

**ELECTROMYOGRAPHIC ACTIVITY OF QUADRICEPS MUSCLE DURING
FUNCTIONAL ACTIVITIES IN PARTICIPANTS WITH AND WITHOUT
PATELLOFEMORAL PAIN.**

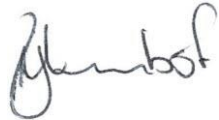
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A research report submitted to the Faculty of Health Sciences, University of the
Witwatersrand, in partial fulfilment of the requirements for the degree of Master of
Science in Medicine in the field of Biokinetics

Johannesburg, 2017

DECLARATION

I, Bertie Herbst declare that this Research Report is my own work. It is being submitted for the degree of Master of Science in Medicine in the field of Biokinetics, at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

A handwritten signature in cursive script, appearing to read 'Herbst', written in dark ink.

8th day of March 2017 in Johannesburg.

To **God**,
For His *Grace* and *Faithfulness*;
To **Manuela** and **Gabriella**,
For all their *Love* and *Support*;
To **Johann**,
For his *Wisdom* and *Inspiration*.

ABSTRACT

Background: Patellofemoral pain (PFP) is a common knee complaint associated with pain around the patella. Research has identified altered electromyographic (EMG) activity of the knee muscles in individuals with PFP compared to a healthy population (Briani *et al.*, 2016).

Purpose: The purpose of this observational study was to identify the EMG activity of the quadriceps muscle during functional activities in participants experiencing PFP and participants with no PFP.

Methods: The onset and sequence timing including the ranking and Q-angle in relation to the rectus femoris (RF), vastus medialis obliquus (VMO) and vastus lateralis (VL) activity was measured with surface EMG in 17 PFP participants and 17 controls during a sit to stand, squat, and step up and step down.

Results: The RM-ANOVA discovered a significant difference in the onset of VMO compared to RF muscle between the activities in the PFP group (-0.11 to 0.07 sec; $p = 0.03$) and the healthy group (-0.18 to -0.03; $p = <0.01$), as well as the VL compared to the RF muscle in the PFP group (-0.07 to 0.13 sec; $p = <0.01$). Significant differences were shown comparing the ranking of EMG onset for the quadriceps muscle to each activity in the healthy group ($p = <0.01$ to 0.04), and in the PFP group for the sit to stand ($p = 0.01$). Onset of VMO activity was predominantly ranked first in the healthy group (56%) and the VL in the PFP group (44%). A Mann-Whitney U-test shown a significant relationship in the healthy group between the Q-angle and the VMO, VL and RF muscles during the step down activity ($r = -0.53$ to -0.55 ; $p = 0.02$ to 0.03).

Conclusion: This study confirms that the quadriceps muscle responds differently to different functional activities in the PFP and healthy population respectively. The healthy group tend to utilize the VMO first, compared to the PFP group with altered onset of quadriceps activation. Furthermore, the greater the Q-angle is, the earlier the onset of quadriceps muscle will be in the healthy group. This relationship was not found in the PFP group.

ACKNOWLEDGEMENTS

Dr Estelle Watson	Supervisor and Lecturer
Dr Johann Lamprecht	Friend, Mentor and Tjopper
Dr Alison Bentley	Biostatistician
Miss Julia Bullock	Assistant
LifeMax	Sponsor
Management and staff at Alice Lane Health Club	
Partner and staff of Donnelly and Herbst Biokineticists	
Staff and lecturers at Centre for Exercise Science and Sports Medicine	

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ABBREVIATIONS AND NOMENCLATURE

ADL:	Activity of Daily Living
ASIS:	Anterior Superior Iliac Spine
Ctrls:	Controls
EMG:	Electromyography
IP:	Incidence Proportion
ISAK:	International Society for the Advancement of Kinanthropometry
PFJ:	Patellofemoral Joint
PFP:	Patellofemoral Pain
PFPS:	Patellofemoral Pain Syndrome
ROM:	Range of Motion
RF:	Rectus Femoris
SD:	Standard Deviation
VAS:	Visual Analog Scale
VI:	Vastus Intermedius
VL:	Vastus Lateralis
VMO:	Vastus Medialis Obliquus
Q-angle:	Quadriceps angle

Closed Kinetic Chain: “A movement sequence starting with a free body segment such as an arm or leg, and finishing at a fixed segment” (Kent, 2005).

Concentric Action: “A form of muscle action which occurs when a muscle develops sufficient tension to overcome a resistance, so that the muscle shortens and moves a body part” (Kent, 2005).

Eccentric Action: “A muscle action in which a muscle exerts a force while lengthening. Such actions are used to resist external forces such as gravity” (Kent, 2005).

Kinematics:	“A branch of mechanics concerned with the descriptive study of motion, including the pattern and speed of movement of different body segments” (Kent, 2005).
Onset Latency	The duration of time it takes for a muscle to activate once stimulated by the neuromuscular system.
Open Kinetic Chain:	“A movement sequence starting with a fixed body movement such as an arm or leg, and finishing in a free sphere” (Kent, 2005).
Ranking	A position in a measure of achievement or classification.
Sequence Timing	A particular order in which related muscles activity or contraction follow each other.

CHAPTER ONE

1. INTRODUCTION

1.1 General Introduction

Electromyography (EMG) is the study of muscle activity through the analysis of the electrical signal that the muscles generate (Basmajian *et al.*, 1985). The study of muscle activity provides an understanding of the movement of the human body (kinesiology). A better understanding of the movement of the human body allows us to discern between normality and ailments identified in injury or illness.

Patellofemoral pain (PFP) is a common knee complaint associated with pain around the patella, or anterior knee pain, during dynamic as well as static activities. It is common among young active individuals, and in particular females. Research has shown that there is altered EMG activity of the knee muscles in individuals with PFP compared to a healthy population (Briani *et al.*, 2016).

The origin and development of PFP is multifactorial and remains largely unknown (Crossley *et al.*, 2001). Factors such as prolonged physical activity, altered kinematics, weakness and tightness of the musculoskeletal system, and skewed force distribution through the body could all lead to the development of knee pain. A noticeable factor commonly seen is excessive lateral patellar tracking caused by an imbalance between the vastus medialis obliquus (VMO) and the vastus lateralis (VL) muscles (Cavazzuti *et al.*, 2010). Excessive lateral or medial patellar tracking leads to increased compressive forces on the retro-patellar subchondral bone, and therefore result in anterior knee pain during functional and sedentary activities (Witvrouw *et al.*, 2014, Cavazzuti *et al.*, 2010).

A number of studies have investigated the recruitment patterns of the vastus muscles in individuals experiencing PFP but are inconclusive (Briani *et al.*, 2016, Cavazzuti *et al.*, 2010, Van Tiggelen *et al.*, 2009, Powers *et al.*, 1996). These studies predominantly examined the VMO and VL muscles only, and did not include the rectus femoris and vastus intermedius. Majority of the studies examined mainly females due to their high prevalence rate for developing PFP, but few have assessed

these issues in the male population (Briani *et al.*, 2016, Cavazzuti *et.*, 2010, Cowan *et al.*, 2001, Powers *et al.*, 1996).

This research report investigates the activity of the quadriceps muscle during various day to day activities in individuals experiencing patellofemoral pain compared to individuals with no patellofemoral pain. Analysed EMG results were used to fulfil the research aims and objectives stated in the section that follows. This research report has also emerged as a result of the author's work in the field as a biokineticist and practitioner, and practical work experiences have shaped the critical questions posed.

The purpose of this study was to assess the behaviour of the quadriceps muscle during daily functional activities in male participants experiencing PFP and participants with no PFP. Essentially, the desired outcome is to understand the behaviour of the individual quadricep muscles within the PFP syndrome, which would facilitate and advise appropriate intervention strategies for the prevention and treatment of PFP.

1.2 Structure of Research Report

This research report is presented in five chapters, with Chapter One as the above introduction. Chapter Two is a literature review that conceptualizes the development and onset of EMG and includes an overview of patellofemoral pain. Chapter Three presents the methodological framework implemented to meet the research aim and objectives. Chapter Four contains the results of the study analysis and focusses on the outcome of the quadriceps muscle behaviour in relation to the functional activities included in this research. Chapter Five discusses these findings in relation to previous work in the field outlined in Chapter Two and leads to a series of recommendations and conclusions. Suggestions for future research in the field are also highlighted, as well as how such studies could add to the existing body of international literature.

CHAPTER TWO

2 REVIEW OF THE LITERATURE

This review explores an overview of PFP including the development and use of EMG, and abnormalities occurring in onset activity of the quadriceps muscle. The review is confined to a discussion of the literature from 1986 to the present.

2.1 Overview of Patellofemoral Pain

2.1.1 Onset of patellofemoral pain

Patellofemoral pain is a common musculoskeletal condition that is clinically described by diffuse pain surrounding the anterior and retropatellar aspect of the knee (Briani *et al.*, 2016; Cavazzuti *et al.*, 2010). Patellofemoral pain is also known by athletes and laymen as ‘runner’s knee’ or clinically as anterior knee pain. The clinical onset of PFP is often deceptive and is exacerbated by physical activities such as ascending and descending of stairs, squatting and hopping, running and hill walking, kneeling and prolonged sitting (Cowan *et al.*, 2001; Witvrouw *et al.*, 2014). These activities all have a common feature in that they cause an increase in patellofemoral joint (PFJ) compression forces (Cowan *et al.*, 2001). Patellofemoral pain is considered to be a debilitating condition, affecting those daily activities such as sports and work-related activities (Witvrouw *et al.*, 2014).

2.1.2 Prevalence and incidence of patellofemoral pain

Patellofemoral pain is common among young active populations and in particular, individuals participating in high intensity activity (Briani *et al.*, 2016). Although PFP is a common knee condition, there is a deficiency of current epidemiological information regarding the prevalence and incidence of PFP. Prevalence is defined as the number of persons within a population that have a particular condition at a set point of time. Incidence is defined as the number of new onsets of a particular condition within a population over a period of time. Prevalence includes both new and old occurrences of a condition at a point in time. Since incidence only includes new onsets of a condition, prevalence could possibly be an overemphasis of the incidence of PFPS.

Epidemiological incidence proportion (IP) has been reported by researchers to be the most common measure of incidence investigating PFPS. The epidemiological IP is defined as the amount of individuals with an injury divided by the number of individuals at risk (Boling *et al.*, 2010).

There are a few studies according to Crossley *et al.* (2016) regarding the prevalence and incidence of patellofemoral pain in the sporting and general populations. Myer *et al.*, (2010) studied 240 middle and high school female athletes. The authors found that the prevalence of PFP was 16.3 per 100 athletes. The incidence risk and development of PFP was 9.66 per 100 athletes and 1.09 per 1000 athletic experiences (Myer *et al.*, 2010). As a result, an estimated 11 to 40% of individuals present with knee pain or injuries to the general practice and sports injury clinics (Crossley *et al.*, 2016, Boling *et al.*, 2010, Bizzini *et al.*, 2010).

Young adolescents appear to have a prevalence of 7 to 28% and an incidence of 9.2% (Crossley *et al.*, 2016, Barber Foss *et al.*, 2012, Callaghan *et al.*, 2007). Barber Foss *et al.* (2012), found a prevalence rate for PFP of 34.4% in high school athletes compared to 23.5% in middle school athletes. Furthermore, Boling *et al.* (2010) reported that the incidence rate for PFPS in a military group was 22/1000 person-years (95% CI: 15/1000, 29/1000 person-years). The incidence rate in males was 15/1000 person-years (95% CI: 7/1000, 22/1000 person-years) and the incidence rate in females was 33/1000 person-years (95% CI: 20/1000, 45/1000 person-years) and (Witvrouw *et al.*, 2014, Boling *et al.*, 2010).

Patellofemoral related problems appear to occur more frequently in woman than in men. Based on the Poisson regression analysis, Boling *et al.* (2010) found that gender was a significant predictor for the incidence of PFPS, with females being 2.23 times (95% CI: 1.16, 4.10) more likely to develop PFPS compared with males (Boling *et al.*, 2010). Boling *et al.* (2010) concluded the prevalence for PFPS in females are 15% and 12% in males. This finding support the literature that there are gender differences in the prevalence and incidence of PFJ related problems between men and woman (Taunton *et al.*, 2002). However, despite the assumption that PFP is more common in woman, there are only a few studies comparing incidence and prevalence between men and woman (Witvrouw *et al.*, 2014).

2.1.3 Contributing factors of patellofemoral pain

The cause and development of PFP has been reported to be multifactorial and remains largely unknown (Crossley *et al.*, 2001). A combination of extrinsic and intrinsic risk factors can possibly contribute to the onset of PFP (Cavazzuti *et al.*, 2010). Various risk factors including altered onset timing of vastus muscles, malalignment of the PFJ, a deficit in quadriceps strength, and abnormal kinematic variables such as gait have been suggested for PFP (Briani *et al.*, 2016, Witvrouw *et al.*, 2014).

Intrinsic risk factors may include abnormal lower-extremity kinematics coupled with increased frequency and prolonged physical activity. A common intrinsic risk factor is malalignment of the PFJ (Caylor *et al.*, 1993). The quadriceps angle (Q-angle) is a common test performed in combination with several other clinical measures to identify contributing factors to PFP, guide rehabilitation and plan surgical interventions (Almeida *et al.*, 2016). “The Q-angle is the angle formed between the longitudinal axis of the femur, demonstrating the pull of the quadriceps muscle, and a line that represents the pull of the patellar tendon” (Figure 2.1) (Freedman *et al.*, 2014). The Q-angle is normally less than 15° and 20° for men and woman, respectively. The Q-angle decreases when the quadriceps muscles are contracted. A Q-angle larger than 20° increases the possibility of the quadriceps drawing the patella laterally, increasing the risk of PFJ disorders such as PFP (Kent *et al.*, 2005

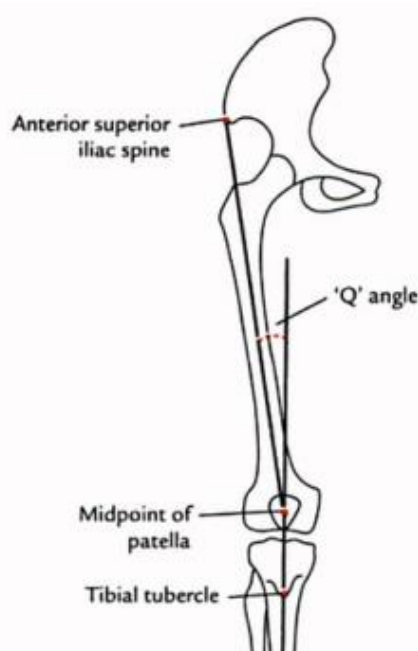


Figure 2.1: Quadriceps angle (Q-angle) (Moss *et al.*, 1992)

A number of intrinsic risk factors are related to patellar tracking. Patellar tracking is a result of the interaction between the surrounding muscles of the patella, passive structures and the neuromuscular system (Cowan *et al.*, 2009). Excessive lateral patellar tracking is due to the increased compressive forces on the retro-patellar subchondral bone between the lateral facet of the patella and the lateral femoral condyle (Figure 2.2) (Almeida *et al.*, 2016, Witvrouw *et al.*, 2014, Cavazzuti *et al.*, 2010). Although a high emphasis has been placed on lateral patellar facet compression, Gross *et al.* (2012) discovered that medial patellofemoral cartilage damage is extremely prevalent. The authors believe that it is possibly more prevalent than lateral patellar facet damage.

