTS							
Clinician: _____				Signature: _____			

APPENDIX E:
NUMERICAL PAIN RATING SCALE

PATIENT NAME: _____ File NO: _____ DATE: _____

PLEASE INDICATE ON THE LINE BELOW, THE NUMBER BETWEEN 0 AND 100
THAT BEST DESCRIBES THE PAIN YOU ARE EXPERIENCING AT THIS MOMENT.

A zero (0) would mean "no pain at all", and 100 would mean "the pain is as bad as can
be". Please only write the number.

APPENDIX F:
ALGOMETER MEASUREMENTS

PATIENT NAME: _____ File NO: _____ DATE: _____

		<u>READING 1</u>		<u>READING 2</u>	
		Left	Right	Left	Right
INITIAL	H/S				
	Quad				
VISIT 1	H/S				
	Quad				
VISIT 2	H/S				
	Quad				
VISIT 3	H/S				
	Quad				

APPENDIX G:
NUMERICAL PAIN RATING SCALE DIARY

PATIENT NAME: _____ File NO: _____ DATE: _____

PLEASE INDICATE ON THE LINE BELOW, THE NUMBER BETWEEN 0 AND 100 THAT BEST DESCRIBES THE PAIN YOU ARE EXPERIENCING 8 HOURS AFTER ECCENTRIC EXERCISE.

A zero (0) would mean "no pain at all", and 100 would mean "the pain is as bad as can be". Please only write the number.

PLEASE INDICATE ON THE LINE BELOW, THE NUMBER BETWEEN 0 AND 100 THAT BEST DESCRIBES THE PAIN YOU ARE EXPERIENCING 16 HOURS AFTER ECCENTRIC EXERCISE.

A zero (0) would mean "no pain at all", and 100 would mean "the pain is as bad as can be". Please only write the number.

PATIENT NAME: _____ File NO: _____ DATE: _____

PLEASE INDICATE ON THE LINE BELOW, THE NUMBER BETWEEN 0 AND 100 THAT BEST DESCRIBES THE PAIN YOU ARE EXPERIENCING 32 HOURS AFTER ECCENTRIC EXERCISE.

A zero (0) would mean "no pain at all", and 100 would mean "the pain is as bad as can be". Please only write the number.

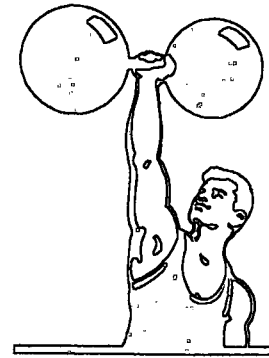
PLEASE INDICATE ON THE LINE BELOW, THE NUMBER BETWEEN 0 AND 100 THAT BEST DESCRIBES THE PAIN YOU ARE EXPERIENCING 40 HOURS AFTER ECCENTRIC EXERCISE.

A zero (0) would mean "no pain at all", and 100 would mean "the pain is as bad as can be". Please only write the number.

APPENDIX H:

ADVERT

ARE YOU.....



Healthy

and between the ages of 20 - 40?

Interested in participating in research?

Research is being conducted
at Durban University of Technology
on Delayed Onset Muscle Soreness

Requirements:

Males between 20 - 40 years of age.

No current exercise regime.

No medical conditions.

Please contact: Helen
(031) 204 2205
082 8517 355

RESEARCH ARTICLE

The relative effect of proprioceptive neuromuscular facilitated stretching immediately after eccentric exercise Vs proprioceptive neuromuscular facilitated stretching post-delayed onset muscle soreness in healthy sedentary male subjects.

Schlebusch, Helen; Docrat, Aadil.

Department of Chiropractic; Faculty of Health; Durban University of Technology

Objectives: Objective 1: To determine the relative effectiveness of proprioceptive neuromuscular facilitated stretching in terms of subjective and objective findings on delayed onset muscle soreness associated with unaccustomed post-eccentric exercise in healthy sedentary male individuals.

Objective 2: To determine the relative effectiveness of proprioceptive neuromuscular facilitated stretching immediately after exercise compared to proprioceptive neuromuscular facilitated stretching once DOMS symptoms are present in terms of subjective and objective findings on delayed onset muscle soreness associated with unaccustomed post eccentric exercise in healthy, sedentary male individuals.

Design: This study was a prospective, randomised controlled clinical trial.

Setting: Chiropractic Day Clinic; Durban University of Technology.

Participants: 30 participants divided randomly into two groups – Group A and Group B.

Intervention: All participants did eccentric exercise in the form of squats until fatigue. There was no pre-exercise warm up period.

All participants underwent PNF stretching, Group A – immediately after exercise and Group B – 24 hours after exercise. Both groups underwent PNF stretching every 24 hours after the initial stretching for three consecutive days.

Main Outcome Measures: NRS and algometer readings.

Results: Both groups showed significant improvements, according to all outcomes measured over time, a significant decrease in NRS readings and increase in algometer readings over time, regardless of the Group.

Conclusion: Results showed that there was greater improvement for Group B with respect to rate of pain reduction experienced in the exercised muscles.

Key words: Delayed onset muscle soreness (DOMS), eccentric exercise, Proprioceptive Neuromuscular Facilitative (PNF) stretching.

