UNIVERSITY OF ALBERTA

DO DIFFERENT ISOKINETIC TESTING VELOCITIES ALTER VASTUS MEDIALIS OBLIQUUS MUSCLE ACTIVATION DURING KNEE EXTENSION EXERCISE?

BY
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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE**

DEPARTMENT OF PHYSICAL THERAPY

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DEDICATION.

I would like to dedicate this work to several, but first and foremost to God Almighty for helping me this far.

To Engr. Layiwola Onibonoje for his priceless support and encouragement.

To mom and dad for being there all the way and to my siblings Layi, Laolu, Akin, Folake, Buki, Damola, Jimi and Kola for their profound and invaluable support.

ABSTRACT.

PURPOSE: The purpose of this study was to compare the effect of changes in isokinetic velocities on the vastus medialis obliquus (VMO) and the vastus lateralis (VL) muscles activation during knee extension.

METHODS: Thirty males and females performed maximum knee extension concentrically and eccentrically on a Kin – Com dynamometer at angular velocities of 60°/s, 120°/s and 180°/s. Electromyographic (EMG) activity and onset of EMG activity of the VMO and vastus lateralis (VL) muscle were recorded. Onset of muscle activity was visually extrapolated and normalized VMO:VL EMG ratio were calculated for both contractions at respective angular velocities.

RESULTS: No significant difference was found on the effect of contraction type, angular velocity and muscle on EMG activity. The VMO muscle had a significantly (F=14.203, p=0.001) earlier onset for EMG activity during concentric contraction than VL muscle. The mean values for onset of EMG activity for concentric VMO muscle contraction were earlier (F=7.973 p=0.008) than those of eccentric contraction of VMO and VL muscles. VMO:VL EMG ratio was greater than 1.0 during concentric contraction.

CONCLUSIONS: The present results demonstrate that the onset of muscle activity was earlier for the VMO muscle than the VL muscle during concentric contraction and changes in angular velocities did not significantly alter the VMO muscle EMG activity and the VMO:VL EMG ratio.

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CHAPTER ONE

INTRODUCTION.

1.1 PROBLEM STATEMENT.

Of all patellofemoral pathologies, patellofemoral pain syndrome (PFPS) is the most prevalent knee disorder causing diffuse anterior knee pain. One out of every four people suffers from PFPS in his or her lifetime, this incidence is known to be higher in athletic populations (Natri et al., 1998; Sheely et al., 1998). PFPS is defined as retropatellar and/or peripatellar pain that results from either physical or biochemical changes in the patellofemoral joint (PFJ). The basic origin and exact pathogenesis of PFPS are unknown. In spite of several studies on this joint, issues regarding etiology, diagnosis and treatment have remained enigmatic and unequivocal among researchers and clinicians (Blond and Hansen, 1998; Zappala et al., 1992).

The elusive nature of this syndrome makes the PFJ the most researched small joint in the body. Not only this, it produces pain and disability that is far out of proportion to its size (Gerrard, 1995). PFPS is generally considered to result from a plethora of factors which may primarily be, but are not limited to, biomechanical faults that include dysplasia of the patella or trochlear groove, increased quadriceps angle (Q-angle), tightness of the lateral retinaculum, hamstrings, iliotibial band and gastrocnemius, quadriceps muscle dysplasia, neuromuscular imbalance between the vastus medialis obliquus (VMO) and the vastus lateralis (VL) muscles (which often results to abnormal patellar tracking) and altered foot mechanics such as abnormal foot pronation. Of profound importance is the neuromuscular imbalance seen in the activation, control and timing pattern of the VMO and VL muscles, which leads to abnormal patellar tracking. This abnormal patellar tracking has been suggested to be the cause of excessive PFJ stress (force per unit area), which is a prelude seen in PFPS (Doucette and Child, 1996; McConnell, 2002).

Several practitioners involved in the management of PFPS have concluded that therapeutic exercise remains the chief cornerstone in the non-operative management of this condition. The goal of rehabilitation is to maximize the quadriceps strength, with emphasis on the VMO, while incurring minimal PFJ reaction force and stress (Shelton and Thigpen, 1991; Steinkamp et al., 1993; Woodwall and Welsh, 1990). The VMO muscle has an important role as a medial stabilizer of the patella and assists in the normal functioning of the PFJ. If the VMO atrophies, it is believed that greater lateral deviation of the patella will occur thus contributing to abnormal PFJ stress and ultimately, PFPS (Zappala et al., 1992). Following this line of reasoning, rehabilitation specialists and researchers have advocated quadriceps strengthening with emphasis on the VMO muscle.

Several studies have been conducted to compare the electromyographic (EMG) activation patterns of the VMO and the VL muscle during different exercises prescribed for rehabilitation (Karst and Jewett, 1993; Laprade et al., 1998; Owings and Grabiner, 2002; Souza and Gross, 1991). What appears to be a consensus is that the VMO muscle cannot be selectively strengthened except for quadriceps setting exercise.

Cerny (1995) studied the VMO:VL activity ratio in a selected number of closed and open kinetic chain exercises. The results of his study showed that open chain kinetic exercise, knee extension with medial rotation, and quads setting showed a higher VMO:VL ratio. This finding seems to be contrary to the clinical approach for the rehabilitation of PFPS patients because closed kinetic chain exercises are usually the prescribed exercises. Tang and coworkers (2001) studied the EMG activity of the VMO and VL in subjects with and without PFPS during open and closed kinetic chain exercise. The high point of their study was that the VMO:VL ratio was not significantly different in either group of subjects during closed kinetic chain exercise, however, the ratio was significantly higher for subjects without PFPS than for those with PFPS during isokinetic open chain leg extension exercise.

In a preliminary study of the effect of patellar taping on quadriceps peak torque and perceived pain, Herrington (2002) found out that increasing the testing speed of the isokinetic dynamometer from 60 degrees/second to 180 degrees/second during leg extension, reduced the pain experienced in patients with PFPS. One of the explanations given for this was that the time for which the PFJ was exposed to load would be decreased at higher testing velocities, thus reducing the pain. The type of muscle fibers within the quadriceps femoris muscle may become an issue when the testing velocities during leg extension using an isokinetic dynamometer are altered. Testing at higher velocities has been shown to preferentially recruit type II (fast twitch) ahead of type I (slow twitch) muscle fibers (Sherman et al., 1982), however, how this affects the activation pattern of the VMO and VL muscles is still unknown. Fast twitch motor units are preferentially recruited during moderate to high velocity eccentric actions (Grimby and Hannerx, 1977). In general, as the intensity of exercise increases in any muscle, the contribution of the fast twitch fibers will increase. This increase is due to the physiologic properties and composition of these fibers. It has been proposed that the small slow twitch oxidative (SO) motor unit is recruited at a low intensity level because it has a low threshold for being recruited. As the intensity increases, larger amounts of higher threshold fast twitch oxidative glycolytic (FOG) and fast twitch glycolytic (FG) motor units are recruited (Hannerx, 1974). It remains somewhat unclear whether preferential activation matters during isokinetic exercise since the exercise requires a maximal or near maximal output from all muscle fibers.

Ahmed et al., (1983, 1988), in cadaveric experiments, found that when they removed the tension in the VMO muscle, the pressure zone shifted from the center of the patella to the lateral facet of the patella. They also showed that reduction of the VMO tension by 50% resulted in a 5mm displacement of the patella laterally. In another study by Goh et al., (1995), they reported that the absence of the VMO muscle caused the patella to be displaced laterally and increased the load on the patellar facet throughout the range of motion. Studies of the EMG activity of the VMO muscle by Escamilla et al., (1998) showed that the EMG activity of the VM muscle was highest between 15° and 55° of knee flexion during open chain leg extension. With this in mind, they believe that if the VMO muscle is activated during this range of knee extension (15° and 55°); the abnormal lateral tracking of the patella would be reduced or conversely, the problem worsens in this range if the VMO is not active.

With the state of present knowledge, there has not been any study that has looked into the EMG analysis of the VMO and the VL muscles at different testing velocities using the KIN COM 500H isokinetic dynamometer during leg extension exercise. Thus, the purpose of this study is to investigate the effect of different isokinetic testing velocities on the EMG activity of the VMO and VL muscles.

1.2 OBJECTIVES.

The objectives of this study were to analyze the effect of changes in knee angular velocity, using an isokinetic dynamometer, on the VMO and the VL muscle recruitment patterns during knee extension.

The questions this study posed to answer include:

- Will the EMG activity of the VMO and the VL muscles be different at different isokinetic velocities during eccentric and concentric knee extension?

- Will the onset of the EMG activity of the VMO and the VL muscles be different at different isokinetic velocities during eccentric and concentric knee extension?
- Are there differences between the VMO:VL EMG activity ratios at different isokinetic velocities during eccentric and concentric knee extension?

1.3 RESEARCH HYPOTHESES.

For this study, it is hypothesized that:

- There will be no significant difference in the EMG amplitude of the VMO and VL muscles at the three different isokinetic velocities (60°/s, 120°/s and 180°/s) during eccentric and concentric knee extension.
- There will be no significant difference in the onset of the EMG activity of the VMO and VL muscles at the three different isokinetic velocities (60°/s, 120°/s and 180°/s) during eccentric and concentric knee extension.
- There will be no significant difference between the VMO:VL EMG amplitude ratio at the three different isokinetic velocities (60°/s, 120 °/s and 180°/s) during eccentric and concentric knee extension.

1.4 DEFINITION OF TERMS.

CONCENTRIC CONTRACTION: occurs when the muscle shortens during the contraction. Technically, it is defined as a contraction with enough force to overcome the external resistance. It is an action taken by the prime mover during the active phase of a movement pattern.

ECCENTRIC CONTRACTION: occurs when the muscle lengthens during a contraction. Technically, eccentric contraction occurs in an already shortened muscle where the external force is greater than the tension created by the muscle contraction. Eccentric contractions are extremely common. Every movement in the direction of gravity is controlled by an eccentric contraction.

EMG: It is an electrical representation of muscle activity. It will be recorded with surface electrodes in this study and expressed as in voltage.

ISOKINETIC EXERCISE: The resistive torque equals the applied (muscle) torque and therefore constant angular velocity concentric or eccentric muscle actions occur.

ONSET OF EMG ACTIVITY: Is defined as the absolute time of onset of the VMO and the VL muscles. This is the time from the start of contraction until the first EMG signal is recorded.

TESTING VELOCITY: Defined as a preset rate of change of angular displacement of the dynamometer, expressed in degrees per second.

VMO:VL EMG AMPLITUDE Ratio: It is the voltage/amplitude of the processed EMG of the VMO muscle divided by that of the VL muscle.

1.5 LIMITATIONS.

The following limitations applied to this study:

- Measurement of the EMG using surface electrodes may not give the exact muscle activity of the intended muscles of interest. This may be due to cross talking (overflow of electrical signals from other muscles) between the muscle of interest and other muscles, the impedance offered by the skin-electrode interface, which may be oil, hair or the amount of adipose tissue between the muscle and the skin. Proper electrode placement and adequate skin preparation was performed to minimize these limitations.

- Muscle soreness is most likely to occur if the subject does not adequately warm up and stretch or the testing session is too rigorous for the subject. Muscle soreness was prevented as much as possible by the investigator ensuring that the subjects were properly warmed up and the muscles are adequately stretched. However, it is important to note that muscle soreness is not an immediate occurrence after an exercise session. If muscle soreness eventually occurred, the subject was adequately instructed on how to use ice for treating this soreness (Ross, 1999). With stringent adherence to the stretching and warm up protocols before testing, muscle soreness was not reported by any of the subjects.

1.6 DELIMITATIONS.

The following delimitations applied to this study:

- Only 30 volunteers (male and females) aged between 19 and 39 years were involved for this study. All subjects were recruited from the University of Alberta community.
- Subjects did not have any musculoskeletal problems affecting the knee joint or history of such affecting the functional ability of the subject.
- The results of this study are only generalized to normal subjects between 19 and 39 years and only applicable to open kinetic chain exercises.

1.7 ETHICAL CONSIDERATIONS.

The isokinetic dynamometer has been used safely in many clinics and sports centers for muscle strengthening and assessment and it exhibits no side effects on the subjects (Dvir et al., 1991). The use of surface electromyography for recording EMG signals provides a safe, easy and non-invasive method that allows objective quantification of muscle activity with no side effects (Cram et al., 1998). Subjects may have an allergic reaction to either the adhesive or the electrolytic paste and develop a rash. Previous experience and studies have shown this reaction to occur in 1 – 2% of participants. The resulting rash typically fades within 24 – 48 hours. None of the subjects reported any reactions to the adhesive surface EMG electrodes.

All subjects in this study were given a detailed explanation of how the testing session will be performed provided in the information letter (Appendix A) and consent form (Appendix B). Subjects were free to participate and withdraw from the study at any time without any consequences.

This proposal was evaluated by the Health Research and Ethics Board (PANEL B) of the University of Alberta.

CHAPTER TWO.

LITERATURE REVIEW.

2.1 THE ANATOMY AND BIOMECHANICS OF THE PATELLOFEMORAL JOINT.

The patella develops from several ossification centers during the third year of life. Its immature form is completely different from the matured form. Its specific form develops during growth by functional strain caused by various activities of daily living. The patella articulates with the distal end of the femur to form what is called the patellofemoral joint. The patellofemoral joint is a sellar joint. Its stability is dependent on the passive and dynamic restraints around the knee. The patella itself has a large articular surface featuring cartilage, which is unusual in a number of ways:

1) It is the thickest cartilage in the human body (up to 7mm thick near the mid sagittal ridge),

2) The cartilage exhibits multiple facets in a pattern, which is unique to each individual. Thus, at different angles of knee movement, different parts of the cartilage are in contact with the femur.

3) The cartilage does not follow the contour of the underlying subchondral bone (limiting the usefulness of X-rays),

4) The articular surface is congruent in the axial (transverse) plane but quite incongruent in the sagittal plane (this affords advantages in lubrication by reducing the coefficient of friction), and

5) The material properties of the cartilage vary throughout the surface and differ significantly from those of the underlying trochlear cartilage because the trochlear cartilage is

believed to have a higher and even distribution of water, electrolytes, chrondrocytes, collagen fibers and proteoglycans. The trochlear cartilage is also less thick, stiffer and more permeable than the patellar cartilage (Ahmed, 1987).

The medial patellofemoral ligament is the primary passive restraint to lateral patellar translation at 20 degrees of flexion, contributing 60% of the total restraining force. The medial patellomeniscal ligament and the lateral retinaculum contribute 13% and 10% of the restraint to lateral translation of the patella, with the latter provided by structures that form the superficial and deep lateral retinaculum (McGinty et al., 2000). The superficial retinaculum consists of fibers from the vastus lateralis and iliotibial band. The deep retinaculum consists of the lateral patellar ligament, the deep fibers of the iliotibial band, and the lateral patellotibial ligament. Tightness of the lateral retinacular structures may result in excessive lateral compression of the patellofemoral joint (McGinty et al., 2000).

The patella glides superiorly and inferiorly on the femur during extension and flexion of the knee, respectively. The total excursion of the patella from full knee extension to full flexion is 5 to 7 cm. Limited superior glide of the patella may result in limited active knee extension. In addition, limited inferior glide of the patella may result in limited knee flexion. Only part of the patella articulates with the femoral trochlear at any given time. The patella is not in contact with the distal femur in full extension but sits above the trochlea notch without significant compressive load. At various degrees of flexion, different facets of the patella are in contact with the femoral groove. At 20 degrees, the inferior portion of the facet contacts the femoral trochlear groove. At 45 degrees, the medial and lateral facets contact the femoral trochlear groove. The contact area moves proximal as the knee flexes so that by 90 degrees of flexion the superior portion of the patella contacts the trochlea. Beyond 90 degrees of flexion, the patella moves down into the intercondylar notch and the quadriceps tendon articulates with the trochlear groove of the femur. It is not until 135 degrees of flexion that the 'odd' facet of the patella makes contact with the medial femoral condyle (Hungerford and Barry, 1979).

The patella transmits force from the quadriceps muscle to the patella tendon, while developing a large patellofemoral joint reaction (PFJR) force. Abnormally high compressive PFJR force produces abnormally high stress across the articular cartilage. Such stress is thought to be one of the initiating factors of chondromalacia, patellofemoral symptoms and subsequent osteoarthritis. Studies that have evaluated patellofemoral force transmission recommend that rehabilitation programs must be designed to minimize PFJR force, but not the quadriceps forces, large isokinetic, isotonic or isometric moments with the knee positioned between 60 and 120 degrees of flexion should be avoided. In this range, the predicted PFJR force is equal to the quadriceps force (Ahmed et al., 1987, Buff et al., 1988 & Van Eijden et al., 1986). With the requirement to minimize the PFJR force, it may be advisable to restrict knee rehabilitation to range between the limits of extension, where the PFJR force is approximately 50% of the quadriceps force and 40 - 60 degrees, where PFJR force is 90% of the quadriceps force.