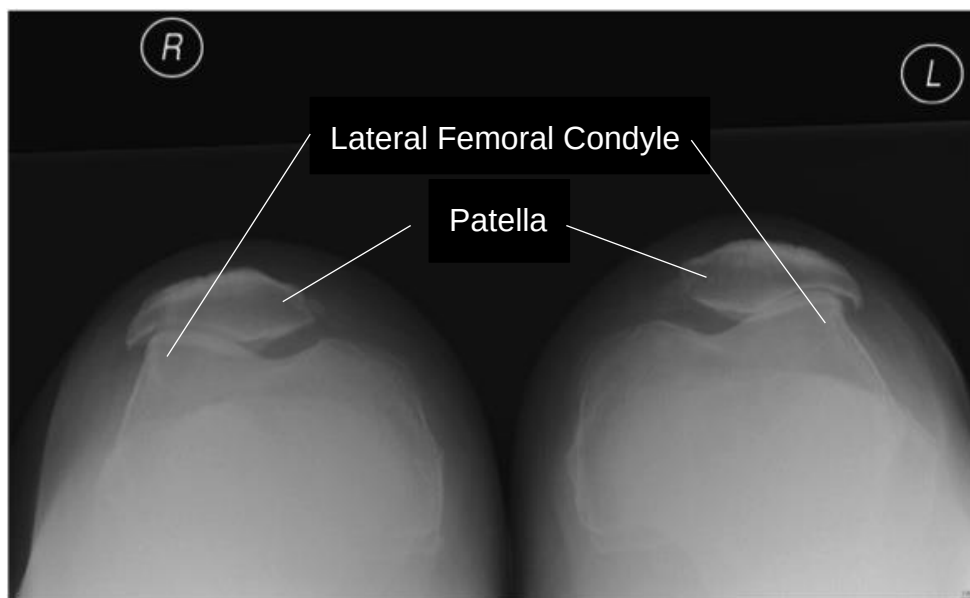


Figure 2.2: Patellar skyline X-ray view showing severe lateral patellar maltracking (Magee, 2006)

A suggested mechanism for patellar maltracking is the presence of a delay in recruitment of the vastus medialis obliquus (VMO) muscle compared to the vastus lateralis (VL) muscle, as well as a delay between the VL and the VMO during functional activity (Boling *et al.*, 2010, Cavazzuti *et al.*, 2010). Furthermore, a reflex activity has been reported as an intrinsic risk factor for the development of PFP due to an altered latency of VMO onset (Cowan *et al.*, 2001). Hypermobility of the patella, and tightness of the hamstrings and patellar retinaculum can also be intrinsic risk factors (White *et al.*, 2009, Cavazzuti *et al.*, 2010).

2.2 Electromyography

2.2.1 Definitions

Basmajian defined Electromyography (EMG) in 1985 as, “an experimental technique to assess the development, analysis and recording of myoelectric signals. Myoelectric signals are formed by physiological variations in the state of muscle fibre membranes”. The authors then simplified the definition to “the study of muscle function through the inquiry of the electrical signal the muscles emanate” (Basmajian *et al.*, p1, 1985). Neurological EMG refers to a simulated muscle reaction as a result of external electrical stimulation evaluated in static conditions which is used for diagnosis purposes in muscular or neurological disorders. Over the past decades, a large emphasis has been placed on kinesiological EMG. Kinesiological EMG can be defined as the examination of the neuromuscular activation of muscles during postural tasks, functional movements, work conditions and treatment/training regimes (Konrad, 2005). This literature review will focus on the development of kinesiological EMG activity of the quadriceps muscle during functional tasks.

2.2.2 Application

The foundation of EMG measurement starts with the simple question: “What are the muscles doing?” Kinesiological EMG is a well-known investigation device, used for applied research, rehabilitation, sports training and integration of the human body to industrial products and work conditions (Konrad, 2005). As shown in figure 2.3 below, EMG allows the researcher or practitioner to directly “look” into the muscle and places an emphasis on the following areas:

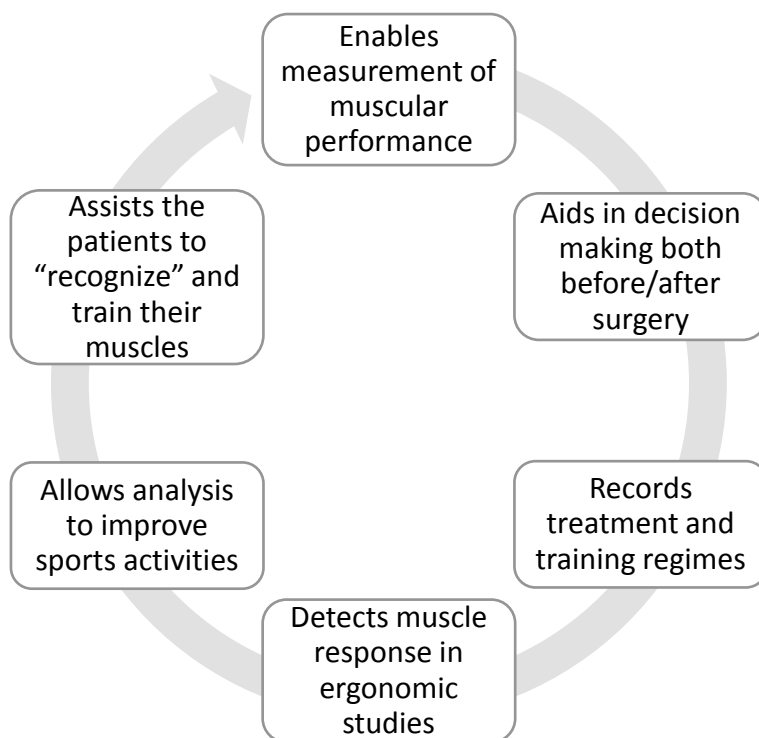


Figure 2.3: Typical benefits of electromyography (Konrad, 2005).

2.2.3 Historical development

The first documented EMG work was by Italian Francesco Redi in 1666. Redi discovered that a highly specialized muscle of the electrical ray fish could generate electricity (Basmajian and De Luca, 1985). Swammerdam discovered that stroking the innervating nerve of a frog's medial gastrocnemius muscle generated a contraction (cited in Clarys, 1994). Thereafter, Galvani in 1791 was the first to observe the connection between electricity and muscle activity by electrically exciting a frog's muscle (Basmajian and De Luca, 1985).

However, the most important development in EMG was accomplished by Duchenne de Boulogne in 1850. De Boulogne studied the dynamics and functions of intact skeletal muscles and electrical stimulations. He developed techniques for the recording and stimulation of both muscle and nerve, and applied electrodes for recording the path of the electric current in contracting muscle fibres (cited in Clarys, 1994). Piper was however, considered to be the first researcher to study the EMG signal. In 1907, Piper developed the metal surface electrode and in 1912 recorded human voluntary muscle activity by utilising the Einthoven's string galvanometer (Pattichis *et al.*, 1999). Thereafter, Proebster in 1928, was able to describe

spontaneous irregular action potentials in the denervated muscle of a human subject. He was thus seen as a key contributor to the field of clinical EMG (Basmajian and De Luca, 1985).

In 1929, Adrian and Bronk, developed the concentric needle electrode (Fine-Wire EMG) which enabled them to conduct studies intramuscularly from muscles located deep in the body on their motor unit action potential. These researchers amplified muscle action potential activities and used this amplified signal to produce an output from a loudspeaker. The information carried by the resulting sound aided in interpreting the EMG signal (Andrian and Bronk, 1929). By using this technique, the researchers determined that there was no spontaneous electrical activity in a completely relaxed normal muscle. This approach, for the first time allowed the measurement and observation of electrical activity related to individual or small groups of muscle fibres (Basmajian and De Luca, 1985).

The first visual format of EMG was introduced by Gasser and Erlanger in 1922. They used a cathode ray oscilloscope in place of the galvanometer, to show electrical signals from muscles (Pattichis *et al.*, 1999). However, kinesiological studies only advanced after the development of an electrically stable silver-chloride electrode and the non-obtrusive wire electrode in 1960. The purpose of the EMG investigation will determine whether surface or fine-wire electrodes will be used. Statistical results confirmed that surface electrodes are more reliable than fine-wire electrodes on day to day investigations (Giroux *et al.*, 1990)

With the introduction of the above mentioned advancements, the accuracy of the EMG signal interpretation was improved and its application has branched from traditional diagnosis of muscle disorders to exercise physiology, movement analysis, rehabilitation, biofeedback and the myoelectric control of prostheses (Basmajian and De Luca, 1985). EMG has contributed significantly to research in the analysis of muscle behaviour, and has become a fundamental tool in research studies and clinical practices.

2.2.4 Neuromuscular anatomy and physiology

A motor unit is the smallest functional unit to describe the neural control of the muscular contraction process. A motor unit is defined as the cell body and dendrites of α -motorneuron with a cell body located in the anterior horn of the spinal cord, the large diameter axon and terminal branches, and the muscle fibres that it innervates (Cram, 2011). Skeletal muscle fibres are innervated by these groups of motor units which are activated by the brain and central nervous system (CNS) (Cram, 2011, Konrad, 2005). The action potentials from the CNS are conducted along the motor nerve to the motor endplate.

The phenomenon of excitability of the muscle membranes can be described by the process of a semi-permeable membrane defining the electrical properties of the sarcolemma. A resting potential at the muscle fiber membranes are formed by the ionic equilibrium between the inner and outer spaces of the muscle cells. This difference which is maintained by the physiological processes of an ionic pump results in a negative intracellular charge of approximately -80 to -90 mV when not contracted compared to the external surface (Cram, 2011).

The motor units are continuously activated by the CNS for as long as the muscle is required to generate force. To produce greater forces, there is an increase excitation to the motor units, which results in a greater number of motor units being activated, and an increase in the firing rates of all active motor units and a larger muscle contraction. The electrical signal that originates from the activation of muscle fibres, and which is within the detectable range of an electrode, is called a motor unit action potential. The motor unit action potential propagates from the innervation zone in both directions along each muscle fibre (Albertus, 2008, Konrad, 2005).

2.3 Electromyographic Activity in the Quadriceps Muscle

In literature, controversy exists as to the relationship of EMG activity of the quadriceps muscle during diverse activities.

2.3.1 Quadriceps anatomy and physiology

The quadriceps femoris, Latin for “four-headed muscle of the femur”, is also called the quadriceps muscle or quadriceps. The quadriceps muscle is a large muscle on the front of the thigh (femur) and plays a key role in moving the body from a seated to a standing position. The quadriceps muscle is considered to be an ‘anti-gravity’ muscle that is used during daily activities including walking up and down stairs, running, cycling, skiing and all jumping sports. The quadriceps muscle consist of four quadricep muscles: rectus femoris (RF), vastus medialis obliquus (VMO), vastus lateralis (VL) and vastus intermedius (Figure 2.4) (Kendall *et al.*, 2005). This study will only look at the rectus femoris, vastus medialis obliquus and the vastus lateralis due to the anatomical orientation of the muscles for surface EMG purpose.

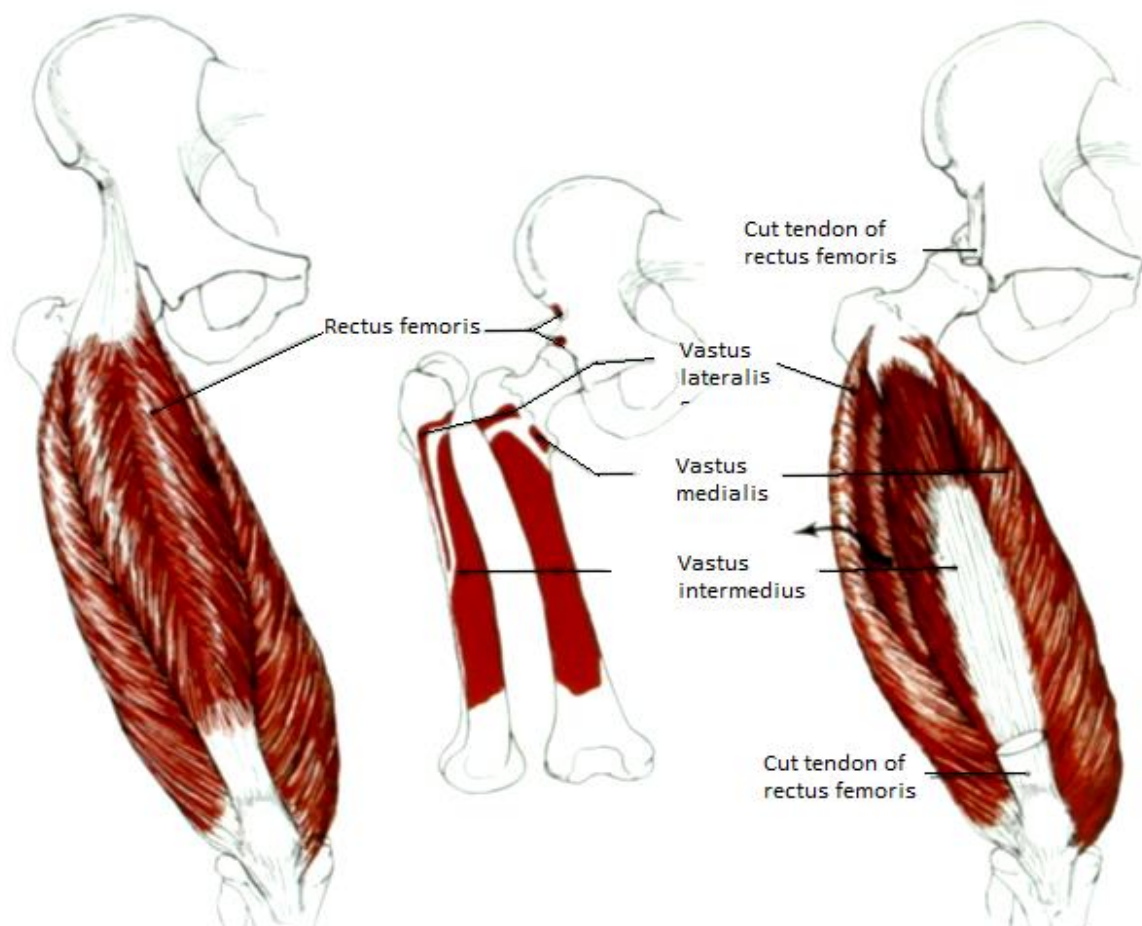


Figure 2.4: Anatomy of Quadriceps Muscle (Kendall *et al.*, 2005).

The origin, insertion and the actions of the VMO, VL and RF muscles are described in Table 2.1. The RF is the only quadriceps muscle to act over two joints, the hip and the knee. The VL is the largest muscle of the quadriceps muscle group. The distal

fibres of the vastus medialis run in an oblique direction near the patella, these fibres make up a division known as vastus medialis oblique. The VMO plays an important role in medial patellar tracking. The fibres of the VMO and the RF fan out to form the medial patellar retinaculum. The lateral retinaculum is an extension of the fibrous ‘aponeurosis’ of the VL muscle (Kendall *et al.*, 2005; Vizniak, 2008).

Table 2.1: Origin, insertion and actions of the quadriceps muscle (Kendall *et al.*, 2005).