Introduction

Delayed onset muscle soreness (DOMS) is a common phenomenon in people just beginning an exercise programme, or who change from their regular activities, by increasing their eccentric load (McArdle *et al.*, 1996; Cheung *et al.*, 2003; Connolly *et al.*, 2003). DOMS is muscular pain which ranges from mild discomfort to severe debilitating pain (McArdle *et al.*, 1996; Connolly *et al.*, 2003). It sets in 12 – 24 hours after the causative activity, and subsides within approximately seven days at (McArdle *et al.*, 1996; Connolly *et al.*, 2003). Eccentric exercise is known to induce more muscle soreness than concentric exercise. (McArdle *et al.*, 1996; Connolly *et al.*, 2003) As little as 15 repetitions of eccentric muscle contractions, which occur when the muscle contracts while lengthening, seem to most often cause DOMS (Albert, 1991; McAtee, 1993; McArdle *et al.*, 1996). However Cleak *et al.* (1992) stated that the amount of tearing, and therefore soreness, depends on the specific activity, as well as on the intensity and duration of the activity.

There are several theories that attempt to explain the cause of DOMS (McArdle *et al.*, 1996). These were reviewed by Cheung *et al.* (2003) as the accumulation of lactic acid, muscle spasm, connective tissue damage, muscle damage and inflammation. The lactic acid theory assumes that there is continued production of lactic acid after exercise. This has, however, been largely rejected, as the

lactic acid levels return to normal within one hour after exercise (McArdle *et al.*, 1996; Cheung *et al.*, 2003). Theories such as the muscle spasm theory and the connective tissue theory are still unclear (Cheung *et al.*, 2003).

Various techniques have been used in the treatment of DOMS. Cheung *et al.* (2003) stated that these included non steroidal anti-inflammatory drugs (NSAIDS), exercise, stretching techniques and electrical modalities such as ultrasound, interferential current therapy (IFC) and transcutaneous electrical nerve stimulation (TENS). Cheung *et al.* (2003) concluded that NSAIDS are thought to have an effect prophylactically, but they may amplify the symptoms of DOMS if taken in large amounts. They also suggested that cryotherapy, static stretching, homeopathy and electrical modalities have no effect on the symptoms of DOMS. However, concentric exercise has been shown to be the most beneficial treatment for the symptoms of DOMS (Cheung *et al.*, 2003).

Stretching has been promoted as an integral part of fitness programmes to decrease the risk of injury, relieve muscle soreness and improve sport performance (Anderson *et al.*, 1991).

The mechanism of action of stretching leading to a reduction of muscle stiffness, is via increased circulation, passive viscoelastic changes, as well as by reflex inhibition and allowing increased range of motion (Anderson, 1980; Garrett, 1990; Best, 1995). In addition, stretching is thought to relieve muscle soreness, by increasing "stretch tolerance", that is, a deeper stretch is perceived more permissible (Magnusson, 1996). Increased stretch tolerance allows the patient to feel less pain for the same force applied to the muscle. This could be due to increased tissue strength, flexibility or analgesia due to increased blood flow (Best, 1995; Magnusson, 1996). The stretch is also thought to disperse the oedema and inflammation, leading to decreased pain perception (Bobbert *et al.*, 1986).

Several studies have been conducted to compare the various types of stretching, (Static, Proprioceptive Neuromuscular Facilitative (PNF) and Ballistic) (Cornelius *et al.*, 1992; Shrier *et al.*, 2000; Feland *et al.*, 2001). Shrier *et al.* (2000) revised

that PNF stretching has resulted in greater increases of range of motion compared to static or ballistic stretching.

PNF stretching is proposed to initiate a deeper stretch of the muscle via reciprocal inhibition by contracting the antagonist muscle during the stretch, resulting in greater flexibility and increased range of motion of the joint (Anderson *et al.*, 1991). However, Ulrike (2005) showed that reciprocal inhibition was not evident during PNF stretching, as the EMG of the antagonist muscle was elevated rather than decreased, showing that there is possible co-contraction. He concluded that the benefit of PNF stretching is possibly from altered stretch perception (a deeper stretch may be perceived as more permissible) and raised pain perception (a greater amount of pain is considered more tolerable). This was later supported by Jasko' lski, *et al.* (2006). Thus during antagonist contraction during PNF stretching, there may be some co-contraction of the muscle being stretched, supporting the theory of Ulrike (2005).

Static stretching alone, according to Cheung *et al.* (2003) and Gulick *et al.* (1996) does not have any effect on the pain perceived in DOMS. Yet concentric contractions were shown by Cheung *et al.* (2003) to decrease the symptoms experienced in DOMS. Therefore PNF stretching, which is thought to elicit a deeper stretch (Shrier *et al.*, 2000), as well as incorporate mild concentric contractions of the antagonist muscle, may have a greater effect on the symptoms experienced in DOMS. Results of this study would contribute to the above, thereby fulfilling the first aim of the study.

Due to the various time periods used in the above studies, and therefore the uncertainty in which to apply a stretch to an eccentrically exercised muscle. The present study also looked at the difference between PNF stretching immediately after eccentric exercise and PNF stretching 24 hours after eccentric exercise. This fulfilled the second aim of the study.

Materials and Methods

Design

This study was a prospective, randomised controlled clinical trial.