2.3 MUSCULAR CONTROL OF THE PATELLOFEMORAL JOINT.

The soft tissues controlling the patella are very critical in the first 20 degrees of flexion, where the position of the patella relative to the femur is determined by the interaction of medial and lateral soft tissue structures. After the first 20 degrees of knee flexion, as the patella engages in the trochlea, the bony architecture (the condylar angles) becomes increasingly responsible for patellofemoral joint stability. Any imbalance between the medial and lateral in soft tissues within the first 20 degrees of knee flexion will cause the patella to enter the trochlea in a non-optimal way (Malone et al., 2002; McConnell, 1996). The primary dynamic restraints are the quadriceps muscles. The quadriceps consists of the rectus femoris, vastus intermedius, vastus lateralis and the vastus medialis. The vastus medialis is divided into the vastus medialis longus and the vastus medialis obliquus (VMO).

The passive structures are more extensive and stronger on the lateral side than they are on the medial side with most of the lateral retinaculum arising from the iliotibial band. If the iliotibial band (ITB) is tight, excessive lateral tracking and/or lateral patellar tilt can occur (Fulkerson and Hungerford, 1990). The quadriceps muscle provides active mediolateral stabilization: on the lateral side by the vastus lateralis (VL) and on the medial side by the vastus medialis (VM). The fibers of the VL are oriented 12 – 15 degrees lateral to the midline in the frontal plane. The VL has an anatomically distinct group of distal fibers, the vastus lateralis oblique (VLO) which interdigitates the lateral intermuscular septum before inserting into the patella (Hallisey et al., 1987).

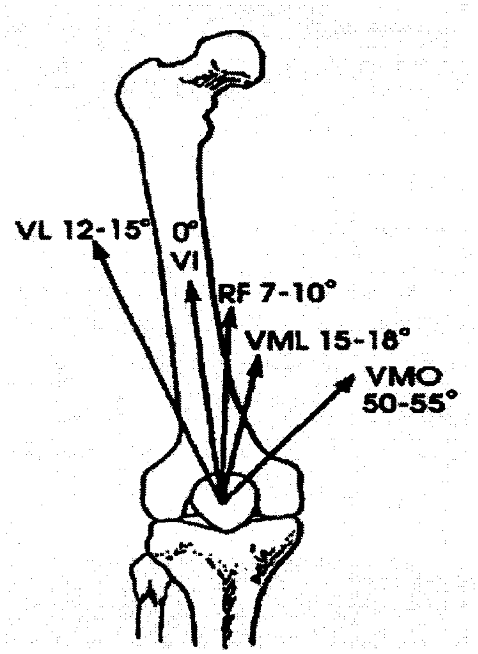

Figure 2 – 1: Fiber orientation of the quadriceps muscle in relation to the femur, showing line and angle of pull of the RF, VI, VL, VML & VMO muscles. (RF= Rectus femoris, VI Vastus intermedius, VL= Vastus lateralis, VML = vastus medialis longus, VMO = vastus medialis obliquus.

The vastus medialis is more distinctly divided than the VL, due to the functional orientation of its fibers. The fibers are functionally divided into two components – the longus in which the fibers are oriented 15-18 degrees medial to midline in the frontal plane and the obliquus, in which the fibers are oriented 50-55 degrees medial to the midline in the frontal plane (Lieb and Perry, 1968). The vastus medialis longus (VML) acts with the rest of the quadriceps to extend the knee. Although the VMO does not extend the knee, it is active throughout knee extension to keep the patella centered in the trochlea of the femur (Lieb and Perry, 1968).

The VMO is arguably the most important muscle about the knee with respect to patellar mechanics. It arises from the tendon of the adductor magnus and longus, and inserts into the superomedial half of the patella. This results in the oblique angle of pull of the patella.

The femoral nerve, which innervates the quadriceps, is the largest branch of the lumbar plexus. It arises from the dorsal divisions of the second, third, and fourth lumbar nerves. The muscular branches supply the four parts of the quadriceps femoris. The branch to the rectus femoris enters the upper part of the deep surface of the muscle, and supplies a filament to the hip joint. The branch to the vastus lateralis, of large size, accompanies the descending branch of the lateral femoral circumflex artery to the lower part of the muscle. It gives off an articular filament to the knee-joint. The branches to the vastus intermedius, two or three in number, enter the anterior surface of the muscle about the middle of the thigh. A filament from one of these descends through the muscle to the articularis genu and the knee-joint. The branch to the vastus medialis descends lateral to the femoral vessels in company with the saphenous nerve. It enters the muscle about its middle, and gives off a filament, which can usually be traced downward, on the surface of the muscle, to the knee-joint. The VMO is supplied in most cases by a separate branch of the femoral nerve from the rest of the vastus medialis (Bose et al., 1980; Gresalmer and Klein, 1998; Lieb and Perry, 1968). The branch to the VMO runs either through or superficially over the tissue plane dividing the VML from the VMO and is present as a separate nerve in 40% of specimens (Gerrard, 1995). A further branch to the VMO arising from the saphenous nerve has been isolated by Gunal et al., (1992), giving extensive innervation to the VMO.

Clinically, the VMO is the only active medial stabilizer of the patellofemoral joint. Therefore, the timing and the amount of activity in the VMO are critical to patellofemoral function. VMO is the primary dynamic restraint to the patella's tendency to track laterally. It is the first muscle to be compromised after prolonged bed rest or immobilization. Atrophy of the VMO is observed in patients presenting with PFPS and a feeling of an unstable knee or dislocated patella (Thomee, 1999). A small effusion in the knee may contribute to the decrease in VMO tension because the VMO is inhibited when only 20ml of fluid is present in the knee joint whereas the VL and the rectus femoris is inhibited when excess of 60ml of fluid is present in the knee joint (Spencer et al., 1984).

Small changes in VMO activity have significant effect on the position of the patellar relative to the femur. A reduction in VMO tension by 50% has been shown to result in a 5 mm displacement of the patella laterally (Ahmed et al., 1988).

↓ VMO function → Quadriceps Imbalance → Over pull by the VL
↑ ↓
Inhibition of muscle function Lateral patella displacement
↑ ↕
Pain + effusion ← Joint Damage ← Articular Cartilage Stress

Figure 2 – 2: Role of VMO dysfunction in the pathogenesis of Patellofemoral Pain Syndrome.

2.3 PATELLOFEMORAL DISORDERS.

Patellofemoral disorders (anterior knee pain) are probably the most common knee pathology encountered by the orthopedic and sport medicine clinician. Unfortunately, there appears to be no consensus in the management of these conditions. Anterior knee pain may be referred to as any one of the following: chondromalacia patellae, recalcitrant anterior knee pain, patellofemoral stress syndrome, patellofemoral pain syndrome, patellofemoral arthralgia or patellalgia (Bray et al., 1999). Wilk et al. (1998), classified patellofemoral disorders into eight categories. The most common of these is patellofemoral pain syndrome (Chesworth et al., 1993). PFPS is defined as retropatellar and/or peripatellar pain that results from either physical or biochemical changes in the patellofemoral joint (PFJ) (Blond and Hansen, 1998). There are several components of this syndrome. It is a syndrome characterized by dysfunction and pain expressed in the anterior and/or retropatellar region of the knee. Signs and symptoms are variable and multiple tissue sources and etiologies exist. PFPS remains one of the most common and challenging musculoskeletal entities encountered by physiotherapist and sports medicine practitioners (Bacquie and Brukner, 1997). The reasons for the pain associated with PFPS remains relatively unknown. The criteria for diagnosis of PFPS include history of peripatellar or retropatellar pain, pain or crepitus on a grinding or apprehension test, pain on palpation of the patellar facets, pain aggravated in activities such as the squat and stair climbing (Crossley et al., 2001).

Generally, it is believed that articular cartilage is aneural, avascular and alymphatic. When damaged, the cartilage does not heal. It is replaced with fibrocartilage and not hyaline cartilage, and does not maintain functional requirements of resistance to deformation (i.e. a frictionless surface and nutrition to underlying cells) (Insall, 1983). This uncertainty has led to theories that pain arises from other structures including subchondral bone, synovium, lateral and medial retinaculum and infrapatellar fat pad. In advanced cases of patellofemoral pain syndrome, the VMO appears to be less active than the VL in the last degrees of knee extension and this is thought to relate to faulty neuromuscular mechanism (Boucher et al., 1992, Hasson, 1994 and Herbert et al; 1994). Because excessive lateral movement of the patella has been correlated with patellofemoral pain, a weakened VM could predispose to patellofemoral dysfunction (Hanten and Schulthies 1990, Lindberg et al., 1986, Lysholm and Nordin 1984, Souza and Gross 1990).

Clients presenting with patellofemoral pain, among other signs and symptoms, have delayed onset of the VMO muscle and reduced activity of the VMO in reference to the VL muscle. Proper rehabilitation protocol and correct exercise technique focusing on the VMO muscle can relieve knee pain and prevent further problems. Initial patellofemoral rehabilitation programs typical follow the sequence: quadriceps femoris setting, straight leg raising and short arc quadriceps exercise (Doucette and Goble, 1992, Insall, 1983 and Smidt, 1973). These exercises are used because both the resultant patellofemoral compression forces are low and the belief that the VMO is more active to other components of the quadriceps femoris during terminal knee extension. Unfortunately, extensive cadaver research, strength training and EMG studies have resulted in conflicting observations both the function of the VMO and the effectiveness of different exercises on the onset and activation of the VMO muscle remains enigmatic (Earl et al., 2001, Grabiner et al, 1991, Hanten and Schulthies, 1990, Hertel et al., 2003, Karst and Jewett, 1993, Laprade et al; 1998, Rice et al., 1995, Sodeberg et al., 1987 & Souza and Gross 1991).

2.4 MODEL OF THE QUADRICEPS FEMORIS MUSCLE.

This muscle, the largest in the body, is the main extensor of the knee joint and has four parts: rectus femoris and the three-vasti muscles; lateralis, intermedius and the medialis. All converge to form the quadriceps tendon that contains the patella and continues as the patellar ligament to be inserted into the tibial tuberosity.

2.4.1 PREVIOUS MODELS OF THE QUADRICEPS FEMORIS MUSCLE.

The quadriceps femoris muscle has usually been described either using muscle – directed models (straight or centroid models) or fiber oriented models. Muscle – directed models describe the muscle's force as a line connecting the muscle's origin and insertion (Brand et al., 1982) or a line represented by the centroid of multiple cross-section (Jensen and Davy, 1975). In order for the muscle-directed model to be valid, several assumptions must be met. First, a muscle's attachment must be sufficiently defined to enable the person to reduce the muscle fibers' multiple forces into one discrete force (Crownshield et al., 1978). The large area of origin of the vastus medialis (VM) and vastus lateralis (VL) however, makes it difficult to locate a single point of origin for each muscle. Models of the quadriceps femoris muscle therefore must divide the VM and the VL into multiple components to accurately describe their forces. Second, muscle directed models assume that the forces developed by muscles are in line with their longitudinal axes. This assumption, however, is not completely true in the quadriceps femoris muscle. Muscles develop force in line with the direction of their individual fibers, which may or may not be the same direction as the muscle's longitudinal axes.

In 1968, Lieb and Perry described five functional components of the quadriceps femoris muscle based on the direction of their fibers: vastus lateralis, rectus femoris, vastus intermedius, vastus medialis and the vastus medialis obliquus. The VM was divided into oblique and long portions because of the 'marked and abrupt change in fiber alignment between its superior and inferior portions'. Scharf et al., 1984, corroborated many of Lieb and Perry's findings using the femoral shaft as their reference using 32 cadaver specimens to determine the average deviations of each component of the quadriceps femoris muscle in the frontal plane. The models proposed by Lieb and Perry and Scharf et al contained some drawbacks. First, although the VM was divided into long and oblique portions, no attempt was made to divide the VL. Second, no attempt was made to measure the force capability of the different components.

2.4.2 CURRENT MODEL DESCRIPTION.

This model combines the muscle-directed models (Schulthies et al., 1995). The quadriceps femoris is divided into eight components with one component consisting of the rectus femoris (RF) and the vasti muscles divided into seven components (Figure 3).

Component 1 consists of the most distal fibers of the VM, originating from the adductor longus muscle tendon and the medial intermuscular septum and inserting on the superior medial border of the patella. Component 2 consists of the middle portion of the VM, originating from the adductor longus muscle's tendon and the medial intermuscular septum and inserting into the movable portion of the quadriceps femoris tendon below the insertion of the distal fibers of the vastus intermedius (VI). Component 3 consists of the proximal portion of the VM, originating from the linea aspera and inserting into the long tendon running proximally up the thigh and divided into the VM and VI. Component 4 consists of the VI. Component 5 consists of the proximal portion of the VL, originating from the linea aspera and the fascia lata and inserting into a tendon dividing the VL and VI. Component 6 consists of the middle portion of the VL originating from the linea aspera, the fascia lata and the lateral intermuscular septum and inserting into the movable portion of the quadriceps femoris tendon below the distal fibers of the VI. Component 8 is the rectus femoris.

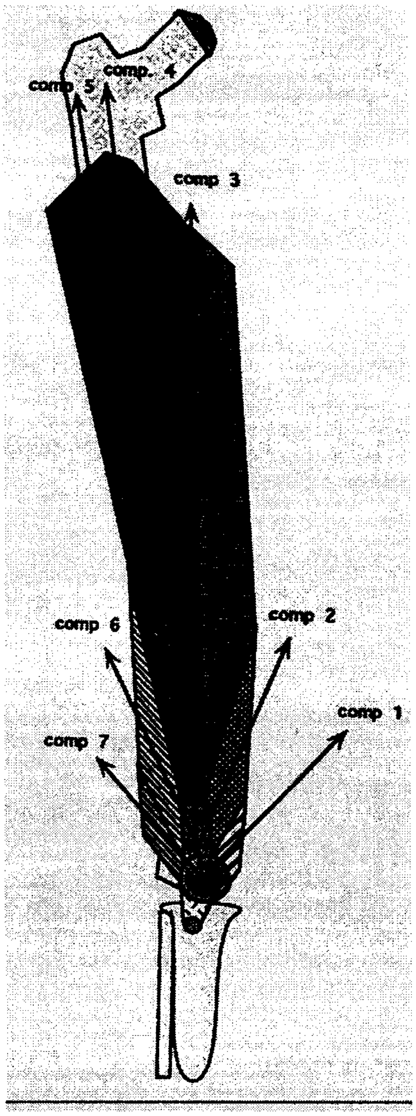

Figure 2 - 3: Components of the vasti muscles (from Schulthies and Francis, 1995. Does the Q-angle reflect the force on the patella in the frontal plane? Phys Ther, 75, (1), 30 - 36.)

2.5 ELECTROMYOGRAPHIC STUDIES OF THE VASTI MUSCLES.

VMO activation can be measured electromyographically, giving information about the intensity and timing of muscle activity. EMG studies of normal subjects have revealed that the normalized VMO:VL ratio should be 1:1 in most static activities, and that the VMO has an earlier onset compared with the VL. However, this ratio is not often 1:1 as the activity changes from static to dynamic activities (Voight and Weider, 1991). On the other hand, EMG recordings in patellofemoral pain sufferers have revealed that the ratio of VMO:VL is less than 1:1, the VL fires significantly faster than the VMO, however, there are findings that suggest that this ratio is activity dependent (Voight and Weider, 1991).

Hanten and Schulthies (1990) examined the effect of maximal isometric knee extension with tibial internal rotation and hip adduction on the VMO and VL. The EMG amplitude was then normalized by way of comparison to the maximal voluntary contraction (MVC) values seen during knee extension. Hip adduction resulted in VMO values that were 61.75% of the MVC during extension, statistically greater than those seen in the VL (45.63%). There were no differences in the VMO:VL ratio during knee extension with internal tibial rotation (47% and 45%). Cerny (1995), Earl et al., (2001) and Miller et al., (1997) reported increased VMO activity when a wall slide or mini squat activity with hip adduction was performed. Hodges and Richardson (1993) also demonstrated increased VMO activity when a static wall – sit was combined with isometric hip adduction. Increases in the EMG activity of the VMO muscle during activity that involve hip adduction may be explained by the simple reason of the anatomical relationship between the vastus medialis and the adductor muscle group. The lower portion of the vastus medialis arises from tendons of the adductor longus and adductor magnus muscles, which are principal adductors of the hip joint. Thus, there is possibility of overflow of activity from the adductor muscles to the vastus medialis muscle when hip adduction movement is combined with knee exercises. The increase in EMG activity does not connote preferential recruitment or selective activation of the VMO muscle during these activities.

Laprade et al. (1998) and Rice et al., (1995) did not find any selective recruitment of the VMO muscle when combining hip adduction with knee extension. In fact, Hertel et al., (2004) collected surface EMG readings from the VMO, VL and gluteus medius muscles during three single leg, weight bearing, isometric exercises (uniplanar knee extension, knee extension/hip adduction, and knee extension/hip abduction). They concluded that uniplanar knee extension exercise produced significantly more EMG activity than the extension/adduction and the extension/abduction tasks.