Rectus Femoris	Vastus Medialis	Vastus Lateralis	Vastus Intermedius
Origin Anterior head: anterior inferior iliac spine (AIIS) Posterior head: superior to rim of acetabulum	Origin Medial lip of linea aspera	Origin Lateral lip of linea aspera	Origin Anterior and lateral surfaces of the proximal 2/3 of the body of the femur, distal half of the linea aspera, and lateral intermuscular septum.
Insertion Proximal border of the patella and across the patellar ligament to the tuberosity of the tibia	Insertion Proximal border of the patella and across the patellar ligament to the tuberosity of the tibia	Insertion Proximal border of the patella and across the patellar ligament to the tuberosity of the tibia	Insertion Proximal border of the patella and across the patellar ligament to the tuberosity of the tibia
Actions Primary: extension of knee joint Secondary: flexion of hip	Actions Primary: extension of knee joint Secondary: none	Actions Primary: extension of knee joint Secondary: none	Actions Primary: extension of knee joint Secondary: none

2.3.2 Electromyography onset timing of the quadriceps muscle

The pre-activation patterns or feed-forward mechanisms in muscle recruitment are imperative in the prevention of musculoskeletal disorders (Motealleh *et al.*, 2015, Van Tiggelen *et al.*, 2009, Grabinier *et al.*, 1994, Voight *et al.*, 1991). The onset of the VMO, VL and RF activity may be of particular importance because of the various forces acting upon the patella during a single quadriceps contraction. In the general population, it is believed that VMO activation must precede activation of the VL to optimally guide the patella over the patellar groove (Kasman, 2011, Voight and

Weider, 1991). Altered onset of the quadriceps muscle activity result in a delayed onset of the VMO activation relative to the VL (Briani *et al.*, 2016, Van Tiggelen *et al.*, 2009).

Delayed onset of VMO activity may result in a lateral pull of the patella as a result of the predominantly lateral directed force of the VL muscle (Grabiniier *et al.*, 1994). Abnormal patellar tracking results in increased patellofemoral contact pressure (Witvrouw *et al.*, 2014, Cavazzuti *et al.*, 2010). This forms the theoretical basis for strengthening the VMO muscle for individuals experiencing PFP to overcome the lateral pull of the much larger VL muscle (Bizzini *et al.*, 2003, Powers, 2000, Hanten *et al.*, 1990). Regardless of the large emphasis on the VMO in the treatment of PFP individuals, assessment of VMO force production in vivo is not possible (Powers *et al.*, 1996). Consequently, EMG has been used to establish the activity patterns of the quadriceps muscle.

One of the primary measures used in cases of PFP has been the relationship in onset timing between the VMO and the VL muscles. An alteration in EMG onset timing was found between the VMO and the VL muscles (Briani *et al.*, 2016, Van Tiggelen *et al.*, 2009, Cowan *et al.*, 2001) (Table 2.2). The authors discovered a delay in VMO onset timing compared to the VL in the PFP group compared to the healthy group. Briani *et al.* (2016) examined four groups respectively, an intense activity PFP group and control group, and a moderate activity PFP and control group. The authors showed a delayed onset of VMO activity compared to the VL muscle for the intense activity PFP group. However, the intense activity control group, as well as the moderate activity PFP and moderate activity control group showed no delayed onset of VMO activity compared to VL muscle. The results from the intense activity control group, and the moderate activity PFP and control groups from Briani *et al.* (2016), correspond with the work of Cavazzuti *et al.* (2010) and Powers (1996) (Table 2.2).

Cavazzuti *et al.* (2010) found no onset timing differences between the VMO and the VL in the PFP group for any of their investigated tasks (Table 2.2). Briani *et al.* (2016) recruited females and measured 43 PFP participants and 38 healthy participants. Cavazzuti *et al.* (2010) recruited males (n=12) and females (n=23) and measured 15 PFP participants and 20 healthy participants. Briani *et al.* (2016) and Cowan *et al.*

Table 2.2: Population characteristics, procedural details and results of five primary studies on EMG and vastus muscles:

Study	PFP participants	Healthy participants	Task	Electrode type; Sampling rate; Signal processing; EMG onset determination method.	Results: Delayed onset of vastus muscles between PFP and control group
Briani et al (2016)	n: 43; (MAPFPG = 26; IAPFPG = 17) M/F: Females only Age (y): MAPFPG 21.79 ± 1.01; IAPFPG 22.77 ± 2.41 Height (cm): MAPFPG 166 ± .08; IAPFPG 165 ± .04 Weight (kg): MAPFPG 60.01 ± 7.10; IAPFPG 61.98 ± 9.13 BMI (kg/m ²): NS Population: Graduated student population from the University of São Paulo	n: 38; (MACG = 26; IACG = 12) M/F: Females only Age (y): MACG 21.33 ± 2.62; IACG 22.21 ± 3.12 Height (cm): MACG 164 ± .07; IACG 165 ± .05 Weight (kg): MACG 59.48 ± 8.13; IACG 63.87 ± 10.81 BMI (kg/m ²): NS Population: Graduated student population from the University of São Paulo	Step down seven step staircase (28cm depth; 18cm high) at natural stair ascent pattern. Five trials collected	Surface electrodes; Sampling rate = 4000Hz; Full wave rectification and low pass filter = 50Hz Onset point at which signal exceeded mean + 3 SD of baseline level for minimum of 25ms.	IAPFPG: Delayed onset of VMO compared to VL (4.06ms). IACG: No delayed onset of VMO compared to VL (-14.4ms) MAPFPG: No delayed onset of VMO compared to VL (-2.48ms) MAPFPG: No delayed onset of VMO compared to VL (-9.89ms)
Cavazzuti et al (2010)	n: 15 M/F: 2/13 Age: 19 ± 9 years Height: NS Weight: NS BMI: NS Population: NS	n: 20 M/F: 10/10 Age: 23 ± 2 years Height: NS Weight: NS BMI: NS Population: NS	Sit to stand Stand to sit Squat Step up and step down three step staircase (21cm height and 22cm depth) Ten trials collected.	Surface electrodes; Full wave rectification and low pass filter = 10Hz; Double-threshold onset detector algorithm.	PFP group: No delayed onset of VMO compared to VL (≤.02s). Control group: No delayed onset of VMO compared to VL (≤.02s).
Cowan et al (2001)	n: 33 M/F: 11/22 Age: 27.0 ± 8.1 years Height: 171.1 ± 9.3cm Weight: 69.1 ± 15.9kg BMI: 23.0 ± .04kg/m ² Population: Recruited from University of Melbourne School of Physiotherapy	n: 33 M/F: 13/20 Age: 23.6 ± 4.9 years Height: 169.8 ± 11.9cm Weight: 64.6 ± 10.9kg BMI: .22 ± .02kg/m ² Population: Recruited from University of Melbourne School of Physiotherapy	Step up and step down a two-step staircase steps (20cm high), at usual stair stepping pace. Five trials collected.	Surface electrodes; Sampling rate = 1000Hz; Full wave rectification and low pass filter = 50Hz; Onset point at which signal exceeded mean + 3 SD of baseline level for minimum of 25ms.	PFP group: Delayed onset of VMO compared to VL (P < .05). Control group: No delayed onset of VMO compared to VL.
Powers et al (1996)	n: 26 M/F: Females only Age: 25.6 ± 7.1 years Height: 165.1 ± 10.4cm Weight: 63.9 ± 9.8kg BMI: NS Population: Participants recruited from orthopedic clinics in the Los Angeles (Calif) area	n: 19 M/F: Females only Age: 27.5 ± 4.7 years Height: 165.3 ± 7.7cm Weight: 59.2 ± 7.5kg BMI: NS Population: Participants recruited from the student population at the University of Southern California and Rancho Los Amigos Medical Center (Downey, Calif)	Free-speed and fast walking on: Level surface Ascending and Descending ramp Step up and step down a four step staircase (15cm height and 27cm depth) Two trials collected	Fine wire; Sampling rate = 2500Hz Full wave rectification and integration over 0.01s intervals; Bandwidth = 150 – 1000HZ Onset point at EMG activity exceeding 5% MIMT	PFP group: No delayed onset of VMO compared to VL. Control group: No delayed onset of VMO compared to VL.
Van Tiggelen et al (2009)	n: 26 M/F: Male only Age: 19.5 ± 1.44 years Height: NS Weight: NS BMI: NS Population: First-year cadets of the Belgian Royal Military Academy	n: 53 M/F: Male only Age: 19.8 ± 2.62 years Height: NS Weight: NS BMI: NS Population: First-year cadets of the Belgian Royal Military Academy	Rocking back on the heels. Ten trials collected.	Surface electrodes; Sampling rate = 1000Hz; Full wave rectification and low pass filter = 10 to 500Hz; Onset point at which signal exceeded mean + 3 SD of baseline level for minimum of 25ms.	PFP group: Delayed onset of VMO compared to VL in PFP group (P = .023). Control group: No delayed onset of VMO compared to VL.

Abbreviations: BMI – Body Mass Index ; cm - centimetre ; F - Female ; Hz – Hertz; IACG – Intense Activity Control Group ; IAPFPG – Intense Activity Patellofemoral Pain Group ; kg - kilograms ; M - Male ; MACG – Moderate Activity Control Group ; MAPFPG – Moderate Activity Patellofemoral Pain Group ; MIMT – Maximum Isometric Muscle Test; ms – milliseconds; NS – Not Stated ; P – Significance; PFP – Patellofemoral Pain; SD – Standard Deviation ; VL – Vastus Lateralis; VMO – Vastus Medialis Obliquus; y – year.

(2001) investigated only the step down activity, while Cavazzuti *et al.* (2010) included more functional tasks such as sit to stand, stand to sit and squatting. Van Tiggelen *et al.* (2009) assessed ten rocking back on the heels. As a result of the limitations identified in the aforementioned studies, this study will focus on the EMG measurement of the quadriceps muscle activity in male participants during functional tasks, and attempts to explain the onset of the quadriceps muscle in PFP and healthy populations.

2.3.3 EMG sequence timing

EMG sequence timing during functional movements involves a sequence of muscle activities to mobilize a joint or segment of the body. The sequence timing of muscles occur in a particular order in which related muscles activity follow each other. Changes in the sequence of muscle activity can cause several musculoskeletal disorders. Voight and Weider (1991) found an altered sequence firing pattern of the vastus muscles during knee extension in patients with anterior knee pain. Compared to a healthy population, patients with anterior knee pain had an earlier onset of the vastus lateralis and a delayed onset of the vastus medialis muscle.

Similarly, studies have demonstrated unbalanced muscle activation after elongating the ACL in the knee joint. They found increases in quadriceps EMG activity but no change in the hamstring activation. Patients with shoulder impingement demonstrate an altered sequence muscle activity of the lower trapezius, subscapularis, and the serratus anterior. Patients with functional ankle instability demonstrate impairment and prolonged reaction times of the peroneal muscle. Other researchers have demonstrated delayed activation of the transversus abdominis in patients with chronic low back pain and groin pain (Page *et al.*, 2010).

Motealleh *et al.* (2015) evaluated the VL, VMO, gluteus maximus (GMAX), gluteus medius (GMED), erector spinae (ES) and the internal obliquus (IO) in fifteen male PFP participants, and fifteen aged-matched controls during a stepping up and stepping down task. The sequence of muscle activation during the stepping up in the PFP group were IO, ES, VL, VMO, GMAX and then GMED respectively. However, the sequence of muscle activation during the stepping down phase were IO, ES, VMO, VL, GMAX and GMED respectively. Therefore, research has shown that pain

and injury can have an effect on the sequence timing of muscles, and further research is warranted in PFP (Motealleh *et al.*, 2015).

2.4 Clinical intervention

Numerous conservative interventions for PFP have been suggested, including education, active and passive interventions (Table 2.3) (Collins *et al.*, 2012). These interventions include exercise, taping, braces, soft tissue manipulation and foot orthoses. The greatest results and patient adherence follows a precise diagnosis, with a clear explanation of the condition and the rationale for the proposed intervention, with some indication of prognosis (Crossley, 2015). Guidelines for management of patellofemoral pain are described in Table 2.3 (Barton *et al.*, 2015, Crossley, 2015, Bhavre and Baker, 2008).

Table 2.3: Guidelines to various interventions for the management of patellofemoral pain

Education	Active Intervention	Passive Intervention
1. Ensure the patient understands potential contributing factors to their condition and treatment options	Principles	Pain reduction
2. Advice of appropriate activity modification	1. Give preference to CKC exercises to replicate function	1. Provide tailored patellar taping to reduce pain in the immediate term
3. Manage the patients expectations regarding rehabilitation	2. Consider OKC exercises in early stages of rehabilitation to target specific strengths deficits and movements	2. Provide PFJ braces where taping is inappropriate (e.g. skin irritation)
4. Encourage and emphasise the importance of participation in active rehabilitation	3. Provide adequate supervision in the early stages to ensure correct exercise techniques, but progress to independence as soon as possible	3. Consider foot orthoses
	4. When independent, limit the number of exercises to 3 or 4 to aid compliance	Optimising biomechanics
	5. Use biofeedback such as mirrors, videos or EMG to improve exercise quality	1. Consider foot orthoses based on assessment findings (i.e. presence of excessive dynamic pronation)
	Specifics	2. Consider massage and acupuncture/dry needling to improve the flexibility of tight muscle and fasciae structures, particularly laterally
	1. Incorporate quadriceps and gluteal strengthening	3. Consider PFJ mobilization but only in the presence of hypo-mobility
	2. Target distal and core muscles where deficits exists	4. Consider mobilization of the ankle and the first ray in the presence of sagittal plane joint restriction
	3. Consider stretching, particular of the calf and hamstrings, based upon assessment findings	
	4. Incorporate movement pattern retraining, particular of the hip	

CKC, Closed Kinetic Chain; EMG, Electromyography; OKC, Opened Kinetic Chain; PFJ, Patellofemoral Joint

2.4.1 Active intervention

According to Collins *et al.* (2012), exercise was effective when compared to a control or placebo group in the treatment of patellofemoral pain. Exercise with both open kinetic chain (OKC) and closed kinetic chain (CKC) methods provide significant and clinically meaningful reductions in patellofemoral pain (Crossley *et al.*, 2004). It has been suggested that preference should be given to CKC exercises to replicate joint function during activity of daily living (ADL). Specific emphasis should then be placed on OKC exercises during the initial stages of rehabilitation in order to assist with strengthening of particular muscles or targeted movements (Collins *et al.*, (2012).

Current evidence strongly supports strengthening of the quadriceps muscle during rehabilitation (Crossley *et al.*, 2004). Imbalanced activity of the VMO compared to the VL has long been assumed by clinicians to be a factor in contributing to excessive lateral tracking of the patella resulting in patellofemoral pain. This principle has formed the theoretical basis for strengthening the VMO muscle as to be essential in overcoming the lateral pull of the much larger VL muscle (Hanten *et al.*, 1990; Powers, 2000; Witvrouw *et al.*, 2014). Numerous exercises have been purported by clinicians to selectively facilitate recruitment of the vastus muscles. These have been evaluated exhaustively and with little controversy (Callaghan and Oldham, 1996, Laprade *et al.*, 1998; Zakaria *et al.*, 1997).

A large volume of literature relates to clinical surface electromyography (SEMG) studies and biofeedback of the knee musculature. SEMG feedback can be combined with routine exercise protocols to enhance motivation, muscle recruitment and exercise technique. Studies found SEMG biofeedback with exercise superior to exercise alone for healthy subjects (Croese, 1986). In the PFP group, mean contraction activity in the biofeedback group of the vastus medialis, and the vastus lateralis muscle, were significantly higher than those of the control group (Durdan *et al.*, 2011). On the other hand, Collins *et al.* (2012) argued that combining EMG feedback with exercise does not improve rehabilitative outcomes measured at 4 weeks or at 8 to 12 weeks. Although controversy exists in literature on the use of EMG feedback during exercise, other biofeedback mechanisms such as mirrors and video recordings are incorporated to facilitate reversal of poor hip and knee mechanics seen in clinical practices.