Sample Group

Thirty healthy sedentary male participants took part in the study.

Inclusion criteria

7. Patients used in this study were required to not have been doing any form of exercise.
8. Patients were required to be asymptomatic and not be suffering from back pain, or any other musculoskeletal or systemic problems (osteoarthritis, cardiovascular disease, etc.)
9. Patients may not be taking any medication or anti inflammatories (for epilepsy or musculoskeletal problems).
10. Patients between the ages of 20 and 40 years. With increased homogeneity, factors related to health and age will influence the study less.
11. Only male patients will be included in this study (homogeneity).
12. Patients who had signed an informed consent form.

Exclusion criteria

11. Patients who were symptomatic for any condition.
12. Patients that were manual labourers were not used in this study.
13. Patients could not be receiving other treatment for the duration of this study.
14. Patients who filled in the informed consent forms incorrectly.
15. Patients who had not signed the informed consent forms were excluded.
16. Patients who did not conform to research protocol were excluded.
17. Patients could not start an exercise routine for the duration of this study.
18. Patients with hyper-flexibility (gymnasts), or connective tissue diseases (Marfans Disease), were not used in this study.
19. Patients who had undergone any form of surgery of the lower extremities or back were excluded.
20. Patients who did not fill out their NRS pain diary.

Subjective Measurement

1. Numerical Pain Rating Scale

The NRS was used to gather subjective information from the patient about the pain experienced in DOMS (Fischer, 1987). Each participant was asked to rate any muscle pain experienced in the Quadriceps Femoris and Hamstring muscles at that moment, on a scale from zero to 100, zero being the absence of pain and 100 being pain at its worst. This was asked at the beginning of each visit and at the end of each visit, over a period of three days.

2. NRS Diary

A NRS diary was given to each participant to take home. They were asked to fill it in, using the same concept as the NRS filled out at the visits, at eight-hour intervals. This was used to gather further subjective information from the patient.

Objective Measurement

1. Algometer

To gather objective information, in kilograms per centimetre squared, of the muscle sensitivity (pain pressure threshold) due to DOMS (Jensen *et al.*, 1986).

These readings were taken at the beginning of each visit and directly after the intervention, over a three-day period. The location of each reading was marked, using Henna dye, at the initial consultation. The middle of the Quadriceps Femoris muscle belly was found at the mid-point between the greater trochanter to the superior pole of the patella. The Hamstring muscle belly was found at the mid-point between the ischial tuberosity and the popliteal fossa.

The footplate of the algometer was placed over the marked spot on the muscle and a pressure was applied at approximately 1kg per centimetre squared per second, in an anterior to posterior direction.

When the participants first felt pain they were requested to say "yes".

At that point the algometer was removed and a reading in kg/cm squared was taken.

Statistical Analysis

Data were captured in an MS Excel Spreadsheet and imported into SPSS version 13 (SPSS Inc., Chicago, Illinois, USA) for analysis. A p value of <0.05 was considered as statistically significant.

Descriptive analysis was done using frequency tables (reporting counts and percentages) for categorical variables and summary statistics (reporting mean, standard deviation and range) for quantitative variables. Baseline and demographic characteristics were compared between the two treatment groups using independent t-tests for quantitative variables and Pearson's chi square tests for categorical variables. The treatment effect was assessed using repeated measures ANOVA testing. This process tests three null hypotheses simultaneously:

1. there is no time effect
2. there is no group effect
3. there is no time by group interaction (treatment effect)

In the presence of a significant time by group interaction, a treatment effect is declared. In this case, any significant main effects (time or group effects) cannot be interpreted. Profile plots were done to assess the direction or trend in the treatment effect.

Demographics

Thirty participants were enrolled in the trial and randomized into two treatment groups, A and B. The demographics were compared between the treatment groups, to ensure randomization was complete.

Table 1: T-test to compare mean age of participants between treatment groups

	group	N	Mean	Std. Deviation	Std. Error Mean	t statistic	p value
age	A	15	25.80	4.709	1.216	-0.728	0.473
	B	15	27.00	4.309	1.113		

Table 1 shows that there was no difference in mean age of participants between treatment groups ($p=0.473$). The mean age of group B (25.80) was slightly older than group A (27.00), but this difference was not significant.

Table 2: Cross-tabulation of race and treatment group

			Group		Total
			A	B	
Race	Black	Count	2	5	7
		% within Race	28.6%	71.4%	100.0%
	Indian and Coloured	Count	3	1	4
		% within Race	75.0%	25.0%	100.0%
	White	Count	10	9	19
		% within Race	52.6%	47.4%	100.0%
Total		Count	15	15	30
		% within Race	50.0%	50.0%	100.0%

Pearson's chi square 2.338, $p=0.311$

Table 2 shows that there was no statistically significant difference in proportions of the race group between the treatment groups ($p=0.311$). The majority of participants were white (19), and the number of white participants was almost equal between the two groups, 10 in Group A and 9 in Group B. It appeared that group B had more black (5) participants than group A (2) and *vice versa* for Indian and coloured participants, 3 in Group A and 1 in Group B. This slight difference was not statistically significant.

Results

It is important that the baseline outcome measurements, numerical pain rating scale (NRS) and algometer readings, were equivalent between treatment groups, otherwise differences after follow-up could be incorrectly attributed to treatment.

