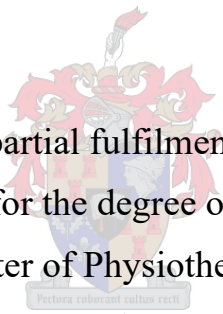


# **The Kinematic Differences between Individuals with Patellofemoral Pain and Matched Controls during a Single Leg Squat**

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## Declaration

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# Abstract

## Background

Patellofemoral pain (PFP) is a common knee condition characterised by retro- or peripatellar pain. It affects 11 percent of people who consult a general practitioner for knee pain. This condition has an impact on the daily lives of those suffering from it and causes pain during activities such as stair climbing, squatting and prolonged sitting. PFP has the tendency to become chronic. Altered lower limb and trunk kinematics may play an important role in the development of PFP and can be evaluated during a single leg squat (SLS). Findings regarding the kinematics of individuals with PFP compared to controls during a SLS are limited and inconsistent.

## Objective

The objective of the study was to describe the lower limb and trunk kinematic differences between individuals with PFP and matched controls during a SLS.

## Methodology

A cross-sectional design was followed in this study. The study was conducted in a laboratory setting in the Neuromechanics unit of the Central Analytical Facility of Stellenbosch University at the Coetzenburg Sports Complex, Stellenbosch. Study participants included 26 cases with PFP and 26 healthy gender- and age-matched controls. The Vicon 3D motion analysis system was utilised to capture the peak values of all outcomes (ipsilateral trunk lean, contralateral pelvic drop, hip adduction, knee abduction, rear-foot eversion, hip internal rotation and knee external rotation) during the static phase of the SLS. The kinematic outcomes of cases and controls were compared using the paired t-test.

## Results

The study population comprised 16 females and 10 males with PFP and their respective control group participants. The PFP group had a mean age of 28.5 years compared to 28 years for the control group. Participants with PFP presented with significantly more peak knee external rotation compared to healthy controls during the static phase of the SLS (MD, 4.68°; 95% CI: 2.83, 6.53;  $p < 0.001$ ). This also was the case when the groups were stratified for gender. When stratified for bilateral and unilateral PFP, only the bilateral PFP group demonstrated

significantly increased peak knee external rotation compared to their control group, with a mean difference of 5.98° (95% CI: 3.79, 8.17;  $p < 0.001$ ). There were no significant differences for the peak values of the other outcomes (ipsilateral trunk lean, contralateral pelvic drop, hip adduction, knee abduction, rear-foot eversion and hip internal rotation). The PFP group, however, presented with larger group means for all the outcomes in comparison with the control group.

## **Conclusion**

Peak knee external rotation was significantly increased in individuals with PFP compared to controls during the SLS. The findings of this study highlight the usefulness of the SLS as a test for altered kinematics in individuals with PFP. Future studies may explore possible contributing factors to excessive knee external rotation, such as trunk and lower limb muscle imbalances. Further studies are needed to evaluate the kinematic differences between individuals with unilateral and bilateral PFP.

## **Keywords**

Patellofemoral pain; anterior knee pain; kinematics; single leg squat

# Opsomming

## Agtergrond

Patellofemorale pyn (PFP) is 'n algemene knietoestand wat deur pyn aan die anterior aspek van die knie gekenmerk word en affekteer 11 persent van mense wat 'n algemene praktisyn vir kniepyn raadpleeg. Hierdie toestand het 'n impak op die daaglikse lewens van diegene wat daaraan ly en lei tot pyn tydens aktiwiteite soos trappe klim, hurk en sit vir lang periodes. Die toestand is ook geneig om kronies te word. Veranderde kinematika van die onderste ledemaat en romp kan 'n belangrike rol in die ontwikkeling van PFP speel en kan gedurende 'n een-been-hurk geëvalueer word. Daar is beperkte en strydige bevindinge rakende die kinematika van individue met PFP in vergelyking met kontroles tydens 'n een-been-hurk.

## Doelwitte

Om die onderste ledemaat en romp kinematiese verskille tussen individue met PFP en ooreenstemmende kontrole deelnemers tydens 'n een-been-hurk te beskryf.

## Metodiek

'n Beskrywende deursnitstudie-ontwerp is vir hierdie studie gevolg. Dit is in 'n laboratorium-omgewing in die Neuromeganika-eenheid van die Universiteit Stellenbosch se Sentrale Analitiese Fasiliteit by die Coetzenburg Sportkompleks onderneem. Die deelnemers aan die studie het 26 gevalle met PFP en 26 geslags- en ouderdom-ooreenstemmende kontrole deelnemers ingesluit. Die Vicon 3D-bewegingsontledingsstelsel is aangewend om die piekwaardes van alle uitkomstes (ipsilaterale romp leun, kontralaterale pelviese sak, heupadduksie, knie-abduksie, agtervoeterversie, heup interne rotasie en knie eksterne rotasie) tydens die statiese fase van die een-been-hurk te meet. Die kinematiese verskille tussen gevalle en kontroles is met behulp van die gepaarde t-toets vergelyk.

## Resultate

Die studie populasie het uit 16 vroue en 10 mans met PFP, en hul ooreenstemmende kontrole groepe bestaan. Die PFP-groep het 'n gemiddelde ouderdom van 28.5 jaar gehad, teenoor 28 jaar vir die kontrole groep. Deelnemers in die PFP-groep het aansienlik meer piek eksterne knie rotasie as die kontroles tydens die statiese fase van die een-been-hurk getoon (gemiddelde

verskil,  $4.68^\circ$ ; 95% VI: 2.83, 6.53;  $p < 0.001$ ). Dit was ook die geval toe die groepe volgens geslag verdeel is. Met die verdeling in bilaterale en unilaterale PFP-groepe, het net die bilaterale PFP-groep aansienlik meer piek knie eksterne rotasie in die mees geaffekteerde been getoon in vergelyking met hul kontrole-groep (gemiddelde verskil,  $5.98^\circ$ ; 95% VI: 3.79, 8.17;  $p < 0.001$ ). Daar was geen beduidende verskille vir piekwaardes van die ander uitkomst nie (ipsilaterale romp leun, kontralaterale pelviese sak, heupadduksie, knie-abduksie, agtervoeteversie, heup interne rotasie), alhoewel die PFP-groep vir alle uitkomst groter groep gemiddelde waardes in vergelyking met die kontrole groep getoon het.

### **Gevolgtrekking**

Piek knie eksterne rotasie tydens die een-been-hurk was aansienlik meer in individue met PFP in vergelyking met kontrole deelnemers. Die bevindinge van hierdie studie beklemtoon die nut van die een-been-hurk as 'n toets vir veranderde kinematika in individue met PFP. Toekomstige studies kan onderliggende redes vir die oormatige knie eksterne rotasie in individue met PFP, soos spierwanbalanse van die romp en onderste ledemaat, ondersoek. Verdere studies is ook nodig om die kinematiese verskille tussen individue met bilaterale en unilaterale PFP te ondersoek.

### **Sleutelwoorde**

Patellofemorale pyn; anterior knie pyn; kinematika, een-been-hurk

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## Glossary

**Angle of inclination of the femur:** The angle formed between the axis through the femoral head and neck and the longitudinal axis through the femoral shaft (in the frontal plane) (Levangie & Norkin, 2011).

**Angle of torsion of the femur:** The angle formed between the axis through the head and neck of the femur and the axis through the femoral condyles (in the transverse plane) (Levangie & Norkin, 2011).

**Anterior knee pain:** A synonym for patellofemoral pain and the terms are used interchangeably in the literature (Crossley, Stefanik, Selfe, Collins, Davis *et al.*, 2016)

**Conditioned pain modulation:** The phenomenon where the stimulus used to cause a change in pain perception (conditioning stimulus) affects the test stimulus (Yarnitsky, Arendt-Nielsen, Bouhassira, Edwards, Fillingim, Granot, Hansson, Lautenbacher, Marchand & Wilder-smith, 2010).

**Dynamic knee valgus:** The excessive medial movement of the lower limb during weight-bearing activities. This excessive medial displacement of the lower limb involves multiple joints and takes place in multiple planes. It is comprised of increased hip adduction and internal rotation; and knee abduction and external rotation, to varying degrees (Schmidt, Harris-Hayes & Salsich, 2017; Powers, 2010).

**Frontal plane projection angle (FPPA):** A two-dimensional measure of dynamic knee valgus. The FPPA is an angle formed by the crossing of two lines. A line from the anterior superior iliac spine to the midpoint of the femoral condyles and a line from the midpoint of the femoral condyles to the midpoint of the ankle malleoli (Herrington, 2014).

**Kinematics:** The branch of biomechanics where the motion of a segment is described without taking into account the forces that are causing the movement (Levangie & Norkin, 2011).

**Knee external rotation:** Describes external rotation of the tibia in this study.

**Non-sampling error:** It may occur as a result of a flaw in the research tool or biased communication (e.g. asking leading questions) (Laxton, cited in Coldwell, 2004).

**Patellofemoral joint reaction forces:** The compression measure of the patella against the femur (Bentley & Dowd, 1984).

**Patellofemoral pain (PFP):** Retro- or peripatellar pain which is aggravated by activities that loads the flexed knee joint, seen in common activities of daily living such as ambulation, running, squatting, kneeling and stair climbing (Crossley, Stefanik, Selfe, Collins, Davis *et al.*, 2016; Witvrouw, Callaghan, Stefanik, Noehren, Bazett-Jones *et al.*, 2014; Crossley, Zhang, Schache, Bryant & Cowan, 2011). On clinical examination, intra-articular joint pathology is absent in people with PFP and the condition usually has an insidious onset (Nunes, Stapait, Kirsten, De Noronha & Santos, 2013; Callaghan & Selfe, 2012; Crossley *et al.*, 2011).

**Single leg squat (SLS):** The single leg squat can be used as an evaluation tool or can be performed as an exercise technique. For this, the individual being tested stands on the tested limb, the contralateral leg is lifted off the ground and the hip is held in a vertical position ( $0^\circ$ ) with the knee flexed to  $90^\circ$ . The individual squats down, holds the lowest knee position for a few seconds and returns to the starting position before placing the non-weight bearing foot on the ground (adapted from Livengood, DiMattia & Uhl, 2004).

**Temporal summation:** When two graded potentials from a single presynaptic neuron occur close together in time it is called temporal summation (Silverthorn, 2007).

## Abbreviations and acronyms

ADL's	–	Activities of daily living
AKPS	–	Anterior knee pain scale
BMI	–	Body mass index
CAF	–	Central analytical facility
CI	–	Confidence interval
FPPA	–	Frontal plane projection angle
ICC	–	Intraclass Correlation Coefficient
KOOS	–	Knee Injury and Osteoarthritis Outcome Score
MD	–	Mean difference
NRSP	–	Numeric rating scale for pain
PFJ	–	Patellofemoral joint
PFP	–	Patellofemoral pain
ROM	–	Range of motion
SD	–	Standard deviation
SLS	–	Single leg squat
UK	–	United Kingdom
VMO	–	Vastus medialis oblique
2D	–	two dimensional
3D	–	three dimensional



# Chapter 1

## INTRODUCTION

### 1.1 Background

Patellofemoral pain (PFP) is a common condition which affects 11% of people who consult a general practitioner for knee pain (Van Middelkoop, van Linschoten, Berger, Koes & Bierma-Zeinstra, 2008). It is the most common overuse injury in runners and is more prevalent in females and younger athletes (Taunton, Ryan, Clement, McKenzie, Lloyd-Smith & Zumbo, 2002). PFP impairs activities of daily living (ADL's), work related activities and, to a greater extent, sporting activities of its sufferers (Weiss & Whatman, 2015; Blond & Hansen, 1998). This condition tends to become a chronic problem and reportedly is a predisposing factor for the development of patellofemoral osteoarthritis (Brukner & Khan, 2012:690; Stathopulu & Baildam, 2003).

PFP is defined as retro- or peripatellar pain which is aggravated by activities that load the flexed knee joint, seen in common ADL's (Crossley, Stefanik, Selfe, Collins, Davis *et al.*, 2016; Witvrouw, Callaghan, Stefanik, Noehren, Bazett-Jones *et al.*, 2014; Crossley, Zhang, Schache, Bryant & Cowan, 2011). Intra-articular joint pathology is absent with PFP and the condition usually has an insidious onset (Nunes, Stapait, Kirsten, De Noronha & Santos, 2013; Callaghan & Selfe, 2012; Crossley *et al.*, 2011). Individuals with PFP will present with pain that is diffusely localised to the anterior knee and is worsened by activities that load the knee joint, including running, jumping, squatting, stair climbing and sitting with prolonged knee flexion (Green, 2005; McConnell, 2002).

The aetiology of PFP is poorly understood, but it has been proposed that increased patellofemoral joint (PFJ) stress may be resultant of the pain experienced in the anterior knee (Farrokhi, Keyak & Powers, 2011). Initially it was believed that malalignment and -tracking of the patella caused PFP, however, current literature proposes a multifactorial nature of PFP (Dutton, Khadavi & Fredericson, 2016). Weakness of the quadriceps, delayed activation of the vastus medialis oblique (VMO), hip muscle dysfunction, soft tissue restraints, training errors and poor lower limb biomechanics may all play important roles in the development of PFP (Dutton *et al.*, 2016; Willson & Davis, 2008a). It is important to consider that non-physical

characteristics may also contribute to the aetiology of PFP. Abnormal pain processing, such as impaired pain modulation and changes in somatosensory processing may be present in individuals with PFP (Rathleff, Peterson & Arendt-Nielsen, 2016; Jensen, Kvale & Baerheim, 2008).

One of the biomechanical risk factors that may contribute to PFP is altered dynamic limb alignment during functional activities. The specific impairments associated with altered dynamic limb alignment may manifest as a lack of control at the trunk, pelvis, hip, knee, ankle and foot in the frontal or transverse plane (Hewett, Lindenfeld, Riccobene & Noyes, 1999). One of the most typical patterns of altered dynamic limb alignment is ‘dynamic knee valgus’. Dynamic knee valgus involves multiple joints and takes place in multiple planes. Dynamic knee valgus comprises increased adduction and internal rotation of the hip and increased knee abduction and knee external rotation<sup>1</sup>, to varying degrees. This phenomenon is visually seen as excessive medial displacement of the knee during weight-bearing activities (Schmidt, Harris-hayes & Salsich, 2017; Powers, 2010). The valgus orientation of the lower limb, can cause laterally directed forces on the patella (Powers, 2010).

Current physiotherapy management strategies for PFP includes, but is not limited to, quadriceps strengthening, hip muscle strengthening, patellar taping, gait retraining, foot orthoses, stretching of the quadriceps, hamstrings and gastrocnemius muscle and activity modification (Collins, Barton, Middelkoop, Callaghan, Rathleff, *et al.*, 2018; Dutton *et al.*, 2016). Despite all the management strategies used for PFP, chronicity remains a problem. It has been reported that up to 75% of individuals with PFP still have pain after a year (Van Middelkoop, van der Heijden & Bierma-Zeinstra, 2017). The fact that not all individuals with PFP respond positively to the current management thereof raises the need to identify underlying factors causing PFP to lead to more effective management strategies.

Altered kinematics have been found at the trunk, hip, knee and ankle in individuals with PFP compared to controls during weight-bearing activities, however, there still are inconsistencies in the literature (Powers, Witvrouw, Davis & Crossley, 2017; Leibbrandt & Louw, 2017a; Nakagawa, Maciel & Serrão, 2015). These altered kinematics needs to be explored further to better understand the aetiology of PFP. The single leg squat (SLS) can be used as a test and provides information about the kinematic alterations of more demanding activities, such as running, without placing the associated high forces on the knee (Alenezi, Herrington, Jones & Jones, 2014). The SLS test can be used clinically to assess dynamic limb alignment (Willson,

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<sup>1</sup> ‘Knee external rotation’ is used to describe external rotation of the tibia in this study.

Ireland & Davis, 2006). The single limb stance position is reproduced during the SLS and is seen during ambulation activities and sports such as rugby, hockey and soccer (Alenezi *et al.*, 2014; Bailey, Selfe & Richards, 2010). Neuromuscular control during the gait cycle may be reflected in the performance of a SLS (Alexander, Crossley & Schache, 2009). The SLS is thus an appropriate tool to assess altered kinematics in individuals with PFP.

To date, five primary studies into lower limb kinematics in individuals with PFP compared to controls during a SLS have been published (Gwynne & Curran, 2018; Nakagawa *et al.*, 2015; Herrington, 2014; Nakagawa, Moriya, Maciel & Serrão, 2012; Willson & Davis, 2008a). These studies investigated 3-dimensional (3D) or 2-dimensional (2D) kinematics of individuals with PFP and controls. These studies demonstrated consistent findings regarding increased ipsilateral trunk lean, hip adduction and knee abduction in individuals with PFP (Gwynne & Curran, 2018; Nakagawa *et al.*, 2015; Herrington, 2014; Nakagawa *et al.*, 2012; Willson & Davis, 2008). However, there was inconsistent findings regarding hip internal rotation and there was only one study supporting increased contralateral pelvic drop and knee external rotation respectively (Nakagawa *et al.*, 2012; Willson & Davis, 2008a). Based on the findings of these studies, there is a need for further research, especially regarding contralateral pelvic drop, hip internal rotation and knee external rotation due to the conflicting evidence and limited number of studies investigating these factors.

Studies investigating the kinematic differences between people with PFP and controls during a SLS with the use of 3D motion analysis are limited. To the investigator's knowledge, no studies assessing the proximal, local and distal kinematics (trunk and lower limb) during a SLS in individuals with PFP, compared to controls have been conducted to date. Investigating this topic further could develop the SLS into a more meaningful clinical test that may assist clinicians to identify kinematic associated factors in individuals with PFP and improve the management thereof accordingly.

## **1.2 Study aim**

To determine the frontal and transverse plane kinematics of the trunk, pelvis, hip, knee and ankle in people with patellofemoral pain during a single leg squat.

### **1.3 Research question**

Are there differences in the frontal and transverse plane kinematics of the trunk, pelvis, hip, knee and ankle in people with patellofemoral pain and matched controls during a SLS?

### **1.4 Study objectives**

- I. To describe the sample demographics.
- II. To describe the frontal and transverse plane kinematics (peak ipsilateral trunk lean, peak contralateral pelvic drop, peak hip adduction, peak hip internal rotation, peak knee abduction, peak knee external rotation, peak rear-foot eversion at the lowest knee position) for participants with PFP during a SLS.
- III. To describe the frontal and transverse plane kinematics (peak ipsilateral trunk lean, peak contralateral pelvic drop, peak hip adduction, peak hip internal rotation, peak knee abduction, peak knee external rotation, peak rear-foot eversion at the lowest knee position) for healthy controls during a SLS.
- IV. To ascertain whether there are any differences in the frontal and transverse plane kinematics (peak ipsilateral trunk lean, peak contralateral pelvic drop, peak hip adduction, peak hip internal rotation, peak knee abduction, peak knee external rotation, peak rear-foot eversion at the lowest knee position) of the affected and unaffected leg/less affected leg in people with PFP during a SLS.

### **1.5 Thesis outline**

This study is presented in thesis format and comprises an Introduction (Chapter 1) and a Literature review on current knowledge with regard to PFP, focusing more on the kinematic associated factors (Chapter 2). The literature review is followed by the Methodology describing the methods and procedures used in this study (Chapter 3). Chapters detailing the Results (Chapter 4) and a Discussion (Chapter 5) follow. The thesis is concluded with a brief Conclusion (Chapter 6).

## Chapter 2

# LITERATURE REVIEW

### 2.1 Introduction

The aim of this literature review is to introduce the reader to the current concepts and the most recent literature on patellofemoral pain (PFP). PFP affects 11% of the general population who consult a general practitioner for knee pain and is more common in females and physically active individuals (Glaviano, Kew & Hart, 2015; Boling, Padua, Marshall, Guskiewicz, Pyne & Beutler, 2009; Van Middelkoop *et al.*, 2008). A burden of this condition is that it has a tendency to be persistent and to develop into a chronic knee condition (Van Middelkoop *et al.*, 2017). This literature review argues why more research is needed on the kinematic differences between individuals with PFP and normal controls during a single leg squat (SLS).

### 2.2 Methodology of the literature review

The following electronic databases were searched for appropriate literature sources from February 2017 to October 2018: PubMed, Google Scholar and Scopus. The search criteria for the literature sources were specified as from inception to October 2018. The key search terms used were: patellofemoral pain; anterior knee pain; patellofemoral pain syndrome; kinematics; squat and single leg squat. Articles that were included were limited to the English language.

### 2.3 Synonyms

The term PFP has many synonyms which are used interchangeably in the literature. These synonyms include PFP syndrome; anterior knee pain and/or syndrome; chondromalacia patella; and runner's knee (Crossley *et al.*, 2016). It was, however, decided at the 4th International PFP Research Retreat in Manchester that 'patellofemoral pain' is the favoured term to use (Crossley *et al.*, 2016). The term patellofemoral pain (PFP) is utilised for the purposes of this study.

### 2.4 Defining PFP

PFP is defined as retro- or peripatellar pain that is aggravated by activities that load the flexed knee joint, as seen in common activities of daily living (ADL's) such as ambulation, running,

squatting, kneeling and stair climbing (Crossley *et al.*, 2016; Witvrouw *et al.*, 2014; Crossley *et al.*, 2011). On clinical examination, intra-articular joint pathology is absent in patients with PFP and the condition usually has an insidious onset (Nunes *et al.*, 2013; Callaghan & Selfe, 2012; Crossley *et al.*, 2011).

## 2.5 The clinical presentation of PFP

A PFP sufferer will usually describe the knee pain as insidious in onset, with no clear event bringing it about. The pain is usually described as a vague ache that is diffusely localised to the anterior knee (McConnell, 2002). Pain is worsened by activities loading the flexed knee joint including running, jumping, squatting, walking down stairs and prolonged knee flexion (Green, 2005). Catching and buckling of the knee may also be reported while walking, and subjective experiences of swelling or stiffness in the knee may occasionally occur. However, if significant swelling is present, another diagnosis should be considered, for instance intra-articular injuries (McConnell, 2002). Equally important, according to Nunes *et al.* (2013), the best available test to diagnose PFP is pain elicited during a squat. The reason for this may be that squatting is a suitable example of an activity that loads the flexed knee joint, and consequently aggravates PFP. The diagnosis of PFP is made according to the area of pain, the duration of symptoms (at least three months), age, aggravating activities, manual palpation and exclusion of other conditions (Leibbrandt & Louw, 2017b).