2.4.2 Passive intervention

Patellar taping according to the method of McConnell has been widely used by clinicians. However, patellofemoral taping appears to be consistently associated with decreased pain and altered SEMG activity from the vastus muscles (Cowan *et al.*, 2002, Gilleard *et al.*, 1998), other investigations have failed to report similar SEMG changes (Salsich *et al.*, 2002). More recently, studies indicate that medially directed patellar taping provides immediate pain reduction. This modality emerged strongly to be introduced in early patient management, to facilitate active engagement and optimise outcomes (Barton *et al.*, 2015). High-quality systematic reviews evaluating the effectiveness of patellar taping in the longer term were reliable with inconsistent findings and varying conclusions were drawn from these studies (Crossley *et al.*, 2016; Barton *et al.*, 2015).

Evidence indicates patellar bracing is effective in providing immediate pain reduction by reducing lateral patellar tracking (Warden *et al.*, 2008). Bracing for patients with skin irritation are recommended by experts where taping is inappropriate. The effectiveness of patellar bracing beyond the immediate term is reported to be inconsistent, possibly due to the multifactorial nature of PFP. Foot orthoses should not be considered for all individuals presenting with PFP symptoms. Directing PFP individuals based on diagnosed pronation may be improved by the effectiveness of foot orthoses.

PFP individuals experiencing greater peak rear-foot eversion during walking and greater mid-foot mobility may also benefit from foot orthoses. Limited evidence indicates acupuncture may be effective in the management of PFP. Further research is needed in acupuncture in the management of PFP, particularly in individuals with PFP who experience muscle tightness, trigger points or chronic pain. There is poor evidence that reveals ultrasound is not an effective treatment modality, and therefore should not be considered for the treatment of individuals with PFP (Barton *et al.*, 2015).

2.5. Statement of purpose

The literature presented in this chapter clearly highlights that the context of EMG analysis, and in particular the analysis of the quadriceps muscle in the PFP population, has evolved in relation to the understanding of contributing factors as well as the management of PFP. A number of studies have been published on the topic of EMG activity in the vastus muscles with inconsistent results (Briani *et al.*, 2016; Cavazzuti *et al.*, 2010; Van Tiggelen *et al.*, 2009; Powers, 2000). The disagreement amongst researchers may possibly be caused by a number of factors. First, studies have investigated only the EMG activity of the VMO and the VL muscles of the quadriceps group, and not the RF or the vastus intermedius. Secondly, studies have examined non-functional reflex tests and limited functional weightbearing activities such as a step up and step down. Only one study investigated the EMG activity response of the vastus muscles during diverse functional movements (Cavazzuti *et al.*, 2010). Lastly, most studies had small sample sizes and also measured predominantly females or females only. Since much of the treatment modalities used in the management of PFP are based on the hypothetical assumption of altered muscle contraction and lateral tracking, further research on the muscle activation patterns is warranted, especially in the under-studied male population.

2.6 Research Question

Is there altered onset timing, sequencing and ranking of the quadriceps muscles in PFP when compared to asymptomatic participants?

2.7 Aim

The aim of this study was therefore to identify the EMG activity of the VMO, VL and RF muscles during sit to stand, squat, and step up, and step down activity in male participants with and without PFP.

2.8 Objectives

In order to achieve the stated aim, this study had the following objectives:

1. To compare the differences in onset timing for each quadricep muscle (VMO, VL and RF) in participants with and without PFP.
2. To compare the sequence of onset timing between the VMO, the VL, and the RF in participants with and without PFP.
3. To compare the ranking for each quadricep muscle in relation to the different functional activities between participants with and without PFP.
4. To compare the relation of the Q-Angle and the onset timing of the quadriceps muscle in participants with and without PFP.

This study thus focuses on the EMG measurement of the quadriceps muscle activity in male participants during functional tasks, and attempts to explain the onset of the quadriceps muscle in healthy and PFP populations.

CHAPTER THREE

3 METHODS

3.1 Study Design

An observational descriptive and comparative quantitative study design was used.

3.2 Site of Study

The research study took place in a Biokinetics practice located at the Alice Lane Health Club, Johannesburg. Individuals from the local community attend the health club for health and fitness purposes. The private practice provides preventative and rehabilitative services to the members of the health club. The health club is situated on the corner of Fredman Drive and 5th Street, Alice Lane, Sandton, 2146.

3.3 Study Population

3.3.1 Sampling

Sample size was statistically calculated using the formula below: Z represent value for a 95% confidence interval. P is the proportion of the population and d is the margin of error that is allowed in the estimation of p.

$$n = \frac{Z^2 \times p \times (1 - p)}{d^2}$$

The target population was based on the physical characteristics of PFP. The study had two groups: one group consisted of volunteers experiencing PFP (PFP group) and the other group consisted of volunteering participants not experiencing PFP (healthy group). Consecutive and convenience sampling was done so that it included all participants that were available making the sample a better representation of the entire population. Based on a 50% probability that participants with PFP might have altered muscle activity, a sample of n=32 was estimated, with a 10% precision error at 95% confidence interval.

3.3.2 Selection and recruitment of participants

Active and inactive male participants ranging in age from 25 to 40 years who volunteered and were eligible for inclusion, were invited to participate. Participants were recruited from the local community, Donnelly and Herbst Biokineticists and referring medical practitioners. Participants in the PFP Group were referred from medical/health practitioners, and participants in the Healthy Group were approached and invited from the health club and local community to participate in this study.

4.3.3. Ethical considerations and clearance

Each participant received an information sheet (Appendix A) as well as an informed consent (Appendix B) form to be signed by the participant and the researcher. An application was submitted to the Human Research Ethics Committee (Medical) for clearance of research. The application was approved on the 29th of August 2014 (Clearance certificate no. M140398)

3.3.4. Inclusion and exclusion criteria

Participants were selected based on the criteria set out in Table 3.1.

Table 3.1: Inclusion and exclusion criteria for participants

Inclusion criteria for PFP group	• Positive sign of immediate onset of reproducible anterior or retro-patellar knee pain on at least two of the following activities commonly associated with PFPS (Cavazzuti <i>et al.</i>, 2010, Cowan <i>et al.</i>, 2001): ○ Running, squatting, hopping, isometric quadriceps femoris muscle contraction and stair ascent or descent. • Display 2 of the following clinical criteria on assessment with a minimal Visual Analog Scale (VAS) of 3/10 during the assessment (Cowan <i>et al.</i>, 2001): ○ Immediate onset of pain on direct compression of the patella against the femoral condyle with full knee
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	extension. ○ Immediate onset of pain on resisted knee extension (starting from 90° of flexion to full extension). ○ Immediate onset of pain with isometric quadriceps contraction against suprapatellar resistance with the knee in 15° extension. ● Negative findings (asymptomatic) in the examination of the following (Cowan <i>et al.</i>, 2001): ○ Knee ligaments, menisci, bursae, synovial plicae, Hoffa's fat pad, iliotibial band, and the hamstrings, quadriceps, and patellar tendons and their insertions (Cowan <i>et al.</i>, 2001):
Exclusion criteria for PFP group and healthy group.	● Participants have had significant injury of the following (Cowan <i>et al.</i>, 2001): ○ PFJ, traumatic patellar dislocation, previous lower limb surgery or any neurological involvement that would affect gait. ○ Impairments of the lower limbs such as Achilles tendinopathy, stress fractures, shin splints or lateral friction syndrome ○ Participants were excluded if they had significant bilateral PFP
Inclusion criteria in healthy group	● Asymptomatic participants in the healthy group were matched for age and gender. ● Participants in the control group were excluded from participating in the study if they had PFP in the past 6 months, Chondromalacia (significant injury of the patellofemoral joint), traumatic patellar dislocation, previous lower limb surgery or any neurological involvement that would affect gait (Cowan <i>et al.</i>, 2001)

3.4 Testing Procedures, Measuring Tools and Instruments

3.4.1 Testing procedures

All measurements and data collection were performed by the researcher. The data collection took place in the following chronological order:

Prior to participation on the day of testing, the participants received a copy of an information sheet (Appendix A) explaining the test. An informed consent (Appendix B) signed by the participant was obtained from all the participants. All participants were coded by assigning an identification number which was used instead of their names and surnames to ensure confidentiality. Participants were informed to wear appropriate and loose fitting clothing to access muscles for the skinfold test, and in order to prevent any artifacts by electrodes produced by tight fitting pants. A data collection sheet (Appendix C) was used to record the following information: participant personal details, history, assessment and observation, and measurements.

For group homogeneity purposes the following information was recorded in order to match PFP participants with controls (healthy group): age, physical activity status, fat percentage, height, body weight, Body Mass Index (BMI), thigh circumference, Q-angle measurement and hand dominance. A physical activity questionnaire (Appendix C) was also completed to determine the current physical activity status of the participant. Participants were tested unilaterally on the PFP side. For participants with bilateral symptoms, only the side with the worst pain (on a pain scale of 1 to 10) was tested. The height, weight, skinfolds and thigh circumference measurements were taken and recorded in accordance with the standards of the International Society for the Advancement of Kinanthropometry (ISAK) (Marfell-Jones, 2001).

Body composition was measured barefoot and only in light weight training clothes. Body mass was recorded with a professional weighing scale (Micro, India). Once the scale was reset to zero, the participants were then instructed to stand steady on the center of the scale with their weight distributed evenly on both feet and without support. The stretch stature method was used to measure height by using a height stadiometer. Participants were instructed to stand with the feet together and the

heels, the buttocks and upper part of the back touching the wall. The head was placed in the Frankfort plane by aligning the orbitale (lower edge of the eye socket) horizontally with the tragon (the notch superior to the tragus of the ear).

The participants were then instructed to take and hold a deep breath while keeping the head in the Frankfort plane. The recorder then placed the head board of the stadiometer firmly down on the Vertex (highest point of the head when placed in the Frankfort plane), flattening the hair as much as possible. The recorder then further assisted by watching that the position of the head was maintained in the Frankfort plane and the feet did not come off the floor. The measurement was taken at the end of a deep inhalation breath. Time of day was recorded to standardize weight and height measurements (Marfell-Jones, 2001).

Body fat percentage was calculated by using the Jackson and Pollock four skinfold method (Marfell-Jones, 2001). The skinfolds included the triceps, supraspinale, abdomen and thigh measurements. The Slimguide skinfold caliper (Galaxy Informatics, India) was used to measure skinfolds. The skinfolds were taken in the same order in each person as indicated on the data collection sheet (Appendix C). Three measurements were taken for each skinfold site. The skinfold sites were identified using the prescribed anatomical landmarks. The skin was grasped and lifted so that a double fold of skin and the underlying subcutaneous adipose tissue were held between the thumb and index finger. The magnitude of fold that was picked-up was sufficient, to ensure that the two skin surfaces of the fold were parallel. Care was taken not to incorporate underlying muscle tissue in the grasp. The nearest edge of the contact faces of the caliper were then applied 1 cm away from the edge of the thumb and finger and the measurement was taken after two seconds (Marfell-Jones, 2001).

For measurement of the Q-Angle, a Whitehall G300 goniometer (Whitehall Manufacturing, Industry, CA) was used. The measurement was taken on the PFP side with the participants lying down in a supine position, with their feet and hips in the neutral position while their quadriceps muscles were relaxed. The angle was obtained by first ensuring that the lower limbs were at a right angle to the line joining the two anterior superior iliac spines (ASIS's). A line was then drawn from the ASIS to the midpoint of the patella on the same side and from the tibial tubercle to the

midpoint of the patella. The angle formed by the crossing of these two lines was the Q-Angle (Magee, 2006).

In preparation for the EMG test skin preparation took place before the electrodes were applied. Hair on the surface of the VMO, VL and RF was removed with a disposable razor (Schick 2, Energizer, CT, USA). Then the skin was cleaned with a special abrasive and conductive cleaning paste which removed the dead skin cells and that cleaned the skin from dirt and sweat. Identification of the electrode location and landmark prominent region was marked with a pen and covered with a pair of surface electrodes. The electrodes (Electrospyres, Johannesburg, RSA) measuring 15mm in diameter, were placed on the VMO, VL and RF with an interelectrode distance of at least 20mm (Shewman and Konrad, 2011, Cavazzuti *et al.*, 2010, Konrad, 2005, Cowan *et al.*, 2001).

The electrode placements (Figure 3.1) corresponded with that previously used by Van Tiggelen *et al.* (2009). The electrodes for the VMO, VL and RF muscles were placed parallel to the muscle fiber direction and the most dominant middle portion of the muscles belly. The electrodes for the VMO were orientated at 55° to the vertical, VL orientated 15° to the vertical and the RF orientated 0° to the vertical.

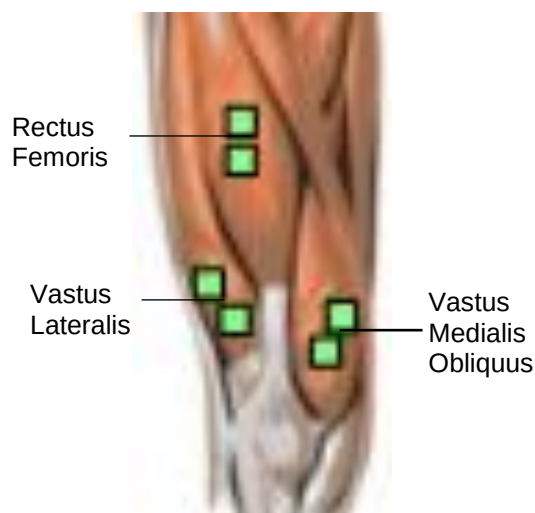


Figure 3.1: Electrode placement of quadricep muscles.

A sequence of PFJ loading tasks that are common during daily activities were used: sit-to-stand, squat, step up and step down. All the tasks were performed barefoot. The activities were illustrated to the participants and they were then instructed to

perform the activities at their self-selected pace (Cavazzuti *et al.*, 2010). Practice trials (five repetitions of each) were allowed to familiarize each participant with the tasks to be completed and for the electrodes to reach a stable electrical condition (Cavazzuti *et al.*, 2010). Baseline measurement was taken in the standing position for a period of ten seconds due to the nature of the activities to be performed.

Five consecutive repetitions for each activity were then performed in the same order as follows:

- Sit-to-stand: Participants sat on a bench with a standard height of 450mm and without a back support and arm rest. The participants was sitting in an upright position with the hip and knees flexed at approximately 90 degrees and the arms crossed in front of the chest. Feet had to be flat on the floor and shoulder width apart from each other. Participants stood up at a self-selected pace with about five seconds of rest from the previous repetition.
- Squat: In a standing position, participants were instructed to fold their arms across the chest, and position their feet at shoulder-width apart. The participants were then instructed to performed squat movements at a self-selected pace to approximately 90° hip and knee flexion without lifting their heels of the floor. Participants rested in a standing position for about five seconds between each squat.
- Step-up: Participants were instructed to step up a step with 350mm tread depth and 200mm step riser). Participants started at the bottom of the step. Participants then stepped-up the step by stepping with the painful leg first.
- Step-down: Participants were instructed to step down the same step as the step-up task. Participants started at the top of the step by stepping down with non-painful leg first.

All raw EMG signals obtained were telemetered from the transmitter to the receiver unit, and the signals were displayed and analysed by the computer. The muscle-reaction timing was determined by a surface EMG system (Myoresearch MT 400 unit, 4-channel, Noraxon USA Inc., Scottsdale, Arizona) to record the EMG signal. The onset of muscle activity was determined (using the Myoresearch XP (MT400 Clinical Edition 1.08.38) software package) as the point at which the EMG amplitude increased by more than 3SD for a minimum of 20 milliseconds from the baseline. The EMG onsets were identified by visual inspection (Van Tiggelen *et al.*, 2009).