Table 3: T-test to compare mean baseline outcomes between treatment groups

	Group	N	Mean	Std. Deviation	Std. Error Mean	t statistic	p value
Initial NRS pre	A	15	1.00	2.803	0.724	-0.603	0.551
	B	15	2.67	10.328	2.667		
Initial Hamstring left algometer	A	15	8.333	2.1057	0.5437	-0.799	0.431
	B	15	8.833	1.2016	0.3102		
Initial Hamstring right algometer	A	15	8.847	1.8574	0.4796	0.066	0.948
	B	15	8.807	1.4139	0.3651		
Initial Quadriceps Femoris left algometer	A	15	7.880	1.8241	0.4710	0.186	0.854
	B	15	7.753	1.9082	0.4927		
Initial Quadriceps Femoris right algometer	A	15	8.540	1.5361	0.3966	0.903	0.374
	B	15	7.993	1.7714	0.4574		

Table 3 shows that there were no significant differences at baseline between the treatment groups for any of the outcomes.

Analysis of the treatment effect

Numerical pain rating scale (NRS)

For NRS, the starting time point chosen was eight hours post-exercise at visit 1. The reason for not using the initial NRS score was that the majority of participants had a zero value, as stiffness had not yet been induced. The reason for not using the immediately post-exercise score was that for some participants the NRS score was still zero as stiffness may have taken a while to develop.

Thus by eight hours post-exercise, all participants had experienced some degree of stiffness. This was thus their baseline score.

Table 4: Within-subjects and between-subjects effects for NRS

Effect	Statistic	p value
Time	Wilk's lambda=0.534	0.007
Group	F = 0.717	0.404
Time*group	Wilk's lambda=0.720	0.138

Table 4 shows that there was a significant time effect ($p=0.007$), which means that NRS values changed significantly over time, regardless of treatment group, as the p value for the intervention effect, time by group, was not significant ($p=0.138$). Thus, for NRS there was no evidence of a differential treatment effect between Group A (PNF stretching immediately post-exercise) or Group B (PNF stretching 24 hours post-exercise). Therefore for NRS readings, PNF stretching directly after exercise was not more beneficial than PNF stretching 24 hours after exercise, according to subjective measurement of pain. This confirms the null hypothesis (H_0).

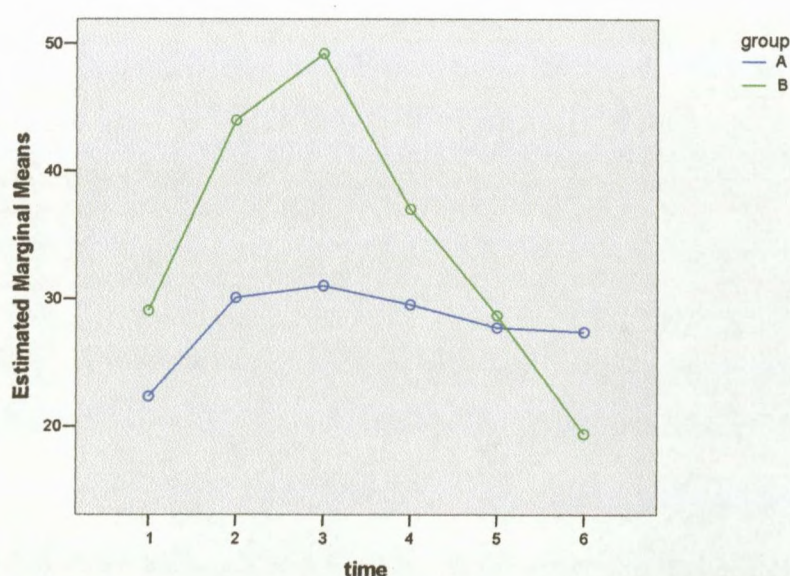


Figure 1: Profile plot of mean NRS over time by treatment group

Figure 1 shows the profile plot of mean NRS, over time, by treatment Group A (PNF stretching immediately post-exercise) and Group B (PNF stretching 24 hours post-exercise). Although the p value for the interaction between treatment and group was not significant, there appears to be a trend of an interaction (non parallel profiles or crossing over of profiles) at time 5. Group B (PNF stretching 24 hours after exercise) appears to decrease NRS score at a faster rate than Group A (PNF stretching immediately post-exercise). Group B (PNF stretching 24 hours post-exercise) returns to lower than their baseline at Time 6, while Group A (PNF stretching immediately post-exercise) remained higher than their baseline score at the end. Therefore Group B (PNF stretching 24 hours post-exercise), showed a faster decrease in pain experienced due to DOMS than Group A (PNF stretching immediately post-exercise) from day 2 of the study. Group B (PNF stretching 24 hours post-exercise) also had a larger decrease in pain experienced than Group A (PNF stretching immediately post-exercise), to less than base line NRS measurements. However, this effect was not statistically significant at the 0.05 level and could be related to lack of statistical power, with only 15 samples per group.

Algometer readings

Left Hamstring algometer readings

For algometer measurements, four time points measurements were compared, using repeated measures ANOVA. The baseline measurement for algometer readings was taken as visit 2, since stiffness was induced at visit 1 and maximum pain was felt on day 2.