## 2.6 The PFP population and prevalence

In the United Kingdom (UK), the annual prevalence of patellofemoral pain is 22.7% for the general population (Dey, Callaghan, Cook, Sephton, Sutton *et al.*, 2016). PFP affects 11% of people who consult a general practitioner for knee pain in the Netherlands and between 1.5 to 7.3% of individuals who consult physicians for orthopaedic care in the United States (Glaviano *et al.*, 2015; Van Middelkoop *et al.*, 2008). In the Western Cape, South Africa, 70% of patients visiting community health centres suffer from knee pain with insidious onset; the common diagnosis being osteoarthritis (Parker & Jelsma, 2010). Unfortunately, there is an absence of epidemiological data concerning PFP, specifically in South Africa. PFP is the most common condition in runners; furthermore it is more common in females and younger athletes (Glaviano *et al.*, 2015; Taunton *et al.*, 2002). Equally important, a study found that 6 to 7% of adolescents are affected by PFP to some degree, which places it among the most common knee conditions in adolescents (Rathleff, 2016; Rathleff, Roos, Olesen & Rasmussen, 2015). Two-thirds of adolescents with PFP are very physically active in sporting activities, which suggests that

excessive or repetitive loading does play a role in a group of adolescents who develop PFP (Rathleff, 2016). Adolescent females specialising in a single sport have an increased risk of developing PFP, compared to adolescent females participating in multiple sports. Possible reasons for this phenomenon are that more repetitive strain may be associated with the specialisation of single sports and a decrease in motor skill development as a result of reduced variety during training for a single sport (Hall, Foss, Hewett & Myer, 2015).

## **2.7 The burden of PFP**

PFP has a limiting effect on the ADL's, work-related activities and, to a greater extent, the sporting activities of its sufferers (Weiss & Whatman, 2015; Blond & Hansen, 1998). A study found that adolescents with PFP were more prone to the cessation or reduction of their sporting activities compared to those who experienced other types of knee conditions (Rathleff, Rathleff, Olesen, Rasmussen & Roos, 2016). The first qualitative study on how PFP affected the lives of individuals suffering from the condition was conducted in the UK (Smith, Moffatt, Hendrick, Bateman, Rathleff *et al.*, 2018). The study included females and males between the ages of 18 and 40 who were diagnosed with PFP. Loss of physical ability, functional ability and self-identity was evident in this study. Furthermore, this study found fear related to pain such as fear-avoidance beliefs with inappropriate strategies to cope; and fear of the future in individuals with PFP. Additionally, PFP sufferers also had pain-related confusion such as difficulty in understanding their knee pain, for example not comprehending how the radiological findings showed no pathology when there was so much pain. The physical activities that were affected in many PFP sufferers in this study were walking, physical exercise, driving, going on vacations, spending time with those close to them, playing with their children, activities at work and kneeling (Smith *et al.*, 2018). It is evident that PFP may cause a daily burden on many levels of everyday life for those suffering from the condition, therefore impacting their quality of life ("WHOQOL: Measuring Quality of Life", 2018).

## **2.8 The aetiology of PFP**

### **2.8.1 The multifactorial nature of PFP**

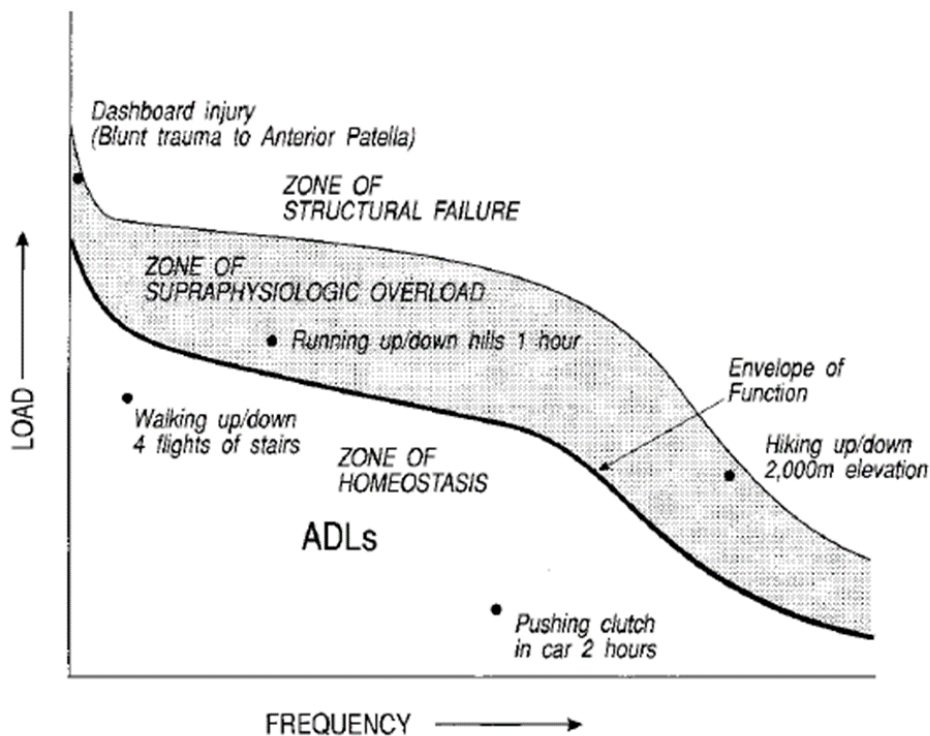
The aetiology of PFP is poorly understood, but it seems as if the pain associated with PFP may be the result of increased patellofemoral joint (PFJ) stress (Farrokhi *et al.*, 2011). Initially, it was believed that malalignment and/or mal-tracking of the patella caused PFP, but Dutton *et al.* (2016) have stated that PFP is multifactorial in nature and malalignment or excessive lateral

tracking of the patella may just be one of many causal patterns. Quadriceps weakness, delayed activation of the vastus medialis oblique (VMO), hip muscle dysfunction, soft tissue inflexibility, training errors and poor/altered lower limb biomechanics may play a cardinal role in the development of PFP (Dutton *et al.*, 2016; Willson & Davis, 2008a). Unfortunately, the cause-and-effect relationship of these factors remain unknown. Different perspectives on the causation of PFP are discussed in the next section.

### **2.8.2 Dye's theory on tissue homeostasis**

Dye (2005) used his theory of “tissue homeostasis” to describe the aetiology of PFP. “Homeostasis” refers to the situation where relatively constant conditions are maintained within an internal environment (Silverthorn, 2007). Dye (2005) stated that pathophysiological processes regularly caused by overload best describes the aetiology of PFP. Increased intraosseous pressure and osseous metabolic activity; inflamed synovial lining and fat pad tissues; and retinacular neuromas may all contribute to the perception of pain among PFP sufferers (Besier, Draper, Gold, Beaupré & Delp, 2005; Dye, 2005; Biedert & Sanchis-Alfonso, 2002). These processes together may be seen as a loss of tissue homeostasis. One loading event of a great magnitude or a number of smaller repetitive loading events may initiate the reparative biochemical process that suggests the loss of normal tissue homeostasis with PFP. The “envelope of function” is described as the range of pain-free loading in line with tissue homeostasis of a joint without the occurrence of a structural or physiological injury (Dye, 2001) (Figure 2.1). Maintaining activity levels within the “envelope of function” and restoring the “envelope of function” for example with rehabilitation exercises will therefore also restore tissue homeostasis (Dye, 2005; Dye, 2001). This concept may be helpful in understanding a possible cause of PFP and that activity modification, the correct management of PFP and rehabilitation of PFP will facilitate restoring pain-free function. It should be noted that this theory remains an expert opinion (level 5 evidence), although it has been presented exclusive to the pathophysiology of PFP (Powers, Bolgla, Callaghan, Collins & Sheehan, 2012).





**Figure 2.1: Envelope of function graph (Dye, 2001)**

### 2.8.3 Patho-mechanics of the kinetic chain

Poor dynamic limb alignment may be an important contributing factor to PFP. It presents as altered control at the trunk and lower limb joints in the frontal and transverse plane (Earl, Hertel & Denegar, 2005; Hewett *et al.*, 1999). In 2003, Professor Christopher Powers published his theoretical perspective on the influence of altered lower limb kinematics on dysfunction of the PFJ. In this paper Powers stated that PFP may be affected by lower limb segments and joints. More specifically, PFJ mechanics may be affected by altered movements of the femur and tibia in the frontal and transverse planes, increasing the laterally directed forces on the patella (Powers, 2003). Increased dynamic knee valgus of the knee produced by excessive hip adduction, hip internal rotation, knee abduction and knee (tibial) external rotation may, for example, increase the laterally directed forces on the patella (Salsich, Graci & Maxam, 2012). Additionally, it may be internal rotation of the femur underneath a stationary patella that could cause a lateral tilt and translation of the patella in a weight-bearing position, and not the patella itself (Powers, 2010). The assumption that an increased quadriceps-angle (Q-angle) will cause patellar lateralisation due to the patella moving on the femur is now questioned and is discussed in the next section (Powers, 2010).

### 2.8.3.1 Moving from a static Q-angle to dynamic knee valgus

The Q-angle is the acute angle formed by the crossing of two imaginary lines: a line formed from the anterior superior iliac spine (ASIS) to the middle of the patella and a line from the tibial tubercle to the middle of the patella (Levangie & Norkin, 2011: 430). For many years it has been believed that an increased static Q-angle was an important causative factor for PFP. However, there is conflicting evidence on this matter and the assumption that an increased Q-angle will lead to patellar lateralisation is now questioned (De Oliveira Silva, Briani, Pazzinatto, Gonçalves, Ferrari *et al.*, 2015; Powers, 2010). During functional weight-bearing activities, the patellar lateralisation may be due to the femur rotating internally underneath the patella. Furthermore, measuring the Q-angle in a non-weight-bearing position e.g. supine, does not account for femoral rotation (Powers, 2010). An increased static Q-angle, thus possibly is not a factor in the aetiology of PFP. However, a dynamic equivalent to the static Q-angle may play a role in the aetiology of PFP.

The dynamic equivalent of the Q-angle is dynamic knee valgus and may instead contribute to the development of PFP, when increased (Powers, 2010). Dynamic knee valgus involves multiple joints and takes place in multiple planes. Dynamic knee valgus is comprised of increased adduction and internal rotation of the hip; and increased knee abduction and knee (tibial) external rotation, to varying degrees. This phenomenon is visually seen as excessive medial displacement of the knee during weight-bearing activities (Schmidt *et al.*, 2017; Powers, 2010). A study was conducted to compare three different types of Q-angles between PFP cases and controls which involved a static clinical Q-angle test, a static measurement with a three-dimensional (3D) system and peak dynamic knee valgus during stair ascent. Results indicated a greater peak dynamic knee valgus in the PFP group, demonstrating the best discriminatory capability between the three Q-angle measurements. There were no significant differences between groups in the two static tests, therefore indicating poor discriminatory capability for the static tests (De Oliveira Silva *et al.*, 2015). It is better to observe PFP mechanisms during dynamic activities due to the higher mechanical and muscular demands required in the performance of the activity (De Oliveira Silva *et al.*, 2015). The influence of the kinematics on the different limb segments are discussed in more detail in section 2.11.

### 2.8.4 Non-physical features

PFP may be identified by physical, as well as non-physical features (Maclachlan, Collins, Matthews, Hodges & Vicenzino, 2017). Maclachlan *et al.* (2017) found that there may be an

elevation in anxiety, depression, fear of movement and catastrophising in PFP sufferers. Furthermore, the mentioned psychological characteristics correlated with pain severity and physical function in a linear manner. Abnormal pain processing such as impaired pain modulation and changes in somatosensory processing may also be present in PFP sufferers (Rathleff, Peterson, Arendt-Nielsen, Thorborg & Graven-Nielsen, 2016; Jensen, Kvale & Baerheim, 2008).

The first study investigating altered pain processing in young females with PFP was conducted by Rathleff, Peterson *et al.* (2016). They found that young females (between the ages of 19 and 21 years) with chronic PFP had a lower conditioned pain modulation<sup>2</sup> response than gender and age matched controls. However, no difference was found in facilitated temporal summation<sup>3</sup> between the groups. Conditioned pain modulation is an inhibitory mechanism and temporal summation is a facilitating mechanism of the central nervous system (Rathleff, Peterson *et al.*, 2016; Le Bars, Menetrey, Conseiller & Besson, 1975). The results of this study suggest that it may predominantly be the inhibitory mechanism of central processing that is affected in young females with PFP. If a painful conditioning stimulus cannot increase the pain thresholds, it may indicate a deficiency in the endogenous pain modulatory ability of the body (Rathleff, Peterson *et al.*, 2016). Contrary to these findings, another study found that there is no difference between adult males and females with PFP and age and sex matched controls in conditioned pain modulation and pain pressure thresholds (Rathleff, Rathleff, Stephenson, Mellor, Matthews *et al.*, 2017). Possible reasons that the authors provided for their results were that the cases were older and developed the PFP in their twenties compared to in their adolescent years, as in Rathleff, Peterson *et al.* (2016). Furthermore, the base line pain levels of the cases with PFP were lower than that of PFP participants in Rathleff, Peterson *et al.* (2016). Preliminary evidence suggests that pain experiences during adolescence or childhood may cause persistent effects which is not seen in adults (de Lalouviere, Ioannou & Fitzgerald, 2014). It is evident that more research is needed on pain processing in people with PFP to better understand its role in the aetiology or persistence of PFP.

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<sup>2</sup> Conditioned pain modulation is the phenomenon where the stimulus used to cause a change in pain perception (conditioning stimulus) affects the test stimulus (Yarnitsky, Arendt-Nielsen, Bouhassira, Edwards, Fillingim, Granot, Hansson, Lautenbacher, Marchand & Wilder-smith, 2010).

<sup>3</sup> When two graded potentials from a single presynaptic neuron occur close together in time it is called temporal summation (Silverthorn, 2007).

## 2.8.5 Recognition of risk factors

PFP is a condition that is known to be persistent and likely to develop into a chronic condition (Stathopulu & Baildam, 2003). If PFP had a clear aetiology, the chronicity problem would most probably also be addressed through more focused management strategies, especially for long-term management. The aetiology of PFP is an intricate interaction among various biomechanical, anatomical, psychological and social influences (Powers *et al.*, 2017). Recognition of the risk factors of PFP will lead to better and more individually tailored management and prevention of recurrence (Dutton *et al.*, 2016).

## 2.9 Current management strategies

### 2.9.1 Initial management

Initial treatment for PFP usually consists of activity modification (daily activities, as well as sporting activities) to a pain-free level, modalities for pain management and a short course of nonsteroidal anti-inflammatory drugs (Dutton *et al.*, 2016; Dye, 2005). Isolated quadriceps strengthening, guided by a physiotherapist, is proven to be superior to education to reduce pain and improve function in the management of PFP (Kooiker, Van De Port, Weir & Moen, 2014). With acute PFP and associated weakness, open kinetic chain exercises between 90° to 45° of knee flexion are better tolerated than closed kinetic chain exercises, due to the pain. Closed kinetic chain exercises, however, lead to better improvement in function in males and females with PFP (Barton, Lack, Hemmings, Tufail & Morrissey, 2015; Bakhtiary & Fatemi, 2008; Witvrouw, Lysens, Bellemans, Peers & Vanderstraeten, 2000; Stiene, Brosky, Reinking, Nyland & Mason, 1996). Closed kinetic chain exercises should thus be commenced in the management as soon as the PFP patient can tolerate it with regard to pain (Barton *et al.*, 2015).

Isolated VMO exercises and general quadriceps strengthening programmes both demonstrated improvement in subjective function and quality of life; and reduced pain in males and females with PFP. There was, however, no benefit in isolated VMO exercises above a general quadriceps strengthening programme (Syme, Rowe, Martin & Daly, 2009). A well-rounded general quadriceps strengthening programme is recommended (Dutton *et al.*, 2016).

## 2.9.2 Taping

Patellar taping is very commonly used in PFP management (Crossley, Cowan, Bennell & McConnell, 2000). Although there is a wide variety of taping techniques, McConnell taping is the most renowned in this study population. Patellar glide, tilt and/or spin are controlled during activities with this taping technique (Crossley *et al.*, 2000). Under dynamic MRI, McConnell taping appears to improve the position of the patella in the trochlear groove and increases the contact area between the patella and the femur (Derasari, Brindle, Alter & Sheehan, 2010). A systematic review conducted by Chang, Chen, Lee, Lin and Lai (2015) found that McConnell taping leads to pain relief and improved patellar alignment, whereas Kinesio taping may improve muscle flexibility and reduce pain in persons with PFP. Another systematic review found that evidence to support the effectiveness of McConnell taping for altering biomechanics or muscle activation patterns in males and females with PFP is still lacking (Leibbrandt & Louw, 2015). The routine use of McConnell taping is now in question and may not be indicated for all individuals suffering from PFP.

## 2.9.3 Combined treatments

A combination of McConnell taping, quadriceps strengthening and quadriceps stretching shows better improvement in pain measured with the Visual Analogue Scale (VAS), muscle strength (measured with a dynamometer) and muscle flexibility in PFP sufferers than the three modalities in isolation, although each modality on its own also demonstrated improvement (Mason, Keays & Newcombe, 2011). There is a lack of evidence advising lower limb muscle stretching in isolation in the management of PFP. There is evidence, however, that suggests that stretching of the quadriceps, hamstring, iliotibial band, and gastrocnemius in combination with strengthening exercises demonstrates benefits with regard to pain reduction and functional improvements in individuals with PFP (Dutton *et al.*, 2016). Foot exercises and foot orthosis added to a knee-targeted exercise programme in males and females with PFP with an everted foot posture, demonstrated significant changes in the pain subscale of the Knee Injury and Osteoarthritis Outcome Score (KOOS). The changes in the pain subscale of the KOOS was only significant at a four-month follow up, but not after 12 months (Mølgaard, Skovdal, Andreassen, Christensen, Lundbye-christensen *et al.*, 2018).

#### 2.9.4 Motor skill learning and functional training

Noehren, Scholz and Davis (2011) investigated the effect of real-time feedback during gait training on hip kinematics and pain in PFP participants while running. They found significantly reduced pain levels and hip adduction and contralateral pelvic drop ranges when running. These changes were maintained at a one-month follow-up. This study suggested that the underlying mechanisms, in this case atypical hip mechanics, should be attended to, as a reduction of pain in PFP sufferers also occurred with the improvement of the atypical hip mechanics.

Dawson and Herrington (2015) compared the outcomes of skill acquisition training<sup>4</sup> and a hip strengthening programme on lower limb kinematics in healthy recreationally active adults. The skills acquisition group were educated with regard to the correct way to perform a SLS and concerning common faults. The training originally was done in front of a mirror and with the contralateral foot on the floor. The hip strengthening group did four strengthening exercises of the gluteus medius and gluteus maximus. Both interventions improved the kinematics during the SLS after six weeks. However, only the skill acquisition training groups' kinematics were retained after 12 weeks, indicating changes in motor patterning that may prevent injuries fundamental over the long term (Dawson & Herrington, 2015). Skill acquisition training may show benefits in the management of PFP, but it should be tested in a PFP population first.

A feasibility study was conducted for a novel task-specific exercise programme for women with PFP (Salsich, Yemm, Steger-may, Lang & Van Dillen, 2018). The task-specific exercises included single limb stance, SLS's, sitting to standing, stair climbing and running focusing on optimal limb alignment and preventing common errors such as contralateral pelvic drop or dynamic knee valgus. Hip and knee kinematics, function and pain showed significant improvements following the programme. This kind of intervention can easily be performed in the home and will possibly translate into normal daily activities. However, further research is needed on this topic. In the above-mentioned study, the adherence of the study participants to the exercises was 79%. However, in another study, the adherence of young adolescents to exercise therapy was found to be low, with subsequent poor outcomes in patient-reported outcome measures, as well as physical activity level (Rathleff, Rathleff, Holden, Thorborg & Olesen, 2018). Possible reasons for the poor adherence of the young adolescents may be that they found the exercise sessions to be "boring" or too time consuming. The fact that the parents were not involved may also be a possible reason, however further research is needed on the

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<sup>4</sup> Through motor learning.

poor adherence of young adolescents to exercise therapy (Rathleff, Rathleff *et al.*, 2018). Individually tailored interventions for specific age groups will possibly improve adherence and outcomes.

### **2.9.5 Recommendations of an expert panel**

Recommendations for PFP management, based on the highest level of evidence available, were made by expert panels from the 4<sup>th</sup> and 5<sup>th</sup> International PFP Research Retreats, at Manchester (UK) and the Gold Coast (Australia) respectively (Collins *et al.*, 2018; Crossley, Van Middelkoop, Callaghan, Collins, Rathleff & Barton, 2016). Registrants at these retreats were world leading researchers of PFP. A number of key recommendations were made, including that exercise therapy is beneficial for an improvement in function and a reduction in pain; and combining hip and knee exercises may yield better results in decreasing pain and improving function than knee exercises only. Moreover, combining PFP interventions leads to decreased PFP in the short to medium term; and foot orthoses leads to a reduction in pain in the short term (at six weeks). Electrotherapy and mobilisations of the PFJ, knee and lumbar area was not found to be beneficial in the management of PFP and thus not recommended as interventions.

Conflicting evidence for the use of patellar taping, gait retraining, soft tissue therapy, blood flow restriction training and dry needling in the management of PFP remains. A limitation of randomised control trials of exercise therapy for PFP was the omission of a detailed exercise therapy prescription such as the dosages, sets and repetitions. This limitation of exercise prescription may prevent clinicians from applying findings in clinical practice effectively (Holden, Rathleff, Jensen & Barton, 2018). The multifactorial nature of PFP necessitates a multimodal approach to allow better management efficiency (Barton *et al.*, 2015). Although positive short-term outcomes have been shown in the management of PFP, the long-term outcomes are less convincing and this can be linked to the chronicity of PFP which is discussed in more detail in the next section (2.10).

## **2.10 The chronicity of PFP**

PFP has the tendency to develop into a chronic knee condition (Stathopulu & Baildam, 2003). A study investigating the prognosis of PFP in adults and adolescents of both genders at a one-year follow-up, found that nearly 75% of participants still had pain at their follow-up appointments (Van Middelkoop *et al.*, 2017). Rathleff, Rathleff *et al.* (2016) concluded from their cohort study that there is a 1.26 higher relative risk for adolescents with PFP to still

experience pain at a two-year follow-up compared to other types of knee pain. PFP reportedly is a predisposing factor for the development of patellofemoral osteoarthritis (Brukner & Khan, 2012:690). A retrospective study conducted by Stathopulu and Baildam (2003) found that 91% of individuals with PFP during adolescence still had pain after four to 18 years.