The muscle activity onsets were averaged over 5 consecutive trials (Cavazzuti *et al.*, 2010). The variance in milliseconds for the onset of EMG activity between the VMO, VL and RF was calculated by subtracting the activity of the VL from the VMO, the RF from the VMO and the RF from the VL activity. A negative value indicated that the VMO triggered before the VL, the VMO before the RF and the VL before the RF respectively. A positive value showed that the VL preceded the VMO, the RF preceded the VMO, and the RF preceded the VL respectively (Van Tiggelen *et al.*, 2009).

The sequence of onset timing for the quadriceps muscle was identified by the particular order in which the VMO, VL and RF activities follow each other. The ranking of the quadricep muscles were determined by the sum of EMG onsets of each quadricep muscle for each activity in the PFP group and the healthy group respectively. The percentage of onsets for each quadricep muscle was calculated and then ranked according to first (1st), second (2nd) and third (3rd) position in the EMG measurement.

3.4.2. Validity of electromyography signal

The following steps were taken to ensure accuracy of the surface EMG signal:

Step 1: Evidence of EMG signal validity. The following basic questions were addressed (Konrad, 2005):

1. Was the quadriceps muscles tested?
2. Was the correct leads attached to the correct quadriceps muscle?
3. Was a sensitivity check done of the EMG baseline at an electrode site against local pressure such as sitting on the transmitters?

Identification of the EMG signal was measured through the use of an isolated static muscle contraction by the participant that gave a clear and visible signal of the EMG recording. To avoid the risk of accidentally exchanging the transmitters designated for the quadriceps muscle, the exact connections will confirm the EMG signal by a single muscle contraction (Konrad, 2005).

Step 2: Inspection of the raw EMG baseline quality. The visual inspection of the raw EMG baseline was the utmost essential step (Konrad, 2005). This sensitive signal could have been influenced by external noise sources or other artefact sources. Electrical grounding of equipment such as the treadmill and the stationary bicycles in the testing area were checked to avoid any ground noise. The average baseline noise level did not exceed 3.5 microvolt. EMG baseline signal could have been affected if the participant did not relax at the start of the measurement, and therefore an “offset correction” function was used to correct this shift before the data was recorded. A visible shift of more than 5 milliseconds from baseline indicated a signal artefact. This occurs when the geometry of the muscle belly and electrode change or due to local pressure. Proper electrode placement and good skin preparation was implemented to avoid these signal artefacts (Konrad, 2005).

3.5 Statistical analysis

Data was analysed using the Graphpad Prism (Version 5.02) software package. Anthropometric data in the PFP and healthy groups were compared using unpaired *t* tests. A Mann-Whitney *U*-test was used to compare the physical activity between the PFP and healthy groups. Unpaired *t* tests was used to calculate the onset latencies directly between the PFP and healthy groups. A Tukey post hoc test was used in conjunction with an analysis of variance with repeated measure (RM-ANOVA) design to investigate the differences between muscle group onset latency and between all the activities. A Mann-Whitney *U*-test was then used to calculate the differences in muscle onset latency between the PFP and healthy groups for any activity. A Fishers exact test was used to calculate the difference in the quadriceps sequence timing of activation. The sequence of activation for the muscle groups was then compared between the PFP and healthy group using a Wilcoxon signed rank test. The quadriceps sequence of activation for each activity was established using a Chi-squared test.

The ranking of the quadriceps muscle activity was calculated manually, and then a Chi-squared test was used to compare between the activities for each quadricep muscle. A Chi-squared test was also conducted to compare the ranking of each quadricep muscle in each activity. The correlations between the Q-angle and onset

latencies of the quadricep muscles and the different activities were calculated using the Spearman's rank correlation coefficient test. A Mann-Whitney *U*-test was used to compare the Q-angle and onset latencies between the PFP and healthy groups. The mean and standard deviation was provided for normally distributed data, and the median and range was presented for non-normally distributed data. The statistical significance for all tests was set at $p < 0.05$.

CHAPTER FOUR

4 RESULTS

4.1 Demographics

The demographics of the participants ($n = 34$) from both groups are presented in Table 4.1. Unpaired t-tests demonstrated no significant demographic differences in the anthropometric data between the PFP group ($n = 17$) and the healthy group ($n = 17$) for age, BMI, fat percentage, thigh circumference and Q-angle (Table 4.1). The mean age for the PFP group (32.0 ± 4) was slightly higher compared to the healthy group (30.1 ± 4.1) (Table 4.1). The PFP group mean weight was also higher (85.6 ± 10.6) compared to the healthy group (80.1 ± 12.6) (Table 4.1).

The mean BMI findings for both groups indicated that they were slightly overweight according to the World Health Organization's (WHO) normative data (overweight = 25.0 to 29.9 kg.m^{-2}) (Table 4.1). The fat percentage for the PFP group (11.5 ± 5.4) was greater than the healthy group (8.7 ± 3.1) (Table 4.1). The median value for the Q-angle was 12 in the PFP group and 10 for the healthy group. Although the mean values for the demographic data was higher for the PFP group, the differences were not significant and thus the two groups are statistically matched.

Table 4.1: Anthropometric data of the participants

	Healthy Group ($n = 17$)		PFP Group ($n = 17$)		P Value
	Mean ($\pm$ SD)	Range	Mean ($\pm$ SD)	Range	
Age (y)	30.1 (4.1)	22-38	32.0 (4.0)	26-39	0.19
Height (cm)	1.77 (0.07)	1.67-1.95	1.78 (0.07)	1.64-1.94	
Weight (kg)	80.1 (12.6)	62-116.5	85.6 (10.6)	64.6-101.8	
BMI (kg.m^{-2})	25.4 (2.6)	19.8-30.6	26.5 (3.9)	19.5-36.1	0.34
Fat Percentage (%)	8.7 (3.1)	4.1-15.2	11.5 (5.4)	4.1-22.9	0.09
Circumference (cm)	56.8 (4.8)	51-72	57.0 (4.0)	46-66	0.86
Q-Angle ($^{\circ}$)	10.8 (2.1)	9-18	11.8 (2.7)	6-17	0.24
Activity (0-14)	12	11-14	13	11-14	

PFP, Patellofemoral Pain; n, number; SD, Standard Deviation; P, significance; y, years; cm, centimetre; kg, kilogram; kg.m^{-2} , kilogram per metre squared; %, percentage, $^{\circ}$, degrees.

4.2 Electromyography Onset Latency of the Quadriceps Muscle

The onset latency of the quadriceps muscle is the duration of time it takes for the muscle to activate once stimulated by the neuromuscular system. An Unpaired *t* test showed that there were no significant differences between the PFP and the healthy group in the onset latency of EMG activity for each quadricep muscle during each of the activities performed (Table 4.2).

Although there was no statistical difference, there seems to be a tendency in the quadriceps muscle to activate quicker in the healthy group when compared to the PFP group for specifically the squat, step up and step down activities. On the other hand, in the sit-to-stand activity there was only a minor difference between the two groups compared to the squat, step up and step down activity (Table 4.2).

Table 4.2: Onset latencies between Healthy Group and PFP Group for each muscle and activity.

Activity	Muscle	Healthy Group (n=17) Mean (sec) ($\pm$ SD)	PFP Group (n=17) Mean (sec) ($\pm$ SD)	Percentage Difference (%)	P Value
Sit-to-stand	VMO	22.2 (3.7)	22.6 (4.3)	1.8	0.80
	VL	22.4 (3.6)	22.7 (4.3)	1.3	0.84
	RF	22.3 (3.7)	22.5 (4.3)	0.9	0.84
Squat	VMO	22.4 (8.4)	25.3 (7.8)	11.5	0.30
	VL	22.5 (8.5)	25.4 (7.8)	11.4	0.32
	RF	22.6 (8.5)	25.4 (7.8)	11.0	0.31
Step up	VMO	20.9 (4.3)	22.9 (4.5)	8.7	0.19
	VL	20.9 (4.3)	22.9 (4.5)	8.7	0.19
	RF	20.8 (4.3)	22.9 (4.5)	9.2	0.17
Step down	VMO	22.8 (4.6)	25.4 (4.6)	10.2	0.11
	VL	22.9 (4.6)	25.4 (4.6)	9.8	0.12
	RF	22.9 (4.6)	25.4 (4.7)	9.8	0.14

VMO, vastus medialis obliques; VL, vastus lateralis; RF, rectus Femoris. n, number; *P* value, significance; sec, seconds.

4.2.1 Onset latency of VMO compared to VL muscle

The onset latency of the VMO compared to the VL was calculated by subtracting the onset of the VL from the VMO onset. A negative value indicated that the onset of VMO preceded the VL onset, whereas a positive value indicated that the onset of VMO was delayed compared to the VL onset.

There was no delay in onset of VMO compared to VL in all of the activities for both PFP and healthy group. The average onset across all the activities for the PFP group was -0.03 milliseconds (ms) (± 0.11 ms) and for the healthy group -0.06 ms (± 0.13 ms) (Table 4.3). The RM-ANOVA found no significant difference between all the activities in the PFP group ($p = 0.17$) and the healthy group ($p = 0.70$) (Table 4.3).

Table 4.3: Difference between onset of VMO-VL muscle group and functional activities in PFP and healthy group.

	Healthy Group	PFP Group	Between Groups
Activity	Median (Range) (ms)	Median (Range) (ms)	P Value
Sit to stand	0.00 (-0.03 to 0.03)	-0.08 (-0.77 to 0.05)	0.33
Squat	-0.06 (-0.54 to 0.28)	-0.10 (-0.78 to 0.18)	0.41
Step up	-0.04 (-0.26 to 0.23)	-0.06 (-0.22 to 0.2)	1.00
Step down	-0.01 (-0.34 to 0.43)	-0.08 (-0.5 to 0.36)	0.43
P Value (Between activities)	0.70	0.17	

VMO, vastus medialis obliques; VL, vastus lateralis; P Value, significance; ms, milliseconds.

A Wilcoxon signed rank test show there was no significant difference in the onsets of VMO-VL muscle group between the PFP group and the healthy group (Table 4.3), however there was a notable -0.07ms difference in the step down test between the PFP group and the healthy group. Large variations are seen in the PFP group for the sit to stand, and squat, and in the healthy group for the squat and step down (Figure 4.1).

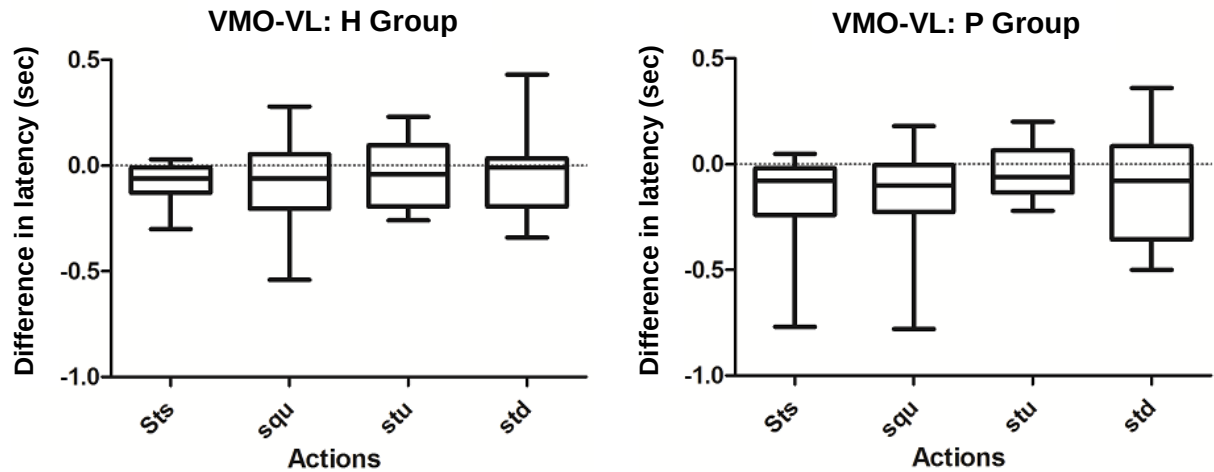


Figure 4.1: Mean difference in EMG onsets of the VMO-VL during functional activities. VMO, vastus medialis obliques; VL, vastus lateralis; H, Health group; P, PFP group; sts, sit to stand; squ, squat; stu, step up; std, step down; sec, seconds.

The sequence of onset timing for the VMO-VL muscle group is the particular order in which the VMO and VL activities follow each other. A Fisher's exact test showed there was no significant difference in the sequence of onset timing of the VMO and the VL for each activity between the PFP and healthy group ($p > 0.05$) (Table 4.4). The average onset of VMO activity preceded the VL in 67% of the PFP group and 69% in the healthy group for all activities completed (Table 4.4).

Table 4.4: Muscle sequence activity of the VMO-VL muscle group between the PFP and healthy group

Activity	Healthy Group (n = 17)		PFP Group (n = 17)		P Value
	VMO n (%)	VL n (%)	VMO n (%)	VL n (%)	
Sit to stand	14 (82)	3 (18)	15 (88)	2 (12)	1.00
Squat	13 (77)	4 (18)	11 (65)	6 (36)	0.71
Step up	10 (59)	7 (41)	11 (65)	6 (36)	1.00
Step down	14 (82)	3 (18)	9 (53)	8 (47)	1.00

PFP, patellofemoral pain; VMO, vastus medialis obliques; VL, vastus lateralis; P Value, significance.

4.2.2 Onset latency of VMO compared to RF muscle

The onset latency of the VMO compared to the RF was calculated by subtracting the onset of the RF from the VMO onset. A negative value indicated that the onset of VMO preceded the RF onset, whereas a positive value indicated that the onset of VMO was delayed to the RF onset.

There was no delay in onset of VMO in all of the activities for the PFP group, however, there was a delay in onset of VMO in the sit to stand and step up activity for the healthy group (Table 4.5). The onset of VMO and RF was simultaneous in the step down activity for the healthy group (Table 4.5), but -0.18sec for the PFP group. The average onset across all the activities for the PFP group was -0.03 milliseconds (ms) (± 0.13 ms) and for the healthy group -0.01 ms (± 0.19 ms) (Table 4.5).

The RM-ANOVA discovered a significant difference in the PFP group ($p < 0.01$) for sit to stand versus step down activity, squat versus step up activity, and step up versus step down activity. The RM-ANOVA also discovered a significant difference in the healthy group ($p = 0.03$) for the sit to stand versus squat activity (Table 4.5).

Table 4.5: Difference between onset of VMO-RF muscle group and functional activities in PFP and healthy group.

	Healthy Group	PFP Group	Between Groups
Activity	Median (Range) (sec)	Median (Range) (sec)	P Value
Sit to stand	0.07 (-0.3 to 0.51)	-0.03 (-0.64 to 0.46)	0.30
Squat	-0.11 (-0.43 to 0.13)	-0.14 (-0.94 to 0.27)	0.69
Step up	0.02 (-0.31 to 0.31)	-0.04 (-0.22 to 0.79)	0.31
Step down	0.0 (-0.64 to 0.33)	-0.18 (-0.75 to 0.2)	0.15
P Value (Between activities)	0.03*	<0.01*	

VMO, vastus medialis obliques; RF, Rectus Femoris; P Value, significance (*).

A Wilcoxon signed rank test show there were no significant differences found through all the activities for the VMO-RF muscle group between the PFP group and the healthy group (Table 4.5), however the largest difference was again seen in the step down activity. Variations are seen in the PFP group for the sit to stand, squat, and

step up, and step down activities, and in the healthy group for the sit to stand and step down (Figure 4.2).