Karst and Jewett (1993) asked their subjects to perform a series of quadriceps exercises: quadriceps setting (QS), straight leg raising (SLR), SLR with hip lateral rotation and SLR with hip adduction. The greatest muscle activity was seen during QS and none of the variations provided additional emphasis to the vasti muscles. Gryzlo et al; (1994) analyzed five commonly used patellofemoral exercises (SLR, short arc extension, short arc extension with hamstring co-contraction, squat and isometric co-contraction of quadriceps and hamstrings) through EMG activity. Only the short arc extension showed a statistical significant increased activity of the VMO over the VL muscle. However, the VMO and VL were both active during terminal knee extension of the short arc extension. It is difficult to tell whether isolated or selective recruitment of the VMO muscle is possible, simply for the fact that this muscle does not act independent of the other parts of the quadriceps during lower extremity movement. There appears to be some questions about the conclusions of these studies. Standards with which EMG data were processed are different. For instance, Cerny (1995) reported integrated EMG data. Integrated EMG values are not filtered. It is area under a curve over a time interval. Noise and other unwanted signals are often processed with integrating EMG data. In other instances, for example Miller et al., (1997) and Hodges and Richardson (1993) did not normalize EMG data. Failure to normalize EMG makes EMG results non-comparable. It is important to note here that normalization is necessary for all EMG data for purposes of comparison with similar data from other studies. When normalization is performed, it should be decided whether a static effort or a dynamic effort is to be used as the reference muscle contraction. The most frequently used value is the maximal voluntary isometric contraction. There have been trends over the last 15 years to use alternatives such as (1) a percentage of the MVIC (2) the peak EMG value obtained during dynamic activity or (3) the mean EMG value obtained during a dynamic activity. Soderberg and Knutson (2000) suggest the use of isometric contraction. However, the use of this is dependent on the ability to maximally activate all motor units, training level and motivation. The use of MVIC for normalization without proper training of the subjects can be 20% to 40% less than the true maximum. Without proper training, Tata and Peat (1987), Yang and Winter (1984) and Young et al., (1989), recommend the use of a value taken from the dynamic activity performed. For dynamic activities, it is recommended using the mean or peak EMG value from the dynamic contraction because doing so reduces the inter-subject coefficient of variation, thus reducing the variability among the population studied (Yang and Winter, 1984).

2.6 THE PATELLOFEMORAL JOINT IN OPEN AND CLOSED KINETIC CHAIN EXERCISES.

Kinetic chain terminology was derived originally for linkage analysis in mechanical engineering and has since been applied to human body kinetics. Steindler (1955) proposed that, in the human body, each limb could be thought of as a chain consisting of rigid overlapping segments connected by a series of joints. He observed that when the foot or hand meet considerable resistance, muscle recruitment and joint motion differ from that seen when the foot or hand could move without restriction. He thought that the difference was important enough to warrant distinction of the two conditions with separate terms. Specifically, with an open kinetic chain exercise (OKC), the distal segment is free to move; as in the case where one is not weight bearing on the lower extremities. The OKC entails a movement that is not resisted manually or through weight bearing. Movement of one joint does not necessarily cause movement in the other joints. In a closed kinetic chain (CKC), the distal segment is fixed as in weight bearing of the lower extremity. In this state, movement at one joint induces movement at the other joint.

A primary goal in rehabilitating patients with PFPS is to condition the quadriceps muscles while maintaining moderate loads in the joints. High stresses on the articular surfaces can exacerbate symptoms of pain and the perhaps damage the cartilage.

OKC exercises have been traditionally used in rehabilitation of patients with knee joint problems. One of the proposed drawbacks for OKC exercise is that it exposes the patellofemoral joint to supraphysiologic loads (Hungerford and Barry, 1979). However, Kaufman et al., (1991) showed that at low flexion angles (less than 20 degrees), the patellofemoral joint reaction forces were low, so exercising within these low ranges of flexion will not load the patellofemoral joint severely but will still strengthen the quadriceps muscles.

CKC exercises have been advocated for rehabilitation and exercise training because of their effect on the hip, knee and ankle joints simultaneously. In addition, it is thought that CKC exercises improve the general function of muscles coordination and physical performance (Augustsson, 1998). Nevertheless, patients who have patellar subluxation often have difficulty with CKC regimens. This is primarily due to fear of a reoccurrence of the condition.

Open chain exercises are generally better tolerated than closed chain exercises by patients in the postoperative period, when many are unstable on their feet. It should be emphasized that joint forces seen in isokinetic are not the largest in the body. Kaufman (1991, pp 305) reported that:

> *"... average tibiofemoral force of 4 times body weight whilst testing isokinetically. This is equal to that obtained during walking; the anterior shear force was on average 0.3 times body weight which is larger than expected during walking but lower than that expected during stair climbing (1.7 times body weight) or running (3 times body weight); posterior shear force was on the average 1.7 times body weight which is larger than walking but on par with stair climbing and lower than running; and the patellofemoral joint force reaches 5.1 times body weight at 60 degrees/second. This can be compared to 0.5 times body weight during walking, 3.3 times body weight whilst ascending stairs, 7.6 times body weight in squatting or 20 times body weight during jumping."*

Witvrouw et al., (2000) compared a group of 60 patients with patellofemoral pain who were randomized to a five-week program of only closed kinetic chain or only open kinetic chain exercises. Results showed that at five weeks and three months, both groups demonstrated statistically significant improvement in pain and improvement in functional performance as compared to baseline measurements. Strength measures improved in both groups for the hamstrings and the quadriceps. There were minor differences for some functional activities, such as jumping for those performing the closed-chain exercises; otherwise, most differences were minimal. This study suggests that both exercise programs can be effective in the treatment of patients with patellofemoral pain.

CHAPTER THREE.

METHODS.

3.1 SUBJECTS.

This study was a within subject (repeated measure) experimental design. A sample of convenience of 30 (fifteen males and fifteen females) healthy individuals (see sample size calculation in Appendix C) was used. Inclusion criteria were:

- male and female subjects between the ages of 19 and 39,
- fifteen males and fifteen females made up the sample size,
- no history of knee joint complex pathology (ies),
- no pain on palpation of the patellar facets,
- no pain in activities such as squat and stair climbing.

Subjects were excluded from the study if any of the following are present on examination:

- history of past or present knee joint injury or treatment,
- patellofemoral joint pathology,
- a positive response to patellar apprehension test,

Subjects were recruited from the University of Alberta community with the aid of posters, class talks in different departments and email messages from the Graduate Student Association electronic newsletter (see Appendix D).

3.2 DATA COLLECTION.

3.2.1 Procedure.

Prior to participation, and once it was determined that the subject was eligible to participate in the study (see inclusion and exclusion criteria in section 3.1), informed and written consent of each subject was obtained. Each subject signed a consent form approved by the Health Research Ethics Board of the University of Alberta. All measurements were conducted in the Department of Physical Therapy, Faculty of Rehabilitation Medicine, University of Alberta, Edmonton.

Prior to testing, all subjects performed standard stretching exercises for the lower limb including stretching of the quadriceps, hamstrings, iliotibial band and calf muscles, and warm up for 5 minutes on a stationary bicycle. Stretching and warm up before an exercise procedure has been shown to increase flexibility, decrease the incidence of musculoskeletal injuries including muscle soreness and improve athletic performance (Anderson and Burke, 1991 and Beaulieu, 1981). Since the isokinetic resistance is a novel experience, subjects were adequately informed and familiarized with the isokinetic concept of leg extension exercise before testing. Familiarization involved three submaximal and three maximal isokinetic knee extension and flexion activity and an explanation of how the device works.

3.2.2 Variables.

In this study, the dependent variables were

- the muscle activity (normalized EMG amplitude) of the VMO and VL muscles, as recorded by the BIOPAC MP150 EMG device,

- the VMO:VL EMG amplitude ratio (calculated from the VMO and VL EMG output) and
- onset (seconds) of EMG activity of the VMO and VL muscles.

The output of the BIOPAC MP 150 was recorded in millivolts (mV) for EMG amplitude and milliseconds for EMG onset. All EMG values were subject to further calculations including normalization and other basic mathematical computations. The KINCOM 500H isokinetic dynamometer measured torque output in Newton meters (Nm) and the angular velocity in degrees/second.

The independent variables were

- the testing velocity,
- the type of contraction
- the VMO and VL muscles.

Both testing velocity and type of contraction were functions adjusted by the dynamometer.

3.2.3 <u>Isokinetic Knee Extension Exercise.</u>

The KINCOM 500H dynamometer, Chattanooga Group Inc., Hixson Tennessee, was used to provide the testing velocities during eccentric and concentric contraction. There were three testing velocities: 60°/s, 120°/s, and 180°/s (slow, medium and fast). The test-retest reliability (ICC) of the KINCOM 500H in the seating position and at testing velocities between 30°/s and 180°/s for concentric and eccentric knee extension, in both male and female, has been shown to be range between 0.76 and 0.97 (Kannus, 1994, Wilhite et al., 1992). The test-retest reliability of various isokinetic dynamometers has been established at a spectrum of velocities and in different test positions. Perrin (1993) summarized reliability as adequately established, respectable and high across the various dynamometers, velocity spectrum and positions. Intraclass correlation coefficient (ICC) for the seating position for velocities ranging between 60 and 330 degrees/second for knee extension and flexion (both concentrically and eccentrically in males and females) has been established to range between 0.76 and 0.97. Perrin (1993) defined ICC values greater than or equal to 0.80 as very good and values above 0.90 as excellent.

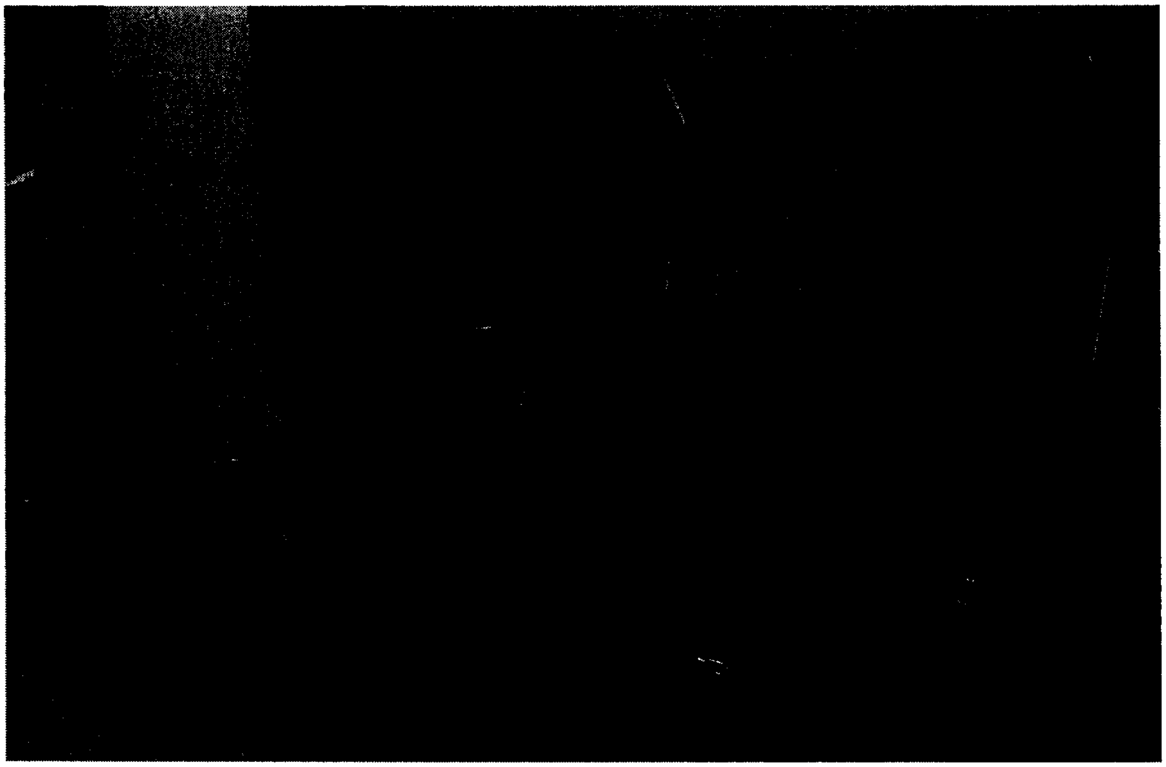

Figure 3 – 1 : KINCOM Isokinetic dynamometer

The subjects sat on the KINCOM machine (Figure 3 – 1) and the load cell recorded the torque applied at each testing velocity. The subjects' positioning on the dynamometer was according to the manufacturer's protocol, with the back supported and hips flexed to approximately 80°. Trunk and thigh straps were fastened for stabilization. The knee joint and the dynamometer were properly aligned such that the knee joint axis and the axis of rotation of the dynamometer were on the same plane. The isokinetic knee extension exercise was performed between 60 degrees of knee flexion to 0 degrees extension (0 – 60 degrees) for each of the three test velocities. The load cell of the dynamometer was fixed at the distal end of the lower leg being tested. Start and stop angles were programmed into the Kin-Com's computer after positioning the subjects. The anatomical zero was obtained by having the subject perform full active knee extension without the tibial plate attached. The tibial plate (the part attaching to the leg) was lowered to the fully extended limb. The Kin-Com's goniometer was calibrated to read this position as anatomical zero. Both start and stop angles had a 2° difference, thus 2° and 62° start and stop angles were chosen to compensate for additional motion gained from compression of the tibial pad during the initiation of a muscle contraction and the end of contraction to ensure full end range contraction of the VMO and VL muscle.

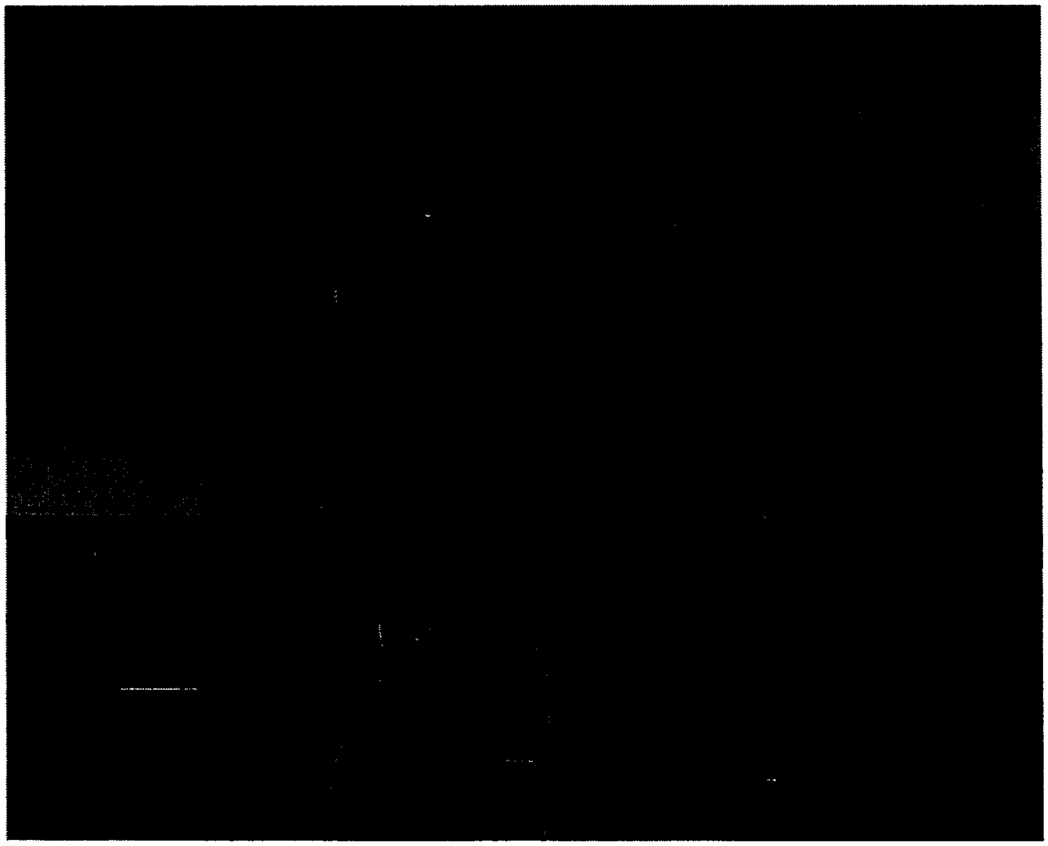

Figure 3 – 2 : Subject position without stabilization straps showing electrode placement.

A warm up session at sub maximal intensity on a stationary bicycle ergometer was conducted before the subjects perform the test. Prior to actual testing, a familiarization session involving three submaximal and three maximal repetitions was performed. This has been shown to be adequate to obtain reliable measurements (Perrin, 1986). The actual test session included two quadriceps eccentric and concentric contractions and were recorded between 2° and 62° of knee flexion at the 3 different testing velocities. During each test session, the velocities of testing and the type of contraction were randomized (See Appendix C).

Randomization involved the subject picking a card from a box containing six cards. The card showed the order which the test were performed. A rest session between 30 seconds to 2-minute is necessary during isokinetic assessment (Perrin, 1993). For this study, a 1-minute rest interval was observed after each contraction was performed to allow the muscles tested to recover fully from the previous session.