A retrospective study comparing PFP in early life between patellofemoral arthroplasty patients and medial unicompartmental arthroplasty patients was conducted by Utting, Davies and Newman (2005). Twenty-two percent of the patellofemoral arthroplasty patients had PFP as adolescents or early in adulthood compared to 6% of the medial unicompartmental arthroplasty patients ( $p < 0.001$ ). It is evident from supporting studies that the chronicity of PFP may lead to a decline in the quality of life and sports participation in individuals, especially adolescents, diagnosed with PFP (Smith *et al.*, 2018). The rapid growth spurt during adolescence and rigorous training programmes (in adolescent athletes) may increase adolescents' risks for repetitive strain injuries (Dalton, 1992). It is fit to say that PFP is not as self-limiting and harmless as initially considered. Causative factors of PFP should be identified to follow a more targeted approach in the management of the condition. Altered kinematics present one of the factors that may contribute to PFP; this is discussed in more detail in the next section (2.11).

## **2.11 Kinematics in the PFP population**

Poor dynamic limb alignment may be an important contributing factor to PFP and may be assessed by investigating the kinematics of the joints (Hewett *et al.*, 1999). Kinematics is the branch of biomechanics where the motion of a segment is described without regarding the forces that are causing the movement (Levangie & Norkin, 2011). Initially, kinematics was assessed with 2-dimensional (2D) motion analysis (using a video camera). Transverse plane movements could not be measured with 2D motion analysis, however. It was only after 2007 that 3D motion analysis was used to investigate the kinematics of dynamic limb alignment in activities such as a SLS in people with PFP (Bailey *et al.*, 2010). Three-dimensional motion analysis has become the 'gold standard' for investigating the kinematics of "high risk manoeuvres" associated with knee injuries, including PFP (McLean, Walker, Ford, Myer, Hewett & Van den Bogert, 2005).

### **2.11.1 The SLS as a test**

The SLS test is a simple, convenient, inexpensive test that can be used clinically to assess dynamic limb alignment (Willson *et al.*, 2006). The single limb stance position is taken up



during the SLS test and is seen during ambulation activities and sports such as rugby, hockey and soccer (Alenezi *et al.*, 2014; Bailey *et al.*, 2010). Furthermore, the SLS test provides information about the kinematics of these more demanding activities, without placing the associated high forces on the knee (Alenezi *et al.*, 2014). Neuromuscular control during the gait cycle may be reflected in the performance of a SLS (Alexander *et al.*, 2009). Additionally, Nunes *et al.* (2013) found that the best available test to diagnose PFP is pain elicited during a bilateral squat. However, the SLS has only recently been used as a test among researchers to assess PFP (Bailey *et al.*, 2010).

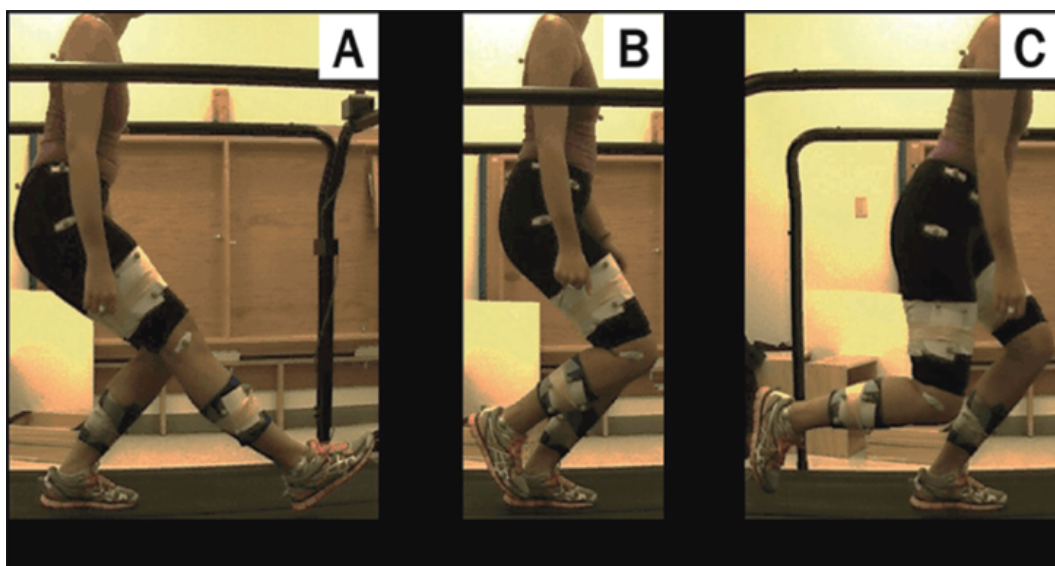
### **2.11.2 The history and methods of performing the SLS**

In 2002, Liebenson, a chiropractor from the United States of America, was the first to use the SLS exercise as a test to identify movement dysfunctions within the kinetic chain (Bailey *et al.*, 2010). Livengood, however, was the first to describe the method of performing the SLS in 2004. The tested individual has to stand on the tested limb, the contralateral leg is lifted off the ground and the hip is flexed to about 45° with the knee flexed to 90°. The shoulders are flexed forward to 90°, the elbows are in extension and the hands are clasped together. The individual squats down to about 60° knee flexion and returns to the starting position within six seconds (Livengood *et al.*, 2004). Many studies do not use Livengood's method (Nakagawa *et al.*, 2015; Herrington, 2014; Nakagawa *et al.*, 2012; Willson & Davis, 2008a). The reason for this may be the unnatural positions of the upper limbs used in this method. Instead, a number of authors have used their own methods or they omit the description of the joint angles and positions during the execution of the SLS in their studies (Bailey *et al.*, 2010). It is therefore difficult to compare different SLS studies due to the variability in the upper limb and lower limb joint angles and positions during the performance of the SLS.

### **2.11.3 The importance of describing segment positions during SLS performance**

Khuu, Foch and Lewis (2016) conducted a study on how the position of the non-weight-bearing leg during a SLS affects biomechanics in three different positions in healthy female participants: SLS-back (with the non-weight-bearing hip in a vertical position), SLS-middle (the non-weight-bearing foot is held in line with the weight-bearing ankle) and SLS-front (the non-weight-bearing knee is extended to the front) (Figure 2.2). SLS-back had the most joint kinematic differences when compared to the other two positions. More specifically, SLS-back showed the greatest amount of ipsilateral trunk lean and contralateral pelvic drop. The largest

effects of changing the non-weight-bearing leg position were observed at the hip and pelvis. It is evident that joint positions are important to describe during a SLS, as it may affect the angles at the other joints. The position of the non-weight-bearing leg should be taken into consideration when comparing SLS studies.



**Figure 2.2: Non-stance limb position. (A) SLS-front, (B) SLS-middle, (C) SLS-back (Khuu, 2016)**

#### **2.11.4 Systematic review on SLS studies in the PFP population**

Studies investigating the lower limb and trunk kinematics in individuals with PFP during a SLS are limited. Leibbrandt and Louw (2017a) synthesised the evidence base of lower limb kinematic factors associated with PFP during aggravating activities including the SLS. This is the only systematic review investigating the kinematics of the SLS in the PFP population to date. Supporting evidence was found of two or more cross-sectional studies with consistent and significant results supporting increased ipsilateral trunk lean, increased knee abduction and increased hip adduction in individuals with PFP, thus making these factors priority contributing factors to PFP. Only one cross-sectional study with significant findings supporting increased contralateral pelvic drop as a contributing factor to PFP, was included in this review. Numerous methodological limitations were evident in the included studies. Some studies only included females and none of the studies investigated distal factors such as the ankle and foot. One study used 2D kinematics, which omits the description of movements in the transverse plane. The position of the non-weight-bearing limb and arms (during the SLS) was not specified in some of the studies, which makes it difficult to compare results (Nakagawa *et al.*, 2015; Herrington, 2014; Nakagawa *et al.*, 2012; Willson & Davis, 2008a). Evidently, there is a need for further

research addressing these methodological limitations. The individual studies included in this review are discussed in more detail in section 2.11.8.

### **2.11.5 Frontal plane kinematics in persons with PFP**

This section addresses the frontal plane trunk and lower limb kinematics of individuals with PFP and it will be addressed in a proximal to distal order. There is evidence in support of increased frontal plane trunk movements in individuals with PFP during walking (Nakagawa *et al.*, 2015). Furthermore, increased ipsilateral trunk lean during closed-chain activities was found in people with PFP (Nakagawa *et al.*, 2012). The trunk comprises more than 50% of the body weight and immoderate motion at the trunk may thus increase loading at the knee and possibly also PFJ stress (Powers, 2010). It was found that persons with PFP demonstrated decreased trunk muscle strength, compared to controls (Nakagawa *et al.*, 2015). The weaker trunk muscles may account for the increased ipsilateral trunk lean in persons with PFP.

Ipsilateral trunk lean may be a compensatory strategy to decrease the loads on weaker hip abductor muscles responsible for the frontal plane stability of the pelvis (Dierks, Manal, Hamill & Davis, 2008). Weakness of the hip abductor muscles may also account for increased contralateral pelvic drop in persons with PFP during weight-bearing activities by moving the centre of mass more medially relative to the weight-bearing limb (Powers, 2010). Hip adduction may be a result of the drop of the contralateral pelvis, the femur adducting in relation to the pelvis, or a combination of both (Nakagawa *et al.*, 2012). It is important to account for the effects that the movement of different joints will have on each other in the kinetic chain during weight-bearing activities.

The hip and the knee joints share the femur as a segment; this characteristic may explain why abnormal kinematics at the hip can contribute to altered tibiofemoral kinematics (Powers, 2010). The combination of hip adduction, hip internal rotation, knee abduction and knee external rotation leads to medial displacement or valgus formation of the knee (Salsich *et al.*, 2017; Willson & Davis, 2008a). A moderate association has been found between increased hip adduction and PFP, proved by the conclusions of two systematic reviews (Neal, Barton, Gallie, O'Halloran & Morrissey, 2016; Meira & Brumitt, 2011). Excessive hip adduction may be revealed in persons with PFP during activities such as running and jump landings (Neal *et al.*, 2016; Meira & Brumitt, 2011). Furthermore, the results of a prospective study showed that runners who went on to develop PFP had larger hip adduction angles (Noehren, Hamill & Davis, 2013). However, another study found that runners with PFP demonstrated less hip

adduction during running, compared to controls (Dierks, Manal, Hamill & Davis, 2011). Conflicting evidence in the literature supporting or not supporting the existence of increased hip adduction in individuals with PFP evidently remains.

Nakagawa *et al.* (2012) found that hip adduction and hip internal rotation kinematics were larger in females compared to males with PFP. Furthermore, a systemic review found that females with PFP had significantly weaker hip abductors, extensors and external rotators when compared to healthy female controls (Van Cant, Pineux, Pitance & Veronique, 2014). Furthermore, another study reported that males with PFP only demonstrated deficits in hip extensor strength, but not in the external rotators or abductors of the hip (Hoglund, Burns & Stepney, 2018). Differences in strength deficits in the hip musculature of males and females with PFP may account for the differences in their hip kinematics. Contradictory evidence was reported in a prospective study that found that adolescent females who later developed PFP had greater hip abductor muscle strength than their counterparts who did not develop PFP (Herbst, Barber Foss, Fader, Hewett, Witvrouw *et al.*, 2015). It was furthermore concluded, from a systematic review and meta-analysis including reported prospective studies, that there is no association between hip strength and the development of PFP and that PFP may rather cause hip muscle weakness, instead of the other way around (Rathleff, Rathleff, Crossley & Barton, 2014).

Increased hip adduction, hip internal rotation and knee abduction have been reported to be correlated with self-reported pain and function in PFP sufferers (Nakagawa, Serrão, Maciel & Powers, 2013). Individuals with PFP demonstrate increased knee abduction during gait, squatting, stepping and hop landings, but interestingly not during running or stair descent (Powers *et al.*, 2017). Laterally directed forces acting on the patella may be increased by knee abduction (Powers, 2003). Moreover, an increase in rear-foot eversion may contribute to tibial abduction relative to the femur and thus also to an increased dynamic knee valgus (Levinger, Gilleard & Sprogis, 2006).

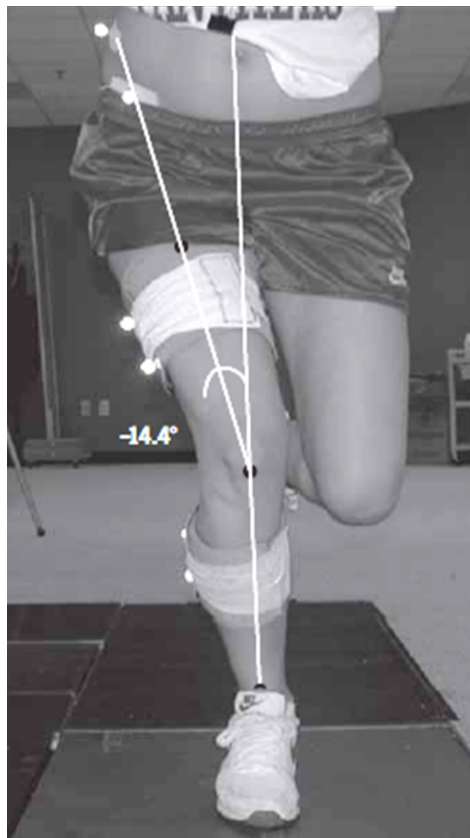
An increase in dynamic knee valgus was found to be associated with increased rear-foot eversion in basketball players with a knee injury history (Kagaya, Fujii & Nishizono, 2015). Increased rear-foot eversion may also be a kinematic risk factor for the development of PFP, due to its association with dynamic knee valgus. Furthermore, females with PFP demonstrated increased rear-foot eversion during the transition phase<sup>5</sup> of a single leg triple hop test ( $p = 0.019$ ) (Dos Reis, Ferrari Correa, Bley, Dos Anjos Rabelo, Fukunda & Garcia Lucareli, 2015). A recent

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<sup>5</sup> A weight-bearing position between a landing and a hop.

study found that there is a positive correlation between greater peak rear-foot eversion and increased peak hip adduction in runners with PFP during running (Calazans Luz, Flávia dos Santos, Carvalho de Souza, de Oliveira Sato, Nawoczenski & Serrão, 2018). Kinematic alterations at different levels of the kinetic chain may thus influence each other.

The frontal plane projection angle (FPPA) is a 2D measure of dynamic knee valgus and can be used to measure dynamic knee valgus during a SLS (Wyndow, Jong, Rial, Tucker, Collins, Vicenzino *et al.*, 2016; Herrington, 2014). The angle is formed by the crossing of two lines: a line from the anterior superior iliac spine to the midpoint of the femoral condyles and a line from the midpoint of the femoral condyles to the midpoint of the ankle malleoli (Herrington, 2014) (Figure 2.3). The FPPA has been found to be correlated with 3D kinematics of the knee during dynamic tasks such as running which enhances the clinical utility of the test (Whatman, Hing & Hume, 2011). It has been found that the FPPA, during a SLS, correlated significantly with the 3D knee external rotation angle and not with knee frontal plane movement (adduction or abduction of the tibia) (Willson & Davis, 2008b). Transverse plane motions of the lower limb may therefore contribute more towards a dynamic knee valgus than current beliefs suggest.



**Figure 2.3: Frontal plane projection angle (Willson & Davis, 2008b)**

### 2.11.6 Transverse plane kinematics in individuals with PFP

This section addresses the transverse plane hip and knee kinematics of individuals with PFP. Conflicting evidence supports increased hip internal rotation in individuals with PFP. A moderate association has been demonstrated between hip internal rotation and PFP during running in one systematic review (Neal *et al.*, 2016). Powers (2003) found decreased hip internal rotation in persons with PFP during walking and reasoned that this might happen as a compensatory mechanism to decrease retro-patellar stress. Furthermore, this compensation might be easier during less demanding activities such as walking and possibly partially successful during higher demand activities such as a SLS. In the same way, increased external rotation of the knee has been demonstrated in females with PFP during running, SLS's and jumping (Willson & Davis, 2008a). However, greater knee internal rotation has been reported in persons with PFP during stair decent (Schwane, Goerger, Goto, Blackburn, Aguilar & Padua, 2015). There evidently is also conflicting evidence regarding transverse plane knee kinematics in individuals with PFP, which could be indicative of an insufficient amount of available literature addressing the transverse plane knee kinematics in individuals with PFP.

It was found that the contact area between the patella and femur increases with an increase in knee flexion (Besier *et al.*, 2005; Salsich, Ward, Turk & Powers, 2003). During lower knee flexion activities such as gait and running, there may thus be less available contact area for the distribution of PFJ reaction forces<sup>6</sup> (Powers *et al.*, 2017). Internal rotation of the femur in relation to the tibia demonstrated an association with decreased PFJ contact area, as well as increased PFJ stress at a knee flexion angle between 15° to 45° (Liao, Yang, Ho, Farrokhi & Powers, 2015), but not at 60° (Besier, Gold, Delp, Fredericson & Beaupré, 2008). Femoral internal rotation thus has a smaller effect on contact area during larger knee flexion angles (Powers *et al.*, 2017). On the other hand, external rotation of the tibia may reduce the contact area of the patella and increase PFJ stress (Lee, Yang, Sandusky & McMahon, 2001).

The biomechanical effects that rotation of the femur and the tibia has on the PFJ are distinctly different due to the patellar tendon attaching on the tibial tuberosity. During external rotation of the tibia (when the tibial tuberosity moves laterally), the patellar tendon will pull on the inferior pole of the patella and cause a rotational movement of the patella in the frontal plane and pull the inferior pole of the patella laterally. This rotation movement about the centre of the patella causes the superior edge of the patella to move medially (Lee, Morris & Csintalan,

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<sup>6</sup> The PFJ reaction forces are the compression measure of the patella against the femur (Bentley & Dowd, 1984).

2003). Lee *et al.* (2003) reported that the contact pressure will increase on the ipsilateral facets of the patella during rotation of the tibia. Thus, external rotation of the tibia will lead to increased contact pressure on the lateral patellar facets, and that might contribute to the pain experienced by persons with PFP. The opposite will happen during femoral rotation: there will be an increase in contact pressure on the contralateral facets of the patella. Thus, with internal rotation of the femur, the contact pressure will increase on the lateral patellar facets (Lee *et al.*, 2003).

### **2.11.7 The amount of kinematic alterations**

A study investigated the kinematics of females with PFP at the proximal, local and distal levels of the lower limb kinetic chain (peak hip adduction, peak knee flexion and peak rear-foot eversion, respectively). It was found that participants with more kinematic alterations (three alterations) had higher pain levels and a lower functional level compared to those with only two kinematic alterations (Ferrari, Briani, de Oliveira Silva, Pazzinatto, Ferreira *et al.*, 2018). It is worth noting that not all kinematic alterations occurred at the same lower limb level (proximal, local and/or distal). Some women had alterations at the proximal and local level, while others had it at the distal and local levels or distal and proximal levels. PFP is multifactorial in nature and it also seems so when it comes to the kinematic associated factors (Ferrari *et al.*, 2018).

### **2.11.8 SLS studies in the PFP population**

Researchers in Brazil assessed 3D kinematics in a cross-sectional study involving subjects with PFP and controls (Nakagawa *et al.*, 2012). Their findings showed that, compared to controls, individuals with PFP had increased ipsilateral trunk lean, contralateral pelvic drop, hip adduction and knee abduction when performing a SLS. Another study, by the same authors, compared kinematics between PFP participants and controls and also found that the PFP group showed increased ipsilateral trunk lean, hip adduction and knee abduction during a SLS (Nakagawa *et al.*, 2015). Interestingly, in this study increased ipsilateral trunk lean was associated with smaller hip adduction angles and with increased knee abduction only in controls. However, it was hypothesised that this would also be the case for the PFP participants, as less hip adduction may occur with the compensatory lean of the trunk towards the weight-bearing limb (Dierks *et al.*, 2011). These findings suggest that poor dynamic limb alignment and altered kinematics may be important contributing factors in the development or aggravation of PFP. However, further investigations are required to advance the understanding of how one kinematic alteration impacts the next.

Willson and Davis (2008a) conducted a study to determine whether activities increasing in difficulty would lead to greater differences in kinematics between females with PFP and female controls. Running, SLS's and repetitive jumps were performed and measured with 3D motion analyses. The individuals with PFP had more knee external rotation, more hip-adduction and less internal rotation of the hip across all three activities, compared to the controls. No significant difference was found in the biomechanics with more demanding activities in either group. The PFP group, however, demonstrated similar abnormal kinematics across all activities.

In contrast to the findings by Willson and Davis (2008a), Herrington (2014) investigated the knee valgus angle in PFP participants compared to healthy controls. The FPPA during a SLS and a single leg hop landing task was measured. The PFP group had a significantly greater knee valgus angle for both tasks, compared to their unaffected leg and to controls. It was more difficult for both the cases and controls to maintain limb alignment with an increase in task demands (SLS to single leg hop landing task). More demanding activities may increase the stress on the PFJ, for example in athletes who perform more demanding activities. These two studies thus had conflicting findings regarding the kinematic differences in PFP sufferers with an increase in activity demands (Herrington, 2014; Willson & Davis, 2008a). It may be that persons with PFP employ compensation strategies if the pain level reaches a certain point or if the activity is still easy enough for the individual to use compensation strategies (Powers, 2003).

Studies investigating the kinematics of the ankle and foot during a SLS in individuals with PFP are limited. An increase in the peak rear-foot eversion angle was found in PFP participants compared to controls during a SLS (Levinger *et al.*, 2006). This increase in rear-foot eversion may contribute to tibial abduction relative to the femur and thus also to an increased knee valgus angle (Levinger *et al.*, 2006). This statement relates to the findings above of an increase in knee abduction in individuals with PFP during a SLS (Nakagawa *et al.*, 2015; Herrington, 2014; Nakagawa *et al.*, 2012). Investigating the kinematics of the distal joint factors of the kinetic chain (e.g. ankle and foot) during a SLS can contribute to the knowledge base of the associated factors of PFP. Common aggravating activities of PFP are weight-bearing in nature (with a flexed knee) and thus closed-chain activities are appropriate when investigating kinematic alterations in individuals with PFP (Crossley *et al.*, 2016).



## 2.12 Conclusion

PFP is a common condition that affects its sufferers on a daily level. This condition furthermore tends to become chronic, despite the extensive literature base (including management strategies) on PFP (Van Middelkoop, *et al.*, 2017). The fact that the majority of individuals with PFP do not respond to the current management thereof raises the need to identify underlying factors for PFP development to lead to more effective management strategies. Studies investigating the kinematic differences between participants with PFP and controls during a SLS are limited with conflicting findings especially with regards to the transverse plane kinematics of the hip and the knee. Investigating this topic further could develop the SLS into a more meaningful clinical test that may assist clinicians to identify kinematic associated factors in individuals with PFP and improve the management thereof accordingly. The next chapter (Chapter 3) provides a discussion of the methodology implemented in this study with the aim of identifying the kinematic associated factors in PFP participants and addressing methodological limitations from previous SLS studies (see section 2.11.4).

## Chapter 3

# METHODOLOGY

### 3.1 Introduction

This chapter details and motivates the methodology, including the design, setting and population of the study, the procedures followed, data management and the pilot study implemented to answer the research question. The ethical and legal considerations of the study are also discussed in this chapter.