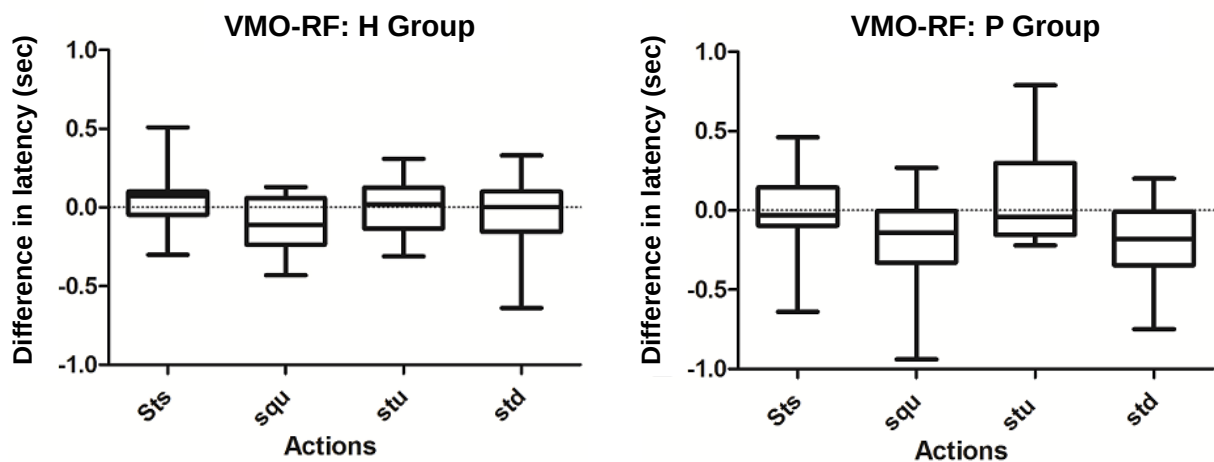


Figure 4.2: Mean difference in EMG onsets of the VMO-RF during functional activities. VMO, vastus medialis obliques; RF, rectus femoris; H, Health group; P, PFP group; sts, sit to stand; squ, squat; stu, step up; std, step down; sec, seconds.

The sequence of onset timing for the VMO-RF muscle group is the particular order in which the VMO and RF activities follow each other. Fisher's exact test revealed that there was no significant differences in the order of VMO and the RF onset for each activity between the PFP and healthy group ($p < 0.05$) (Table 4.6). Although not statistically significant, a trend was noticed in the sit to stand ($p = 0.08$) whereby, 71% of the healthy group activated VMO first as compared to 36% of the PFP group.

Table 4.6: Muscle sequence activity of the VMO-RF muscle group between the PFP and healthy group

Activity	Healthy Group (n = 17)		PFP Group (n = 17)		P Value
	VMO n (%)	RF n (%)	VMO n (%)	RF n (%)	
Sit to stand	12 (71)	5 (30)	6 (36)	11 (65)	0.08
Squat	13 (77)	4 (24)	11 (65)	6 (36)	0.71
Step up	10 (59)	7 (41)	6 (36)	10 (59)	0.30
Step down	14 (82)	3 (18)	8 (47)	9 (53)	0.07

PFP, patellofemoral pain; VMO, vastus medialis obliques; RF, rectus femoris; P Value, significance.

Furthermore, in the step down ($p = 0.07$), 82% of the healthy group activated VMO first, as compared to only 47% of the PFP group. On the other hand, little differences were found in the squat ($p = 0.71$) and step up ($p = 0.30$) activity (Table 4.6).

4.2.3 Onset latency of VL compared to RF muscle

The onset latency of the VL compared to the RF was calculated by subtracting the onset of the RF from the VL onset. A negative value indicated that the onset of VL preceded the RF onset, whereas a positive value indicated that the onset of VL was delayed to the RF onset.

There was a delay in onset of VL in the sit to stand, squat and step up activity for the PFP group (Table 4.7). There was a delay in onset of VL in all of the activities for the healthy group (Table 4.7). No significant differences were found between the healthy and the PFP group, however there was a -0.06sec difference between the healthy and PFP group in the step down activity. The average onset across all the activities for the PFP group was -0.02 milliseconds (ms) (± 0.17 ms) and for the healthy group 0.02 ms (± 0.15 ms) (Table 4.7).

The RM-ANOVA discovered a significant difference in the PFP group ($p < 0.01$) for sit to stand versus step down activity, step up versus step down activity. Furthermore, the RM-ANOVA found no significant difference between all the activities in the healthy group ($p = 0.08$).

Table 4.7: Difference between onset of VL-RF muscle group and functional activities in PFP and healthy group.

Activity	Healthy Group	PFP Group	P Value
	Median (Range) (sec)	Median (Range) (sec)	
Sit to stand	0.12 (-0.22 to 0.66)	0.13 (-0.06 to 0.54)	0.79
Squat	0.03 (-0.43 to 0.24)	0.01 (-0.29 to 0.35)	0.63
Step up	0.08 (-0.54 to 0.39)	0.05 (-0.37 to 0.86)	0.51
Step down	0.01 (-0.72 to 0.48)	-0.07 (-0.46 to 0.22)	0.15
P Value	0.08	<0.01*	

VL, vastus lateralis; RF, rectus femoris; P Value, significance (*).

A Wilcoxon signed rank test show there were no significant differences found through all the activities for the VL-RF muscle group between the PFP group and the healthy group (Table 4.7). Large variations are seen in the PFP group for the sit to stand and step up, and in the healthy group for the sit to stand, step up and step down (Figure 4.3). The biggest differences were found in the step down activity, whereby the healthy group appeared to activate RF before VL, whilst the PFP group tended to activate VL first.

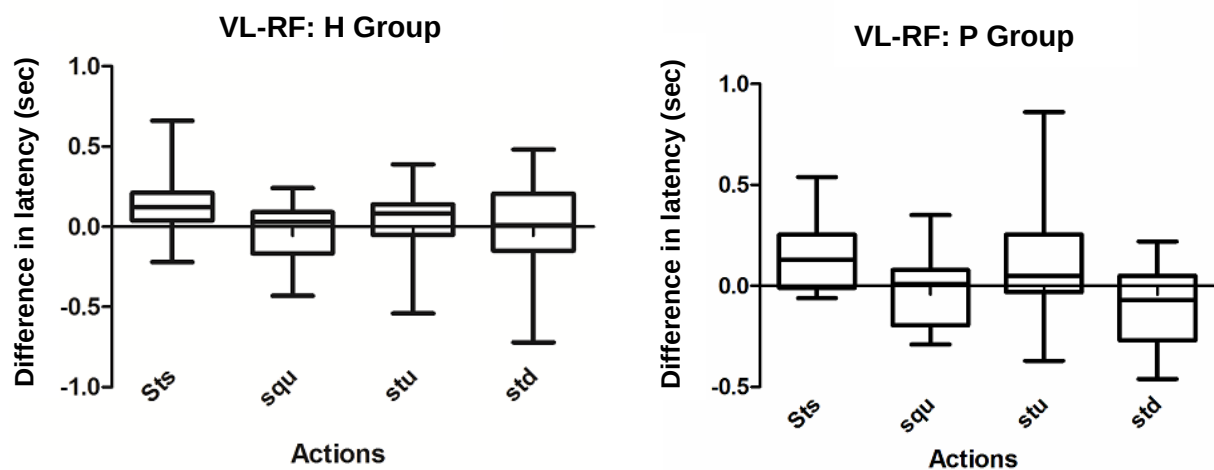


Figure 4.3: Mean difference in EMG onsets of the VL-RF during functional activities. VL, vastus lateralis; RF, rectus femoris; H, Health group; P, PFP group; sts, sit to stand; squ, squat; stu, step up; std, step down; sec, seconds.

The sequence of onset timing for the VL-RF muscle group is the particular order in which the VL and RF activities follow each other. Fisher's exact test show there was no significant difference in the sequence of onset timing of the VL and the RF for each activity between the PFP and healthy group ($p < 0.05$) (Table 4.8). However, 77% of the healthy group activated VL first in the step down activity, compared to only 47% of the PFP group ($p=0.16$). A trend was noticed for the step down ($p = 0.16$) activity, compared to the sit to stand ($p = 1.00$) squat ($p = 1.00$) and step up ($p = 1.00$) activity (Table 4.8).

Table 4.8: Muscle sequence activity of the VL-RF muscle group between the PFP and healthy group

Activity	Healthy Group (n = 17)		PFP Group (n = 17)		P Value
	VL n (%)	RF n (%)	VL n (%)	RF n (%)	
Sit to stand	4 (24)	13 (77)	3 (18)	14 (82)	1.00
Squat	8 (47)	9 (53)	7 (41)	10 (59)	1.00
Step up	5 (30)	12 (71)	5 (30)	12 (71)	1.00
Step down	13 (77)	4 (24)	8 (47)	9 (53)	0.16

PFP, patellofemoral pain; VL, vastus lateralis; RF, rectus femoris; P Value, significance

4.2.4 Onset latency of quadriceps muscle in all functional activities

The percentage of participants in the healthy and PFP group for each activity in which the onset of quadricep muscles activated earliest is illustrated in figure 4.4. In the sit to stand, the VMO onset had the highest percentage for the healthy group by 59%, and the VL onset in the PFP group by 65%. The VMO onset had the largest percentage in the squat for the healthy group (65%) and the PFP group (47%). The VMO onset for the step up had the highest percentage in the healthy group (47%), and in the PFP group the VMO and VL onset was each 35%. In the step down, the VMO onset had the largest percentage for the healthy group by with 53%%, and the VL onset in the PFP group with 47% 65%.

The VMO had an average percentage of 56% in the healthy group and 35% in the PFP group across all the activities. The VL had an average percentage of 29% in the healthy group and 44% in the PFP group through all the activities. The RF onset had the lowest percentage for all the activities with an average of 15% in the healthy group and 21% in the PFP group. Although there were no statistical significant differences, there seems to be a tendency for the highest percentage of VMO onset in the healthy population and the VL onset in the PFP population.

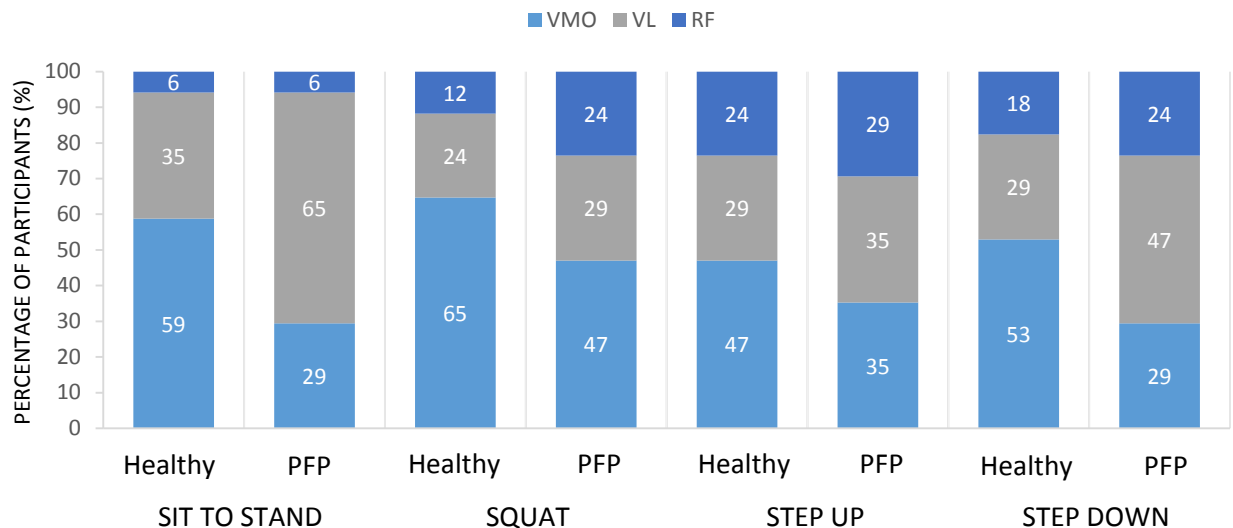


Figure 4.4: Percentage of participants in which the EMG onset of activation for the VMO, VL and RF muscle in the healthy and PFP group for each activity.

4.3 Electromyography Ranking of the Quadriceps Muscle

The ranking of the quadricep muscles were determined by the sum of EMG onsets of each quadricep muscle for each activity in the PFP group and the healthy group respectively. The percentage of onsets for each quadricep muscle was calculated and then ranked according to first (1st), second (2nd) and third (3rd) position in the EMG measurement. A Chi-squared distribution analysis was performed to determine significance ($p < 0.05$) in each of the quadricep muscles for each activity.

4.3.1 Comparing the quadriceps muscle to each activity

Significant differences were discovered in the healthy group between the ranking of the VMO, VL and RF for the sit to stand ($p < 0.01$), squat ($p = 0.01$), step up ($p = 0.04$), and step down ($p < 0.01$) activities (Table 4.9). The VMO onset ranked position across all four activities, for the majority of the healthy participants (Table 4.9). The VL onset ranked second place for the squat (47%), step up (47%), and step down (41%) for most of the participants; and third place for the sit to stand (41%) (Table 4.9). The RF onset ranked second place for most of the participants for the sit to stand (65%) and step up (53%) activity; and was most often third place for squat (47%) and step down (65%) activity (Table 4.9).

Table 4.9: Ranked order position of the quadricep muscles for each activity in the healthy group

Activity	Sit to stand			Squat			Step up			Step down		
Muscle	VMO n (%)	VL n (%)	RF n (%)	VMO n (%)	VL n (%)	RF n (%)	VMO n (%)	VL n (%)	RF n (%)	VMO n (%)	VL n (%)	RF n (%)
Ranking												
1 st	10 (59)	6 (35)	1 (6)	11 (65)	4 (24)	2 (12)	8 (47)	5 (30)	4 (24)	9 (53)	5 (30)	3 (18)
2 nd	2 (12)	4 (24)	11 (65)	2 (12)	8 (47)	7 (41)	1 (6)	8 (47)	9 (53)	7 (41)	7 (41)	3 (18)
3 rd	5 (30)	7 (41)	5 (30)	4 (24)	5 (30)	8 (47)	8 (47)	4 (24)	4 (24)	1 (6)	5 (30)	11 (65)
P Value	<0.01*			0.01*			0.04*			<0.01*		

VMO, vastus medialis obliquus; VL, vastus lateralis; RF, rectus femoris. *P* value, significance (*).

The order of ranked position of onset was similar for sit to stand and step up, VMO positioned first, followed by RF in second position and VL in third position. The squat and step down activities were ranked similarly with VMO positioned first, followed by VL in second position and then RF in third position (Table 4.9).

A significant difference was shown in the PFP group between the quadricep muscles for the sit to stand ($p = 0.01$) activity (Table 4.10). There were no significant differences noticed in the PFP group between the quadricep muscles for the squat ($p = 0.65$), step up ($p = 0.15$), and step down ($p = 0.65$) activity (Table 4.10). The VMO onset ranked in first position for the majority of the participants in the squat (47%), and third position for most participants for the sit to stand (65%), step up (53%), and step down (36%) (Table 4.10). The VL ranked in first position for most participants for the sit to stand (65%), and step down (47%); and third position for the squat (36%) activity (Table 4.10). The RF ranked second position for most participants for the sit to stand (77%) and squat (41%); and in third position for squat (47%) and step down (36%) (Table 4.10). In the sit to stand, the ranked order of position of onset was VL, then RF and lastly VMO. Although the other activities had no statistical significance, there seems to be a trend for the step up and step down activity ($p = 0.15$). The order of position of onset for the step up and step down activity was VL, then RF and lastly VMO.