Table 5: Within-subjects and between-subjects effects for algometer – left Hamstring

Effect	Statistic	p value
Time	Wilk's lambda=0.638	0.008
Group	F = 0.027	0.872
Time*group	Wilk's lambda=0.887	0.367

Table 5 shows that, for the left Hamstring, there was a significant time effect ($p=0.008$). There was a change in algometer readings over time, regardless of the group. No group effect ($p=0.872$) was shown, no difference between Group A (PNF stretching immediately post-exercise) and Group B (PNF stretching 24 hours post-exercise). There was no evidence of a treatment effect ($p=0.367$), no difference between groups A (PNF stretching immediately post-exercise) or B (PNF stretching 24 hours post-exercise) over time, once again confirming the null hypothesis (H_0).

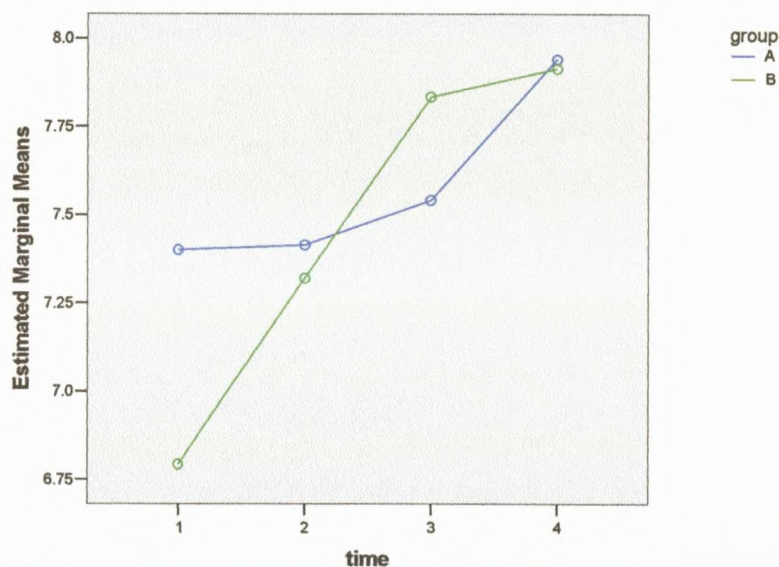


Figure 2: Profile plot of mean algometer – left Hamstring over time by treatment group

Figure 2 shows that both treatment groups A (PNF stretching immediately post-exercise) and B (PNF stretching 24 hours post-exercise) showed a mean increase in algometer measurements over time, indicating that there was decreased muscle pain experienced in the left Hamstring muscle over time. There was the suggestion that Group B (PNF stretching 24 hours post-exercise), improved at a faster rate than Group A (PNF stretching immediately post-exercise), but this was not statistically significant ($p=0.367$).

Right Hamstring algometer readings

Table 6: Within-subjects and between-subjects effects for algometer – right Hamstring

Effect	Statistic	p value
Time	Wilk's lambda=0.558	0.001
Group	F = 0.038	0.847
Time*group	Wilk's lambda=0.960	0.779

For the right Hamstring muscle, Table 6 shows that there was a highly significant time effect ($p=0.001$) and no treatment effect ($p=0.779$), meaning that both Groups A (PNF stretching immediately post exercise) and B (PNF stretching 24 hours post exercise) showed improvement in algometer readings for the right Hamstring muscle over time. This improvement was not, however, different between the treatment groups. This confirms the null hypothesis (H_0), by showing that the pain experienced in DOMS improved at approximately the same rate, whether PNF stretching was done immediately, or 24 hours post-exercise.

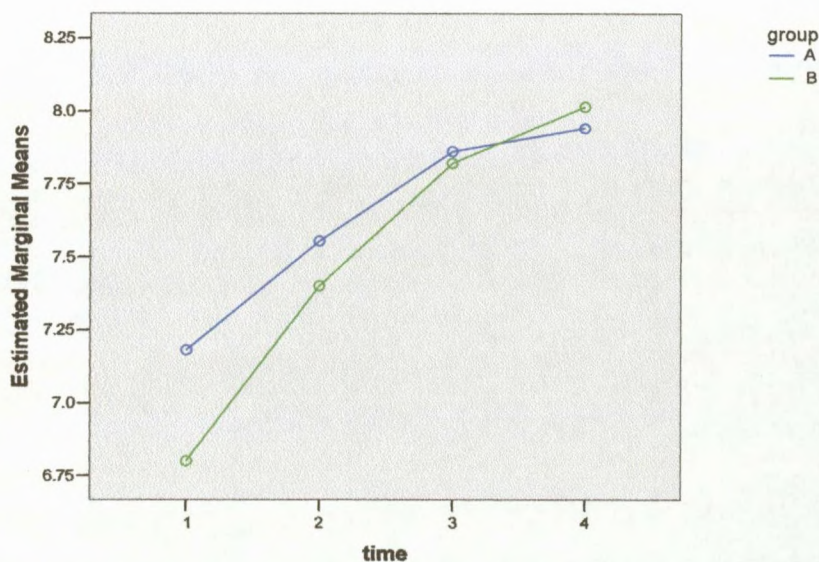


Figure 3: Profile plot of mean algometer – right Hamstring over time by treatment group

Figure 3 shows that both Groups A (PNF stretching immediately post-exercise) and B (PNF stretching 24 hours post-exercise) improved over time with regard to algometer measurements of the right Hamstring, but that the rate of improvement was similar in both groups. However, there was a slight crossing over of profiles at time 3, where the rate of improvement in Group B (PNF stretching 24 hours post-exercise), overtook that of Group A (PNF stretching immediately post-exercise). This shows that PNF stretching 24 hours after exercise may improve the pain experienced in DOMS quicker than PNF stretching immediately after exercise.