### 3.2 Study design

The design of the study is that of a descriptive cross-sectional study as it is relatively cost and time efficient. Both the outcome and the exposure of study participants were measured at the same time.

### 3.3 Study setting

The study took place in a laboratory setting at the Central Analytical Facility (CAF) Neuromechanics unit at the Coetzenburg Sports Complex, Stellenbosch University, Stellenbosch, South Africa. The unit has a team of instrument specialists who provide technical support to researchers, product designers or service providers in a range of different fields such as physiotherapy, ergonomics, biomedical engineering and sport science (Neuromechanics Unit, 2013).

### 3.4 Study population

Males and females between the ages of 14 and 50 years who reside in the Cape Town Metropolitan and Cape Winelands district formed the study population. Half of the participants had patellofemoral pain (PFP) and the other half comprised healthy controls matched for age and gender to the PFP group. Participants were recruited from March 2018 to August 2018.

### **3.4.1 Inclusion and exclusion criteria**

Males and females who met the 'checklist for the diagnosis of anterior knee pain' created by Leibbrandt and Louw (2017b) were considered for inclusion. The objective tests on Leibbrandt and Louw's evidence-based clinical checklist are based on high quality evidence.

#### **3.4.1.1 Inclusion criteria for possible PFP participants (cases) were**

- Participants had to be between the ages of 14 and 50 years (to exclude Osgood-Schlatter's disease and possible osteoarthritis);
- The area of pain had to be peripatellar or retro-patellar;
- There had to be insidious onset of the PFP not related to an injury or trauma;
- The pain had to be present for longer than three months;
- The PFP had to be aggravated by prolonged sitting with a flexed knee, squatting, kneeling or stair climbing (ascending or descending).

#### **3.4.1.2 Exclusion criteria for possible PFP participants**

- Age of participants if older than 50 years, due to a greater likelihood of degenerative joint changes such as osteoarthritis;
- Previous surgery performed to the lower limb, lumbar or pelvic area (Single leg squatting is a strenuous functional activity and previous surgery of the mentioned areas may affect the kinematics of the squat.);
- A history of trauma to the knee;
- Presence of a rheumatological condition (In the subjective evaluation participants were asked whether they had ever been diagnosed with a rheumatological condition, as such a condition might affect lower limb biomechanics.);
- Intra-articular knee pathology such as a ligament injury and osteoarthritis;
- Patellar instability or subluxation/ dislocation based on the history in the subjective examination and patellar mobility in the objective examination;
- Effusion of the knee based on the subjective evaluation and the patellar ballottement test performed during the objective examination;
- Fat pad impingement/ bursitis or patellar tendinopathy in the participant;

- History or presence of Osgood Schlatter's disease;
- Referred pain from the hip or lumbar spine as evaluated during the objective examination.

### **3.4.1.3 Matching criteria for possible controls**

The matching criteria for controls and cases were age and gender, as used in a similar study that also investigated the kinematics of individuals with PFP compared to controls during a SLS (Nakagawa *et al.*, 2012). The matching factors represent the most common clinical considerations that could have influenced the main study outcomes. We focussed on the most clinical-relevant factors, as deemed by the research team, so that recruitment of study participants remained feasible.

### **3.4.1.4 Exclusion criteria for possible controls**

- Previous injuries to the knee of the participant;
- Previous surgery performed to the lower limb, lumbar or pelvic areas;
- A major injury sustained to the lower extremity in the preceding six months;
- Presence of an existing rheumatological condition;
- Injuries or pain present at the time of testing.

## **3.4.2 Sample size and power analysis**

The sample size was calculated using the hip adduction range of motion during a single leg squat (SLS) from a similar study that also compared the kinematics of PFP participants and controls (Nakagawa *et al.*, 2012). Hip adduction range of motion was chosen, because there is supporting evidence that people with PFP have increased hip adduction compared to controls during a SLS (Leibbrandt & Louw, 2017a). Calculations for the current study were made using alpha ( $\alpha$ ) = 0.05, power = 80%, standard deviation (SD) = 6.7 and an expected difference between groups of 4°. It was decided on a 4° difference for this study as hip adduction range of motion during functional activities is usually small, thus 4° should indicate a difference. In addition, Nakagawa *et al.* (2012) used an expected difference of 4.1° between cases and controls. Based on these parameters, a sample size of 25 subjects per group was estimated to adequately power this current study.

### **3.5 Recruitment and sampling method**

Convenience sampling was used to recruit the study participants as the time and costs involved is much less than other sampling techniques and was appropriate for this master's level study (Convenience sampling, 2012). Advertisements were distributed in communities, universities, colleges, public schools and private schools in and around Stellenbosch (Appendices A & B). Electronic advertising was also used on Facebook pages of various sports groups such as running and athletics clubs. These methods of advertising attracted a diverse group of participants of different ages, backgrounds, activity levels and sporting codes, with the aim to reduce selection bias and sampling error. Additionally, invitational letters and advertisements were sent to sporting clubs, physiotherapy practices, general medical practitioners and orthopaedic surgeons to invite potential participants with PFP (Appendix C). Participants who volunteered to partake in the study and complied with the inclusion criteria of either the case or the control groups formed part of the study. The electronic advertising had the greatest response rate and most participants were recruited through this method.

### **3.6 Data collection tools**

The data collection tools utilised in the study are described in a chronological order (as utilised in the study) in this section.

#### **3.6.1 Initial screening questionnaires for cases and controls**

A 'PFP initial screening questionnaire' (Appendix D), as well as a 'Control initial screening questionnaire' (Appendix E), was created for the screening process of potential participants. Information that was obtained from the 'PFP initial screening questionnaire' was age, gender, the area of the knee pain, the duration of symptoms, aggravating activities and previous injuries or surgeries. A few questions were added to the original 'PFP initial screening questionnaire' to further exclude other knee conditions and to decrease the chances of excluding participants only after the physical examination. The 'control initial screening questionnaire' included sections for demographics, activity level/sport participation, previous injuries or previous surgeries and current injuries or pain.

### 3.6.2 ‘Checklist for the diagnosis of anterior knee pain’

The ‘checklist for the diagnosis of anterior knee pain’<sup>7</sup> created by Leibbrandt and Louw (2017b) was developed for researchers and clinicians to use in the diagnosis of PFP and was utilised in this study (Appendix F). Two systematic reviews were identified to create the checklist. Subjective factors were only included if both systematic reviews identified it as important in diagnosing PFP. Two or more reviews needed to show a sensitivity of 70% or greater or a positive likelihood ratio of five or greater for objective tests to be included. The ‘Checklist for the diagnosis of anterior knee pain’ has already been used successfully in a South African study (Leibbrandt & Louw, 2018).

Subjective information obtained with this checklist concerned age, area of symptoms, chronicity, aggravating activities and a list of exclusion criteria. The objective tests on Leibbrandt and Louw’s evidence based clinical checklist are based on high quality evidence (Leibbrandt & Louw, 2017b). The objective tests include squatting, kneeling, ascending and descending a flight of stairs (a minimum of three steps), isometric quadriceps contraction, palpation of the patella borders, patellar compression test, and patellar tilt test. Most of these tests or certain combinations of them had to be positive for the diagnosis of PFP (Leibbrandt & Louw, 2017b). If the Lachman’s test, McMurray’s test, posterior drawer test, varus stress test, valgus stress test or patellar ballottement test was positive, the PFP diagnosis could not be made, because no imaging or other diagnostic tests were performed to exclude other conditions.

### 3.6.3 Anterior knee pain scale (AKPS)

The AKPS is a functional questionnaire, comprising 13 items dealing with tasks that are performed daily by most PFP sufferers and may contribute to the pain experienced (Kujala, Jaakkola, Koskinen, Taimela, Hurme & Nelimarkka, 1993). The scale is scored out of 100 points. The higher the score, the less disability the participant is experiencing. The AKPS has been found to have good test-retest reliability with an intraclass correlation coefficient (ICC) of 0.81. It has also been found to be one of the most responsive and valid outcome measures to indicate the effect of PFP treatment (Crossley, Bennell, Cowan & Green, 2004). A 10-point change (out of 100 points) for the AKPS will demonstrate a clinically significant change in the sufferer’s symptoms (Crossley *et al.*, 2004) (Appendix G).

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<sup>7</sup> Anterior knee pain is a synonym for PFP and the terms are used interchangeably in the literature.

### 3.6.4 H-frame as a guide for knee range of motion (ROM)

A H-frame structure was used as a range of motion guide, assisting participants to reach the target knee flexion angle during the SLS (Clark, Akins, Heebner, Sell, Abt, Lovalekar & Lephart, 2016). Two stools with a string spanned between them formed a H-frame structure (see Figure 3.1). Tape was placed on the floor in line with the string, as a reference point for participants as to where to place their feet (the participant's toes had to touch the tape). The goal was for the string to touch the knee of the participant at the lowest position during the SLS. It was decided to aim for a knee flexion angle of  $50^\circ$  (between  $40^\circ$  to  $60^\circ$  was accepted). Aiming for a standard knee flexion angle (about  $50^\circ$ ) for all participants was expected to make the frontal and transverse plain angles of all participants more comparable, as differing squat depths among participants might have been a potential confounding factor (Horan, Watson, Carty, Sartori & Weeks, 2014; Salsich *et al.*, 2012). Evidence suggests that the contact area and patellar cartilage stress are affected by the degree of knee flexion. Internal rotation of the femur in relation to the tibia demonstrated an association with decreased contact area, as well as increased patellar cartilage stress at slightly lower knee flexion angles, but not at angles as big as  $60^\circ$  (Liao *et al.*, 2015; Besier *et al.*, 2008). It was decided not to make participants squat to  $60^\circ$  or deeper (as in similar studies), as many PFP sufferers may not have been able to squat so deep (due to pain), which might have excluded many participants.



**Figure 3.1:** H-frame structure. A white line was added over the string in this image to make it more visible for demonstration purposes

### 3.6.5 3D Movement analysis system

The Vicon Motion Analysis (Ltd) (Oxford, UK) 3D system collected the 3D motion analysis data. It has been proven that this system is highly accurate and reliable (Ehara, Fujimoto, Miyazaki, Mochimaru, Tanaka & Yamamoto, 1997). The Vicon Vantage 5 motion-capturing system demonstrates a unique combination of high-speed accuracy and resolution. For this study, a modified Oxford foot model was utilised to inform the location of reflective markers placed on the participant's skin (Appendix L). This foot model is an extension of the Conventional Gait Model which is implemented in Vicon Plug-in Gait (VICON, n.d.). This model enabled the measurement of rear-foot eversion. Marker data acquisition and biomechanical modelling of the joint angles were performed in Vicon Nexus 2.7 by a biomedical engineer (Neuromechanics Unit, Central Analytical Facilities, Stellenbosch University). Joint angles were low-pass filtered utilising a fourth order (zero lag) Butterworth filter. The engineer also constructed the data visualisations using MATLAB R2017a (version 9.2). The main researcher remained involved in the process to meet the required outcomes.

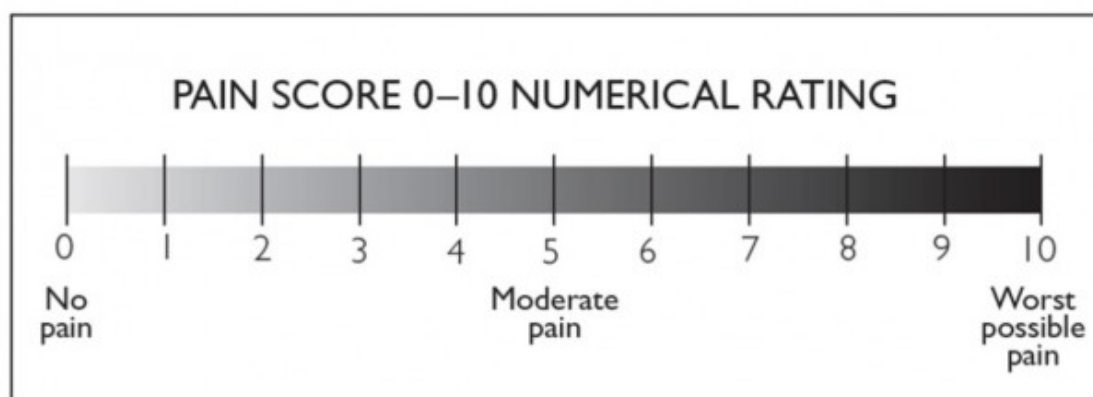
The participants' height was the only Vicon-specific anthropometric measurement that needed to be obtained. Leg length and knee and ankle diameter were calculated by the Nexus system using the placed markers. The participants' weight was measured at the beginning of the 3D testing, while the participant stood on the Bertec Force plate. The main researcher placed all markers and received training for this procedure before commencement of the study. Participants stood on the Bertec Fully Instrumented treadmill, while performing the SLS, as it has a build-in force plate. The Bertec force plate has superior accuracy and high resolution (Bertec Force Plates, 2016).

### 3.6.6 Numeric rating scale for pain (NRSP)

Pain is a dominant feature of people with PFP and therefore a pain rating scale such as the NRS for pain (NRSP) is suitable to measure pain levels (Crossley *et al.*, 2004). Pain intensity, which is a subjective experience, is measured with a unidimensional measure (McCormack, Horne & Sheather, 1988). The NRSP is represented by a horizontal line or bar and is divided into 11 points by the numbers 0-10 (Figure 3.2). The line is anchored by a descriptive word at each end of the scale to describe the symptom extremes (Hawker, Mian, Kendzerska & French, 2011). The descriptive words on the line are "no pain" (which gives a score of 0); "moderate pain" (which gives a score of 5) and "pain as bad as you can imagine" (which gives a score of 10). The descriptive word "moderate pain" describes the pain in the middle of the line. A higher



score represents a higher pain intensity (Hawker *et al.*, 2011). The NRSP score may be obtained verbally, making rapid and easy administration and scoring possible (Jensen, Karoly & Braver, 1986).



*Figure 3.2: Numeric rating scale for pain (“Numeric Pain Rating Scale”, n.d.)*

### **3.7 Study procedures**

#### **3.7.1 Initial screening**

When a potential study participant was referred to the study, the ‘PFP initial screening questionnaire’ (Appendix D) or ‘control initial screening questionnaire’ (Appendix E) was completed via email or telephone to establish whether the individual was eligible to be included in the study.

#### **3.7.2 Informed consent**

Prior to the start of the study, informed consent was obtained from potential participants and from parents or guardians if the individual was younger than 18 years. Potential participants were informed about the aims, requirements, procedures, risks and benefits of the study in the language that was best understood by the individual. There was no need for translators as all participants could speak English or Afrikaans. The main researcher obtained written informed consent from potential participants. Additionally, all potential participants were given ample time and privacy to make their decision. Once the potential participant understood all the information about the study and all the questions had been answered, the informed consent document was signed. It was emphasised to potential participants that the study was entirely voluntary and that they could discontinue their participation in the study at any point without any consequences to themselves, by verbalising it to the main researcher.

### **3.7.3 Preparation and evaluation on test day**

Participants were booked for 90-minute time slots at the Stellenbosch University CAF Neuromechanics unit on the day of testing. Participants were instructed beforehand to wear shorts and a strappy top or T-shirt and sport bra (for females). The tests were performed unshod (without shoes). When potential participants arrived at the laboratory, they were asked to complete the 'PFP informed consent form' (Appendix H) or 'Control informed consent form' (Appendix I) after all their questions regarding the study had been answered by the main researcher. Participants under the age of 18 completed the 'PFP child assent form' (Appendix J) or the 'Control child assent form' (Appendix K) and informed consent was obtained from parents or guardians.

#### **3.7.3.1 Subjective evaluation**

Subjective information obtained from each potential participant's initial screening questionnaire was confirmed and the cases were also asked to indicate the exact area of their main symptoms at the affected knee to the main researcher. The subjective questions from the 'checklist for the diagnosis of anterior knee pain' (Appendix F) were then asked to confirm the participants' answers from the 'PFP initial screening questionnaire'. For the control participants confirmation was sought that there were no previous knee injuries, previous lower limb surgery or major injuries sustained to the lower extremity in the preceding six months. To establish the activity level of the PFP participants and controls, the main researcher asked participants in which activities they participated. Any activity could be named and participants could name more than one activity. Participants were also asked how many times per week they participated in physical activities.

#### **3.7.3.2 Physical examination**

A physical screening examination of the cases and controls was conducted prior to the 3D Vicon testing. The purpose of this physical examination was to exclude other knee conditions and confirm the PFP diagnosis for the cases. The main researcher, who is a physiotherapist, performed the physical examination. The objective tests of Leibbrandt and Louw's (2017b) evidence-based clinical checklist were performed. Most of the objective tests or certain combinations of them had to be positive for the diagnosis of PFP to be made. If Lachman's test, the posterior drawer test, McMurray's test, valgus stress test, varus stress test or patellar ballottement test was positive, participants were excluded from this study. If the control

participants had injuries at the time of testing or pain/discomfort during a squat was found, individuals were excluded from this study.

### **3.7.3.3 Anterior Knee Pain Scale (AKPS)**

If the PFP diagnosis was confirmed by the main researcher, the AKPS was completed to determine the participants' disability levels and pain on test day (Appendix G). The original English version of the AKPS was utilised. The multiple-choice questions were orally addressed to each participant by the main researcher. Any question that was unclear was explained in the same manner to each participant to reduce the risk of non-sampling error.<sup>8</sup> A score of less than 60 indicated severe functional impairment; 60 to 79 indicated moderate functional impairment; 80 to 99 suggested minor functional impairment; and 100 indicated that there is no functional impairment (Leibbrandt, 2018:119).

### **3.7.3.4 Preparation for Vicon testing: height**

The main researcher measured the height of each participant with a wall mounted stadiometer. This measurement was done before the markers were placed on participants so that the participant could stand with their back against the wall for the measurement.

### **3.7.3.5 Setting up the H-frame structure for each participant**

The purpose of the string of the H-frame structure was to touch the anterior knee of the participant at the lowest position during the SLS. A skin pencil was used to mark the lateral malleoli, lateral centre of the knee joint and greater trochanter of each leg as reference points for knee flexion goniometry. The participant had to put his/her big toe in line with the tape on the floor and squat until the point where 50° of knee flexion was reached (measured with the goniometer). The string of the H-frame was adjusted to the corresponding height where the participant reached 50° of knee flexion. This procedure was performed to save time. After the static and dynamic calibration procedure (explained in section 3.6.3.7) the research team observed whether the degree of knee flexion was satisfactory on the Vicon Nexus system.

### **3.7.3.6 Marker placements**

The main researcher did the placements of the retro-reflective markers on the bony landmarks of the participants (Figure 3.3). The placements were done according to the Oxford foot model

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<sup>8</sup> Non-sampling error may occur as a result of a flaw in the research tool or biased communication (e.g. asking leading questions) (Laxton, cited in Coldwell, 2004).

(Oxford, 2012) (Appendix L). If needed, for example the participant used moisturising cream, the skin over the bony landmarks was cleaned with alcohol swabs to ensure that the markers stick firmly on to the participant's skin.



*Figure 3.3: Marker placements according to the Oxford foot model*

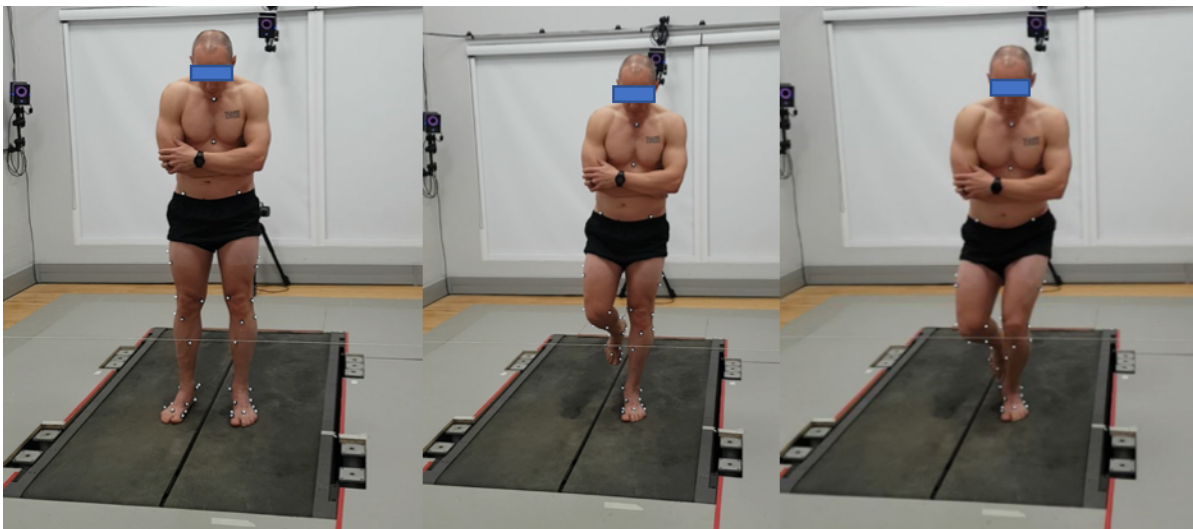
### **3.7.3.7 Calibration for Vicon testing**

A static calibration trail as well as a dynamic calibration trail of the Oxford foot model marker set was performed prior to the commencement of the formal testing. After completion of the static and dynamic calibration, the participant performed one SLS on each leg to determine whether the knee flexion angle was indeed between  $40^\circ$  and  $60^\circ$ . It took approximately three minutes to obtain this information from the Vicon Nexus system. If the knee flexion angle was not satisfactory, the string on the H-frame structure was adjusted accordingly and the SLS was re-tested until the knee flexion angle was between  $40^\circ$  and  $60^\circ$ .

### **3.7.4 Testing procedure**

Participants performed the SLS on the Bertec Fully Instrumented treadmill with a built-in force plate. The exact same procedure was followed for cases and controls. Cases were informed

before the squatting procedure that they would be asked about pain levels experienced during the squatting procedure directly after the squats, so that the participant could first focus on performing the SLS. The participant stood on the tested limb with the non-weight bearing femur in the vertical position (approximately  $0^\circ$  hip flexion) and the knee bent to approximately  $90^\circ$ . The participant's arms were crossed over the abdomen/lower chest, to prevent trunk and pelvic markers from being covered. Furthermore, crossing the arms over the chest prevented compensation strategies of the arms during the squatting procedure. The squatting knee flexed to approximately  $50^\circ$  of knee flexion (until the point where the H-frame's string was touched) and was held at that position for five seconds (Figure 3.4). Instructions to participants were: "ready, lift, down, hold, 5, 4, 3, 2, 1 (count down), up and foot-down". The SLS was performed on the right leg first and then on the left leg. The non-weight bearing foot only went down on "foot-down". Three SLSs were performed on each leg. If the degree of knee flexion during the first squat on each leg was satisfactory, only two more squats were performed on each leg. The main researcher asked about the pain (NRSP) on each leg during the SLS directly after the squats.