Table 4.10: Ranked order of position between quadricep muscles for each activity in the PFP group

Activity	Sit to stand			Squat			Step up			Step down		
Muscle	VMO n (%)	VL n (%)	RF n (%)	VMO n (%)	VL n (%)	RF n (%)	VMO n (%)	VL n (%)	RF n (%)	VMO n (%)	VL n (%)	RF n (%)
Ranking												
1st	5 (30)	11 (65)	1 (6)	8 (47)	5 (30)	4 (24)	6 (36)	6 (36)	5 (30)	5 (30)	8 (47)	4 (24)
2nd	1 (6)	3 (18)	13 (77)	4 (24)	6 (36)	7 (41)	2 (12)	7 (41)	8 (47)	6 (36)	4 (24)	7 (41)
3rd	11 (65)	3 (18)	3 (18)	5 (30)	6 (36)	6 (36)	9 (53)	4 (24)	4 (24)	6 (36)	5 (30)	6 (36)
P Value	0.01*			0.65			0.15			0.65		

VMO, vastus medialis obliquus; VL, vastus lateralis; RF, rectus femoris; *P* value, significance (*).

The ranking of each quadricep muscle for each activity for the healthy group was compared to the PFP group. There were no significant differences noticed for the ranked order of onset in each quadricep muscle for each activity between the PFP group and the healthy group (Table 4.11).

Table 4.11: Ranking of each quadricep muscle for each activity between the PFP group and healthy group.

		Sit to Stand			Squat			Step Up			Step Down		
Muscle		VMO n	VL n	RF n	VMO n	VL n	RF n	VMO n	VL n	RF n	VMO n	VL n	RF n
Healthy Group (n=17)	1st	10	6	1	11	4	2	8	5	4	9	5	3
	2nd	2	4	11	2	8	7	1	8	9	7	7	3
	3rd	5	7	5	4	5	8	8	4	4	1	5	11
PFP Group (n=17)	1st	5	11	1	8	5	4	6	6	5	5	8	4
	2nd	1	3	13	4	6	7	2	7	8	6	4	7
	3rd	11	3	3	5	6	6	9	4	4	6	5	6
P Value		0.12	0.20	0.72	0.53	0.78	0.62	0.71	0.92	0.92	0.09	0.47	0.20

VMO, vastus medialis obliques; VL, vastus lateralis; RF, rectus Femoris; *P* Value, significance.

Although there were no statistical significance, there seems to be a tendency in the VMO for the sit to stand ($p = 0.12$) and step down ($p = 0.09$) when compared to the squat ($p = 0.53$) and step up ($p = 0.71$) (Table 4.11).

4.4 The Relationship between Q-Angle and Onset of Quadriceps Muscle

The relationship between the Q-angle and the onset latency of the quadriceps muscle for each activity was determined by a Spearman's rank correlation coefficient.

4.4.1 Correlation of Q-angle and onset of quadriceps muscle

A significant, moderate negative correlation was found in the healthy group between the Q-angle and the onset of VMO ($p = 0.03$), VL ($p = 0.02$) and RF ($p = 0.03$) for the step down activity (Table 4.12). As a result, the greater the Q-angle, the earlier the onset latency of the quadriceps muscle will be. There were no significant relationship noticed between Q-angle and onset of any of the quadriceps muscles for the sit to stand, squat and step up activity ($p < 0.05$).

Table 4.12: Relationship between Q-angle and quadricep muscles for healthy group

Activity	Muscle	R Value	P Value
Sit to stand	VMO	-0.27	0.29
	VL	-0.28	0.28
	RF	-0.26	0.32
Squat	VMO	-0.42	0.09
	VL	-0.42	0.09
	RF	-0.42	0.09
Step up	VMO	-0.31	0.22
	VL	-0.30	0.24
	RF	-0.31	0.23
Step down	VMO	-0.53	0.03*
	VL	-0.55	0.02*
	RF	-0.53	0.03*

VMO, vastus medialis obliques; VL, vastus lateralis; RF, rectus Femoris; P value, <0.05 = significance*.

There seems to be a trend for negative relationship between Q-angle and the VMO ($p = 0.09$), VL ($p = 0.09$) and RF ($p = 0.09$), in the squat activity (Table 4.12).

There were no significant relationship in the PFP group between the Q-angle and the quadriceps muscle for each activity ($p < 0.05$) (Table 4.13). Although there were no statistical significance, there seems to be a tendency for a negative correlation in the sit to stand activity between the Q-angle and the VMO ($p = 0.10$), VL ($p = 0.09$) and RF ($p = 0.11$) (Table 4.13).

Table 4.13: Relationship between Q-angle and quadricep muscles for PFP group

Activity	Muscle	R Value	P Value
Sit to stand	VMO	-0.41	0.10
	VL	-0.42	0.09
	RF	-0.40	0.11
Squat	VMO	-0.19	0.48
	VL	-0.18	0.49
	RF	-0.18	0.49
Step up	VMO	-0.27	0.29
	VL	-0.26	0.31
	RF	-0.26	0.32
Step down	VMO	-0.04	0.87
	VL	-0.05	0.85
	RF	-0.05	0.84

VMO, vastus medialis obliques; VL, vastus lateralis; RF, rectus Femoris; *P* value, significance.

CHAPTER FIVE

5 DISCUSSION

In this study we looked at the surface EMG data from the VMO, VL and RF muscles during several functional activities in participants with PFP and healthy participants. The functional activities included sit to stand, squat, step up and a step down. The onset and sequence timing was calculated for all three muscles and then compared between the functional activities and between participants with PFP and healthy participants. The ranking of muscle activity and the correlation between the Q-angle and the quadriceps muscle activity was assessed. This study is one of the few studies to investigate the EMG onset activity of the RF muscle in relation to the VMO and VL muscles during functional activities, as well as the ranking for the onset of quadriceps muscle respectively. This is also one of the first studies to evaluate the Q-angle in relation to the onset of quadriceps activity during different functional activities between PFP participants and healthy participants.

The results of this study show no significant difference in onset timing of EMG activity for each quadricep muscle between the PFP group and the healthy group. Although there appeared to be a delay in onset in the VMO-RF and VL-RF muscle groups for the step down activity between the PFP group and the healthy controls, this difference was not statistically significant. From a sequencing perspective, there was no statistically significant difference in VMO activity compared to the VL between the two groups, however VMO appeared to activate earlier than VL in the healthy group when compared to the PFP group for the step down activity. A significant difference was noticed in the PFP and healthy group for the VMO-RF muscle group when comparing between the different activities. The RF preceded the VMO in the PFP group in all the activities and in the healthy group only the squat activity. Also a significant difference was noticed in the PFP group for the VL-RF muscle group activation when comparing between the different activities, with RF preceding VL in all activities except for the step down activity.

This study found that VMO appears to rank first for all activities in the healthy group, with RF ranking 2nd in the sit-to-stand and VL 2nd in the squat and step down. In the PFP group, the muscle ranking appeared to evenly matched (no significant

differences between the ranking), except for the sit to stand, where VL ranked first. However, the differences between the two groups were not statistically significant. A significant relationship was shown in the healthy group between the Q-angle and the quadriceps muscle during the step down activity. No significant correlation was shown in the PFP group between the Q-angle and the quadriceps activity.

5.1 Onset Timing

Onset of the VMO activity may be of particular importance because in the healthy population it has been theorized that the onset of the VMO must be activated earlier than the VL to track the patella optimally (Briani *et al.*, 2016). This study revealed that there was no significant delay in onset of VMO, VL or RF activity in the PFP compared to the healthy group. In comparison, other studies have shown a delayed onset of VMO activity compared to VL activity in the PFP group and not the healthy group possibly due to an activity imbalance between VMO and VL (Briani *et al.*, 2015, Van Tiggelen *et al.*, 2010, Cowan *et al.*, 2001).

However, although there was no statistical difference between these groups, there seems to be a tendency in all the quadriceps muscle to activate quicker in the healthy group when compared to the PFP group for specifically the squat, step up and the step down activities. Pain is often regarded as a contributor to muscle activity inhibition, as well as delayed muscle activation due to its self-protective mechanisms to protect the joint. Therefore, investigations suggest that PFP individuals who experiences pain may suffer from delayed onset of muscle activity as seen in a few of the activities in this study. The controversial agreement amongst the published data hinders the understanding of the contribution of quadricep muscle onset to the development of PFP (Briani *et al.*, 2016), and the current study did not find conclusive evidence for delayed onset in muscle activation in the PFP group.

5.2 Sequence Timing

Functional movements involves a sequence of muscle activities to mobilize the respected joint or segment of the human body. Majority of studies that investigated

the VMO-VL relation to functional activity studied only the step up and step down activities. This study included a sit to stand and a squat movement that is similar with the activities used by Cavazzuti *et al.* (2010). The results of this study support the findings of Cavazzuti *et al.* (2010) that there is no delayed onset of VMO activity in relation to the VL muscle during functional activities in the PFP population.

Although no statistical significance was found in relation to the VMO onset timing, this study found that the step down activity for the VMO-VL muscle group in 82% of the healthy group used VMO 1st compared to only 53% of the PFP group. These results conclude that there was a tendency for the healthy group to activate VMO first, indicating that the PFP group may present with altered onset activity that may lead to PFP. However, these findings were not significant and as a result further studies are needed.

In support of this finding, numerous papers have been published on this topic with inconsistent results, mainly as a result of insufficient participants, lack of standardised methodology and diverse subpopulations (Cavazzuti *et al.*, 2010, Van Tiggelen *et al.*, 2009, Cowan *et al.*, 2001). Van Tiggelen *et al.* (2009) and Cowan *et al.* (2001) discovered a delay in VMO onset timing compared to the VL in the PFP group and not in the healthy group. In contrary, Cavazzuti *et al.* (2010) found no delayed onset timing of VMO activity compared to VL activity. Consequently, this study support the hypothesis of a balanced control in neutral traction of the patella between participants with PFP and healthy participants.

The study of the onset of RF during daily functional activities is relatively new to literature, and therefore cannot be directly compared to other studies. However, Simões *et al.* (2008) investigated the EMG activity of the RF, VMO and VL in ten soccer players during a pre and post maximum isometric voluntary contraction (MVIC) of knee extension. The authors found no significance for the RF muscle activity, but discovered a significant difference in the VL and VMO muscles between pre and post activity. Furthermore, they discovered the RF showed first signs of fatigue as well as a lesser EMG activity amplitude compared to the VMO and VL muscles (Simões *et al.* 2008).

The current study found a significant difference in the healthy group for the onset activity of the VMO-RF muscle group when comparing between the sit to stand and the squat activities. A significant difference was also found in the PFP group for the onset activity of the VMO-RF muscle group when they were compared between the sit to stand and the step down, the squat and the step up, and the step up and the step down activity. In the healthy group, the VMO was delayed in the sit to stand, step up and step down, and in the PFP group only the squat activity.

The results obtained from these activities of the VMO-RF muscle group may possibly be supported by the type of muscle contraction required to assist in the kinematics of the activity. The onset of physical activity for the sit to stand and the step up are primarily controlled through the concentric contraction phase, while the squat and the step down are controlled through the eccentric contraction phase. Furthermore, the VMO muscle greatly assist in PFJ control and stability, while the RF muscle assist mainly with hip flexion. This may explain the differences seen between the sit to stand, squat, and step up and step down activities. Weakness of the VMO muscle may result in hyperactivity of the RF muscle to assist the kinematics of the knee-hip relationship during gait. An increased range of motion (ROM) of the hip joint may lead to increased PFJ compression forces due to a decreased knee extension ROM.

In the VMO-RF muscle group for the step down activity, 71% of the healthy group used VMO 1st compared to 36% of the PFP group, and 77% of the healthy group used VMO 1st in the sit to stand compared to 47% of the PFP group. Furthermore, no significant differences were found between the PFP and healthy group in the VMO-RF, and the VL-RF muscle groups for any activity. This study does not support the findings of Simões *et al.* (2008) that there is no significant difference in RF onset timing compared to VMO and VL activity.

The current study found a delayed onset of VL compared to RF activity in the PFP group during the sit to stand, squat, and step up activities. A delayed onset of VL activity was also noticed in the healthy group across all of the activities. This finding may be supported by the weakness of the VL muscle causing an overcompensation activity of the RF muscle in particular to hip flexion associated during these activities (Kendall *et al.*, 2005). A significant difference was found in the PFP group for the onset activity of the VL-RF muscle group when they were compared between the sit

to stand and step down, and the step up compared to the step down activity. This finding may possibly support the findings discovered in the VMO-RF muscle group by the type of muscle contraction required to assist in the kinematics of the gait activity, and as a result increase PFJ compression forces that may lead to development of PFP

The onset activity of the VMO-RF and VL-RF muscle groups had a statistical significant difference when the concentric and eccentric compelled contractions were compared to each other for the PFP group. This finding may support the idea that different functional movements elicit different muscle behaviours, and therefore certain activities may contribute to the cause and development of PFP. Data on the VL-RF muscle group and the comparison of this group to the different activities and the participant groups are also new to literature and cannot be compared to previous studies.

5.3 Ranking

Previous studies did not investigate the ranking for each quadricep muscle during various functional activities, and is possibly explained by the lack of quadricep muscles included in their EMG analysis (Briani *et al.*, 2016, Van Tiggelen *et al.*, 2010, Cowan *et al.*, 2001). In this study the ranking of each muscle for each activity was included to establish the superseding latencies of the respected quadricep muscles. The ranking of the quadricep muscles were determined by the position of the muscles in the EMG measurement according to first, second and third position. This study discovered that the ranked order for the VMO, VL and RF in the healthy group, was significantly different to each other for the sit to stand, squat, and step up and step down activities. The order for ranked position of onset in the healthy group was similar for sit to stand and step up activities, VMO positioned first, followed by RF in second position and VL in third position. The squat and step down activities were ranked similarly with VMO positioned first, followed by VL in second position and then RF in third position.

Furthermore, this study discovered a significant difference in the PFP group for the VMO, VL and RF during the sit to stand activity, where VL was ranked first. There

were no significant differences noticed in the squat, step up and step down activities, and therefore no particular muscle was favoured amongst each other. The ranked order position of onset for the sit to stand, step up and step down activities were firstly VL, then RF, and lastly VMO. However, because there was no significant difference, they were actually all quite evenly matched. The statistical difference noticed in the sit to stand for the healthy and the PFP group respectively, may possibly be explained by the altered onset activity of the quadriceps muscle in the PFP population, which resulted in a delayed onset of the VMO compared to the VL activity (Briani *et al.*, 2016, Van Tiggelen *et al.*, 2010).

Delayed onset of VMO activity possibly allows the predominance lateral directed force of the VL to laterally track the patella that may lead to increased PFJ compressive forces resulting in PFP (Briani *et al.*, 2015, Van Tiggelen *et al.*, 2010, Cowan *et al.*, 2001). In the current study, the healthy group used the VMO first and the PFP group used the VMO last for the sit to stand. Therefore, the statistical difference observed during the sit to stand for both healthy and PFP groups should place greater emphasis on investigating the ranked order of quadriceps muscle activity for this particular movement in future studies.

5.4 Relationship between Q-angle and onset of the quadriceps muscle

The magnitude of the Q-angle is often proposed to be an etiological factor for PFP. It is believed that individuals with a greater Q-angle being more prone to develop PFP due to the lateral force of the patella, which increases the retropatellar pressure between the lateral facet of the patella and the lateral femoral condyle (Almeida *et al.*, 2016, Freedman *et al.*, 2014). Previous investigations disprove the believed hypothesis of Q-angle being a possible risk factor for the cause and development of PFP (Almeida *et al.*, 2016, Park and Stefanyshyn, 2011). Freedman *et al.*, (2014) found no patellar kinematic correlation between the Q-angle and patellar lateral displacement, and confirmed the Q-angle does not represent the true angle of quadriceps force. The Q-angle also did not present any relationship to pain intensity, functional capacity and knee angle forces in PFP individuals (Almeida *et al.*, 2016). On the other hand, Levinger *et al.*, (2007) found a significant difference for increased femoral frontal angles in PFP individuals.