Because encouragement may not be consistent during test sessions in different subjects (Perrin, 1993), each subject was instructed to produce a maximum effort before each series of repetitions, and the researcher remained silent during the test session.

3.2.4 MUSCLE ACTIVITY

The BIOPAC MP 150-electromyography device (see Figure 6 and Appendix E for specifications) and Acqknowledge software® were used to obtain and analyze surface EMG readings from the vastus medialis obliquus (VMO) and vastus lateralis (VL) during eccentric and concentric leg extension exercise.

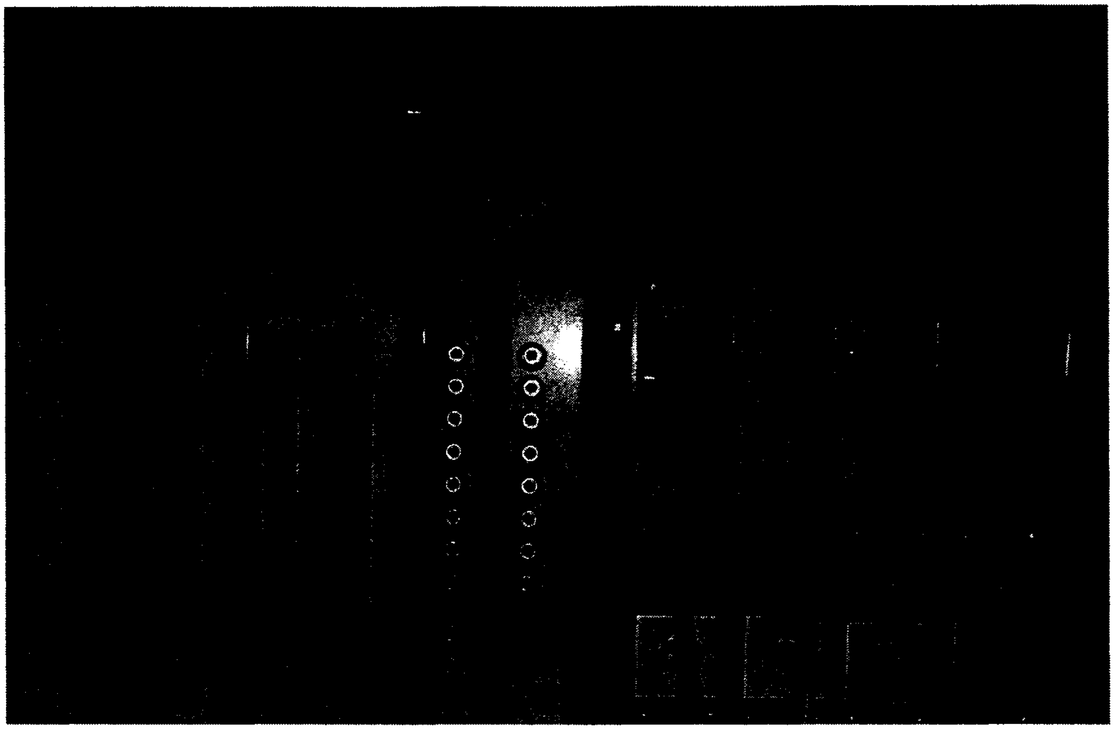

Figure 3 - 3: BIOPAC® system for EMG data collection.

In a review of nine studies that assessed the reliability of surface electromyography (sEMG) recordings on the same day on a variety of muscles, the Pearson correlation was between 0.77 and 0.98 (Cram et al., 1998). Within day reliability are quite trustworthy and respectable. In another review of five studies that assessed reliability across days, Pearson correlation was as high as 0.92 and as low as 0.32. The variability of findings increases as time between recordings increases. One might want to consider surface EMG as a "state" rather than a "trait" measure; changing in response to task and environment (Cram et al., 1998).

The implication of this is that measurements should be taken during one test session as reliability and validity tend to be reduced across days.

3.2.5 ELECTRODES

The recording surface electrodes were placed on the VMO and the VL muscles as described according to the procedure of Basmaijan and Blumenstein's atlas of electromyography (Figure 5 and Appendix FI and FII). The reference or ground electrode was placed on the patella. The patella was chosen because it is the closest bony prominence to the site of the recording electrodes. The reference electrode acted as a filter to selectively allow only signals unique to the recording electrodes to pass on for further processing. The direct contact electrode with a diameter of 0.5 – 1.0cm made of disposable silver-impregnated plastic that was coated with a thin layer of silver chloride to help stabilize the electrical signal of the skin was used in this study. The skin was prepared to reduce the impedance between the skin and the electrodes by shaving the hair over the skin portion where the electrodes were to be placed and the skin cleaned with methylated spirit.. The subject's VL and VMO were identified during a maximal isometric quadriceps muscle contraction. The largest area of the muscle mass of the VL and VMO was prepared and used for electrode placement. The inter-electrode distance should be as small as possible to ensure effective recording from the electrodes. The center-to-center distance between the electrodes was approximately 22mm (see appendix FI and FII). The recording surface electrodes were placed on the longitudinal axis of belly of each muscle so that the electrodes could record the maximal muscle activity. The VMO electrodes were aligned approximately at 50° - 55° angle medially to the longitudinal axis of the femur. The VL electrodes were aligned approximately at a 12° - 15° laterally to the longitudinal axis of the femur

3.2.6 EMG DETECTION, SAMPLING AND PROCESSING.

The bandwidth frequency ranged from 15-500Hz and was sampled at 1000 Hz. The input impedance of the amplifier was set at 20,000KΩ and the amplitude of the raw EMG signals were expressed in millivolts. The common-mode rejection ratio (CMRR) was set at 130Decibels (dB). The CMRR worked together with the surface electrodes. It allowed signals common to both recording electrodes in (reference to the ground electrode) to be eliminated from further amplification. This reduced the environmental noises that might have otherwise contaminated the signals. For effective amplification, the CMRR should not be less than 90dB.

Since the raw EMG signals resemble noise signals with a distribution around the zero point, any interpretation of these signals with respect to muscle activation and force production was difficult. Thus, the EMG signals were processed by full wave rectification (only the absolute magnitudes of the signal were considered). Full wave rectification is preferred to other forms of rectification because the entire signal was retained. In addition, full wave rectification allows for further signal processing. The signals were smoothed (removal of high frequency content of raw signal); by passing it through a low-pass filter. Removal of high frequency content of the EMG record allowed for better relation of the EMG signal to the contractile features of the muscle tested.

3.2.7 EMG NORMALIZATION

Little is known about the best standard to use for normalization. The rationale for selection has generally been based on logic or opinion (Soderberg & Knutson, 2000). When using EMG, it is necessary to normalize or standardized data by establishing the parameters of the EMG activity of the muscles and the force (torque) of the muscles measured in

Newtons (maximal voluntary contraction). This normalization must be performed before doing any testing, in order to compare data between each subject at different times (De Luca, 1997). Burden and Barlett (1999) stated that this method should be used to standardize the amplitude of the EMG if the objectives are to compare these data between subjects, muscles, and tasks, or to retain the natural variation between individuals. The International Society of Electrophysiology and Kinesiology (1999), recommends the use of maximum voluntary contraction for purposes of normalization.

The mean dynamic EMG value during maximum voluntary contraction (MVC) at 30°/s during eccentric and concentric contraction was used for normalization. EMG activity values for 60°/s, 120°/s and 180°/s were divided by the EMG activity reading at 30°/s. The value obtained from this calculation was referred to as the normalized EMG value.
For this study, this method was preferred above the isometric MVC or the peak EMG technique for the following reasons. Firstly, there is consistency of EMG activity over the range of motion, secondly, it offers the ability to compare activity between different muscles, across time and between different individuals, thirdly, it represents maximum activation capacity of the muscle under non – isometric conditions and lastly, it reduces inter-subject variations (Burden and Barlett 1999). This procedure was performed for both the VMO and VL muscles during eccentric and concentric contraction.

Normalized VMO and VL muscle EMG amplitude signals in both concentric and eccentric leg extension exercises were presented as a VMO/VL amplitude ratio. A value of more than 1.0 implied that the VMO exerted a larger contractile intensity than the VL muscle, and for values less than 1.0, the VL muscle exerted a larger contractile intensity than the VMO muscle.

The time of onset of the EMG activity of the VMO and VL muscles was the absolute time at which the first EMG activity was observed visually on the BIOPAC EMG monitor. Once EMG activity data was collected, the cursor was used to trace where the first onset of EMG activity was observed. The corresponding time output from the EMG monitor was recorded as the onset of EMG activity. This method was aided by visual inspection to ensure the consistency of values obtained and prevent rater bias.

3.3 STATISTICAL ANALYSIS.

The dependent variables were the mean VMO and VL EMG activity, onset of EMG activity of the VMO and VL muscles and VMO:VL EMG activity signal ratio during knee extension. The independent variables were the testing velocity and the type of muscle contraction.

A repeated measure within – subject ANOVA was used for analysis. The major advantage of this design is its ability to control for potential influences of individual differences. Therefore, differences observed among the variables were likely to reflect variable effect and not variability between subjects. The downside of this approach was the possibility of practice effects and carryover effects (Portney and Watkins 2000). A randomization technique (see appendix C) was used to reduce these effects.

For inferential statistics, the 3-factor repeated analysis of variance (ANOVA) was used to determine whether there was any significant difference between the mean normalized VMO and the VL EMG activity ratio at the 3 different testing velocities during eccentric and concentric knee extension.

A 2-factor repeated analysis of variance (ANOVA) was used to determine whether there was any significant difference between the VMO:VL EMG activity ratio at the three different testing velocities during eccentric and concentric knee extension.

A 3-factor repeated analysis of variance (ANOVA) was used to determine whether there was any significant difference between the onset of EMG activity of the VMO and VL muscles at the three different testing velocities during eccentric and concentric knee extension (see Appendix G for data collection sheet sample).

The level of significance was set at $\alpha = 0.05$.The sample size was based on a power of 0.80 and an effect size of 0.30. All analysis was performed using the Statistical Package for Social Science (SPSS) software version (12.0).

A summary of the analysis is outlined in Table 3 - 1

Variables	ANALYSIS
EMG activity of the VMO and VL muscles	**3-factor repeated ANOVA (factors are type of contraction, speed of contraction and VMO and VL muscles)**
Onset of EMG activity	**3-factor repeated ANOVA (factors are velocity of contraction, the VMO and VL muscles and type of contraction)**
VMO: VL EMG ratio	**2-factor repeated ANOVA (factors are velocity of contraction and type of contraction)**

Table 3 - 1 : Statistical methods for data obtained from this study.

3.4 SUMMARY STATEMENT.

It has been established that weak activation and delayed onset of contraction of the VMO muscle, relative to the VL, are major factors contributing to abnormal lateral patellar tracking. This abnormal lateral patellar tracking is seen in patients with patellofemoral pathologies. Means by which these two factors, weak activation and delayed onset, can be corrected could prove to be invaluable to the management of patients with pathologies relating to the patellofemoral joint.

With this study, it is hypothesized that the electromyographic activity of the vastus medialis obliquus (VMO) muscle would be stronger and occur earlier as the velocity of contraction of the muscle is increased using the isokinetic dynamometer. It was hoped the outcome of this study would help clinicians and other sports medicine practitioners to learn whether exercising maximally at high or low speeds, eccentrically or concentrically recruited the VMO muscle before the VL muscle during leg straightening. It would also serve as a guide for future research and to pool of knowledge in the study of patellofemoral pathologies.

CHAPTER FOUR

RESULTS

The present study analyzed the effect of changes in the knee angular velocity, using an isokinetic dynamometer, on the VMO and the VL muscle recruitment pattern during eccentric and concentric knee extension among normal individuals without patellofemoral pathologies. All participants were aged between 19 and 39 years. They were screened to ensure that they met the established inclusion criteria and were not excluded by the exclusion criteria.

4.1 SUBJECT CHARACTERISTICS.

Thirty – nine subjects were screened. Thirty, 15 male and 15 female, subjects were finally included in the study. Four subjects had poor quality of EMG and five did not meet the established inclusion and exclusion criteria.

4.2 NORMALIZED ELECTROMYOGRAPHIC ACTIVITY OF ALL SUBJECTS FOR ECCENTRIC CONTRACTION AT 60°/s, 120°/s AND 180°/s.

Table 4 – 1 presents the mean and standard deviation of the normalized EMG activity of the VMO and VL muscles at 60°/s, 120°/s and 180°/s for all 30 subjects during eccentric contraction. Figure 4 – 1 shows the mean normalized EMG activity of the VMO and VL muscle during eccentric contraction at 60°/s, 120°/s and 180°/s.

Table 4 – 1 : Mean and standard deviation of normalized EMG activity of VMO and VL muscle at 60°/s, 120°/s and 180°/s eccentric contraction.

VMO Eccentric Contraction	Mean	SD
60°/s	0.15011	0.08396
120°/s	0.14926	0.09155
180°/s	0.15349	0.10500
VL Eccentric Contraction		
60°/s	0.12324	0.07284
120°/s	0.14216	0.11152
180°/s	0.13833	0.10418

Normalized EMG values are ratios of the maximum reference contraction at 30 degrees/second.

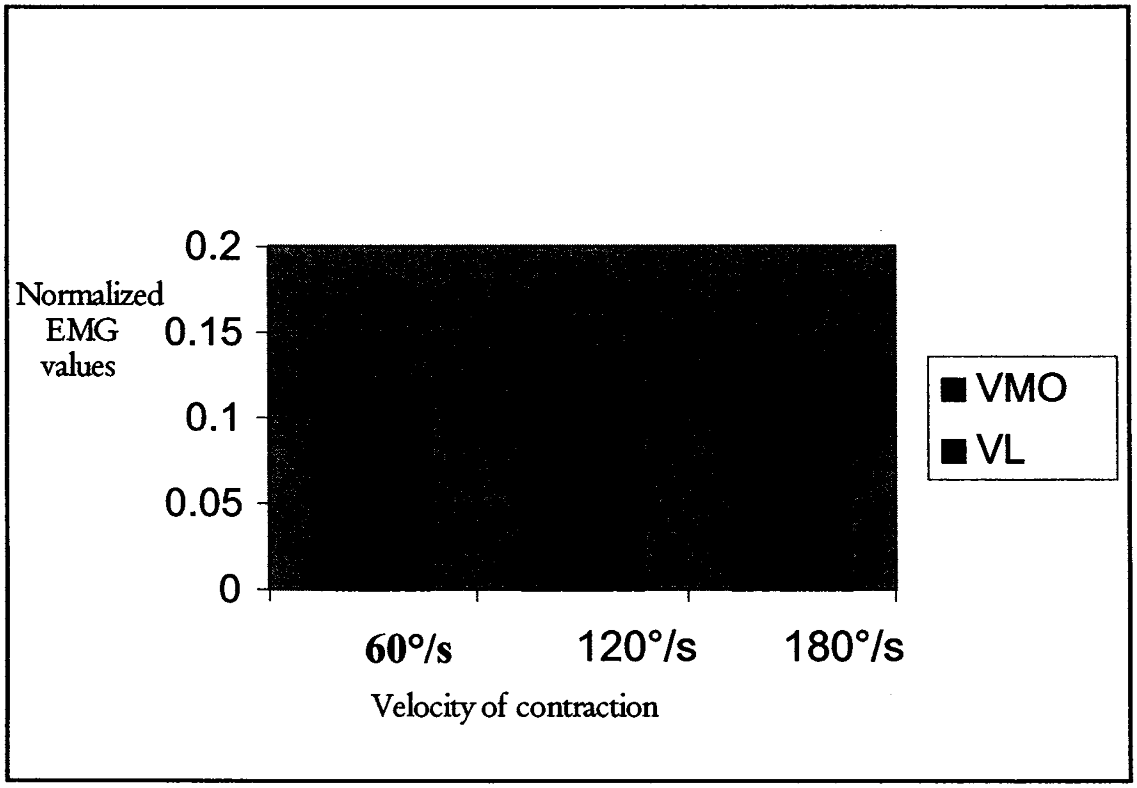

Figure 4 – 1 : Mean normalized EMG activity of the VMO and VL muscles during eccentric contraction at 60°/s, 120°/s and 180°/s. (Normalized EMG values are ratios of the maximum reference contraction at 30 degrees/second).

The VMO muscle had higher values for EMG activity at the 3 different velocities. The highest EMG activity difference was observed at 60°/s and the least was at 120°/s. The VL muscle showed slightly lower EMG activity at the 3 different velocities.

4.3 NORMALIZED ELECTROMYOGRAPHIC ACTIVITY OF ALL SUBJECTS FOR CONCENTRIC CONTRACTION AT 60°/s, 120°/s AND 180°/s.

Table 4 – 2 presents the mean and standard deviations of the normalized EMG activity of the VMO and VL muscles at 60°/s, 120°/s and 180°/s for all 30 subjects during concentric contraction. Figure 4 – 2 shows the mean normalized EMG activity of the VMO and VL muscle during concentric contraction at 60°/s, 120°/s and 180°/s.