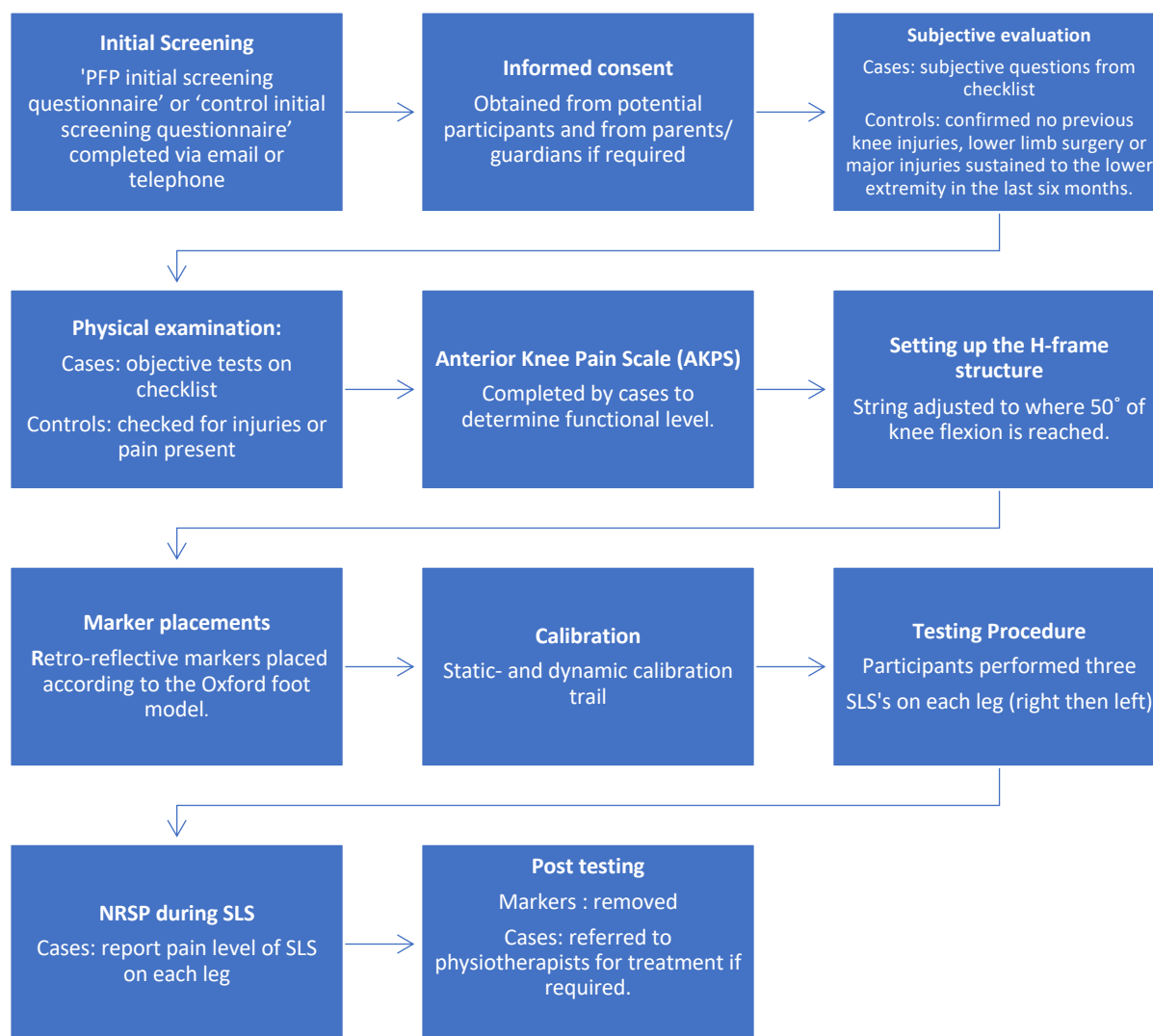


*Figure 3.4: Performing the SLS*

### **3.7.5 Post testing**

After testing, the markers were carefully removed from the participant's skin (by the main researcher) as the double-sided tape sticks firmly to the skin and skin might be sensitive to its removal. The PFP participants received a complimentary treatment session from the main researcher for their knee pain which included: education on PFP and the management thereof, McConnell taping and functional rehabilitation exercises based on current research on PFP

management (Chang *et al.*, 2015; Dawson & Herrington, 2015). Participants who needed follow-up treatments were referred to physiotherapists closer to their residential areas. The controls, on the other hand, received a free sport massage on the area of their choice for 20 minutes (by the main researcher). The study procedures are summarised in Figure 3.5.



**Figure 3.5: Flow diagram demonstrating study procedures**

### 3.8 Pilot study

A pilot study performed on 06/12/2017 included one participant who complied with the inclusion and exclusion criteria of the controls. The aim of the pilot study was to test the study and Vicon testing procedure. The pilot study confirmed that 60 minutes was not enough time to prepare, test and treat/massage an individual. It was decided to increase the time of a testing session to 90 minutes. The knee flexion angle obtained during the SLS in the pilot study was

not available on the same day. However, when data became available it was evident that the depth of the SLS performed by the pilot study participant was not deep enough (less than 40°). The H-frame structure functioned as a range of motion guide (also to squat to the same depth with both legs). However, the knee flexion angle at the lowest knee position still needed to be confirmed on the Vicon Nexus system after each squat for better accuracy. The data of the pilot study participant were not included in the main study because of the changes that were made to the study and test procedure.

### **3.9 Data management**

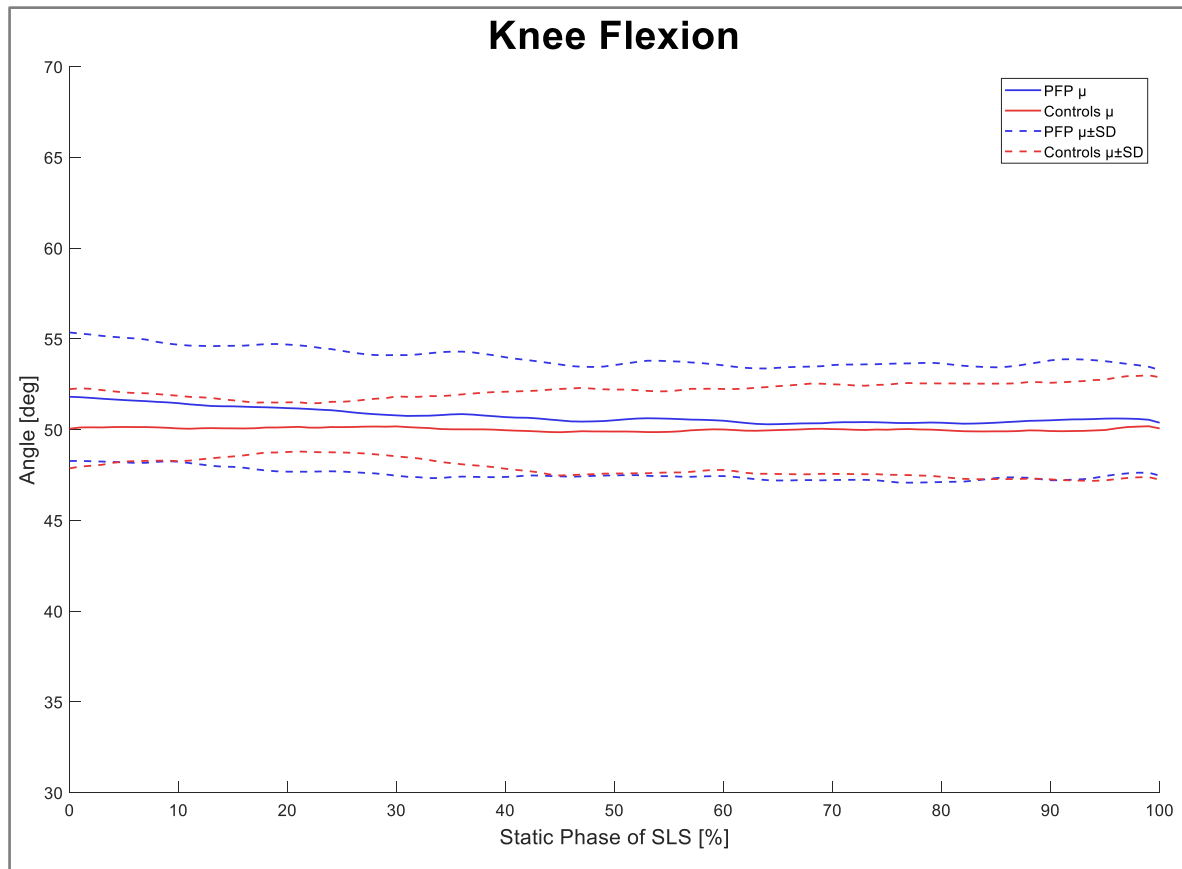
A code was assigned to each study participant so that no personal information could be used to identify them. Confidentiality of information was maintained by this action. The main researcher did the coding of each participant and the entering of the data. The cases had the code PFP and a number e.g. PFP01 and the control participants had the code CTRL and a number e.g. CTRL01.

Information from the ‘checklist for the diagnosis of anterior knee pain’, AKPS and NRSP were entered into Microsoft Excel spread sheets to keep data organised and to make the comparison of data easier. The laptop used was password protected and stored in a secure location when not in use. Back-ups of all data were made regularly, on a password protected external hard drive. Hardcopies of study documents such as informed consent forms were stored at the CAF facility in a securely locked location. This approach to data management ensured confidentiality, safety and security of all data collected.

### **3.10 Data reduction and outcomes**

The SLS was divided into three phases to facilitate and aid data capturing. The three phases were: the “eccentric-down phase”; the “static phase” (5-second hold period) at approximately 50° of knee flexion; and the “concentric-up phase”. The peak value of each movement in the frontal- and transverse plane (peak ipsilateral trunk lean, peak contralateral pelvic drop, peak hip adduction, peak hip internal rotation, peak knee abduction, peak knee/tibial external rotation, peak rear-foot eversion) during the static phase (the deepest knee flexion position) was captured. It was decided to report on the static phase of the SLS, as that is the lowest knee position during the SLS and four of the other SLS studies in the PFP population also only reported on the kinematics at the lowest knee position during the SLS (Gwynne & Curran, 2018; Nakagawa *et al.*, 2015; Herrington, 2014; Nakagawa *et al.*, 2012). This would enable the

findings of the current study to be comparable to existing studies. Out of the three squats that each participant performed on each leg, the squat with the average knee flexion value closest to 50° (during the static phase) was used. The mean and standard deviation knee flexion angles during the static phase of the SLS of the PFP group and the control group are displayed in Figure 3.6 for a better understanding of what the knee flexion angle looked like during the static phase of the SLS. It is evident that the PFP group had a larger standard deviation.



**Figure 3.6:** The mean ( $\mu$ ) and standard deviation (SD) of the knee flexion angle during the static phase of the SLS for the PFP group and the control group

### 3.11 Data analysis

The demographic information, activity levels, pain and functional scales were analysed using descriptive statistics such as mean, standard deviation, range and proportions. The kinematic variables of interest included peak ipsilateral trunk lean, peak contralateral pelvic drop, peak hip adduction, peak hip internal rotation, peak knee abduction, peak knee external rotation, and peak rear-foot eversion, and was also described descriptively.



To assess for differences in trunk and lower limb kinematics during the SLS, the affected leg of the PFP participant was matched to the same leg of the matched control. If the case presented with bilateral symptoms, the most affected side was matched to the corresponding limb of the matched control. The analysis was then stratified by gender and by unilateral PFP/ bilateral PFP (Table 3.1). The affected and unaffected legs of each PFP participant were compared. The analysis was then split by gender and by unilateral PFP/ bilateral PFP (Table 3.2).

**Table 3.1: Between-group analysis**

<b>PFP participants</b>	<b>Matched control participants</b>
Affected or most affected leg of the PFP participant	Corresponding leg of the matched control
Affected or most affected leg of the PFP participant (split by gender)	Corresponding leg of the matched control (split by gender)
Affected or most affected leg of the PFP participant (split by unilateral vs bilateral pain)	Corresponding leg of the matched control (split by unilateral vs bilateral pain)

**Table 3.2: Within group analysis**

Affected leg/ most affected leg of PFP participant	Unaffected leg/ less affected leg of PFP participant
Affected leg/ most affected leg of PFP participant (split by gender)	Unaffected leg/ less affected leg of PFP participant (split by gender)
Affected leg of PFP participant with unilateral knee pain	Unaffected leg of PFP participant with unilateral knee pain
Most affected leg of PFP participant with bilateral knee pain	Less affected leg of PFP participant with bilateral knee pain

### 3.12 Statistical analysis

The main researcher consulted a statistician at the Biostatistics unit (Stellenbosch University) for the statistical analysis of the captured data. The continuous variables were summarised using means and standard deviations while the categorical variables were summarised using count

and percentages. Categorical variables included gender, leg dominance, which leg was affected, unilateral or bilateral symptoms, subjective aggravating activities and objective tests.

The demographics of the cases and their matched controls were also compared with the paired t-test as they were individually matched. The kinematic outcomes were compared using the paired t-test. We reported the associational effects with the corresponding 95% confidence intervals. Alpha ( $\alpha$ ) of 0.05 was used as the criterion for statistical significance and SPSS version 25 was used for analysis (IBM SPSS Statistics for Windows, 2017).

### **3.13 Ethical and legal considerations**

Before the commencement of the study, ethical approval was obtained from the Health Research Ethics Committee of Stellenbosch University (Appendix M). The project ID is 1279 and ethics reference number is S17/09/177. The annual progress report was submitted and accepted in October 2018 (Appendix N).

#### **3.13.1 Informed consent**

Informed consent from participants and from parents or guardians if the participant was younger than 18 years of age was obtained prior to the study. All the details regarding informed consent in the current study are explained in detail in section 3.6.2.

#### **3.13.2 Confidentiality**

Personal details of the participants and data collected during the study were handled confidentially (see section 3.8).

#### **3.13.3 Risk-benefit ratio**

There was a small risk that participants could develop a skin reaction due to the retro-reflective markers. This skin reaction would settle within a day or two and would usually not require treatment. The benefits of identifying the kinematic differences of PFP participants and controls, during a SLS, outweigh this small risk. The SLS may be developed into a more meaningful clinical test for physiotherapists to identify kinematic associated factors for PFP. In the long-term this may also lead to better treatment and prevention strategies of PFP.

### **3.13.4 Dissemination of the findings**

Feedback on the study findings will be communicated to participants by email. The findings of the study may be published in scientific journals and presented at scientific meetings or conferences.

## **3.14 Conclusion**

This chapter described the methodology that was followed to answer the research question. A cross-sectional design was employed and the study was conducted in a laboratory setting. The Vicon 3D motion analysis system was utilised to capture the peak values of the kinematic outcomes during the static phase of the SLS and the kinematic outcomes of cases and controls were compared using the paired t-test. The results obtained after following the study methods are discussed in the following chapter (Chapter 4).

## Chapter 4

# RESULTS

### 4.1 Introduction

The results obtained after implementing the study methods (described in the previous chapter) are presented in this chapter. The demographics, symptom presentation and activity level of study participants will be provided. The kinematic results of the comparison between cases and controls are presented and, lastly, the between-leg comparison of the PFP participants is provided.

### 4.2 Demographics of study participants

The total number of participants included in this study was 52 (26 in the PFP group, with 26 gender- and age-matched controls). The majority of the participants were females ( $n = 32$ ; 61.54%). The ages of the PFP group ranged from 14 to 45 years with a mean age of 28.5 years compared to 28 years for the control group (Table 4.1). The cases and controls were similar with respect to height, weight and BMI ( $p > 0.05$ ), but not in age ( $p = 0.016$ ). When the PFP and control groups were stratified by gender, there was no significant difference for age.

### 4.3 Symptom presentation of the PFP group

Fifteen of the PFP group had bilateral knee pain ( $n = 15$ ; 57.69%) and 14 (53.85%) of the PFP group reported the right knee as the affected (more affected) leg (Table 4.2). The duration of the PFP symptoms ranged from three months to 168 months, with a mean duration of 34.5 months. Measured with the numeric rating scale for pain (NRSP), the score for the mean 'highest pain level on a normal day' was 5.9/10. The mean anterior knee pain scale (AKPS) score for all PFP participants was 79.5 out of 100 points, which indicated moderate functional impairment. The mean pain level that the PFP participants experienced on the affected leg (NRSP) during the SLS was 3.6/10 and on the unaffected or less affected leg it was 1/10.

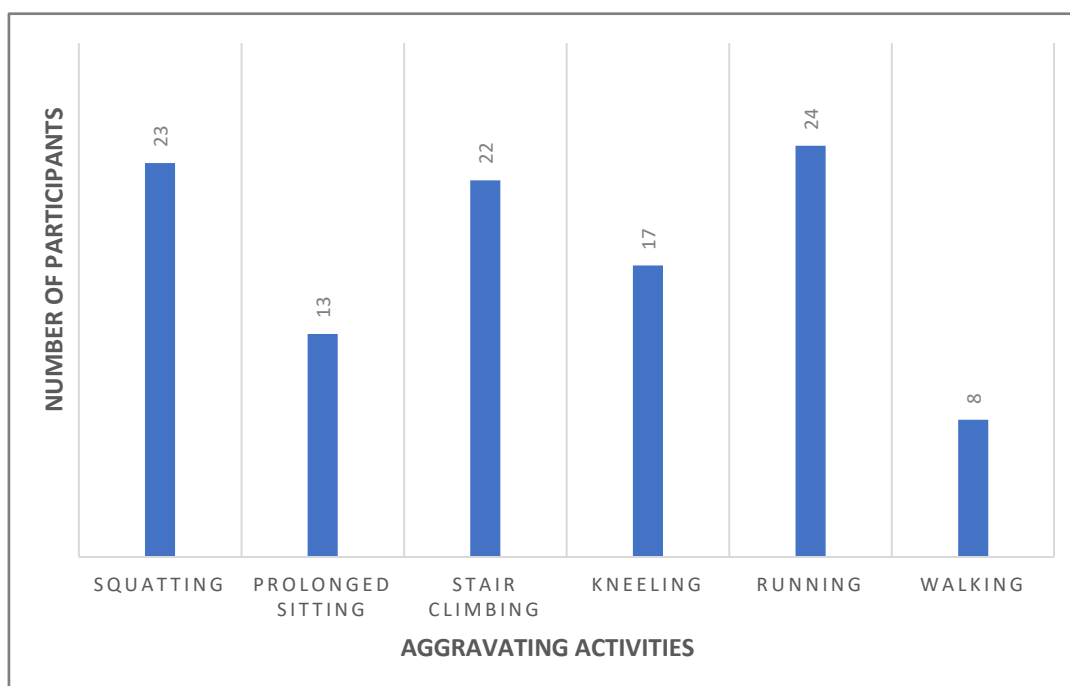
**Table 4.1: Demographics of the PFP and control groups**

	All PFP (n = 26)	All controls (n = 26)	p-value	Female PFP (n = 16)	Female controls (n = 16)	p-value	Male PFP (n = 10)	Male controls (n = 10)	p-value
Age (years)*	28.5 (8.8)	28 (8.5)	<b>0.016</b>	26.9 (8.3)	26.5 (8.1)	0.110	31.1 (9.4)	30.4 (9.0)	0.089
Height (m)*	1.72 (0.09)	1.74 (0.08)	0.205	1.67 (0.07)	1.68 (0.03)	0.550	1.80 (0.04)	1.83 (0.04)	0.212
Weight (kg)*	73.6 (17.5)	69.9 (10.3)	0.292	67.0 (14.0)	65.2 (7.4)	0.670	84.2 (18.1)	77.3 (10.3)	0.304
BMI*	24.7 (4.4)	23.1 (2.4)	0.109	23.9 (4.1)	23.0 (2.3)	0.484	26.0 (4.8)	23.2 (2.8)	0.114
Dominant leg	R = 26; L = 0	R = 21; L = 5	N/A	R = 16; L = 0	R = 13; L = 3	N/A	R = 10; L = 0	R = 8; L = 2	N/A
<i>R = right leg</i> <i>L = left leg</i> <i>p-value in bold = significant difference</i> <i>* = mean ± standard deviation in degrees</i>									

**Table 4.2: Symptom presentation for the PFP group (n = 26)**

Bilateral knee pain	n = 15 (57.69%)
Most affected leg	R = 14 (53.85%), L = 12 (46.15%)
*Duration of symptoms (months)	34.5
*Lowest pain level on a normal day (NRSP out of 10)	2.3
*Highest pain level on a normal day (NRSP out of 10)	5.8
*AKPS (out of 100)	79.5
*Pain during SLS affected leg (NRSP out of 10)	3.6
*Pain during SLS unaffected/ less affected leg (NRSP out of 10)	1
* = mean	R = Right leg
NRSP = Numeric rating scale for pain	L = Left leg
AKPS = Anterior knee pain scale	

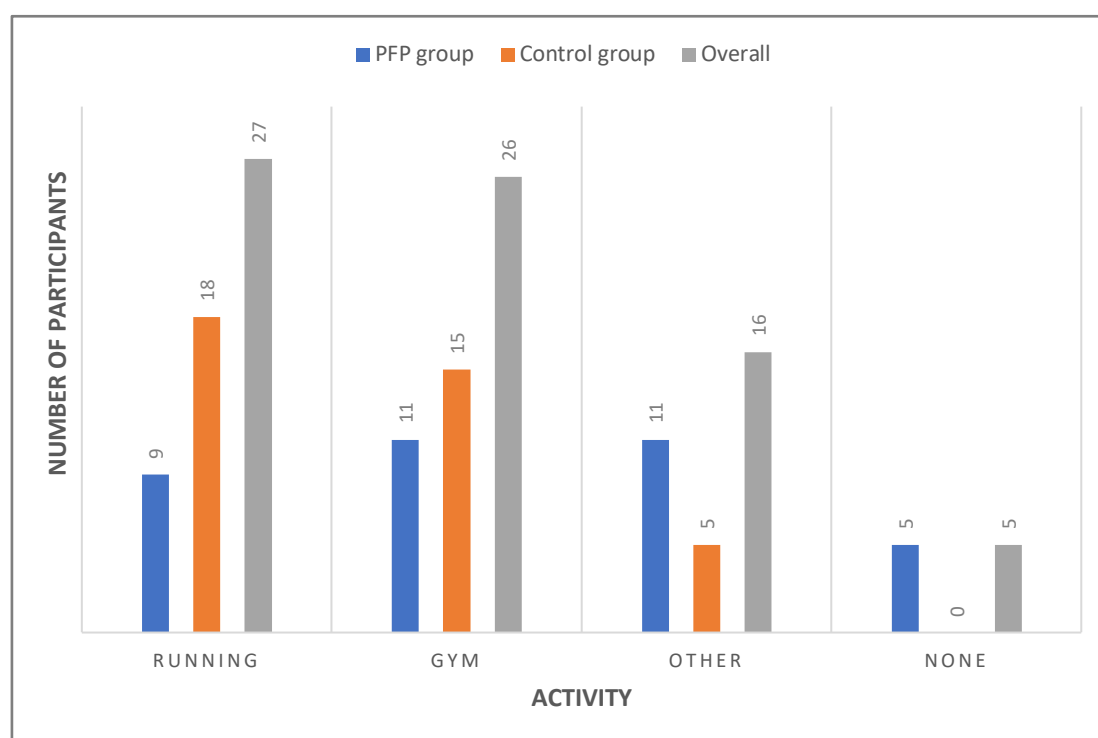
Activities that most frequently aggravated the knee pain of PFP participants were running (n = 24; 92.3%), squatting (n = 23; 88.46%) and stair climbing (n = 22; 84.62%). Other aggravating activities are also shown in Figure 4.1. Information on subjective aggravating activities was obtained from the subjective examination; participants could select more than one activity that aggravated their knee pain.