However, this study found a significant relationship in the healthy group between the Q-angle and the onset of VMO, VL and RF during the step down activity. No significant relationship was shown in the PFP group between the Q-angle and onset of quadriceps muscle and step down activity. Therefore, this study discovered in the healthy group that the greater the Q-angle is, the earlier the onset latency of the quadriceps muscle will be during the step down activity. This outcome may disprove the theory that a greater than norm Q-angle a possible risk factor for PFP could be.

The PFP group had a lesser Q-angle than the healthy group, and as a result, may support the findings from this study of VMO ranked third in position during the step down activity in the PFP population. Although there was no statistical significance in the PFP group, there seems to be a tendency for the sit to stand between the Q-angle and the VMO, VL and RF muscles. Further investigation would be necessary to approve a relationship between the Q-angle and the quadriceps activity. Although the noticeable trend was not statistically significant, it could possibly be as a result of a lack of statistical power due to a small sample size that was used.

5.5 Strengths and Limitations

There are number of strengths and limitations of the present study that must be acknowledged. This study included the RF muscle along with the VMO and VL muscles, and is therefore the first to investigate the RF muscle during functional activities. The present study utilized only functional activities that resembles our daily activities. Majority of previous papers only investigated females due to their high prevalence of developing PFP. However, this study on the contrary investigated only males. This study is also the first study to rank each respected quadricep muscle according to the muscles onset activity into a ranked position.

This study included a small sample size and therefore could have affected the statistical power of this study. For example, this study found trends in the PFP group for delayed onset of all quadriceps muscles when compared to the healthy controls during the squat, step up and step down activities, and this finding may have been inconclusive due to the small sample and lack of power. Therefore, further studies, with a larger sample should be conducted to further test these findings.

This study only included physically active men. Although this subgroup are prone to experience PFP, the data obtained from this study may not be generalized to the entire population of individuals experiencing PFP. Furthermore, pain experienced by participants during activities as well as the pain location on medial or lateral aspect was not identified to compare possible PFJ compressive forces with quadriceps muscles behaviour. Lastly, this study only measured the VMO, VL and RF muscles of the quadriceps group and did not include the vastus intermedius quadricep muscle.

Four functional movements were included into this study, whereby future research should include sport-specific related movements such as running, jumping, sidestepping and push-pull movements. Furthermore, onset activity of muscle groups across multiple joints including tibialis muscles, hamstrings and abdominal muscles should be assessed. A more comprehensive evaluation to muscle strength, endurance, proprioception, and joint mobility should be considered. In general, a set protocol of activities should be established to enable more significant comparisons and meta-analysis.

6. Conclusions and Recommendations

The cause and development of PFP is multifactorial and often requires two or more factors to be present. However, it is also common to encounter individuals with multiple factors who experience no pain and individuals with no factors who experience pain. This study found a delay in quadricep muscle activation for PFP group in the squat, step up and step down, however findings was not statistically significant. Furthermore, the sequence timing of activation in the healthy compared to PFP group tend to activate VMO first for the VMO-VL and VMO-RF muscle groups in sit to stand and step down activities. Significant differences was found in ranking of quadricep muscles for the healthy group utilizing the VMO first, compared to the PFP group with little differences and altered onset of quadriceps activation. This study discovered that the greater the Q-angle is, the earlier the onset of the quadriceps muscle will be in the step down activity for the healthy group, which is contrary for the PFP group. Therefore, a smaller Q-angle in the PFP group may possibly suggest that they are at risk for delayed onset of quadriceps activity in the step down activity.

The results from this study have important clinical implications for the role of the quadriceps muscle during different functional activities in individuals experiencing PFP and the healthy population. This study proposes that the emphasis should be directed on the kinematics of an activity that causes an onset of PFP, rather than focussing on the assumption of onset or sequence of activation of the quadricep muscles themselves. This will enable the clinician to tailor the specific treatment plan according to the needs of the individual who experiences PFP. Furthermore, future research should include various functional movement subgroup populations with PFP. Consistent evaluation protocols need to be established to enable comparisons and meta-analysis. These protocols should consider muscle recruitment patterns across multiple joints, muscle strength, endurance, proprioception, and joint mobility.

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8 APPENDICES

APPENDIX A

Research Information Sheet

Good day my name is Bertie Herbst. I'd like to invite you to take part in my research study as part of a Master's Degree. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Please ask if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

Study title: Electromyographic activity of Quadriceps muscle during functional activities in participants with and without Patellofemoral pain.

Invitation paragraph

Patellofemoral pain syndrome (PFPS) is a debilitating orthopaedic condition most commonly found in females and young active individuals. The term PFPS is commonly used to describe a condition of anterior (front) knee pain (AKP). An estimated 25% of knee injuries are related to AKP. Clinically, the onset of typical AKP is often deceptive and the cause of PFPS remains largely unknown. One proposed mechanism for the possible cause of AKP is the presence of a delay in the recruitment of the quadriceps muscle during functional activity. This research project would like to test the hypothesis that there will be an altered quadriceps muscle activity between participants with PFP and without PFP.

Bertie Herbst will conduct the research?

Bertie Herbst is currently doing this project as part of his Master of Science in Medicine in the field of Biokinetics. He is a qualified biokineticist registered with the Health Professionals Counsel of South Africa (HPCSA – BK 0014265) and is also the practice owner of Donnelly and Herbst Associates. All tests will be undertaken at Donnelly and Herbst Associates, and Bertie will be the only investigator conducting the research.

What is the aim of the research?

The aim of this study is to assess the differences in electromyography (EMG) activity in the quadriceps muscle (Vastus Medialis Obliquus, Vastus Lateralis and Rectus Femoris) in participants with and without PFP. This may assist health professionals to better understand a possible cause of PFP and also to better direct their rehabilitation approach for people experiencing PFP.

Do I have to take part?

Your participation is voluntary. We would like you to consent to participate in this study as we believe that you could make an important contribution to the research. If you decide to take part you are free to withdraw at any time without prejudice.

What would I be asked to do if I took part?

If you are happy to participate in the research we will ask you to read this information sheet and sign the consent form. You will then be assigned into one of two groups depending on the physical characteristics of PFPS, one group will consist of participants experiencing PFP and the other group will consist of participants not experiencing PFPS. Your age, height, weight, skinfold and Q-angle (Quadriceps angle; the angle formed between the longitudinal line of the thigh bone, representing the pull of the quadriceps muscle, and a line that represents the pull of the kneecap tendon) measurement will be recorded. Electrodes will be placed on the skin over one of your quadriceps muscle and then be measured using an electromyography device. Before applying the electrodes, you will be asked to remove the hair on your quadriceps muscle if there is any hair as this can affect the recording of the data. A few practice trials (five repetitions of each) will be done to familiarize each subject with the tasks to be completed. The tasks I have to perform are tasks that are common during daily activities I use. My participation will involve five consecutive repetitions for each task: sit-to-stand, step-up, step-down and squat. I only have to participate once in the study and the expected duration of the study will be no longer than 60 minutes.

Would I experience any discomfort or pain?

The research in which I will be participating does not involve more than minimal risk. I understand there are foreseeable risks or discomforts to me if I agree to participate in the study. I have been informed that I may experience a similar pain that I normally

experience during my daily activities. Possible discomforts include: knee pain on at least two of the following activities: squatting, hopping, static quadriceps muscle contraction and stair ascent or descent. Pain on direct compression of my knee cap against the bottom end of my thigh bone with my leg fully extended. Pain on resisted leg extension and on static quadriceps muscle contraction with my knee cap pushed upward and held with my knee in 15% extension.

What happens to the data collected?

All information you provide to us will be kept confidential. Only the researcher and supervisor will have access to it. Information gained during the research will be used as part of a larger sample, and will remain anonymous. The data collected will be securely stored. As required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed. The outcomes of the research will be available in one or more of the following sources; scientific papers in peer reviewed academic journals, presentations at a regional conference, local seminars, and presented as group results with no individuals identified.

The participants will be offered further treatment if possible treatable findings are revealed from the data collected. Any further treatment or evaluation will be for their own account.

For further information regarding the ethics approval for this study, contact the HREC chairman Professor Peter Cleaton-Jones on 011 717 2635 or email peter.cleaton-jones@wits.ac.za

Contact details:

Bertie Herbst

(Alice Lane Health Club, Alice Lane, Fredman Drive Entrance, Sandton)

(Tel) 011 783 9898 (Cell) 083 389 1569

bio.herbst@gmail.com

APPENDIX B

Informed Consent

Electromyographic activity of Quadriceps muscle during functional activities in participants with and without Patellofemoral pain

1. I understand that the results of the research study may be published but that my name or identity will not be revealed. In order to maintain confidentiality of my records, the researcher will assign an identification number which will be used instead of my name. The computer generated report will be saved and a hard copy will also be printed for analysis. The data collected will be securely stored. Therefore all data collected will be kept confidential and at the end of the project any personal information will be destroyed as required by the University's research policy.
2. I have been informed that should I request advice on my condition, this will be provided at no cost
3. I have been informed that any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by Bertie Herbst (investigator); Alice Lane Health Club, Alice Lane, Fredman Drive Entrance, Sandton; 011 783 9898/ 083 389 1569.
4. I have been informed that I may experience a similar pain that I normally experience during my daily activities.
5. I understand that in case of injury, if I have questions about my rights as a participant in this research, or if I feel I have been placed at risk, I can contact the Chair of the Human Research Ethics Committee.
6. I have read the above information. The nature, demands, risks and benefits of the project have been explained to me. I knowingly assume the risks involved and understand that I may withdraw my consent and discontinue participation at any

time without penalty or loss of benefit to myself. A copy of this consent form will be given to me.

PARTICIPANT:

Printed Name	Signature	Date and Time
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7. I certify that I have explained to the above participant the nature and purpose, the potential benefits, and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature.

8. These elements of informed consent conform to the Assurance given by the University of the Witwatersrand to the Department of Health and Human Services to protect the rights of human subjects.

9. I have provided the participant a copy of this signed consent document.

INVESTIGATOR:

Printed Name	Signature	Date and Time
---------------------	------------------	----------------------

WITNESS:

Printed Name	Signature	Date and Time
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APPENDIX C

Study title: Electromyographic activity of Quadriceps muscle during functional activities in participants with and without patellofemoral pain.

DATA COLLECTION SHEET

Investigator

Full Name: Bertie Herbst

Test Date: d d m m y y y y

Participant

Identification number:
Race:

Birth Date: d d m m y y y y
Age:

History

Exclusion criteria

If the participant is a female

Have you had any of the following in the past six months?

1. Significant injury and/or trauma to the knee
2. Knee cap dislocation
3. Lower limb surgery and/or neurological injury
4. Achilles tendinopathy or shin splints or stress fracture
5. Iliotibial band syndrome - ITBS

Y / N	L / R

Observation and Assessment

1. Dominance:

Inclusion criteria

If the participant is a male

Do you experience any of the following?

1. Knee pain on at least two of the following activities: Squatting
Hopping and/or running
Walking up and/or down stairs
Resisted knee extension
2. Display two of the following with a minimal visual analog scale of 3/10:
Pain with direct compression on knee cap
Pain on resisted knee extension
Pain with isometric quadriceps contraction against suprapatellar resistance with knee in 15° extension
3. Negative findings on all of the following:
Knee ligaments, menisci, bursa, synovial plicae, Hoffa's fat pad, ITB, hamstrings, quadriceps and patellar tendons and their insertions.

Y / N	L / R

Physical activity status

Training Principle

Score

Activity

Intensity

- 5
- 4
- 3
- 2
- 1

- Sustained heavy breathing and perspiration
Intermittent heavy breathing and perspiration, as in soccer
Moderately heavy, as in cycling and other recreational sports
Moderate, as in cricket
Light, as in fishing

Duration

- 4
- 3
- 2
- 1

- Over 30 minutes
20 to 30 minutes
10 to 20 minutes
Less than 10 min

Frequency

- 5
- 4
- 3
- 2
- 1

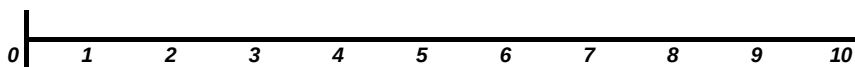
- 6 to 7 times per week
3 to 5 times per week
1 to 2 times per week
A few times per month
Less than once a month

Score

PROFORMA

Involved side

For bilateral symptoms, indicate which side is worse, left (L) or right (R) on the scale of 1 - 10 (10 being worse)



Measurements

Basic

1 Height (m)

--

2 Body weight (kg)

--

BMI

--

Skinfolds (mm)

3 Triceps

Trial 1

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Trial 2

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Trial 3

--

Median

--

Sum of 4

--

%BF

--

4 Suprailiac

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--

--

5 Abdominal

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--

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6 Thigh

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Circumference (mm)

7 Thigh (Involved side)

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Q-Angle

8 Degrees (Involved side)

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EMG

9 Onset timing (ms):

1 VMO

Baseline

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Sit-to-Stand

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Squat

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Step-Up

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Step-down

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10 Sequence of activation (no)

1

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2

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3

--

11 Overall sequence of activation

1

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2

--

3

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APPENDIX D

Ethics Clearance Certificate



R14/49 Mr Bertie Herbst

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M140398

NAME: Mr Bertie Herbst
(Principal Investigator)

DEPARTMENT: Biokinetics
Centre for Exercise Science and Sport Medicine
D & H Biokineticists
Centre of Advanced Medicine, Johannesburg

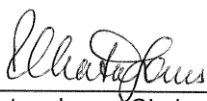
PROJECT TITLE: Electromyographic Activity of Quadriceps Muscle
during Functional Activities in Participants with and
without Patellofemoral Pain

DATE CONSIDERED: 28/03/2014

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Estelle Watson

APPROVED BY: 
Professor Cleaton-Jones, Chairperson, HREC (Medical)

DATE OF APPROVAL: 29/08/2014

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report.**

Principal Investigator Signature _____

Date _____

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

APPENDIX E

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CHAPTER ONE

1. INTRODUCTION

1.1 General Introduction

Following up on the last chapter, this chapter introduces the research project. It starts with a brief overview of the research project, followed by a detailed description of the research objectives, research questions, and research hypotheses. The chapter concludes with a summary of the chapter and a preview of the next chapter.

The research project is a quantitative study that aims to investigate the relationship between the independent variable (X) and the dependent variable (Y). The research objectives, research questions, and research hypotheses are as follows:

The research objectives are:

- To investigate the relationship between the independent variable (X) and the dependent variable (Y).
- To determine the direction of the relationship between the independent variable (X) and the dependent variable (Y).
- To determine the strength of the relationship between the independent variable (X) and the dependent variable (Y).

The research questions are:

- What is the relationship between the independent variable (X) and the dependent variable (Y)?
- Is there a significant difference in the dependent variable (Y) between the two groups (X1 and X2)?
- Is there a significant difference in the dependent variable (Y) between the two groups (X1 and X2) after controlling for the confounding variable (Z)?

The research hypotheses are:

- H1: There is a positive relationship between the independent variable (X) and the dependent variable (Y).
- H2: There is a significant difference in the dependent variable (Y) between the two groups (X1 and X2).
- H3: There is a significant difference in the dependent variable (Y) between the two groups (X1 and X2) after controlling for the confounding variable (Z).

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APPENDIX F

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PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

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I BERTIE HERBST (Student number: 767305) am a student
registered for the degree of MSc (Med) in Biostatistics in the academic year 2016.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.
- I have included as an appendix a report from "Turnitin" (or other approved plagiarism detection) software indicating the level of plagiarism in my research document.

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