Table 4 – 2 : Mean and standard deviation of normalized EMG activity of VMO and VL muscle at 60°/s, 120°/s and 180°/s during concentric contraction.

VMO Concentric Contraction	Mean	SD
60°/s	0.16006	0.09212
120°/s	0.17156	0.10796
180°/s	0.16796	0.09965
VL Concentric Contraction		
60°/s	0.12207	0.06481
120°/s	0.13754	0.06263
180°/s	0.14996	0.11659

Normalized EMG values are ratios of the maximum reference contraction at 30 degrees/second.

In Figure 4 – 2, it was observed that the VMO muscle had a higher value for EMG activity. The highest value being at 60°/s. The relative contribution of the VMO muscle to knee extension in the 60 ° ROM at the knee appears to be more than that of the VL muscle. From Figures 4 – 1 and 4 – 2, it can be seen that the EMG activity differences were slightly larger when concentric contractions were compared to eccentric contractions.

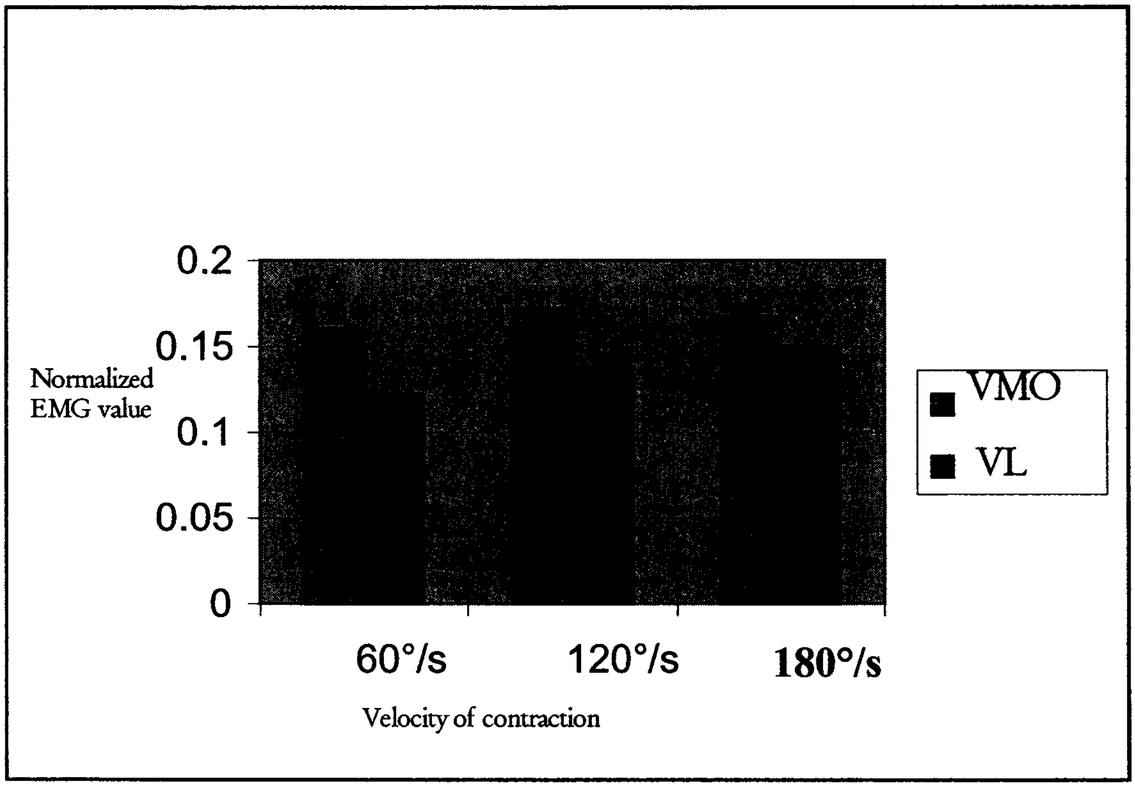

Figure 4 - 2 : Mean normalized EMG activity of the VMO and VL muscles during concentric contraction at 60°/s, 120°/s and 180°/s. (Normalized EMG values are ratios of the maximum reference contraction at 30 degrees/second.)

4.4 ELECTROMYOGRAPHIC ONSET OF VMO AND VL MUSCLES OF ALL SUBJECTS FOR ECCENTRIC CONTRACTION AT 60°/s, 120°/s AND 180°/s.

Table 4 - 3 presents the mean and standard deviations of the onset of EMG activity (seconds) of the VMO and VL muscles at 60°/s, 120°/s and 180°/s for all 30 subjects during eccentric contraction. Figure 4 - 3 shows the mean onset of EMG activity of VMO and VL muscles at 60°/s, 120°/s and 180°/s for all 30 subjects during eccentric contraction.

Table 4 – 3 : Mean and standard deviation of onset EMG activity of VMO and VL muscles at 60°/s, 120°/s and 180°/s during eccentric contraction.

VMO Eccentric Contraction	Mean	SD
60°/s	0.01423	0.004394
120°/s	0.01400	0.005488
180°/s	0.01535	0.008248
VL Eccentric Contraction		
60°/s	0.015117	0.005583
120°/s	0.015517	0.005177
180°/s	0.016917	0.001166

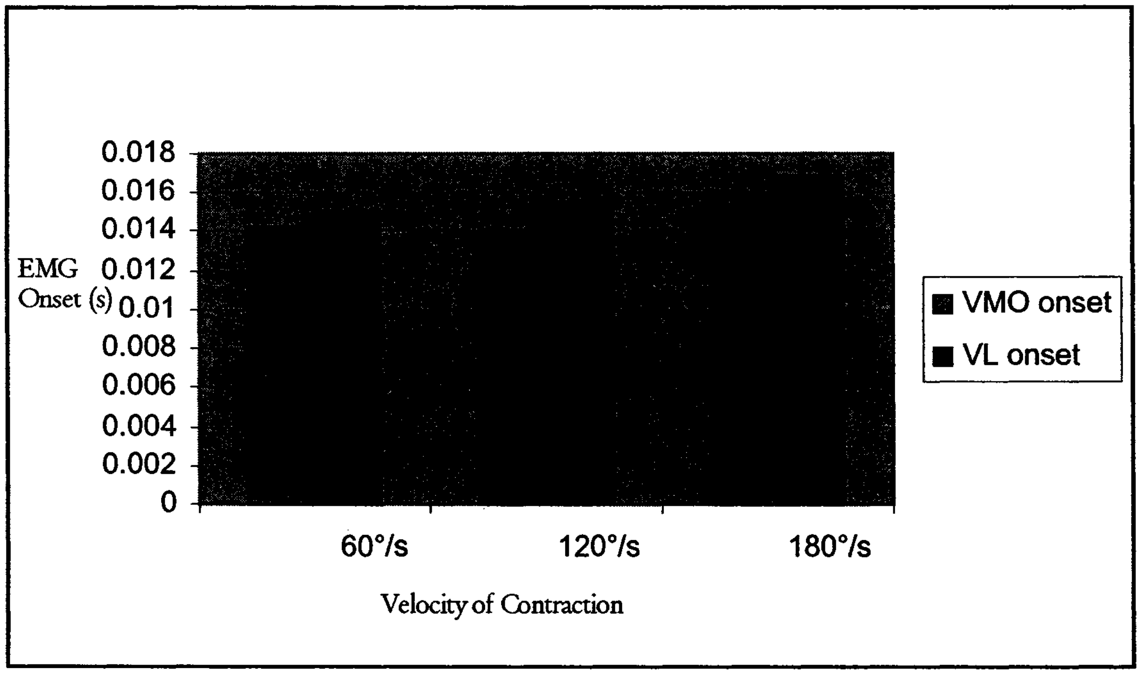

Figure 4 – 3 : Mean onset of EMG activity of VMO and VL muscles at 60°/s, 120°/s and 180°/s for all 30 subjects during eccentric contraction.

In Figure 4 – 3, the VMO muscle had an earlier onset of EMG activity. At 60°/s and 120°/s, onset of EMG activity for the was similar and delayed at 180°/s. The onset for the VL muscle were slightly lower at the 3 angular velocities.

4.5 ELECTROMYOGRAPHIC ONSET OF VMO AND VL MUSCLES OF ALL SUBJECTS FOR CONCENTRIC CONTRACTION AT 60°/s, 120°/s AND 180°/s.

Table 4 – 4 presents the mean and standard deviation of the onset of EMG activity (seconds) of the VMO and VL muscles at 60°/s, 120°/s and 180°/s for all 30 subjects during concentric contraction. Figure 4 – 4 shows the mean onset of EMG activity of VMO and VL muscles at 60°/s, 120°/s and 180°/s for all 30 subjects during concentric contraction.

Table 4 – 4 : Mean and standard deviation of onset of EMG activity of VMO and VL muscles at 60°/s, 120°/s and 180°/s during concentric contraction.

VMO Concentric Contraction	Mean	SD
60°/s	0.01407	0.006764
120°/s	0.01200	0.004895
180°/s	0.01325	0.005174
VL Concentric Contraction		
60°/s	0.01835	0.006798
120°/s	0.01668	0.005514
180°/s	0.02142	0.001926

In Figure 4 – 4, the onset of EMG activity for the VMO muscle were more apparent at 60°/s and 120°/s and the highest difference was observed at 180°/s when compared to that of the VL muscle.

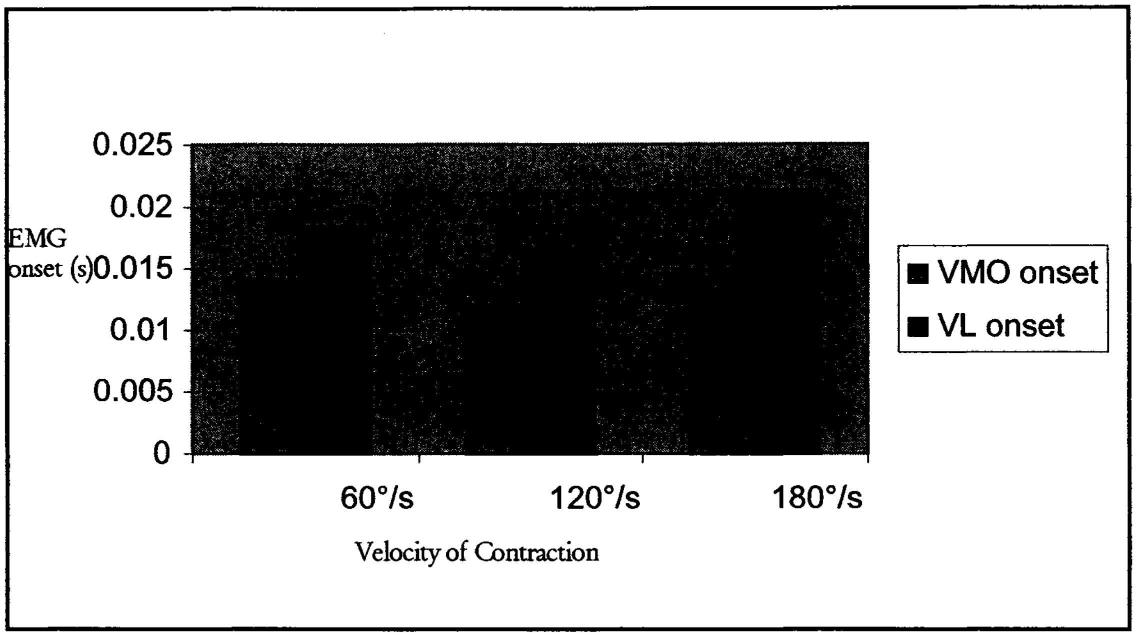

Figure 4 – 4 : Mean onset of EMG activity of VMO and VL muscles at 60°/s, 120°/s and 180°/s for all 30 subjects during concentric contraction.

4.6 NORMALIZED VMO:VL ELECTROMYOGRAPHIC RATIO OF ALL SUBJECTS FOR ECCENTRIC CONTRACTION AT 60°/s, 120°/s AND 180°/s.

Table 4 – 5 presents the mean and standard deviation for normalized VMO:VL EMG ratio for eccentric contraction for all 30 subjects at 60°/s, 120°/s and 180°/s. Figure 4 – 5 shows the mean values for VMO:VL EMG ratio for eccentric contraction for all 30 subjects at 60°/s, 120°/s and 180°/s.

Table 4 – 5: Mean and SD for normalized VMO:VL EMG ratio at 60°/s, 120°/s and 180°/s during eccentric contraction.

Eccentric Contraction VMO:VL EMG ratio	Mean	SD
60°/s	0.985970	0.25450
120°/s	0.941220	0.31326
180°/s	0.957325	0.28036

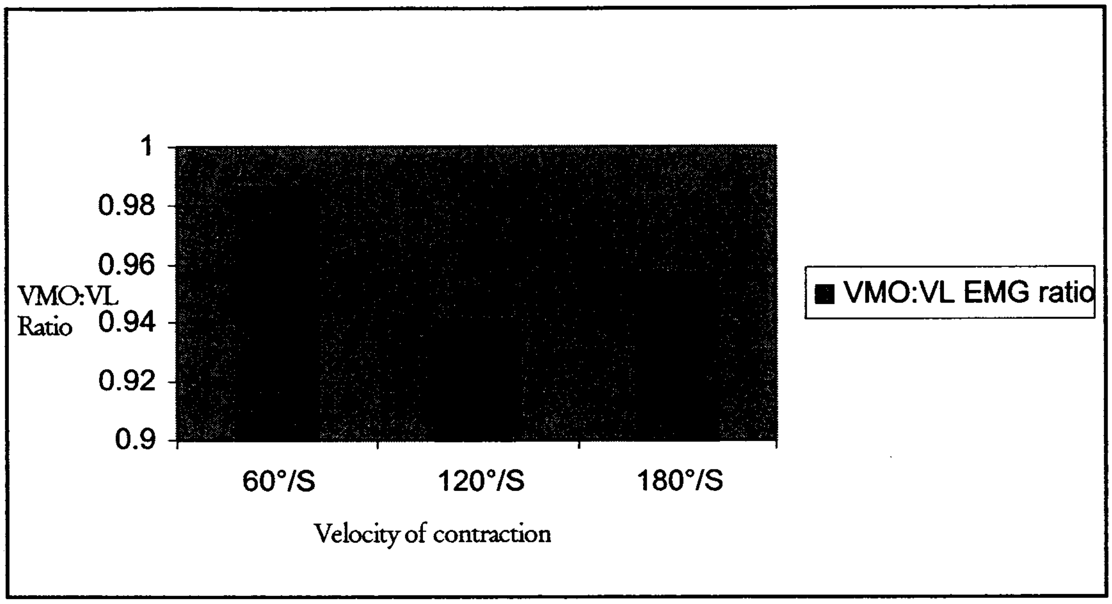

Figure 4 - 5: Mean values for VMO:VL EMG ratio for eccentric contraction for all 30 subjects at 60°/s, 120°/s and 180°/s.

In Figure 4 - 5, the VMO:VL EMG ratios were less than 1.0 at all the 3 test velocities. With values less than 1.0, one can conclude that the relative contribution of the VL muscle was more than the VMO muscle.

4.7 NORMALIZED VMO:VL ELECTROMYOGRAPHIC RATIO OF ALL SUBJECTS FOR CONCENTRIC CONTRACTION AT 60°/s, 120°/s AND 180°/s.

Table 4 - 6 presents the mean and standard deviation for normalized VMO:VL EMG ratio for concentric contraction for all 30 subjects at 60°/s, 120°/s and 180°/s. Figure 4 - 6 shows the mean values for VMO:VL EMG ratio for concentric contraction for all 30 subjects at 60°/s, 120°/s and 180°/s.

Table 4 – 6: Mean and SD for normalized VMO:VL EMG ratio at 60°/s, 120°/s and 180°/s during concentric contraction.