**Figure 4.1: Subjective aggravating activities of PFP group**

#### 4.4 Activity level of all study participants

Running (n = 27; 51.9%) and gym (n = 26; 50%) were the activities in which most cases and controls participated. Participants could name more than one activity in which they participated during a normal week. In the subjective examination, participants were asked about the activities in which they participated and any activity could be named. However, for the purposes of this study, the activities were grouped into ‘running’, ‘gym’, ‘other’ and ‘none’.

Overall, 16 (30.8%) of the PFP group and controls participated in other activities such as cycling, hockey, netball, dancing, pilates/yoga and tennis. Eighteen (69.2%) participants in the control group participated in running as a sport compared to nine (34.6%) cases (Figure 4.2). However, seven PFP participants specifically stopped running due to knee pain and another two PFP participants mentioned that they run less due to knee pain. Five participants in the PFP group did not participate in any activities at the time of testing and three (of the group of five) had stopped due to the knee pain. All control participants participated in physical activities at some level. The PFP group participated in physical activities for an average of 3.27 times a week, compared to 4.63 times a week for the control group.



**Figure 4.2: Activity level for the PFP, control and total participants in the study**

## 4.5 Kinematic results of the PFP group and control group

The mean knee flexion range during the static phase of the SLS for the PFP group was  $50.63^\circ \pm 2.66$  (mean  $\pm$  SD), compared to  $50.02^\circ \pm 1.96$  (mean  $\pm$  SD) for the control group. This comparison between the PFP and control group was statistically insignificant. Cases demonstrated significantly greater peak knee (tibial) external rotation than controls during the static phase of the SLS (Mean difference (MD),  $4.68^\circ$ ; 95% Confidence interval (CI): 2.83, 6.53;  $p < 0.001$ ). There were no significant differences ( $p > 0.05$ ) between cases and controls for peak ipsilateral trunk lean, contralateral pelvic drop, hip adduction, knee abduction, rear-foot eversion and hip internal rotation, although all these outcomes were increased in the cases (Table 4.3).

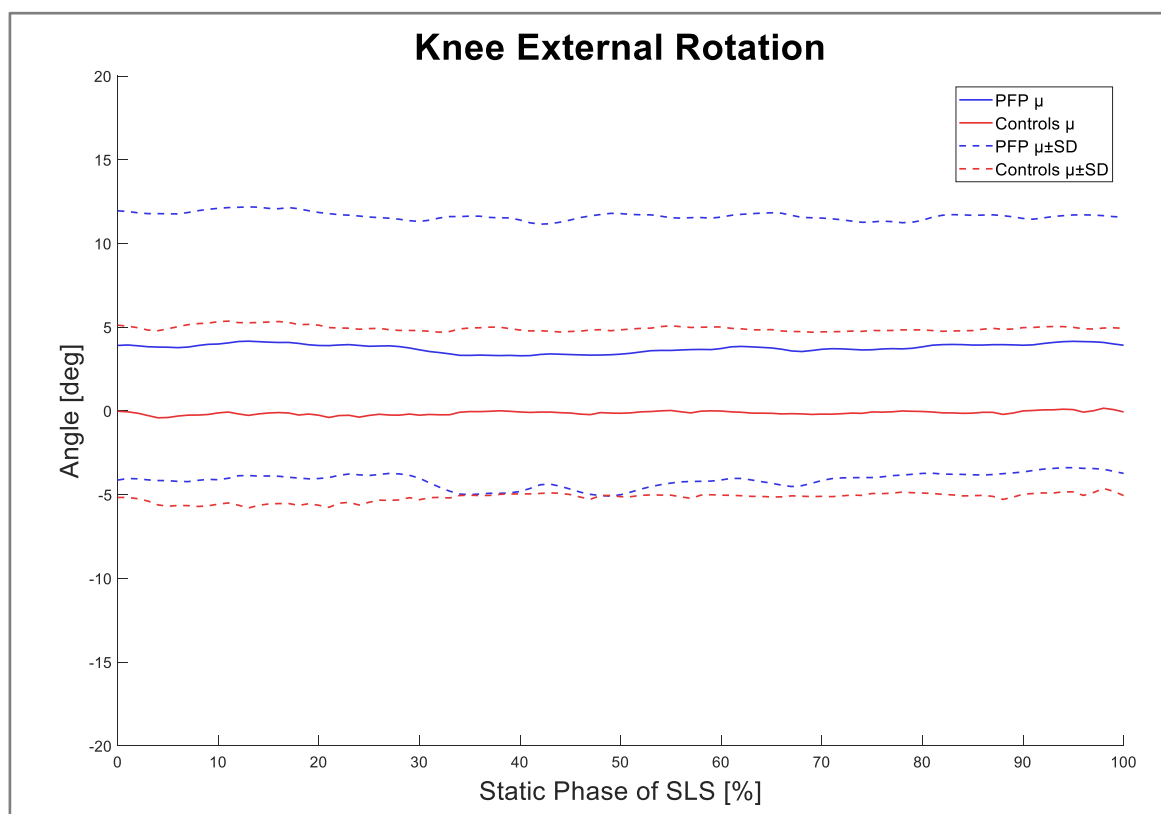
Figure 4.3 displays the mean and standard deviation of knee external rotation (in the transverse plane) for the PFP group and the controls during the static phase of the SLS. The mean knee external rotation values are clearly larger in the PFP group. The PFP group also demonstrated a larger standard deviation during the static phase of the SLS. In contrast, there were no significant differences between groups in the knee frontal plane kinematics (mean knee abduction angles during the static phase of the SLS) (Figure 4.4). The standard deviation, however, is larger in the PFP group.<sup>9</sup>

**Table 4.3: Between-group comparison of the peak values of the transverse plane and frontal plane movements for the PFP and control groups**

	Kinematic outcome	All PFP (n = 26) *	All controls (n = 26) *	p-value
Frontal plane	Ipsilateral trunk lean	5.98 (4.95)	4.36 (3.77)	0.174
	Contralateral pelvic drop	1.13 (4.44)	1.08 (4.05)	0.964
	Hip adduction	7.38 (6.88)	6.91 (7.11)	0.805
	Knee abduction	-0.89 (4.92)	-0.94 (4.55)	0.969
	Rear-foot eversion	-1.54 (5.56)	-2.40 (4.74)	0.539
Transverse plane	Hip internal rotation	0.68 (5.86)	-1.21 (6.26)	0.235
	Knee external rotation	5.87 (4.29)	1.19 (5.16)	<b>&lt; 0.001</b>
*Data show mean $\pm$ standard deviation (in degrees)				
p-value in bold = significant difference				

<sup>9</sup> The mean (standard deviation) figures for all other outcomes can be viewed in Appendix O.





**Figure 4.3:** Knee external rotation during the static phase of the SLS mean (standard deviation) for the PFP group and controls

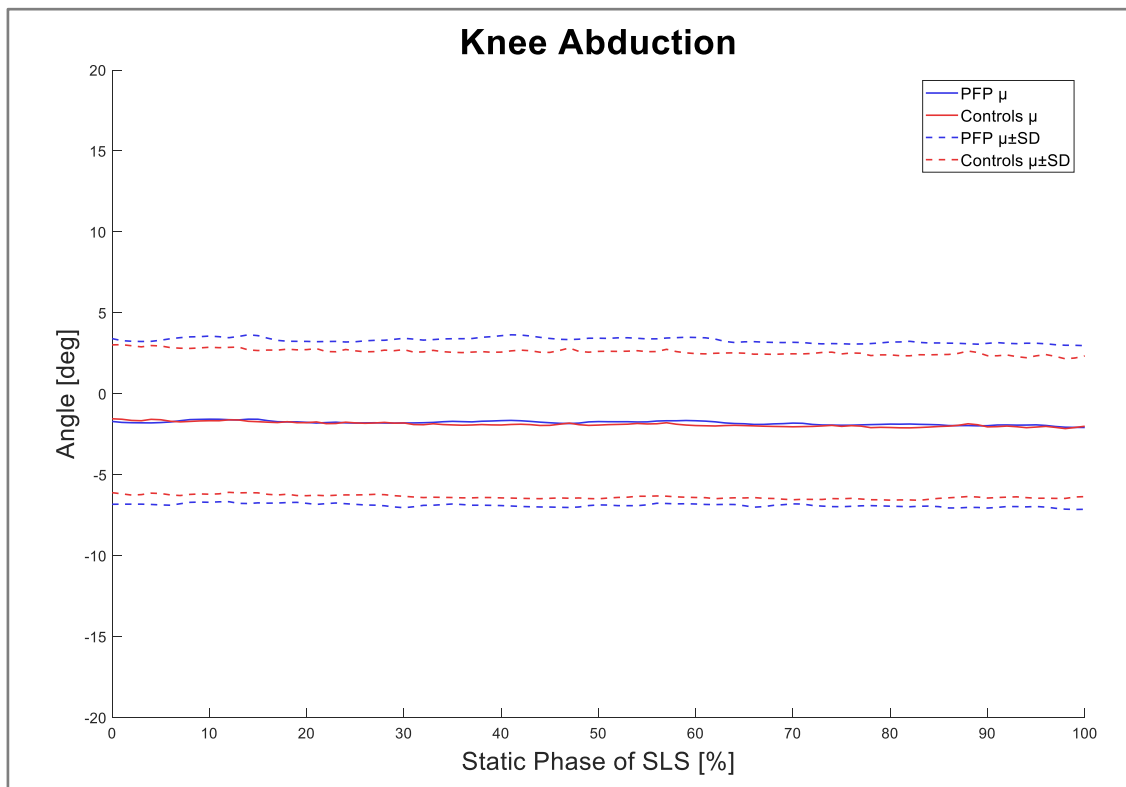
#### 4.6 Kinematic results for males and females in the PFP group compared to control group

There was a borderline insignificant increase in peak ipsilateral trunk lean in females with PFP compared to female controls, with a mean difference of  $2.83^\circ$  (95% CI: -0.02, 5.68;  $p = 0.052$ ) (Table 4.4). Females with PFP demonstrated significantly greater peak knee external rotation than female controls (MD,  $4.49^\circ$ ; 95% CI: 2.07, 6.92;  $p < 0.001$ ). At the same time, there were no statistically significant differences between females with PFP and female controls ( $p > 0.05$ ) in peak contralateral pelvic drop, hip adduction, knee abduction, rear-foot eversion and hip internal rotation.

Peak knee external rotation was the only outcome with a significant difference between males in the PFP group and male controls (MD,  $4.98^\circ$ ; 95% CI: 1.49, 8.47;  $p = 0.010$ ). All other outcomes between males with PFP and male control participants were statistically insignificant.

**Table 4.4: Between-group comparison of the peak joint values of frontal and transverse plane movements for males and females with and without PFP**

Kinematic outcome		Female PFP (n = 16) *	Female controls (n = 16) *	p-value (females)	Male PFP (n = 10) *	Male controls (n = 10) *	p-value (males)
Frontal plane	Ipsilateral trunk lean	6.41 (4.09)	3.58 (3.67)	0.052	5.28 (6.26)	5.61 (3.76)	0.876
	Contralateral pelvic drop	1.77 (4.18)	1.64 (3.61)	0.917	0.11 (4.87)	0.18 (4.73)	0.976
	Hip adduction	9.80 (5.56)	7.97 (7.32)	0.413	3.51 (7.29)	5.23 (6.78)	0.627
	Knee abduction	-0.01 (4.50)	-0.09 (5.20)	0.965	-2.30 (5.47)	-2.31 (3.00)	0.996
	Rear-foot eversion	-1.62 (3.59)	-2.47 (4.95)	0.499	-1.39 (8.03)	-2,31 (4.64)	0.781
Transverse plane	Hip internal rotation	1.73 (5.28)	-1.0 (5.80)	0.157	-1.00 (6.63)	-1.54 (7.24)	0.853
	Knee external rotation	5.51 (3.75)	1.02 (3.17)	<b>0.001</b>	6.44 (5.21)	1.46 (7.55)	<b>0.010</b>
<i>*Data show mean ± standard deviation (in degrees)</i>							
<i>p-value in bold = significant difference</i>							



**Figure 4.4: Knee abduction during the static phase of the SLS mean (standard deviation) for the PFP group and controls**

#### **4.7 Kinematics in PFP participants with unilateral and bilateral knee pain compared to controls**

The bilateral PFP group demonstrated significant increased peak knee external rotation compared to their control group, with a mean difference of  $5.98^\circ$  (95% CI: 3.79, 8.17;  $p < 0.001$ ). However, the unilateral PFP group did not demonstrate significantly greater peak knee external rotation compared to their control group (MD,  $2.91^\circ$ ; 95% CI: -0.44, 6.25;  $p = 0.081$ ) (Table 4.5). Participants with unilateral PFP demonstrated a borderline statistical insignificant increase in peak contralateral pelvic drop compared to their control group (MD,  $2.95^\circ$ ; 95% CI: -0.09, 5.99;  $p = 0.056$ ). Additionally, there was no significant difference in peak contralateral pelvic drop between individuals with bilateral PFP and their control group (MD,  $-2.07^\circ$ ; 95% CI: -5.36, 1.21;  $p = 0.198$ ). There also was no significant difference for peak ipsilateral trunk lean, hip adduction, knee abduction, rear-foot eversion and hip internal rotation for both the unilateral PFP group and the bilateral PFP group compared to their respective control groups.

**Table 4.5: Between-group comparison of the peak joint values of frontal and transverse plane movements for the bilateral PFP group, unilateral PFP group and their control groups**

	Kinematic outcome	Unilateral PFP (n = 11) *	Unilateral control group (n = 11) *	p- value (unilateral)	Bilateral PFP (n = 15) *	Bilateral control group (n = 15) *	p-value (bilateral)
Frontal plane	Ipsilateral trunk lean	6.17 (6.27)	4.67 (3.82)	0.496	5.84 (3.95)	4.13 (3.84)	0.221
	Contralateral pelvic drop	3.15 (3.61)	0.19 (2.90)	0.056	-0.34 (4.51)	1.73 (4.71)	0.198
	Hip adduction	9.09 (6.88)	5.31 (4.97)	0.127	6.13 (6.84)	8.09 (8.31)	0.473
	Knee abduction	-2.36 (3.86)	-0.25 (3.57)	0.098	0.18 (5.44)	-1.45 (5.22)	0.410
	Rear-foot eversion	-1.28 (7.03)	-1.99 (4.86)	0.787	-1.73 (4.46)	-2.72 (4.80)	0.551
Transverse plane	Hip internal rotation	1.31 (5.98)	-1.99 (6.96)	0.204	0.22 (5.94)	-0.63 (5.86)	0.683
	Knee external rotation	4.34 (4.26)	1.44 (5.02)	0.081	6.99 (4.09)	1.01 (5.43)	<b>&lt; 0.001</b>
<i>*Data show mean ± standard deviation (in degrees)</i>							
<i>p-value in bold = significant difference</i>							

#### 4.8 Comparison of the affected leg in the PFP group with their unaffected or less affected leg

Peak knee external rotation was greater in the affected leg compared to the unaffected or less affected leg in the PFP group (MD,  $-1.18^\circ$ ; 95% CI: -2.40, 0.03;  $p = 0.056$ ), but this result was borderline statistically insignificant (Table 4.6). Stratification of the groups for gender, revealed a statistically significant difference between the affected leg and the unaffected or less affected leg in female PFP participants for peak knee external rotation (MD,  $-1.66$ ; 95% CI: -3.21, -0.10;  $p = 0.038$ ). There was no significant difference in peak knee external rotation for males with PFP (MD,  $-0.43$ ; 95% CI: -2.70, 1.84;  $p = 0.680$ ).

**Table 4.6: Comparison of the peak values for frontal and transverse plane movements between the affected/most affected leg and the unaffected/less affected leg in the PFP group**

Kinematic outcome		All affected/ most affected leg (n = 26) *	All unaffected/ less affected leg (n = 26) *	p-value
Frontal plane	Ipsilateral trunk lean	5.98 (4.95)	5.46 (4.38)	0.676
	Contralateral pelvic drop	1.13 (4.44)	-0.62 (4.53)	0.325
	Hip adduction	7.38 (6.88)	5.56 (7.47)	0.293
	Knee abduction	-0.89 (4.92)	-0.02 (5.81)	0.405
	Rear-foot eversion	-1.54 (5.56)	-1.58 (5.56)	0.971
Transverse plane	Hip internal rotation	0.68 (5.86)	-0.14 (7.98)	0.569
	Knee external rotation	5.87 (4.29)	4.69 (4.37)	0.056
* Data show mean $\pm$ standard deviation (in degrees)				
<i>p</i> -value in bold = significant difference				

#### **4.9 Comparison of the affected leg in the PFP group with the unaffected or less affected leg, stratified for unilateral PFP and bilateral PFP**

There was greater peak contralateral pelvic drop in the affected leg of participants with unilateral PFP, compared to the unaffected leg (MD,  $-2.65^\circ$ ; 95% CI:  $-5.38, 0.08$ ;  $p = 0.056$ ), but this difference was borderline statistically insignificant (Table 4.7). There was no difference between legs of PFP participants with bilateral PFP for peak contralateral pelvic drop. There also were no statistically significant differences in peak ipsilateral trunk lean, hip adduction, knee abduction, rear-foot eversion, hip internal rotation and knee external rotation between the affected and unaffected/less affected legs ( $p > 0.05$ ) of the unilateral PFP group or bilateral PFP group.

#### **4.10 Conclusion**

The population of the study comprised 16 females and 10 males with PFP and their respective control group participants. The PFP group had a mean age of 28.5 years compared to 28 years for the control group. Participants with PFP presented with significantly more peak knee external rotation compared to healthy controls during the static phase of the SLS. This also was the case when the groups were stratified for gender. When stratified for bilateral and unilateral PFP, only the bilateral PFP group demonstrated significantly increased peak knee external rotation compared to the control group. There were no significant differences between the PFP group and control participants for the peak values of the other kinematic outcomes (ipsilateral trunk lean, contralateral pelvic drop, hip adduction, knee abduction, rear-foot eversion and hip internal rotation). The results are interpreted and compared with the current literature on PFP in the discussion that follows in Chapter 5.

**Table 4.7: Within-group comparison of the peak joint values of frontal and transverse plane movements for individuals with unilateral and bilateral PFP**

	Kinematic outcome	Unilateral PFP affected leg (n = 11) *	Unilateral PFP unaffected leg (n = 11) *	p- value	Bilateral PFP most affected leg (n = 15) *	Bilateral PFP less affected leg (n = 15) *	p-value
Frontal plane	Ipsilateral trunk lean	6.17 (6.27)	6.36 (5.31)	0.929	5.84 (3.95)	4.81 (3.61)	0.503
	Contralateral pelvic drop	3.15 (3.61)	0.50 (4.49)	0.056	-0.34 (4.51)	-0.47 (4.68)	0.945
	Hip adduction	9.09 (6.88)	5.06 (9.04)	0.130	6.13 (6.84)	5.93 (6.40)	0.933
	Knee abduction	-2.36 (3.86)	-1.90 (4.17)	0.708	0.18 (5.44)	1.36 (6.57)	0.472
	Rear-foot eversion	-1.28 (7.03)	-2.13 (4.64)	0.730	-1.73 (4.46)	-1.19 (6.28)	0.736
Transverse plane	Hip internal rotation	1.31 (5.98)	0.77 (7.10)	0.831	0.22 (5.94)	-0.80 (8.76)	0.567
	Knee external rotation	4.34 (4.26)	3.07 (4.71)	0.197	6.99 (4.09)	5.87 (3.84)	0.183
*Data show mean $\pm$ standard deviation (in degrees)							
<i>p-value in bold = significant difference</i>							

## Chapter 5

# DISCUSSION

### 5.1 Introduction

The results reported in the previous chapter are interpreted and compared with the current literature on patellofemoral pain (PFP) in this chapter. The main study objective of comparing the kinematic differences between cases and controls during a single leg squat (SLS) will be discussed first. Thereafter, the between-limb comparison (affected leg vs the unaffected or less-affected leg) of the PFP participants and the study demographics are dealt with. The clinical applicability of our findings is presented in conclusion.

### 5.2 The main objective of the study

The main objective of our study was to compare joint kinematics of the trunk and lower limb between individuals with PFP and healthy matched controls during a SLS. We measured the peak values of ipsilateral trunk lean, contralateral pelvic drop, hip adduction, knee abduction, rear-foot eversion, hip internal rotation and knee (tibial) external rotation. The kinematics between the case and control groups during the SLS was mostly similar. The only statistically significant difference was that participants with PFP had significantly increased peak knee external rotation during the SLS in comparison with healthy controls.

To our knowledge, our study is the second to report on transverse plane knee kinematics in persons with PFP compared to controls during a SLS. It is also the first study in South Africa to investigate the trunk and lower limb kinematics in individuals with PFP in comparison with controls during a SLS. We found a significant difference (mean difference,  $4.68^\circ$ ) for peak knee external rotation between individuals with PFP and the controls ( $p < 0.001$ ). It is worth noting that the study by Willson and Davis (2008a) also found an increase in knee external rotation in individuals with PFP, but the difference was insignificant. Willson and Davis (2008a) found that females with PFP performed the SLS, running and single leg jumps with a  $4.3^\circ$  greater knee external rotation than healthy controls ( $p = 0.06$ ). According to the literature, this degree of difference is sufficient to significantly increase patellofemoral joint (PFJ) stress (Li, DeFrate, Zayontz, Park & Gill, 2004). External rotation of the tibia reduces the contact area of the patella



to the femur and increases the contact pressure on the patellar facets (Lee *et al.*, 2003). The PFP experienced due to high compressive forces can originate from various structures, for example the subchondral bone, synovial plicae, retinacula, knee joint capsule, patellofemoral ligaments and infrapatellar fat pad (Besier *et al.*, 2005; Biedert & Sanchis-Alfonso, 2002). Clinically, the aim should be to reduce the retro-patellar stress by addressing the excessive knee external rotation.