Left Quadriceps Femoris algometer readings

Table 7: Within-subjects and between-subjects effects for algometer – left Quadriceps Femoris

Effect	Statistic	p value
Time	Wilk's lambda=0.471	<0.001
Group	F = 0.251	0.620
Time*group	Wilk's lambda=0.867	0.286

Table 7 shows that there was a highly significant time effect ($p < 0.001$) without a treatment effect ($p = 0.286$), indicating that both groups A (PNF stretching immediately post-exercise) and B (PNF stretching 24 hours post-exercise) had improvement of pain perception for the left Quadriceps Femoris muscle algometer readings at the same rate, thus confirming the null hypothesis (H_0).

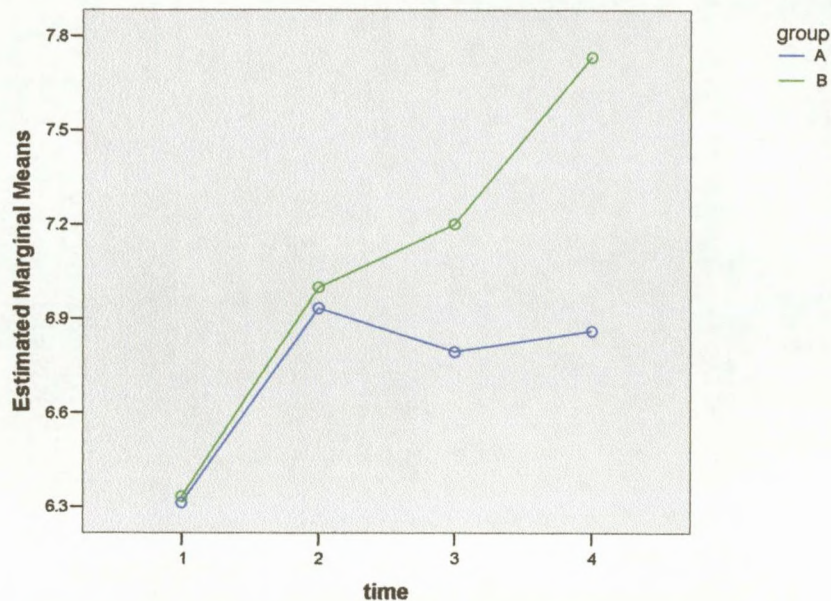


Figure 4: Profile plot of mean algometer – left Quadriceps Femoris over time by treatment group

With respect to the results in Table 7, Figure 4 shows that the rate of improvement was the same up to time 2, whereafter Group B (PNF stretching 24 hours post-exercise) continued to show improvement while Group A (PNF stretching immediately post-exercise) levelled off their algometer measurements. Thus there is a trend towards a more beneficial effect of Group B (PNF stretching 24 hours post-exercise), but there is insufficient statistical evidence. With a larger sample size, this time by group treatment effect may have been significant. The present study might thus have been underpowered.

Right Quadriceps Femoris algometer readings

Table 8: Within-subjects and between-subjects effects for algometer – right Quadriceps Femoris

Effect	Statistic	p value
Time	Wilk's lambda=0.530	0.001
Group	F = 0.060	0.809
Time*group	Wilk's lambda=0.870	0.298

Table 8 shows that there was a highly significant time effect ($p=0.001$) without a treatment effect ($p=0.298$), indicating that both groups A (PNF stretching immediately post-exercise) and B (PNF stretching 24 hours post-exercise) improved at the same rate, but there were no differences between the two groups, thus confirming the null hypothesis (H_0).

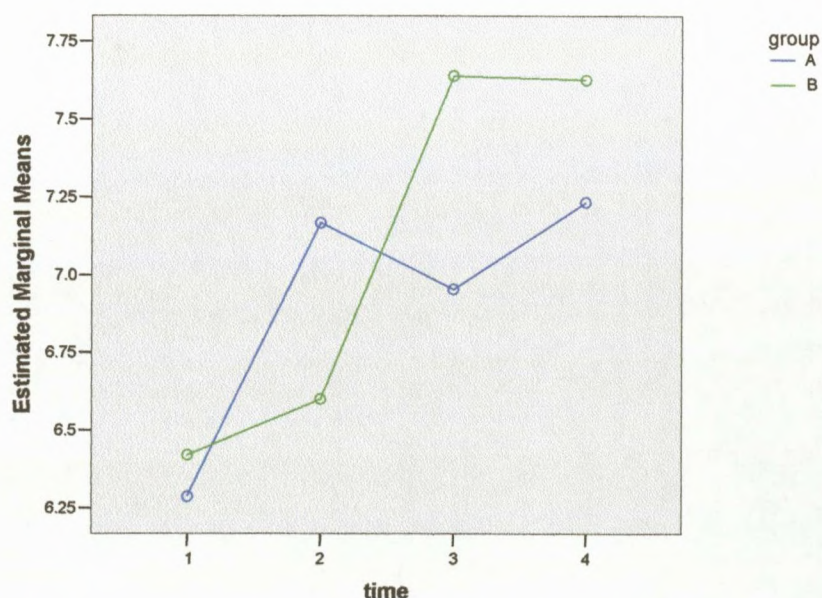


Figure 5: Profile plot of mean algometer – right Quadriceps Femoris over time by treatment group