Concentric Contraction VMO:VL EMG ratio	Mean	SD
60°/s	1.23578	0.796071
120°/s	1.051775	0.238216
180°/s	1.233507	0.892592

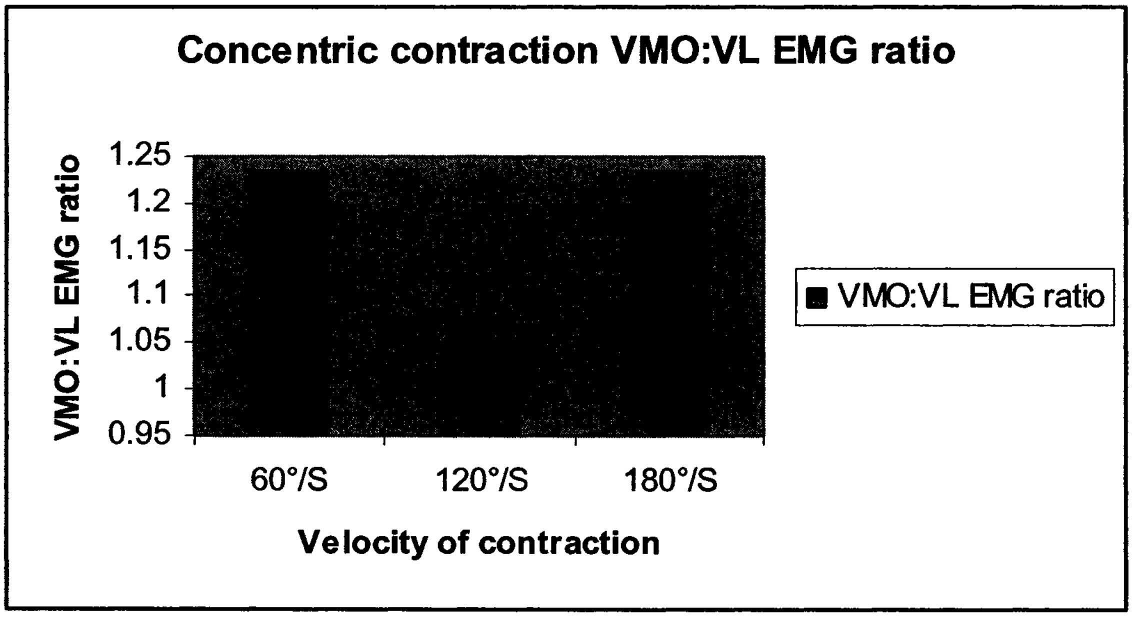

Figure 4 – 6: Mean values for VMO:VL EMG ratio for concentric contraction for all 30 subjects at 60°/s, 120°/s and 180°/s.

Figure 4 – 6 depicts that at all the 3 velocities during concentric contraction, VMO:VL EMG ratios were greater than 1.0. This connotes that the VMO muscle was more active during the phase of contraction and contributes than the VL muscle. The ratio index was similar at 60°/s and 180°/s but lower at 120°/s.

4.8 ANALYSIS OF EFFECT OF MUSCLE (VMO and VL), ANGULAR VELOCITY (60°/s, 120°/s and 180°/s) AND TYPE OF CONTRACTION (ECCENTRIC and CONCENTRIC) ON MEAN NORMALIZED VMO AND VL EMG ACTIVITY.

A 3-factor analysis of variance (ANOVA) with repeated measures was used to test for statistical significance of the EMG activity/amplitude for eccentric and concentric contraction of the VMO and VL muscles at 60°/s, 120°/s and 180°/s on both VMO and VL muscles. The alpha (α) level was set at 0.05. The dependent variable was the normalized EMG amplitude for the VMO and VL muscles. The independent variables were muscle (VMO and VL), angular velocity (60°/s, 120°/s and 180°/s) and type of contraction (eccentric and concentric contraction). The results demonstrated that there were no significant differences between the normalized EMG amplitude and all the independent variables (muscle, velocity of contraction and type of contraction). Table 4 – 7 presents the F values and significance value for all variables.

TABLE 4 - 7: A Three - factor ANOVA with repeated measure of analysis of effect of muscle, type of contraction and angular velocity on EMG activity.

Source	Type III Sum of Square	Df	Mean Square	F value	Sig. value
MUSCLE	3.734	1	3.734	2.365	0.135
Error (Muscle)	45.776	29	1.578	-	-
VELOCITY	2.816	2	1.502	1.764	0.183
Error (velocity)	46.305	58	0.851	-	-
TYPE OF CONTRACTION	1.104	1	1.104	0.458	0.504
Error (Type of contraction)	69.909	29	2.411	-	-
MUSCLE X VELOCITY	1.345	2	0.773	1.031	0.363
Error (Muscle X velocity)	37.850	58	0.750	-	-
MUSCLE X TYPE OF CONTRACTION	3.517	1	3.517	1.669	0.203
Error (Muscle X Type of contraction)	60.042	29	2.070	-	-
VELOCITY X TYPE OF CONTRACTION	0.548	1	0.351	0.341	0.660
Error (Velocity X Type of contraction)	46.636	29	1.031	-	-
MUSCLE X VELOCITY X TYPE OF CONTRACTION	0.741	2	0.437	0.529	0.563
Error (Muscle X Velocity X Type of Contraction)	40.636	58	0.826	-	-

4.9 ANALYSIS OF EFFECT OF MUSCLE (VMO and VL), ANGULAR VELOCITY (60°/s, 120°/s and 180°/s) AND TYPE OF CONTRACTION (ECCENTRIC and CONCENTRIC) ON ONSET OF EMG ACTIVITY.

A 3-factor analysis of variance (ANOVA) with repeated measures was used to test for statistical significance of the onset of EMG activity (seconds) for eccentric and concentric contractions of the VMO and VL muscles at 60°/s, 120°/s and 180°/s on both the VMO and VL muscles. The dependent variable was the onset of EMG activity for the VMO and VL muscles. The independent variables were muscle (VMO and VL), angular velocity (60°/s, 120°/s and 180°/s) and type of contraction (eccentric and concentric contraction). The results demonstrated that there was significant difference (main effect) between the EMG activity onset and type of muscle (VMO and VL), (F=14.203, p=0.001). There was significant difference (interaction effect) between muscle (VMO and VL) and type of contraction (concentric or eccentric), (F= 7.973 p=0.008). No significant difference (F=0.448 p=0,614) was observed with angular velocity and onset of EMG activity. Table 4 – 8 presents the F values and significance value for all variables.

TABLE 4 – 8: A three – factor ANOVA with repeated measures of analysis of effect of muscle, type of contraction and angular velocity on onset of EMG activity.

Source	Type III Sum of Square	Df	Mean Square	F value	Sig. value
MUSCLE	0.001	1	0.001	14.203	0.001*
Error (Muscle)	0.002	29	7.92E-005		
VELOCITY	0.000	2	0.000	2.536	0.109
Error (velocity)	0.003	58	8.06E-005		
TYPE OF CONTRACTION	5.64E-005	1	5.64E-005	1.057	0.312
Error (Type of contraction)	0.002	29	5.34E-005	-	-
MUSCLE X VELOCITY	8.64E-005	2	5.56E-005	0.726	0.454
Error (Muscle X velocity)	0.003	58	7.66E-005	-	-
MUSCLE X TYPE OF CONTRACTION	0.000	1	0.000	7.973	0.008*
Error (Muscle X Type of contraction)	0.002	29	5.53E-005	-	-
VELOCITY X TYPE OF CONTRACTION	6.12E-005	2	4.81E-005	0.497	0.529
Error (Velocity X Type of contraction)	0.004	58	9.67E-005	-	-
MUSCLE X VELOCITY X TYPE OF CONTRACTION	5.31E-005	2	3.06E-005	0.448	0.614
Error (Muscle X Velocity X Type of Contraction)	0.003	58	6.84E-005	-	-

4.10 ANALYSIS FOR THE MAIN EFFECT OF TYPE OF MUSCLE ON ONSET OF EMG ACTIVITY

The onset of EMG activity had a significant main effect on the type of muscle. From tables 4 – 3 and 4 – 4, the mean values for the onset of EMG activity for the VMO muscle for both eccentric and concentric contraction is earlier than that of the VL muscle. The earlier onset of EMG activity for VMO muscle was 12ms while that for VL muscle was 15.1ms. The mean value for the slowest onset for VMO EMG activity was 15.4ms while that for VL muscle was 21.4ms.

4.11 ANALYSIS FOR THE MUSCLE - TYPE OF CONTRACTION INTERACTION EFFECT.

An analysis of the interaction effect of the type of muscle and type of contraction is shown in the figure below. Figure 4 – 11 shows the interaction between VMO and VL muscles at 60°/s.

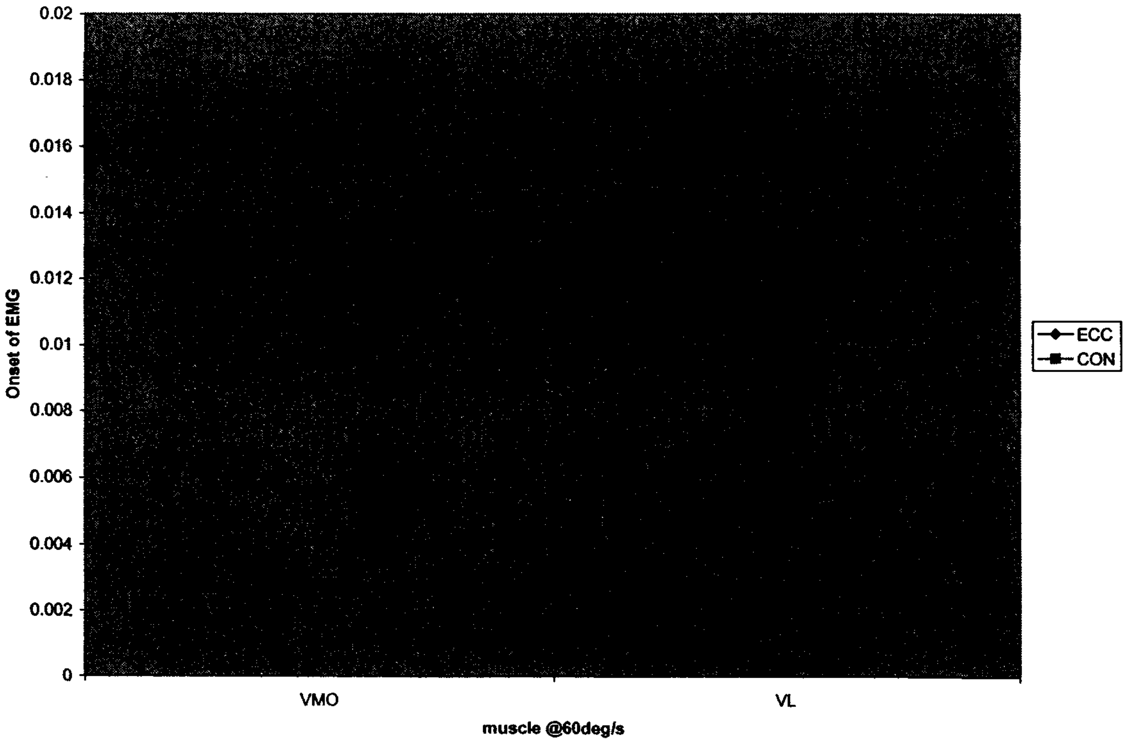

Figure 4 – 7: Interaction effect between VMO and VL muscle during eccentric and contraction at 60°/s.

At 60°/s, the onset of EMG activity shows a significant interaction for the VL muscle during eccentric and concentric contraction with the VMO muscle showing an earlier onset for EMG activity during concentric contraction. Although the onset of EMG activity for the VMO muscle is earlier than the VL, the onset of EMG activity does not appear to be different for VMO for either the concentric or the eccentric contraction.

Figure 4 – 8 shows the interaction between the VMO and VL muscle at 120°/s. At 120°/s, the interaction effect between the eccentric and concentric contraction demonstrates that the VMO muscle working concentrically had an earlier onset of EMG activity compared with the VL. The mean onset time for the VMO muscle was12ms for concentric contraction compared to 14ms during eccentric contraction.

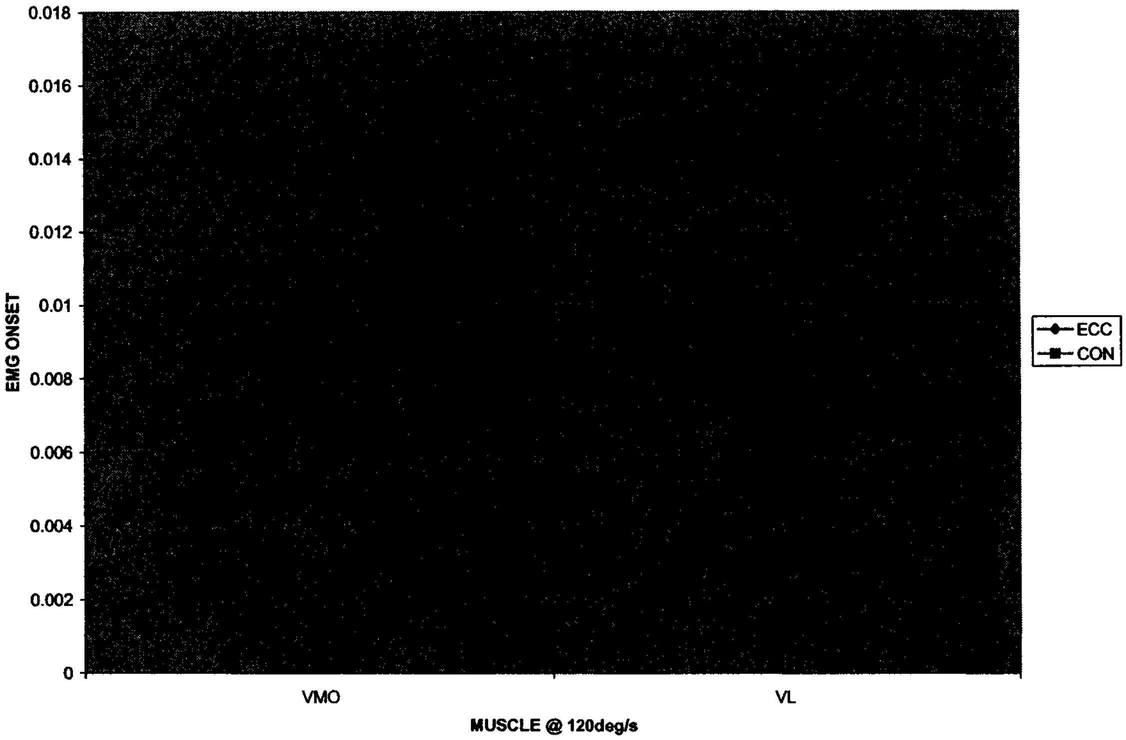

Figure 4 – 8: Interaction effect between VMO and VL muscle during eccentric and contraction at 120°/s.

Figure 4 – 9 shows the interaction effect between the VMO muscle and VL muscle at 180°/s. At this velocity, concentric contraction for the VMO muscle shows an earlier onset of activity when compared with eccentric contraction.

For both eccentric and concentric contractions, at the three different velocities, the EMG onset time was earlier for the VMO than the VL muscle.

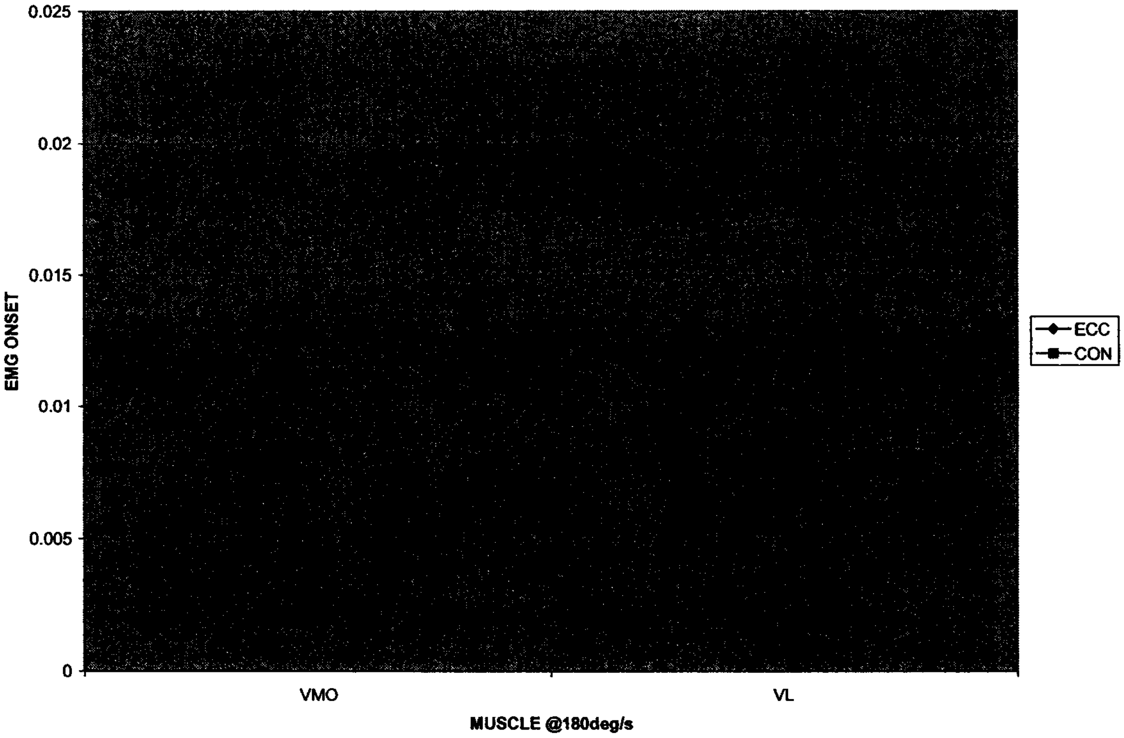

Figure 4 - 9: Interaction effect between VMO and VL muscle during eccentric and contraction at 180°/s.