Rotation of the tibia is important in normal knee biomechanics as it is coupled with flexion and extension of the knee. The medial femoral condyle lies slightly more distal than the lateral femoral condyle, which necessitates rotation to accompany the sagittal plane motion for normal flexion and extension to take place at the knee (Levangie & Norkin, 2011). External rotation of the tibia involves the tibial tuberosity moving laterally; the patellar tendon will pull on the inferior pole of the patella and cause a rotational movement of the patella in the frontal plane and pull the inferior pole of the patella laterally (Lee *et al.*, 2003). This rotational movement about the centre of the patella causes an increase in contact pressures between the ipsilateral facets of the patella and the femur (Lee *et al.*, 2003). An American study found that greater knee external rotation during weight-bearing activities such as squatting was associated with increased pain during these activities in individuals with PFP (Salsich *et al.*, 2012). Investigation of the underlying reasons for increased knee external rotation during weight-bearing activities is encouraged for future studies. Underlying reasons could be muscular weakness or altered neuromuscular control (Dutton *et al.*, 2016; Aminaka, Pietrosimone, Armstrong, Meszaros & Gribble, 2011). To date, weakness or altered neuromuscular control of the knee internal rotators (semitendinosis, gracilis, sartorius and popliteus) and over activation or inflexibility of the knee external rotator (biceps femorus) have not been investigated in a PFP population and future studies could conduct such an investigation. Clinicians should assess these possible contributing factors to excessive knee external rotation in patients with PFP, especially if an increase in knee external rotation is suspected.

We found no difference in peak knee abduction between cases and controls during the SLS, despite the difference in knee external rotation (see Figures 4.3 and 4.4 in Chapter 4). Our finding concurs with Willson and Davis (2008b), who found that knee external rotation may contribute more to a dynamic knee valgus<sup>10</sup> in persons with PFP, instead of tibial abduction.

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<sup>10</sup> Dynamic knee valgus involves multiple joints and takes place in multiple planes. Dynamic knee valgus comprises increased adduction and internal rotation of the hip and increased knee abduction and tibial/knee external rotation, to varying degrees. This phenomenon is visually seen as excessive medial displacement of the knee during weight-bearing activities (Schmidt *et al.*, 2017; Powers, 2010).

Willson and Davis, (2008b) found that the frontal plane projection angle (FPPA) (indicating medial displacement of the knee) correlated significantly with the 3D knee external rotation angle ( $p = 0.002$ ) during a SLS. Surprisingly, knee frontal plane movement (tibial abduction) had the weakest correlation with the FPPA. Knee abduction is not a major contributor to dynamic knee valgus during a SLS and may also not play as big a role in PFP as previously hypothesised (Schmidt *et al.*, 2017). It may pose challenges to clinicians to evaluate kinematic alterations in patients and subjective evaluation of kinematic alterations during functional tasks has moderate reliability (Chmielewski, Hodges, Horodyski, Bishop, Conrad & Tillman, 2007). The SLS test with the FPPA can be used clinically to screen for PFP patients who will benefit from kinematic retraining to reduce excessive external rotation of the knee during weight-bearing activities (Willson & Davis, 2008b).

Once it is known that an individual with PFP has increased dynamic knee valgus during weight-bearing activities, the focus should be on avoiding the dynamic knee valgus as a rehabilitation principal, as it is associated with increased pain in individuals with PFP, especially the knee external rotation component (Salsich *et al.*, 2012). Management strategies for persons with PFP and excessive knee external rotation may therefore include functional movement exercises focusing on correcting the dynamic knee valgus during weight-bearing activities and indirectly correcting excessive knee external rotation.

Five primary studies comparing lower limb and trunk kinematics of persons with PFP to controls during a SLS have been published (Gwynne & Curran, 2018; Nakagawa *et al.*, 2015; Herrington, 2014; Nakagawa *et al.*, 2012; Willson & Davis, 2008a). These studies demonstrated consistent findings regarding increased ipsilateral trunk lean, hip adduction and knee abduction in individuals with PFP. However, there was conflicting and limited evidence supporting increased contralateral pelvic drop, hip internal rotation and knee external rotation in individuals with PFP (Nakagawa *et al.*, 2012; Willson & Davis, 2008a). We did not find significant differences for peak ipsilateral trunk lean, contralateral pelvic drop, hip adduction, knee abduction, rear-foot eversion and hip internal rotation. Compared to the controls, however, the PFP group demonstrated larger group means for all outcomes, showing a trend towards larger frontal plane and transverse plane motion in the PFP group (see Table 4.3 in Chapter 4).

A possible reason for these insignificant findings might be the result of the small sample size ( $n = 26$  participants per group) in this study. However, a power analysis was calculated for this study using hip adduction range of motion with alpha ( $\alpha$ ) = 0.05 and power = 80%, as used in a similar study (Nakagawa *et al.*, 2012). A second reason for the insignificant differences

between groups could be that both males and females were included in this study. In previous SLS studies, only females were included and larger trunk and lower limb kinematic differences were demonstrated in PFP participants when compared to controls (Herrington, 2014; Nakagawa *et al.*, 2012; Willson & Davis, 2008a).

The average knee flexion position achieved during the static phase of the SLS was statistically insignificant between the case and control groups in our study. Cases and controls thus all reached close to the target angle of 50° and the knee flexion angle during the static phase of the squat position and could therefore not be a covariate for the differences noted in knee external rotation (Horan *et al.*, Salsich *et al.*, 2012). However, the knee flexion position can thus also not be a reason for the insignificant differences seen in the other outcomes. The depth of the SLS in our study was less deep than the SLS used in similar studies where the squat depth was more than 60° of knee flexion (Nakagawa *et al.*, 2015; Nakagawa *et al.*, 2012). The smaller squat depth in our study may similarly account for smaller kinematic differences between cases and controls, as a deep squat is a more demanding functional task (Horan *et al.*, 2014). A deep squat requires more dynamic limb control in the transverse and frontal planes and greater hip flexion and ankle dorsiflexion range of motion (Kim, Kwon, Park & Jeon, 2015; Horan *et al.*, 2014)

There was larger frontal and transverse plane motion in females with PFP than in males with PFP in our study. More specifically, ipsilateral trunk lean, contralateral pelvic drop, hip adduction, knee abduction, and hip internal rotation presented larger group means in the females with PFP than in the males with PFP. This is consistent with the findings of Nakagawa *et al.* (2012), who found that the trunk and lower limb kinematic alterations were larger in females with PFP compared to their male counterparts. Females have a smaller angle of inclination of the femur (due to the wider female pelvis) and a larger angle of torsion of the femur, compared to males (Levangie & Norkin, 2011). These anatomical differences between genders may also be responsible for biomechanical differences between genders during functional activities. The largest kinematic difference seen between female cases and controls was peak ipsilateral trunk lean. There was a borderline statistically insignificant increase in peak ipsilateral trunk lean in females with PFP compared to healthy female controls ( $p = 0.052$ ). The males with PFP, however, did not demonstrate any increase in ipsilateral trunk lean compared to male controls. Ipsilateral trunk lean may be a compensatory strategy to reduce the demands on weak hip abductor muscles of the weight-bearing limb that stabilises the pelvis in the frontal plane (Dierks *et al.*, 2008). The primary hip abductors that may be weak in this case include the gluteus medius, gluteus minimus and tensor fascia latae (Clark & Haynor, 1987).

Ipsilateral trunk lean may control for excessive hip adduction by elevating the contralateral pelvis (Dierks *et al.*, 2008). A systemic review found that females with PFP had significantly weaker hip abductors, extensors and external rotators compared to healthy female controls. Furthermore, another study reported that males with PFP demonstrated deficits in hip extensor strength only, but not in the external rotators or abductors of the hip (Hoglund *et al.*, 2018). This difference in hip muscle strength between males and females may account for increased peak ipsilateral trunk lean only in females with PFP in our study. Nevertheless, trunk muscle weakness may also lead to increased ipsilateral trunk lean in individuals with PFP. It was found that persons with PFP demonstrated decreased trunk muscle strength compared to controls (Nakagawa *et al.*, 2015). Trunk muscle strength was not evaluated in our study. It is recommended that future studies should consider trunk muscle strength and specifically consider the lateral stability of the trunk during functional weight-bearing activities.

When stratifying the participants for bilateral and unilateral PFP, only the bilateral PFP group demonstrated significantly more peak knee external rotation in their affected leg (more affected leg) during the SLS, compared to their control group (see Table 4.5 in Chapter 4). A possible reason may be that both knees are painful in those with bilateral PFP, so there is not a pain-free leg to compensate with during daily activities. A study reported that there are greater between-limb kinematic asymmetries during gait in people with symptomatic bilateral knee osteoarthritis in comparison with people with unilateral osteoarthritis (Mills, Hettinga, Pohl, Ferber & Cat, 2013). This may also be the case for individuals with PFP. Individuals with bilateral PFP symptoms may present with greater kinematic differences and may employ different movement strategies compared to individuals with unilateral PFP. To our knowledge, there currently are no studies that compare the kinematics of individuals with unilateral and bilateral PFP. Our study therefore adds to the current evidence base of PFP and highlights the need for further investigations into the extent of kinematic differences between individuals with unilateral and bilateral PFP.

### **5.3 Between-limb comparison of the PFP group**

In the present study, another objective was to ascertain whether there are any differences in the frontal and transverse plane kinematics of the affected and unaffected or less affected leg in individuals with PFP during the SLS. Peak knee external rotation was the only outcome with a borderline statistically insignificant increase ( $p = 0.056$ ) in the affected leg, compared to the unaffected or less affected leg in PFP participants. When stratifying the PFP group by gender, there was a statistically significant increase in peak knee external rotation in the affected leg of

female PFP participants ( $p = 0.038$ ), but not for males with PFP. This is consistent with the findings of Nakagawa *et al.* (2012) who also found that the kinematic alterations were larger in females than in males with PFP. These findings suggest that there are differences in the transverse plane motion between the affected and unaffected leg or less affected leg of individuals with PFP and these differences should be investigated in greater depth in future studies.

## 5.4 Study demographics

The cases and controls in this study were similar with respect to height, weight and BMI ( $p > 0.05$ ), but not in age ( $p = 0.016$ ). Some matched pairs were not exactly the same age as it was challenging to find perfect matches and there were time constraints to data collection. When the groups were stratified by gender, there were no significant difference for age, which might have been because the groups were smaller when stratified (a smaller sample size decreases the power of a study and increases the p-value). It was decided, however, to still match the cases and controls individually as age difference of a year or two would not affect kinematics.

In this study, the majority of PFP participants were females (61.54%) which is consistent with literature stating that females are more likely than males to develop PFP (Smith *et al.*, 2018; Taunton *et al.*, 2002). There were no restrictions on the number of participants of a certain gender that would be included in this study and participants were tested as they were referred or contacted the research team. Future studies on similar PFP topics could focus on males only to investigate whether there still are statistically significant differences between males with PFP and control males if females are excluded.

PFP is common in physically active individuals (Boling *et al.*, 2009). In this study, 80.8 % of individuals with PFP were physically active. There were five participants in the PFP group who did not participate in any activities at the time of testing and three of them specifically stopped activities due to their PFP. PFP may cause pain during functional activities and thus lead to a lower activity level (Utting *et al.*, 2005). Eighteen (69.2%) controls participated in running as a sport, compared to nine (34.6%) cases. However, it is important to note that seven PFP participants had specifically stopped running due to PFP and two PFP participants mentioned that they ran less often due to PFP. Linking to this finding, another study found that adolescents with PFP were more prone to the cessation or reduction of their sporting activities compared to those who experienced other types of knee conditions (Rathleff, Rathleff *et al.*, 2016). Additionally, a qualitative study found that physical exercise was one of the activities that was

negatively influenced by PFP (Smith *et al.*, 2018). It is evident that PFP has limiting effects on the activity level of its sufferers, causing them to reduce or stop certain physical activities. The underlying reason for the adaptation or cessation of physical activities should be explored further in qualitative studies, as this can inform holistic management of PFP patients.

The findings of our study reiterated the persistence of PFP symptoms as the cases reported a mean duration of 34.5 months of PFP symptoms. In an American study conducted by Schmidt *et al.* (2017), the mean duration of symptoms experienced by individuals with PFP was 54.5 months and a PFP group in an Australian study suffered symptoms for a mean duration of 38.6 months (Crossley *et al.*, 2004). It was reported in the literature that this condition tends to be persistent and generally develop into a chronic knee condition (Van Middelkoop *et al.*, 2017). The identification of causal and contributing factors is therefore crucial to improving management strategies for PFP and to prevent chronicity of this condition.

## **5.5 Clinical applicability**

The SLS can be used in a clinical setting to evaluate the dynamic limb alignment of patients with PFP. Increased dynamic knee valgus observed during a SLS may be indicative of increased knee external rotation. It is also important to take note of ipsilateral trunk lean during a SLS, especially in females with PFP, as females with PFP have demonstrated increased peak ipsilateral trunk lean compared to controls in our study. It is important to still consider the multifactorial nature of this condition in clinical practice and to evaluate and treat each patient individually. The following chapter (Chapter 6) concludes the study, limitations encountered in this study are described and recommendations for future research are provided.

## Chapter 6

# CONCLUSION

### 6.1 Conclusion

The main objective of this study was to describe the kinematic differences between individuals with patellofemoral pain (PFP) in comparison with matched controls during a single leg squat (SLS). Our findings showed that there was a significant increase in peak knee (tibial) external rotation in the PFP group, compared to the control group. Similarly, when the groups were stratified, males and females with PFP and individuals with bilateral PFP presented with significantly increased knee external rotation in the affected leg, compared to controls. All other outcomes showed insignificant differences, although there was a trend towards larger frontal and transverse plane motion in the PFP group.

This finding adds to the limited evidence base of an increase in knee transverse plane motion (specifically knee external rotation) in individuals with PFP during a SLS. Our findings strengthen the SLS as a test for assessing altered kinematics in individuals with PFP. The findings suggest that excessive knee external rotation may play an important role in altered lower limb kinematics in individuals with PFP. Future studies may explore possible contributors to the excessive external rotation in the knee, such as muscle imbalances at the trunk and lower limb. Further studies are required on the kinematic differences between individuals with unilateral and bilateral PFP.

### 6.2 Limitations

Our study encountered limitations that need to be taken into consideration. Due to the cross-sectional design of the study, it was not possible to draw any cause-and-effect conclusions between the kinematic factors and PFP. Another limitation of this study was the fairly small sample size of 26 participants per group. However, a power analysis was calculated for this study using hip adduction range of motion with alpha ( $\alpha$ ) = 0.05 and power = 80%, as used in a similar study (Nakagawa *et al.*, 2012). The further division of the sample into gender groups decreased the statistical power of the groups. There were less males than females in our study, but this phenomenon is consistent with the gender prevalence of PFP, as well as with what has

been reported for similar studies on populations with PFP (Herrington, 2014; Willson & Davis, 2008a; Taunton *et al.*, 2002).

All participants who met the criteria on the ‘Checklist for the diagnosis of anterior knee pain’ were included in the study regardless of their pain levels (NRSP on a normal day). Higher pain levels could have caused compensatory movement strategies during the SLS procedure. A study that also compared the kinematics between a PFP group and controls during a SLS, had restrictions on activity level for inclusion of participants (Willson & Davis, 2008a). Furthermore, all participants in the study by Willson and Davis (2008a) had to have an activity level of five or greater on the Tegner activity scale (an activity rating scale). It might have been useful to add restrictions to the activity level in the current study as well. However, participants who were very active when they developed the PFP, and were then forced to decrease or stop their activities due to pain, would have been excluded from the study in such a case. Future studies should therefore consider activity level selection criteria of PFP participants according to their activity level prior to the start of PFP symptoms, or participants could be placed in subgroups according to their activity level.

Participants were only matched for gender and age; however, it may have been beneficial to also match individuals according to height, weight and activity level (type of sport and hours per week active, or not active). With more precise matching of cases and controls, the influence of other factors that may have an effect on the trunk and lower limb kinematic differences could be minimised. However, given the time constraints of this study, it was not feasible to match individuals in the case and control groups according to stricter criteria. The less-affected leg of participants with bilateral PFP could not be tested as an “affected leg” as well, because the less-affected leg often did not meet the inclusion criteria of the PFP group: the pain of the less-affected knee often was not present for three months and also was not aggravated by the required amount of activities as stated in the ‘checklist for the diagnosis of anterior knee pain’ to be diagnosed as “PFP”. Furthermore, the less-affected leg could also not be classified as “pain-free” to be compared with the pain-free limbs of the control group. The selection criteria of PFP participants in kinematic studies thus are very important as PFP by nature can affect both knees.



### 6.3 Future research

Prospective cohort studies with larger sample sizes can be conducted on similar topics to establish a cause-and-effect relationship between the associated kinematic factors and the development or persistence of PFP. Segmenting individuals with PFP into subgroups according to age, gender and activity level (type of sport and hours per week), might show that some kinematic associated factors are only relevant to some groups and that individuals with PFP should be evaluated or treated according to their subgroup.

Future studies are encouraged to investigate the underlying reasons for increased knee external rotation in individuals with PFP. For instance, the association of impaired muscle strength or altered neuromuscular control of the trunk and lower limb muscles should be investigated. Weakness or altered neuromuscular control of the knee internal rotators (semitendinosis, gracillis, sartorius and popliteus) and over activation or inflexibility of the knee external rotator (biceps femorus) has not been investigated in a PFP population to date and future studies could look into that. However, a holistic approach to the evaluation and management should be followed for individuals with PFP. Future studies should also include the investigation of psychological factors, as an elevation in anxiety, depression, fear of movement and catastrophising has been reported in PFP sufferers (Maclachlan *et al.*, 2017). Furthermore, Maclachlan *et al.* (2017) also found that these psychological characteristics correlated with pain and physical function in a linear manner in people with PFP.

To the investigators' knowledge, studies comparing the trunk and lower limb kinematics between individuals with unilateral and bilateral PFP have not been undertaken yet. Individuals with unilateral and bilateral PFP should be compared in larger samples (that are powered for this subgroup specifically). In these studies, participants with bilateral PFP should have two diagnostic checklists in place (one for each leg), for the participant to truly fall in a bilateral PFP group. More studies can additionally be conducted on persons with bilateral PFP only, as PFP tends to become bilateral.

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# Are you experiencing pain in front of your knee?

The CAF 3D movement analysis unit, Stellenbosch University, invites you to take part in our research project:

'The kinematic differences between individuals with patellofemoral pain compared to matched controls, during a single leg squat'

Participants will be assessed by the physiotherapist at the Coetzenburg laboratory

You will receive 1 FREE treatment session for your knee pain



Volunteers may contact us at: [lanimeiring@gmail.com](mailto:lanimeiring@gmail.com) or 078 3955 978 for further enquiries





## Appendix B: Advert Controls

# Are you a healthy, active individual between the ages of 14 and 50?

The CAF 3D movement analysis unit, Stellenbosch University, invites you to take part in our research project:

'The kinematic differences between individuals with patellofemoral pain compared to matched controls, during a single leg squat'

Participants will be assessed by the physiotherapist at the Coetzenburg laboratory and compare your results to that of participants with knee pain

You will receive a  
**FREE SPORT  
MASSAGE**



Volunteers may contact us at: [lanimeiring@gmail.com](mailto:lanimeiring@gmail.com) or 078 3955 978 for further enquiries



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## Appendix C: Invitation letter

Faculty of Medicine & Health Sciences  
Division of Physiotherapy  
Stellenbosch University  
Teaching Building, 4th floor  
Tygerberg  
7505

Dear colleague

### **Re: invitation of patients to patellofemoral pain study**

My name is Solané Meiring Stephens and I am a physiotherapist and Master's student at the Division of Physiotherapy, Stellenbosch University. The aim of my study is to investigate the biomechanical differences between individuals with patellofemoral pain and matched controls during a single leg squat. Identifying these biomechanical differences during a single leg squat may develop the single leg squat test into a more meaningful clinical test to identify biomechanical predisposing factors. In the long-term this may also lead to better treatment and prevention strategies of patellofemoral pain. I therefore kindly request the referral of potential participants complying with the following criteria:

- Males or females between the ages of 14 and 50.
- The area of pain must be peripatellar or retro-patellar.
- There must be an insidious onset of the knee pain, not related to an injury or trauma.
- The knee pain should be aggravated by prolonged sitting with a flexed knee, squatting, kneeling or stair climbing (ascending or descending).
- No previous surgery was performed to the lower limb.
- No ligament injury or osteoarthritis is present.

This study will take place at the Stellenbosch CAF neuromechanics unit at the Coetzenburg Sports Complex, Stellenbosch University. There will be no costs involved for the participants and they will receive R100 travel fee as well as a free physiotherapy treatment session.

Ethical approval was obtained from the Health Research Ethics Council of Stellenbosch University. The study will be conducted according to the guidelines and standards of the Declaration of Helsinki. Informed consent will be obtained from participants before commencement of the study.

If you have any questions or potential study participants, please do not hesitate to contact me at: .

Kind Regards,

Solané Meiring Stephens

Physiotherapist

## Appendix D: PFP initial screening questionnaire<sup>11</sup>

Name: ..... Date: .....

Gender: .....

Age: .....

Cellphone number: .....

Email: .....

Affected knee (or most painful knee if both are affected):

Left	Right
------	-------

Current pain level on a scale of 0-10:

1. Do you feel the pain in any of the following areas?

	Yes	No
At the front of the knee cap		
Behind the knee cap		
At the front of the knee just below the knee cap		
Deep inside the knee		
On the outside of the knee		
On the inside of the knee		

2. For how long have you had knee pain?

	Yes	No
Less than 3 months		
More than 3 months		

3. Please indicate which of the following activities make your pain worse. You can tick yes for more than one

	Yes	No
Squatting		
Sitting for a long time		
Walking up or down the stairs		
Standing for a long time		
Kneeling		
Lunging		
Jumping		

---

<sup>11</sup> Adapted version of D Leibbrandt

4. Please indicate which of the following are true regarding your knee:

	Yes	No
Previous knee or lower limb surgery		
Ligament injury of the painful knee		
Arthritis of the painful knee		

5. When did the knee pain start for the first time?

.....  
 .....

6. Was there a specific incident or did the knee pain spontaneously start?

.....  
 .....

7. Did a health professional ever diagnose your knee pain?

.....  
 .....

8. Any previous injuries? Please specify on the type of injury and when you sustained the injury.

.....  
 .....