Figure 5 shows that the rate of improvement in Group B (PNF stretching 24 hours post-exercise) was higher than in Group A (PNF stretching immediately post-exercise). There is thus a trend towards a more beneficial effect of Group B (PNF stretching 24 hours post-exercise), but there is insufficient statistical evidence. Once again, underpowering was a problem, as clinical significance without statistical significance was achieved.

This study has failed to demonstrate a statistically significant difference between PNF stretching immediately after exercise and PNF stretching 24 hours after exercise, Groups A and B, respectively. Both groups showed significant improvements according to all outcomes measured over time, a significant decrease in NRS readings and increase in algometer readings over time, regardless of the Group. PNF stretching immediately after exercise and PNF stretching 24 hours after exercise results in significant improvements over time, thus confirming the null hypothesis (H_0) that there is no difference between Groups A and B over time. However, trends showed that Group B (PNF stretching 24 hours after exercise) was perhaps more beneficial than immediate PNF stretching, for all the outcomes measured. This cannot be concluded with any statistical certainty, since no statistically significant treatment effects were observed for any outcomes. This may have been due to an underpowered study due to low sample size. Further studies, with larger samples, should be undertaken to confirm these findings.

Discussion

Demographic data

The average age of the participants between the two treatment groups was compared in Table 1. The results show that there was no difference in average age of participants between treatment groups and therefore there was a relatively even age spread between the two groups. The participants were from 20 to 32 years of age. The average age of Group B was slightly older (27) than Group A (25.8), but this difference was not significant. In a similar study Lund et al. (1993) used healthy, untrained women between the slightly older ages of 28 and 46. These participants underwent eccentric exercise of the right Quadriceps Femoris until exhaustion, as well as daily static stretching. Gulick *et al.* (1996) later

conducted a study assessing which of the known treatment techniques used for relief of DOMS were most effective, such as NSAIDS, concentric muscle contractions, ice massage, static stretching and arnica ointment. They used participants between the ages of 21 and 40 and had similar results in this age group. In subsequent studies, the researchers used similar age groups; Bonnar *et al.* (2004) used active participants between the ages of 18 and 29 and Ulrike *et al.* (2005) used participants between the ages of 17 and 44. Feland *et al.* (2001) assessed the acute changes in flexibility of Hamstring muscles from static and PNF stretching before activity in 55 to 79 year old athletes. They found that the results differed between participants that were less than 65 years of age and the participants that were older than 65 years of age. Therefore there seems to be a trend showing that homogeneity occurs in age groups ranging from 18 to approximately 45. This could possibly be due to the connective tissue change observed with increasing age (Feland *et al.*, 2001).

Table 2 compares the race distribution between the treatment groups. Results show that there was no statistically significant difference in proportions of the race groups between the treatment groups. The majority of participants were white (19 participants), and the number of white participants was almost equal between the two groups, 10 in Group A and nine in Group B. However it appeared that Group B had more black participants, five in total, than Group A, two in total, and *vice versa* for Indian and coloured participants, one in Group B and three in Group A. However this slight difference was not statistically significant. There were no comparisons made according to race in other similar published articles. In the present study, no statistically relevant results were found according to race.

Baseline outcomes measurements

Table 3 assesses the average baseline outcomes, NRS and algometer readings between treatment groups. All baseline measurements were taken before any exercise or stretching was done at visit one. No significant differences were found at baseline between the treatment groups for any of the outcomes. Therefore all the participants in either group had similar NRS and algometer readings to begin with, the average initial NRS reading for group A was 1 and

group B was 2.67 and the average algometer readings were as follows: for the left Hamstring both Group A and Group B averaged 8.333 force/kg, for the right Hamstring algometer readings, Group A averaged 8.847 force/kg, and Group B averaged 8.807 force/kg, and similar results were found with the Quadriceps Femoris averages, left Quadriceps Femoris averages Group A showed 7.880 force/kg, and Group B showed 7.753 force/kg. Right Quadriceps Femoris Group A showed an average of 8.540 force/kg and Group B showed an average of 7.993 force/kg. These similar results at baseline allow increased reliability of the subsequent results for comparison. Gulick *et al.* (1996) used similar measurement tools to interpret muscle pain, the visual analogue scale and algometer were used. Baseline measurements were equal or similar in all participants in the study.

Analysis of the treatment effect

Numerical Pain Rating Scale (NRS)

Table 4 shows that the NRS values for both the treatment groups changed significantly over time. For NRS there was no evidence of a differential treatment effect. Even though there was a significant change over time for all participants pain perception, there was no significant difference between Groups A and B.