4.12 ANALYSIS OF EFFECT OF ANGULAR VELOCITY AND TYPE OF CONTRACTION ON THE NORMALIZED VMO:VL EMG RATIO.

A 2 – factor ANOVA with repeated measures was used to determine whether there were any significant difference(s) of the velocity (60°/s, 120°/s and 180°/s) and type of contraction (eccentric and concentric) on the VMO:VL EMG ratio The results showed that there were no significant differences between type of contraction and velocity of contraction on the VMO:VL EMG ratio (F=0.683, p=0.485). there was no significant difference on velocity (F=1.32 p=0.268) and type of contraction (F=3.059 p=0.091) on the VMO:VL EMG ratio. Table 4 – 11 presents the F values and significant values.

TABLE 4 – 11: A Two factor ANOVA with repeated measures of analysis of effect of angular velocity and type of contraction on VMO:VL EMG ratio.

Source	Type III Sum of Square	Df	Mean Square	F value	Sig. value
VELOCITY	0.462	2	0.236	1.320	0.268
Error (velocity)	10.154	58	0.268	-	-
TYPE OF CONTRACTION	2.026	1	2.036	3.059	0.091
Error (Type of contraction)	19.207	29	0.662	-	-
VELOCITY X TYPE OF CONTRACTION	0.238	2	0.142	0.683	0.485
Error (Velocity X Type of contraction)	10.085	58	0.208	-	-

CHAPTER FIVE

DISCUSSION.

The study of the muscular control of the patellofemoral joint has been given enormous attention. In spite of the pool of investigations on the subject, findings remain conflicting.

Many exercise treatments emphasize the importance of the vastus medialis obliquus (VMO) muscle because of its unique function of providing medial stability to the patella (Bose et al., 1980, Hehne, 1990, Lieb and Perry, 1968). Some researchers (Doucette and Goble, 1992, Hanten and Schulties, 1990, McConnell, 1987) suggest that contraction of the hip adductor and quadriceps femoris muscles simultaneously would activate the VMO. Coqueiro et al., 2005 concluded that adding hip adduction to semi squat exercise does not preferentially activate the VMO muscle. Other studies report that the vastus medialis muscle is activated preferentially in response to valgus stress at the knee caused by hip lateral rotation during knee extension exercises and that hip medial rotation, therefore decreases the activity of the vastus medialis muscle (Doucette and Goble, 1992, Wheatley and Jahnke, 1951). Cerny (1995) concluded that neither medial nor lateral hip rotation significantly altered the VMO:VL EMG ratio. Knee extension exercise with tibial rotation has been proposed because the VMO is purported to prevent lateral rotation of the tibia and therefore decreases the quadriceps angle and lateral patellar tracking (Hanten and Schulties, 1990, Wheatley and Jahnke, 1951). Unfortunately, no consensus has been reached on what exercise will preferentially activate the VMO muscle. The present researcher decided to study the effect of eccentric and concentric knee extension exercise in the last 60° of knee extension at different angular velocities on the activation pattern of the VMO muscle.

The purposes of this study were

- To determine whether the EMG activity of the VMO and VL muscles would be different at isokinetic velocities of 60°/s, 120°/s and 180°/s during eccentric and concentric knee extension.
- To determine whether the onset of EMG activity of the VMO and VL muscles would be different at isokinetic velocities of 60°/s, 120°/s and 180°/s during eccentric and concentric knee extension.
- To determine whether the VMO:VL EMG activity ratio would be different at isokinetic velocities of 60°/s, 120°/s and 180°/s during eccentric and concentric knee extension.

In order to answer the questions posed by this study, the results of this study are discussed under the following headings: (1) Effect of type of contraction, angular velocity and muscle on the EMG activity. (2) Effect of type of contraction, angular velocity and muscle on the onset of EMG activity. (3) Effect of type of contraction and angular velocity on VMO:VL EMG ratio. (4) Strengths and weaknesses of this study.

5.1 EFFECT OF TYPE OF CONTRACTION, ANGULAR VELOCITY AND MUSCLE ON THE EMG ACTIVITY.

The first hypothesis of this study was: the EMG activity of either VMO or VL muscles at isokinetic velocities of 60°/s, 120°/s and 180°/s will not be different during eccentric and concentric knee extension exercise. This was based on evidence suggests that the neuromuscular activation of the quadriceps is reduced with high-tension muscle loading. The exact mechanisms responsible for this inhibition in neuromuscular activation are unknown. Also, that within a normal population, there will be no significant variations in muscle recruitment patterns.

The results of this study confirmed the hypothesis. The findings from this study are similar to that of Boucher et al., (1992) who found no difference in integrated EMG signals of the VMO and VL muscles. Results from previous research have been equivocal. Previous studies revealed that EMG activity is markedly lowered during voluntary slow eccentric and concentric quadriceps contractions (Seger and Thorstensson, 1994 and Westing, Cresswell and Thorstensson, 1991). Contrary to this result, Mirzabeigi et al., 1999 found a consistent trend for lower EMG activity in the VMO muscle than in the VL muscle. They suggested that the VMO muscle was at a disadvantage during isokinetic exercises. In Mirzabegi's study, quadriceps exercise was performed through a 90° range of motion. In the present study, the VMO and VL muscles were challenged in a 60° range of motion. Greater average EMG amplitudes suggest that the exercise is effective in activating the muscle throughout the range of motion tested. The present study found a consistently higher EMG activity of the VMO muscle compared with the VL muscle at all 3 velocities during both contraction. Alterations in the surface EMG signal are known to be a result of numerous factors related to position and orientation of the recording electrode to the activated muscle fibers and the position of the joint tested. As a result of a change in knee angle, the magnitude of the EMG signal, during maximal voluntary efforts, will change as the length of the activated muscle fibers increases.

At more flexed knee angles, prolonging of muscle activity occurs and this is known to lengthen the temporal aspect of the action potential and increase the area underneath the EMG tracing. This may account for higher EMG activity of the VL compared to the VMO at more flexed angles of the knee because the VL is larger than the VMO muscle. Suter and Herzog (1997) demonstrated that the VL muscle EMG activity was significantly greater at 90° flexion but was not different from that of the VMO muscle between 15 °, 30°, 45 °and 60° flexion. Although Zabik and Dawson 1996, observed no significant change in the in the VMO muscle EMG activity during maximal effort contraction at different knee angles, making a blanket comparison would be misleading because Zabik and Dawson only tested isometric exercises. Since the three portions of the superficial quadriceps femoris muscle exhibit unique anatomical features, a change in knee angle may result in relatively different muscle fiber length excursion, thereby affecting the recording of the EMG signal.

Although previous findings suggest that there are differences in motor control strategies for eccentric versus concentric muscle actions, in this study, the results showed that whether concentric or eccentric contractions, the EMG activity of the VMO and VL muscle is not different. This is in agreement with Perry-Rana et al's (2003) findings that the suggested differences in motor control patterns were not evident between eccentric and concentric contractions. The rationale for why concentric EMG is greater than eccentric EMG is explained by the superior metabolic efficiency of muscle lengthening (Basmaijan and De Luca, 1985). The above concept only holds true when the concentric and eccentric phases of the exercise involve the same force (Matheson et al., 2001). In this study, one cannot be sure that a consistent effort was applied through the range of motion in which the muscles were tested. It is presently unclear whether metabolic efficiency is correlated with EMG activity.

It is difficult to make precise comparison with the studies sited above because of different EMG processing procedures, methodological variances in performing quadriceps exercises and amount of load used for resistance.

With the EMG activity of the VMO muscle greater than that of the VL muscle alludes to the fact that the VMO muscle plays a crucial role in maintaining optimum patella tracking and stability in the last 60° of knee extension.

5.2 EFFECT OF TYPE OF CONTRACTION, ANGULAR VELOCITY AND MUSCLE ON THE ONSET OF EMG ACTIVITY.

The second hypothesis of this study was: the onset of EMG activity of either VMO or VL muscles at isokinetic velocities of 60°/s, 120°/s and 180°/s would not be different during eccentric and concentric knee extension exercise. This hypothesis was based on limited study that compared parameters of angular velocity, type of contraction and muscle on the onset of EMG activity. The results obtained from this present study refuted the second hypothesis. The onset of EMG activity was different between the VMO and VL muscle and the onset of EMG activity differed with type of contraction but was unaffected by changes in angular velocity.

When comparing across muscle, velocity and type of contraction, average onset for EMG activity occurred earlier during concentric VMO contraction at 120°/s (12.0 ± 4.8 ms) and was most delayed during concentric VL muscle contraction at 180°/s (21.4 ± 5.5 ms). At this level of significance (F=14.203, p=0.001), the observed power (calculated power) was 0.95 and the effect size was 0.323. The interaction effect for type of contraction and muscle involved showed that for concentric contractions, the VMO muscle had an earlier onset of

EMG activity than the VL muscle at all the velocities except at 60°/s. Statistical calculations for observed power and effect size for the interaction effect were 0.78 and 0.22 respectively.

With concentric contractions, the onset of EMG activity for the VMO muscle was faster than that of the VL muscle and with eccentric contractions; the onset of VMO muscle was faster than that of the VL muscle. Overall, the onset of EMG activity for concentric VMO muscle contraction was superior to those of eccentric contraction of both the VMO and VL muscles. The result found no significant effect of changing velocity that affected the onset of EMG activity.

Previous studies (Cowan et al., 2001, Karst and Willett, 1995, Witrouw et al., 1996, Voight and Wieder, 1991) that worked on the onset of EMG activity of the VMO and VL muscle have found that for normal subjects, there was no significant difference in the onset of muscle activity. These studies looked at muscle onset during functional activities, reflex tasks and isometric exercises not during isokinetic exercise.

Coincidental recruitment of the VMO and VL muscle in an asymptomatic population has been documented in previous studies (Karst and Willett, 1995, Powers et al., 1996, and Sheehy et al., 1998) that concurs with the opinion that the onset of activity of the vasti muscles is relatively balanced in people with no history of patellofemoral pathologies. The results of this study indicate that this opinion may only be applicable to functional and reflex tasks. Sheehy et al. (1998), documented that there was a trend in the onset of peak EMG activity. They commented that the onset of peak EMG activity of the VMO muscle was consistently earlier than the VL muscle during stair ascent and descent activity in individuals without patellofemoral symptoms. It is postulated, however, that the VMO muscle should be active before the VL muscle to maintain patellar position in the asymptomatic population (Ahmed, 1987). This relation was hypothesized because of the larger cross – sectional area and velocity – producing properties of the VL muscle, which are predicted to result in a dominance of laterally directed patellar motion. A possible explanation for the result obtained is that at reduced flexion angles at the knee, the VMO muscle is at a mechanical advantage and by virtue of the obliquity of its fiber orientation. The orientation of the VMO muscle fibers have been extensively reported to be 50° to 55° medial to the shaft of the femur in the frontal plane, whereas the VL muscle is aligned 12° to 15°. This also puts the VMO at a mechanical advantage to balance out the superior force and velocity generating capacity of the VL muscle.

The result showed that for concentric contractions, the onset of EMG activity occurred earlier than eccentric contraction. There is evidence that suggest that the central nervous system (CNS) uses different control strategies for eccentric and concentric contraction (Enoka, 1996). Westing et al., (1991) defined differences seen in motor control strategy as a general inability of the CNS to fully activate the motor neuron pool during maximal eccentric contraction. In addition, there is evidence derived from electroencephalography (EEG) studies that cortical activity during the planning of concentric and eccentric contraction differs (Fang et al., 2001). A second line of evidence that supports incomplete activation and delayed onset of muscle activity during eccentric contraction is the difference in time course of fatigue demonstrated by human subjects performing maximal eccentric or concentric contraction. Repeated isokinetic knee extension produces significant reduction in concentric contraction but much smaller reductions in eccentric contractions (Crenshaw et al., 1995, and Grabiner and Owings, 1999).

A reasoning that also supports the finding in this study is that the CNS could adjust for smaller contractile force and contraction velocity of the VMO muscle by activating the VMO earlier than the VL muscle. Such an activation strategy would also be evident to a greater extent when contractions are initiated with the knee joint extended, a position that increases the extent to which that patella can normally move superomedial within the intercondylar groove.

For onset of muscle activity, patellofemoral pain syndrome (PFPS) patients show a delayed onset of activity of the VMO muscle relative to the VL when ascending and descending stairs by 16 and 19 ms respectively. With this result, seemingly minor differences (5 – 10 ms) appear significant for the CNS to coordinate muscle activity for a certain task. For instance, biomechanical studies have indicated that a delay in VMO onset of 5 ms has significant consequences for patellofemoral joint mechanics in terms of increased peak and average lateral contact force (Neptune et al., 2000). The findings from the present study, particularly regarding the onset of VMO may have clinical implications for how to design training intervention programs for programs for patients suffering from PFPS. This finding suggests that at end phase of rehabilitation when patients are returning to work or sports, concentric knee extension exercise is necessary to improve the onset of activity of the VMO muscle, thus efficiency of the activity of this muscle.

5.3 EFFECT OF TYPE OF CONTRACTION AND ANGULAR VELOCITY ON VMO:VL EMG ACTIVITY.

The third hypothesis of this study was: the VMO:VL EMG at isokinetic velocities of 60°/s, 120°/s and 180°/s would not be different during eccentric and concentric knee extension exercise. This hypothesis was premised on the first hypothesis in this study.

The VMO:VL EMG ratio was used in this study because it reflected the relative contributions of the VMO and VL muscles. Increase in the VMO muscle activity with a specific exercise is meaningless if the relative activity of the VL is unknown as both muscles may be increasing their activity by the same amount. The results show that there were no significant differences in the VMO:VL EMG ratio during eccentric and concentric contractions at the tested angular velocities. Thus, the third hypothesis was accepted. VMO:VL EMG ratio for eccentric contraction ranged from 0.94 to 0.99 and 1.05 to 1.24 for concentric contraction. In both contraction types, VMO:VL EMG ratio was lowest at 120°/s and highest at 60°/s. The values obtained in this study are lower than those reported by Boucher et al., (1992), Laprade et al., (1998) and Sheehy et al., (1998), which ranged from 1.3 to 2.0 for control subjects. The differences reflect, in part, the very different contraction condition during which the EMG data were collected and the analysis used to quantify the signal. It is unknown what magnitude of change in the VMO:VL EMG activity ratio is clinically meaningful (Cerny, 1995), it is reasonable to believe that an increase in the EMG ratio increases the medial stabilizing force on the patella. This will reduce the loading on the lateral facet of the patella on which the pressure is commonly found to be excessive in people with patellofemoral pathology. The results from this study were also dissimilar with that of Tang et al., (2001), who found the VMO:VL EMG ratio was less than 1.0 during concentric contraction and greater than 1 for eccentric contraction. In Tang's et al., study subjects were only tested at an angular velocity of 120°/s and a small sample size was used.

In summary, concentric contractions at knee joint angle of 60° resulted in higher VMO:VL EMG ratio. However, this ratio was not significantly different from that of eccentric contraction and was not altered with changes in angular velocity.

5.4 STRENGTHS AND WEAKNESSES OF THIS STUDY.

5.4.1 STRENGTHS.

This study was the first to investigate the effect of different angular velocity on the EMG activity and onset of EMG activity of the VMO and VL muscles. The results showed that the onset of EMG activity for the VMO muscle was significantly earlier than the VL muscle.

In this study, equal numbers of both sexes were used; strict exclusion and inclusion criteria were met, thus making the sample homogenous for ease of comparison. The effect of gender differences was not expected in this study because there is no direct correlation between EMG activity and amount of torque or force produced and also the sample size consisted of an equal number of males and females. Procedures with which eccentric and concentric contractions were performed were randomized, making the results acceptable. All EMG data were normalized with maximum referential contraction at 30°/s for each muscle, making EMG comparable.

The sample size used was large enough to obtain a power of 0.80 and effect size of 0.30. A good number of studies used sample sizes of less than 15 and did not report the power used. The calculated effect size and observed power were within acceptable limits to improve the validity of the results obtained in this study.

5.4.2 WEAKNESSES.

The results obtained in this research are only a preliminary one that may only be applicable to normal subjects. Direct comparison with a population with patellofemoral pain may be not the same because the muscles may behave differently under pathologic conditions. However, this may be a template for further investigation into future research for a population of patients with PFPS and other patellofemoral pathologies.

Although adequate and proper technical procedures were taken to reduce cross – talking, skin impedance, noise signals and ensure exact electrode placement, measurement of EMG activity using surface electrodes may not give the exact muscle activity of the muscle intended.

The study could not control for fatigue of the quadriceps after repetitive contractions on the isokinetic dynamometer. In addition, in spite of instructing subjects to apply a maximum effort for each contraction, the researcher cannot guarantee for certainty that the subjects actually applied maximal effort throughout the entire experimental procedure.

CHAPTER SIX

SUMMARY AND CONCLUSIONS.

6.1 SUMMARY AND CONCLUSIONS.

The purposes of this study were

- To determine whether the EMG activity of the VMO and VL muscles would be different at isokinetic velocities of 60°/s, 120°/s and 180°/s during eccentric and concentric knee extension.
- To determine whether the onset of EMG activity of the VMO and VL muscles would be different at isokinetic velocities of 60°/s, 120°/s and 180°/s during eccentric and concentric knee extension.
- To determine whether the VMO:VL EMG activity ratio would be different at isokinetic velocities of 60°/s, 120°/s and 180°/s during eccentric and concentric knee extension.

Based on the results of this study, the following conclusions can be made:

1. The EMG activity of the VMO and VL muscles are not different during eccentric and concentric knee extension exercise using the isokinetic dynamometer at angular velocities of 60°/s, 120°/s and 180°/s. Similarly, neither eccentric nor concentric contractions are superior in activating the VMO muscle when performing isokinetic exercise at a knee joint angle of 60°.

2. Irrespective of the velocity of knee extension, the onset of EMG activity was earlier during concentric contraction for the VMO muscle than for the VL muscle. However, changes in angular velocities did not affect the onset of EMG activity.

3. The relative contributions of both the VMO and VL muscles as measured by the VMO:VL EMG ratio was not different during eccentric and concentric contractions. However, a ratio greater than 1.0 was obtained for concentric contractions while a ratio less than 1.0 was eccentric contractions.

4. This study has shown that slow, medium or fast velocities does not have any significant superior effect on EMG activation and onset of EMG activity of the VMO muscle over the VL muscle.

6.2 CLINICAL IMPLICATIONS.

Morphologically, the VMO muscle is the last part of the quadriceps to form and it is the first to undergo atrophy of disuse and last to be rehabilitated following knee injuries (Fox, 1975). It is known for its crucial role as the only medial stabilizer of the patella. Rehabilitation following knee injuries has focused on the VMO muscle with no precise and exact method of strengthening this muscle.

This study did not provide a means of selective strengthening of the VMO muscle. However, it showed that at a knee joint angle of 60° and performing maximal concentric knee extension exercise, the VMO muscle was activated slightly earlier in time but not in magnitude than the VL muscle.

With the findings of this study, one might be tempted to say that at the end stage of rehabilitation when near normal function has been obtained, maximal concentric knee extension exercise through the last 60° of knee ROM might improve the onset of activity of the VMO muscle. However, this study focused only on normal subjects under standardized conditions. Further research is necessary to determine if the small difference in time observed in this study is clinically significant enough to prevent or reduce lateralization of the patella that predisposes patients to pain with patellofemoral pathologies.

6.3 FUTURE RESEARCH.

Some suggestions for future research would be:

1. Investigate the effect of changes in angular velocity during eccentric and concentric knee extension exercise on the VMO muscle activation pattern in symptomatic and non – symptomatic groups.

2. Investigate the effect of different knee angle positions on the EMG activation of the VMO and VL muscles during isokinetic knee extension exercise.

3. Study the effect of limb dominance, age and sex on EMG activation of the VMO and VL muscles during isokinetic knee extension exercise.

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APPENDIX A: INFORMATION LETTER.

DO DIFFERENT ISOKINETIC TESTING VELOCITIES ALTER THE VASTUS MEDIALIS OBLIQUUS MUSCLE ACTIVATION DURING KNEE EXTENSION EXERCISE?

PRINCIPAL INVESTIGATOR: Dr. David Magee, Department of Physical Therapy, Faculty of Rehabilitation Medicine, University of Alberta.

CO-INVESTIGATOR: Onibonoje Olusegun, PT, MSc (student) Department of Physical Therapy, Faculty of Rehabilitation Medicine, University of Alberta.

BACKGROUND: Therapeutic exercise has been the used as a primary treatment of patients with patellofemoral pain syndrome. A stronger and earlier activation of the vastus medialis obliquus (VMO) muscle on or before the vastus lateralis (VL) muscles during exercises are keys to good recovery and better tracking of the patella. It unknown whether different speeds of an isokinetic dynamometer during leg extension will alter the activation of the VMO muscle. This study will attempt to clarify this issue.

PURPOSE: The purpose of this study is to investigate the muscle activity of the VMO and VL muscles at different isokinetic testing speeds using the electromyography (EMG) machine. The outcome of this study may help clinicians and other sports medicine practitioners learn whether exercising maximally at high or low speeds, eccentrically or concentrically recruits the VMO muscle before the VL muscle during leg straightening. It will add to the pool of knowledge in this field.

PROCEDURE: The study involves using three different speeds on the isokinetic dynamometer during eccentric and concentric leg extension. The EMG activity of the VMO and VL muscles shall be recorded during each contraction.

Before actual testing, you will be required to perform a warm up and stretching session that will include stretching your hamstrings, quadriceps, hip and leg muscles. You will be trained in a familiarization session on how the isokinetic dynamometer operates. This will involve performing three submaximal and three maximal leg movements on the dynamometer. You will be asked your age, and your weight and height will be measured.

During the testing and familiarization session, you will be positioned on the dynamometer with your back supported and your hip bent to 80° and your knee will be bent to 60°. Your trunk and thigh will be fastened with straps for stabilization. Only your dominant leg will be tested.

The skin over the VMO and the VL muscles will be cleaned with alcohol and any hair over the VMO and VL muscles will be shaved appropriately, if needed. This is to reduce the impedance between the skin-electrode. Two pairs of electrodes will be placed on the VMO and the VL muscles and a fifth electrode (reference/ground) will be placed on your kneecap. To ensure proper placement of the electrodes, you will perform a maximal quadriceps muscle contraction that will show the bulk of the VMO and VL muscles. You will be asked to perform quadriceps muscle contraction by pressing the back of your knee on a rolled-up towel.

The actual testing will involve you straightening and bending your knee against the resistance offered by the dynamometer at three different speeds of contraction. The leg straightening exercise shall be performed between 60 degrees of knee flexion to 0 degrees extension for each of the three testing speeds. This is done twice for each of the testing speeds. After each session, you will have a 2-minute rest interval. The entire test session will last 45 minutes.

BENEFITS/RISK: The result of this study will increase the pool of knowledge regarding exercising the VMO muscle. It may also provide clinicians with a new means of activation of the VMO muscle. The primary risk associated with isokinetic muscle assessment is muscle soreness following the contraction efforts. This discomfort should be minor and similar to that usually experienced after exercise you are not accustomed to doing. If you develop knee joint pain at any time during the study, your participation in the study will be stopped. If there is muscle soreness after the testing process, ice treatment using the ice-pack method will be applied to the sore muscles for 10 – 15 minutes, to reduce the effects. If there is muscle soreness later, you should apply ice (using the ice-pack method) three to four times a day for 10-15 minutes each session. Subjects may have an allergic reaction to either the adhesive or the electrolytic paste and develop a rash. Previous experience and studies have shown this reaction to occur in 1 – 2% of participants. The resulting rash typically fades within 24 – 48 hours.

If the problem persist, call Olusegun Onibonoje at 780 – 492 – 4824.

CONFIDENTIALITY/PRIVACY: All information and data collected during this study will be kept private, except when the code of ethics or law requires. The data you give will be kept for at least 5 years after the study is completed. The data will be kept in a safe area (i.e. in a locked filing cabinet). Your name or any other identity will not be attached to the data you produce by your test. Your name will not be used in any presentations or publications related to the study results. The data gathered for this study may be looked at again in the future to help us answer any other study questions. If so, an ethics board will first review the study to ensure that the data is ethically used.

FREEDOM TO WITHDRAW: Your participation is voluntary. You can choose to withdraw from the study at any time. You can also choose to withdraw your information from the database of the study at any time.

If you have further questions please ask. We will address them before testing.

If you have any questions, concerns, or complaints regarding the study and procedure, please feel free to contact Dr. Paul Hagler (780-492-9674), Associate Dean – Research in the Faculty of Rehabilitation Medicine.

APPENDIX B: CONSENT FORM.

Title of Project: DO DIFFERENT ISOKINETIC TESTING VELOCITIES ALTER THE VASTUS MEDIALIS OBLIQUUS MUSCLE ACTIVATION DURING KNEE EXTENSION EXERCISE?

Part 1: Researcher Information

Name of Principal Investigator/Supervisor: Dr. David Magee (Supervisor).
Affiliation: Professor, Dept. of Physical Therapy, University of Alberta, Edmonton
Contact Information: 3-50 Corbett Hall, Dept. of Physical Therapy, Faculty of Rehab. Medicine

Name of Co-Investigator: Mr. Onibonoje Olusegun, PT.
Affiliation: M.Sc Student, Physical Therapy, University of Alberta, Edmonton.
Contact Information: 2-50 Corbett Hall, Dept. of Physical Therapy, Faculty of Rehab. Medicine

Part 2: Consent of Subject

	Yes	**No**
Do you understand that you have been asked to be in a research study?		
Have you read and received a copy of the attached information sheet?		
Do you understand the benefits and risks involved in taking part in this research study?		
Have you had an opportunity to ask questions and discuss the study?		
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason and it will not affect your care.		
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records.		
Do you want the investigator(s) to inform your family doctor that you are participating in this research study? If so, please provide your doctor's name: ____ **(This question is optional).**		

Part 3: Signatures

This study was explained to me by: ________________________ **Date:** ____________

I agree to take part in this study.

Signature of Research Participant: ______________________

Printed Name: _____________________________

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

Researcher: __________________________________
Printed Name: __________________________________

*** A copy of this consent form must be given to the subject.**

APPENDIX C: SAMPLE SIZE CALCULATION and RANDOMIZATION TECHNIQUE

The sample size for this repeated measure analysis was derived from the data that will yield the least standard deviation (VMO:VL EMG ratio). The following equation is used to calculate the sample size.

Sample size = (N' - 1) (γ + 1)/N" + 1

VMO:VL EMG ratio

	60°/sec	120°/sec	180°/sec
Eccentric contraction			
Concentric contraction			

Where N' is the value equivalent to the desired power and effect size,

γ = (Number of rows - 1) X (Number of columns - 1)

N" is the number of cells

The VMO:VL EMG ratio statistical analysis table will be used calculate the sample size.

In this study, I desire a power of 0.80 and an effect size of 0.30

Table used in deriving variables used to calculated sample size (Warren, 2004).

From the above table, number of rows = 2 and number of columns = 3

Then, γ = (2-1) (3-1) = 2, N" = 6

From the F tests tables, N' = 52 then

Sample size = (52-1) (2+1)/6 + 1 =26.5 approx. 27

I will allow 10% subject attrition such that the sample size will now be 30. This will include an equal number of males and females.

Randomization technique.

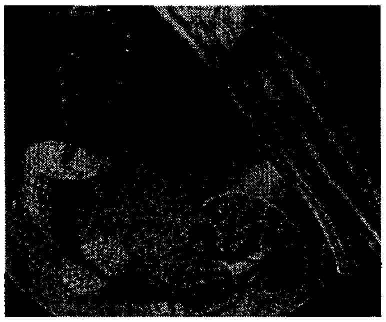
There will be six cards in a box from which the subject will be asked to pick one. Each of the six cards will contain one of the following:

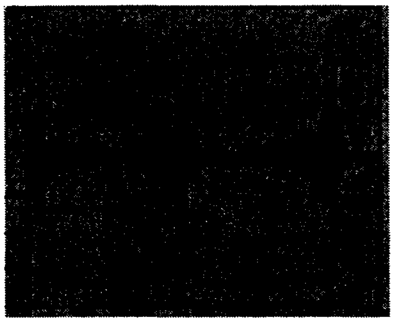
- 30°/second (E/C) followed by 60°/second (C/E) then 180°/second (E/C)
- 30°/second (C/E) followed by 180°/second (E/C) then 60°/second(C/E)
- 60°/second(E/C) followed by 30°/second (C/E) then 180°/second(E/C)
- 60°/second (C/E) followed by 180°/second(E/C) then 30°/second (C/E)
- 180°/second(E/C) followed by 60°/second(C/E) then 30°/second(E/C)
- 180°/second(C/E) followed by 30°/second(E/C) then 60°/second(C/E)

The type of contraction will be randomized. This will involve the first velocity being eccentric followed by concentric contraction i.e. (E/C) the second being concentric followed by eccentric contraction (C/E) in that order.

APPENDIX D: POSTER FOR VOLUNTEERS.

VOLUNTEERS NEEDED.





WHO:

Physically healthy and active males and females between the ages of 19 and 39 years

WHY:

To help us determine how muscles behave when subjected to different speeds of contraction.

WHAT:

Subjects will perform leg extension exercise and the muscle activity will be recorded during this exercise.

Time Commitment: 45 minutes in one session.

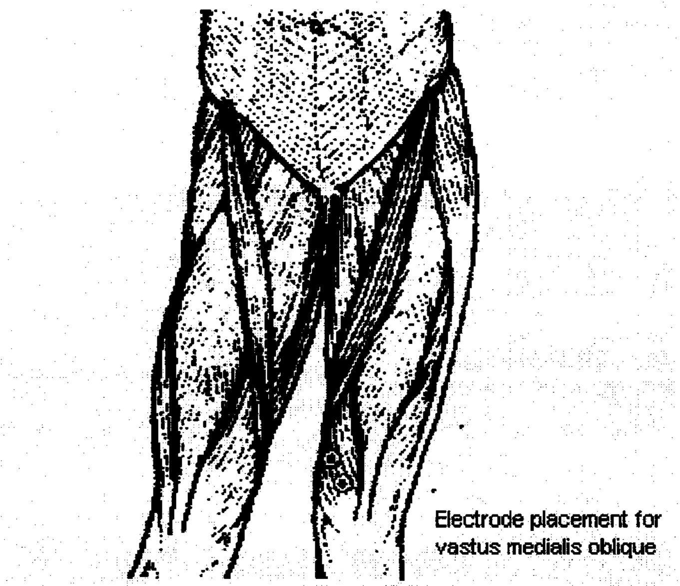
Location: 1 - 26 Corbett Hall, Dept of Physical Therapy University of Alberta.

Interested? Call or e-mail Segun @ 492 - 4824 or olusegun@ualberta.ca

APPENDIX E: MP150 BIOPAC ELECTROMYOGRAPHY DEVICE SPECIFICATIONS.

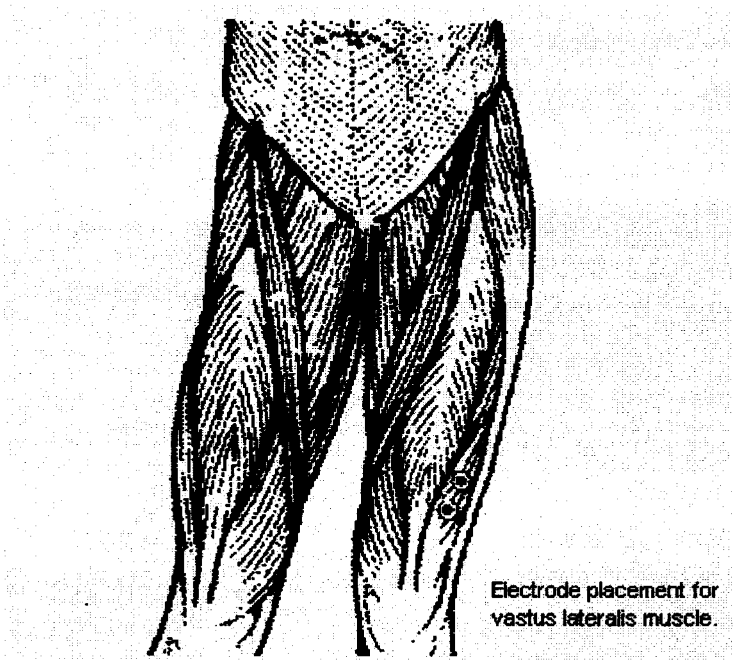
Concept	Desirable range.
Input Impedance	20,000 Kilo ohm
Common Mode rejection CMR	130 decibels
Instrument noise level	0.1-1.0microvolt
Band pass filter width	15-500 Hz sampled at1000Hertz
Range/gain	0-100RMS microvolt
Smoothing options	0.1-10 second time constant
Visual Display	Raw and processed.

APPENDIX FI and FII: ELECTRODE PLACEMENT ON THE VMO and VL MUSCLES.



Electrode placement for vastus medialis oblique

From Cram et al, Introduction to surface electromyography pp 366



Electrode placement for vastus lateralis muscle.

From Cram et al, Introduction to surface electromyography pp 364.

APPENDIX G.
DATA COLLECTION SHEET.

3- FACTOR ANOVA: to determine the effect of muscle, velocity and type of contraction on the EMG activity of the VMO and VL muscle. The EMG activity of the VMO and VL muscles will be the dependent variable.

	VMO			VL		
	60°/s	120°/s	180°/s	60°/s	120°/s	180°/s
ECCENTRIC						
CONCENTRIC						

3-FACTOR ANOVA: to determine the effect of muscle, velocity and type of contraction on the onset of EMG activity. The onset of EMG activity will be the dependent variable.

	VMO			VL		
	60°/s	120°/s	180°/s	60°/s	120°/s	180°/s
ECCENTRIC						
CONCENTRIC						

2-FACTOR ANOVA: to determine the effect of Velocity and type of contraction on the VMO:VL EMG activity ratio. The VMO:VL amplitude ratio will be the dependent variable.

Velocity/ type of Contraction	ECCENTRIC	CONCENTRIC
60°/s		
120°/s		
180°/s		