Figure 1 shows the profile plot of average NRS over time by treatment group. At time 5 (day 2 of the study, at 24 hours after exercise), Group B appears to decrease NRS score at a faster rate than Group A. Group B returns to lower than their baseline at Time 6 while Group A remained higher than their baseline score at the end. This shows that PNF stretching 24 hours after exercise had a greater effect on the pain experienced in DOMS. However, this effect was not statistically significant at the 0.05 level and could be related to lack of statistical power with only 15 samples per group. This sample size is prominent in the majority of previous studies conducted on DOMS (Gulick *et al.*, 1996; Ulrike *et al.*, 2005). Lund *et al.* (1998) used only seven participants in their study, in which they assessed the effects of daily passive stretching on DOMS. It appears that several studies conducted on the effects of a treatment modality on DOMS were statistically underpowered.

Algometer readings

For algometer measurements, 4 time points measurements were compared using repeated measures ANOVA. The baseline measurement for algometer readings was taken as Visit 2, since stiffness was induced at Visit 1 and maximum pain was felt on day 2 (24 hours post-exercise). This does not concur with the findings of Lund *et al.* (1998). They found muscle soreness to peak at 48 hours post-exercise. The differences between the two studies may, however, contribute to these findings, because Lund *et al.* (1998) conducted their study on healthy, untrained females, and the current study was conducted on healthy, untrained males. The former study assessed the effect of static stretching on DOMS and the latter study assessed the effect of PNF stretching on the pain perceived in DOMS. Several other researchers have shown peak soreness to range from 24 to 48 hours (MacIntyre *et al.*, 1995; McArdle *et al.*, 1996; Nie *et al.*, 2005). Dannecker *et al.* (2003) showed that females reported lower muscle pain than males, when pain response was measured 48 hours after eccentric exercise.

Each muscle measured, left and right Hamstrings and left and right Quadriceps, were statistically tested separately. There were thus four separate analyses for algometer readings.

The Hamstring muscles both had a significant time effect, according to the repeated measures ANOVA statistical test for algometer readings. This is shown in Table 5 (left Hamstring) as $p=0.008$ and Table 6 (right Hamstring) as $p = 0.001$. There was a change over time for all participants, regardless of the group. No group effect was found for either the left ($p=0.872$) or the right ($p=0.847$) Hamstrings, indicating no difference between the Groups A and B, as well as no evidence of a treatment effect for left ($p=0.367$) and right ($p=0.779$) Hamstrings respectively. This shows that both treatments, PNF stretching immediately after exercise and PNF stretching 24 hour after exercise, were both as beneficial as each other.

Figures 2 and 3 shows that both the treatment groups, for the left and right Hamstring muscles, respectively, had an average increase in algometer

measurements and therefore increased pressure threshold and decreased pain, over time. There was also the suggestion that Group B improved at a faster rate than Group A, for both Hamstring muscles.

The Quadriceps Femoris muscles algometer readings shown in Tables 7 (left) and 8 (right) demonstrate that there was a highly significant time effect for the left ($p < 0.001$) and right Quadriceps Femoris muscles ($p = 0.001$), without a treatment effect for left ($p = 0.286$) and right ($p = 0.298$) Quadriceps Femoris muscles, indicating that both Groups A and B improved at the same rate for both left and right Quadriceps Femoris muscles. Figures 4 and 5 show that the rate of improvement was the same up to Time 2, whereafter Group B continued to show improvement, while Group A reached a plateau. Thus there is a trend towards a more beneficial effect of Group B, but there is insufficient statistical evidence. With a larger sample size this time by group treatment effect may have been significant.

Feland *et al.* (2001) conducted a similar study in which they compared static stretching to PNF stretching in elderly active participants by assessing Hamstring flexibility only. They stretched the participants prior to the exercise and concluded that both treatment groups had increased flexibility, the PNF group increasing to a greater extent.

Summary

Both groups showed significant improvement according to all outcomes, measured over time. Thus either modality of treatment results in significant improvement over time. However, trends showed that Group B (PNF stretching 24 hours after exercise) was perhaps more beneficial than stretching directly after exercise for all the outcomes measured, NRS and algometer readings. This cannot be concluded with any statistical certainty, since no statistically significant treatment effects were observed for any outcome. However, this may have been due to an underpowered study, due to a low sample size. Further, larger studies should be undertaken to confirm these findings.

Conclusion

The purpose of this study was to determine the most favourable time period in which to apply PNF stretching to eccentrically exercised muscles, directly after exercise or 24 hours later, in order to decrease the pain experienced in DOMS. The results tend to favour PNF stretching 24 hours after the eccentric exercise over PNF stretching immediately after eccentric exercise.

Statistical analysis indicated a significant difference between group A and group B, for both NRS scores and algometer readings. This indicates that PNF stretching 24 hours after the initiating eccentric exercise is more beneficial than PNF stretching immediately after eccentric exercise in relieving the muscle soreness experienced in DOMS.

It is the researcher's opinion that, as PNF stretching employs a contraction of the antagonist muscle while eliciting the stretch, there is increased work done on those muscles in the stretch directly after eccentric exercise and therefore increased muscle damage. This study used both the Hamstring and Quadriceps Femoris muscles for readings and therefore assessed the antagonist work. In agreement with Gulick *et al.* (1996), bouts of concentric exercise after the initiating eccentric exercise may decrease the symptoms of DOMS experienced. Therefore PNF stretching 24 hours later employs a stretch as well as a bout of concentric exercise of the antagonist muscle.

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