9. Activity level (e.g. Sport and how often).

.....  
 .....  
 .....  
 .....

## Appendix E: Control initial screening questionnaire

Name: .....

Cellphone number: .....

Email address: .....

Gender	
Age	
Height	
Weight	
What sport/ activities do you participate in and how often	
Previous injuries (type of injury/ date of injuries/ treatment for the injury)	

## Appendix F: Checklist for the diagnosis of anterior knee pain

### Checklist for diagnosis of anterior knee pain<sup>1</sup>

#### SUBJECTIVE INFORMATION:

Age (must be yes)	YES	NO
14–50 <sup>1,2,3,4,5</sup>		

Area (must be yes)	YES	NO
Front of knee or retropatella <sup>1,2,3,4,5</sup>		

Chronicity	YES	NO
Longer than three months <sup>1,3,5</sup>		

Aggravated by (must be yes for two or more of the following)	YES	NO
Squatting <sup>1,2,3,4,5</sup>		
Prolonged sitting <sup>1,2,3,4,5</sup>		
Stairs (ascending or descending) <sup>1,2,3,4,5</sup>		
Kneeling <sup>1,2,3,4,5</sup>		

Excluded if any of the below is known	YES	NO
Previous lower limb surgery <sup>1,3,5</sup>		
History of trauma <sup>1,3,5</sup>		
Rheumatological conditions <sup>1,3,5</sup>		
Known intra-articular pathology: ligament and osteoarthritis <sup>1,2,3,4,5</sup>		
Patellar instability <sup>1,4</sup>		
Knee effusion <sup>1,5</sup>		
Patella subluxation/dislocation <sup>1,5</sup>		
Fat pad impingement/bursitis <sup>3,5</sup>		
Osgood–Schlatter <sup>1,3</sup>		

<sup>1</sup> (Leibbrandt & Louw, 2017)

**OBJECTIVE TESTS:**

Symptom reproduction with (must be positive for at least one of the following activities)

Squatting <sup>1,2,3,4,5</sup>		
Kneeling <sup>1,2,3,4,5</sup>		
Ascending or descending stairs <sup>1,2,3,4,5</sup>		

Positive for at least one of the following

Patella compression test <sup>1,4</sup>		
Patella tilt test <sup>1,4</sup>		

**OR**

(Minimum two out of three) positive for combination of

Squatting <sup>3</sup>		
Isometric quads <sup>3</sup>		
Palpation of patella borders <sup>3</sup>		

**Excluded if positive for**

Lachmen's test <sup>6,7,8</sup>	ACL		
Posterior drawer test <sup>6,8</sup>	PCL		
Valgus stress test <sup>6,8</sup>	MCL		
Varus stress test <sup>6,8</sup>	LCL		
McMurray's test <sup>6,8</sup>	MENISCUS		
Patellar ballottement test <sup>5</sup>	Effusion		

## Appendix G: Anterior knee pain scale

## APPENDIX

ANTERIOR KNEE PAIN (Sheet code: \_\_\_\_\_)

Name: \_\_\_\_\_ Date: \_\_\_\_\_

Age: \_\_\_\_\_

Knee: L/R

Duration of symptoms: \_\_\_\_\_ years \_\_\_\_\_ months

For each question, circle the latest choice (letter), which corresponds to your knee symptoms.

**1. Limp**

- (a) None (5)
- (b) Slight or periodical (3)
- (c) Constant (0)

**2. Support**

- (a) Full support without pain (5)
- (b) Painful (3)
- (c) Weight bearing impossible (0)

**3. Walking**

- (a) Unlimited (5)
- (b) More than 2 km (3)
- (c) 1-2 km (2)
- (d) Unable (0)

**4. Stairs**

- (a) No difficulty (10)
- (b) Slight pain when descending (8)
- (c) Pain both when descending and ascending (5)
- (d) Unable (0)

**5. Squatting**

- (a) No difficulty (5)
- (b) Repeated squatting painful (4)
- (c) Painful each time (3)
- (d) Possible with partial weight bearing (2)
- (e) Unable (0)

**6. Running**

- (a) No difficulty (10)
- (b) Pain after more than 2 km (8)
- (c) Slight pain from start (6)
- (d) Severe pain (3)
- (e) Unable (0)

**7. Jumping**

- (a) No difficulty (10)
- (b) Slight difficulty (7)
- (c) Constant pain (2)
- (d) Unable (0)

**8. Prolonged sitting with the knees flexed**

- (a) No difficulty (10)
- (b) Pain after exercise (8)
- (c) Constant pain (6)
- (d) Pain forces to extend knees temporarily (4)
- (e) Unable (0)

**9. Pain**

- (a) None (10)
- (b) Slight and occasional (8)
- (c) Interferes with sleep (6)
- (d) Occasionally severe (3)
- (e) Constant and severe (0)

**10. Swelling**

- (a) None (10)
- (b) After severe exertion (8)
- (c) After daily activities (6)
- (d) Every evening (4)
- (e) Constant (0)

**11. Abnormal painful kneecap (patellar) movements (subluxations)**

- (a) None (10)
- (b) Occasionally in sports activities (6)
- (c) Occasionally in daily activities (4)
- (d) At least one documented dislocation (2)
- (e) More than two dislocations (0)

**12. Atrophy of thigh**

- (a) None (5)
- (b) Slight (3)
- (c) Severe (0)

**13. Flexion deficiency**

- (a) None (5)
- (b) Slight (3)
- (c) Severe (0)

Reference: Kujala UM, Jaakkola LH, Koskinen SK, Taimela S, Hurme M, Nelimarkka O: **Scoring of patellofemoral disorders**. *Arthroscopy* 1993, **9**:159-163.



## **Appendix H: PFP informed consent form**

### **PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM**

#### **TITLE OF THE RESEARCH PROJECT**

‘The kinematic differences between individuals with patellofemoral pain and matched controls, during a single leg squat’

#### **REFERENCE NUMBER:**

**PRINCIPAL INVESTIGATOR:** Mrs. S. Meiring Stephens

**ADDRESS:** Faculty of Medicine & Health Sciences, Division of Physiotherapy, Stellenbosch University, 4th floor, Teaching Building, Tygerberg, 7505

**CONTACT NUMBER:**

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the Health Research Ethics Committee at Stellenbosch University and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

#### **What is this research study all about?**

Patellofemoral pain commonly affects teenagers and young adults causing them to be less physically active. The aim of this study is to better understand the joint movement differences between people with and without patellofemoral pain during a single leg squat (bending down on one knee). The information from this study may help physiotherapists to make better use of the single leg squat test when they are assessing their patients and trying to find the reasons for their knee pain.

This study will take place at the at the Stellenbosch CAF neuromechanics unit at the Coetzenburg Sports Complex, Stellenbosch University, Cape Town, South Africa. This project will include individuals aged between 14 and 50 years, who does experience patellofemoral pain and healthy individuals without pain (controls).

The physiotherapist will first do a short physical exam on you and ask you a few questions.

You will then undergo tests to measure your lower limb joint angles during a single leg squat. The joint angles will be captured with 3D motion analysis. This procedure will involve the placement of reflective markers on bony landmarks on your body. We will also measure your height and weight. This procedure is non-invasive. The test will take about 60 minutes and you

will be requested to perform 6 single leg squats (3 squats on each leg). The data will be used to calculate the risk factors that may be related to patellofemoral pain by comparing your results to that of other pain-free participants.

**Why have you been invited to participate?**

You have been invited to participate in this study because you experience pain in the front of your knee and responded to our invitations or advertisements.

**What will your responsibilities be?**

You will be required to visit the Stellenbosch CAF neuromechanics unit at the Coetzenburg Sports Complex once off for knee testing. A sleeveless vest or strappy top and shorts should be worn during the testing session.

**Will you benefit from taking part in this research?**

You will receive one free treatment session for your knee pain and receive R100 to cover your travel costs. You will also be contributing to the research field of patellofemoral pain.

**Are there in risks involved in your taking part in this research?**

There is a small risk that you may develop a skin reaction due to the skin markers. This skin reaction will settle within a day or two and will usually not require treatment.

**If you do not agree to take part, what alternatives do you have?**

You can receive treatment, at your own cost, at the FNB-3D movement analysis clinic or, at any other therapist of your choice.

**Who will have access to your medical records?**

Data collected will be treated as confidential and protected. Only the researchers involved in the study will have access to the data.

The findings of the study may be published in scientific journals and may also be presented at scientific meetings/conferences; anonymity of your identity will be maintained.

**What will happen in the unlikely event of some form injury occurring as a direct result of your taking part in this research study?**

The university's indemnity insurance will cover the cost of any unfortunate incidents incurred during the testing procedures.

**Will you be paid to take part in this study and are there any costs involved?**

There will be no costs involved for you as your transport costs will be covered for the study visit (R100). You will also receive one treatment session for your knee pain at no cost.

**Is there anything else that you should know or do?**

You can contact [REDACTED] on [REDACTED] if you have any further queries or encounter any problems.

You can contact the Health Research Ethics Committee at 021 938 9207, if you have any concerns or complaints that have not been adequately addressed.

You will receive a copy of this information and consent form for your own records.

### Declaration by participant

By signing below, I ..... agree to take part in a research study entitled ‘The kinematic differences of subjects with anterior knee pain compared to matched controls, during a single leg squat’.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ..... on (*date*) .....

.....  
**Signature of participant**

.....  
**Signature of witness**

### Declaration by investigator

I (*name*) ..... declare that:

- I explained the information in this document to .....
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*)

Signed at (*place*) ..... on (*date*) .....

.....  
**Signature of investigator**

.....  
**Signature of witness**

## **Appendix I: Control informed consent form**

### **PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM**

#### **TITLE OF THE RESEARCH PROJECT**

‘The kinematic differences between individuals with patellofemoral pain and matched controls, during a single leg squat’

#### **REFERENCE NUMBER:**

**PRINCIPAL INVESTIGATOR:** Mrs. S. Meiring Stephens

**ADDRESS:** Faculty of Medicine & Health Sciences, Division of Physiotherapy, Stellenbosch University, 4th floor, Teaching Building, Tygerberg, 7505

#### **CONTACT NUMBER:**



You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the Health Research Ethics Committee at Stellenbosch University and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

#### **What is this research study all about?**

Patellofemoral pain commonly affects teenagers and young adults causing them to be less physically active. The aim of this study is to better understand the joint movement differences between people with and without patellofemoral pain during a single leg squat (bending down on one knee). The information from this study may help physiotherapists to make better use of the single leg squat test when they are assessing their patients and trying to find the reasons for their knee pain.

This study will take place at the at the Stellenbosch CAF neuromechanics unit at the Coetzenburg Sports Complex, Stellenbosch University, Cape Town, South Africa. This project will include individuals aged between 14 and 50 years, who does experience patellofemoral pain and healthy individuals without pain (controls).

The physiotherapist will first do a short physical exam on you and ask you a few questions.

You will then undergo tests to measure your lower limb joint angles during a single leg squat. The joint angles will be captured with 3D motion analysis. This procedure will involve the placement of reflective markers on bony landmarks on your body. We will also measure your height and weight. This procedure is non-invasive. The test will take about 60 minutes and you will be requested to perform six single leg squats (three squats on each leg). The data will be used to calculate the risk factors that may be related to patellofemoral pain by comparing your results to that of participants with patellofemoral pain.

### **Why have you been invited to participate?**

You have been invited to participate in this the study because you do NOT experience pain in the front of your knee, met the matching criteria and responded to our invitations or advertisements.

### **What will your responsibilities be?**

You will be required to visit the Stellenbosch CAF neuromechanics unit at the Coetzenburg Sports Complex once off for knee testing. A sleeveless vest or strappy top and shorts should be worn during the testing session.

### **Will you benefit from taking part in this research?**

*You will receive a free sport massage. You will also be contributing to the research field in patellofemoral pain and receive R100 to cover your travel costs.*

### **Are there in risks involved in your taking part in this research?**

There is a small risk that you may develop a skin reaction due to the skin markers. This skin reaction will settle within a day or two and will usually not require treatment.

### **Who will have access to your medical records?**

Data collected will be treated as confidential and protected. Only the researchers involved in the study will have access to the data.

The findings of the study may be published in scientific journals and may also be presented at scientific meetings/conferences; anonymity of your identity will be maintained.

### **What will happen in the unlikely event of some form injury occurring as a direct result of your taking part in this research study?**

The university's indemnity insurance will cover the cost of any unfortunate incidents incurred during the testing procedures.

### **Will you be paid to take part in this study and are there any costs involved?**

There will be no costs involved for you as your transport costs will be covered for the study visit (R100). You will also receive a free sport massage.

### **Is there anything else that you should know or do?**

You can contact [REDACTED] on [REDACTED] if you have any further queries or encounter any problems.

You can contact the Health Research Ethics Committee at 021 938 9207, if you have any concerns or complaints that have not been adequately addressed.

You will receive a copy of this information and consent form for your own records.

### Declaration by participant

By signing below, I ..... agree to take part in a research study entitled ‘The kinematic differences of subjects with anterior knee pain compared to matched controls, during a single leg squat’.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ..... on (*date*) .....

.....  
**Signature of participant**

.....  
**Signature of witness**

### Declaration by investigator

I (*name*) ..... declare that:

- I explained the information in this document to .....
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*)

Signed at (*place*) ..... on (*date*) .....

.....  
**Signature of investigator**

.....  
**Signature of witness**

## Appendix J: PFP child assent form



### PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM



#### TITLE OF THE RESEARCH PROJECT:

‘The kinematic differences between individuals with patellofemoral pain and matched controls, during a single leg squat’

(The differences in joint-movements of people with pain at the front of the knee compared to normal people, without knee pain, while bending down on one leg)

**RESEARCHERS NAMES:** Mrs S. Meiring Stephens, Prof Q.A. Louw, Mrs L. Williams

**ADDRESS:** Faculty of Medicine & Health Sciences, Division of Physiotherapy, Stellenbosch University, 4th floor, Teaching Building, Tygerberg, 7505

**CONTACT NUMBER:**

#### What is RESEARCH?

Research is something we do to find new knowledge about the way things (and people) work. We use research projects or studies to help us find out more about disease or illness. Research also helps us to find better ways of helping, or treating children who are sick.

#### What is this research project all about?

Patellofemoral pain/ pain in the front of the knee is often felt when you are sitting for a long time, climbing up/down stairs or kneeling. It affects teenagers and young adults causing them not to be as physically active as they would like to be. The aim of this study is to better understand the differences in joint movements between people with and without pain in the front of the knee, while they are bending down on one knee (called a single leg squat). When

you are doing a single leg squat, you bend down on one leg with the other leg lifted off the floor. The information from this study may help physiotherapists to make better use of the single leg squat test when they are trying to find the reasons for their patient's knee pain.

This study will take place at the at the Stellenbosch CAF neuromechanics unit at the Coetzenburg Sports Complex, Stellenbosch University, Cape Town, South Africa. People aged between 14 and 50 years, who does experience pain in the front of the knee and healthy people without pain will be included in the study.

### **Why have I been invited to take part in this research project?**

You reported that you have pain in the front of your knee and responded to our invitations or advertisements.

### **Who is doing the research?**

The main researcher, Solané Meiring Stephens, is doing the research as part of Master's degree in Physiotherapy at the Stellenbosch University.

### **What will happen to me in this study?**

The physiotherapist will first do a few tests on you (touching and moving the knee) and ask you a few questions. You will then undergo tests to measure your leg movements during a single leg squat (bending on one leg). We will use special cameras to look at the movements in 3D.

This procedure will involve the placement of markers on specific points on your body. We will also measure how tall you are, how much you weigh and how long your legs are. The tests will take about 60 minutes and you will be requested to perform six single leg squats (you will bend down three times on each leg). This will help us to see if people who have pain in the front of their knee, does a single leg squat differently from people without pain.

### **Can anything bad happen to me?**

There is a small risk that you may develop a skin reaction from the markers that will be placed on your skin. You must inform your parents if you do get a skin reaction. This skin reaction will settle within a day or two and will usually not require treatment.

### **Can anything good happen to me?**

You will receive one treatment session for your knee pain at no cost.

### **Will anyone know I am in the study?**

No, we will use a code instead of your name and all of your information will be stored anonymously. Only the researchers involved in the study will have access to the information collected.

### **Who can I talk to about the study?**

You can contact [REDACTED] at [REDACTED], if you have any questions or problems related to the study.

You can contact the Health Research Ethics Committee at 021 938 9207 if you have any concerns or complaints that have not been adequately addressed.



**What if I do not want to do this?**

You may choose to leave the study at any time, even if your parents agreed for you to take part, and will not get into trouble in any way.

Do you understand this research study and are you willing to take part in it?

 YES NO

Has the researcher answered all your questions?

 YES NO

Do you understand that you can pull out of the study at any time?

 YES NO

.....  
**Signature of Child**

.....  
**Date**

## Appendix K: Control child assent form

	STELLENBOSCH UNIVERSITY FACULTY OF HEALTH SCIENCES	
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### PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM



#### TITLE OF THE RESEARCH PROJECT:

‘The kinematic differences between individuals with patellofemoral pain and matched controls, during a single leg squat’

(The differences in joint-movements of people with pain at the front of the knee compared to normal people, without knee pain, while bending down on one leg).

**RESEARCHERS NAMES:** Mrs S. Meiring Stephens, Prof Q.A. Louw, Mrs L. Williams

**ADDRESS:** Faculty of Medicine & Health Sciences, Division of Physiotherapy, Stellenbosch University, 4th floor, Teaching Building, Tygerberg, 7505

**CONTACT NUMBER:**

#### What is research?

Research is something we do to find new knowledge about the way things (and people) work. We use research projects or studies to help us find out more about disease or illness. Research also helps us to find better ways of helping, or treating children who are sick.

#### What is this research project all about?

Patellofemoral pain/ pain in the front of the knee is often felt when you are sitting for a long time, climbing up/down stairs or kneeling. It affects teenagers and young adults causing them not to be as physically active as they would like to be. The aim of this study is to better

understand the differences in joint movements between people with and without pain in the front of the knee, while they are bending down on one knee (called a single leg squat). When you are doing a single leg squat, you bend down on one leg with the other leg lifted off the floor. We also need normal, healthy people to form part of the study to serve as a normal comparison to others with pain in the front of the knee. The information from this study may help physiotherapists to make better use of the single leg squat test when they are trying to find the reasons for their patient's knee pain.

This study will take place at the at the Stellenbosch CAF neuromechanics unit at the Coetzenburg Sports Complex, Stellenbosch University, Cape Town, South Africa. People aged between 14 and 50 years, who does experience pain in the front of the knee and healthy people without pain will be included in the study.

### **Why have I been invited to take part in this research project?**

You do NOT experience pain at the front of your knee and responded to our invitations or advertisements.

### **Who is doing the research?**

The main researcher, Solané Meiring Stephens, is doing the research as part of Master's degree in Physiotherapy at the Stellenbosch University.

### **What will happen to me in this study?**

The physiotherapist will first do a few tests on you (touching and moving the knee) and ask you a few questions. You will then undergo tests to measure your leg movements during a single leg squat (bending on one leg). We will use special cameras to look at the movements in 3D.

This procedure will involve the placement of markers on specific points on your body. We will also measure how tall you are, how much you weigh and how long your legs are. The tests will take about 60 minutes and you will be requested to perform six single leg squats (you will bend down three times on each leg). This will help us to see if people who have pain in the front of their knee, does a single leg squat differently from people without pain.

### **Can anything bad happen to me?**

There is a small risk that you may develop a skin reaction from the markers that will be placed on your skin. You must inform your parents if you do get a skin reaction. This skin reaction will settle within a day or two and will usually not require treatment.

### **Can anything good happen to me?**

You will receive a free sports massage if you participate.

**Will anyone know I am in the study?**

No, we will use a code instead of your name and all of your information will be stored anonymously. Only the researchers involved in the study will have access to the information collected.

**Who can I talk to about the study?**

You can contact [redacted] at [redacted], if you have any questions or problems related to the study.

You can contact the Health Research Ethics Committee at 021 938 9207 if you have any concerns or complaints that have not been adequately addressed.

**What if I do not want to do this?**

You may choose to leave the study at any time, even if your parents agreed for you to take part, and will not get into trouble in any way.

Do you understand this research study and are you willing to take part in it?

 YES NO

Has the researcher answered all your questions?

 YES NO

Do you understand that you can pull out of the study at any time?

 YES NO

.....  
**Signature of Child**

.....  
**Date**

## Appendix L: Oxford foot model marker placements<sup>12</sup>

LASI RASI	Anterior superior iliac spine
LPSIS RPSIS	Posterior superior iliac spine
SACR	Sacral marker (midway between the posterior superior iliac spines).
LTHI RTHI	Thigh marker
LKNE RKNE	Standard lateral knee
LTIB RTIB	Tibial marker
LHFB RHFB	Lateral head of fibula
LTUB RTUB	Tibial tuberosity
LSHN RSHN	Anterior aspect of shin
LANK RANK	Ankle
LMMA RMMA	Medial malleoli
LCPG RCPG	Peg marker (Posterior end of calcaneus)
LHEE RHEE	Heel
LPCA RPCA	Posterior calcaneus proximal
LLCA RLCA	Lateral calcaneus
LSTL RSTL	Sustentaculum tali
LP1M RP1M	1 <sup>st</sup> metatarsal, proximal dorsal
LD1M RD1M	1 <sup>st</sup> metatarsal, distal medial
LP5M RP5M	5 <sup>th</sup> metatarsal, proximal lateral
LD5M RD5M	5 <sup>th</sup> metatarsal, distal lateral

<sup>12</sup> Oxford Foot Model 1.4 (Oxford, 2012).

LTOE RTOE	Toe
LHLX RHLX	Hallux (proximal end of 1 <sup>st</sup> distal phalanx or distal end of 1 <sup>st</sup> proximal phalanx)

## Appendix M: Ethical approval form



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Approved with Stipulations

New Application

19/10/2017

**Project Reference #:** 1279

**HREC Reference #:** S17/09/177

**Title:** The kinematic differences of subjects with anterior knee pain compared to matched controls, during a single leg squat

Dear Miss Solane Meiring,

The **New Application** received on 25/09/2017 22:33 was reviewed by members of the **Health Research Ethics Committee** via Minimal Risk Review procedures on 19/10/2017 and was approved with stipulations.

**Please note the following information about your approved research protocol:**

Protocol Approval Period: This project is approved for a period of 12 months from the date of this letter.

The stipulations of your ethics approval are as follows:

1. In more recent times, it is preferred not to use the term "subjects". Please change this to "individuals/study participants" or something similar throughout all study documents.
2. In all informed consent and assent documents, please mention that the participant will be required to wear a sleeveless vest/strappy top and shorts during the testing session.
3. For the informed consent documents, please specify that the transport reimbursement is R100.
4. You refer to the SU no-fault insurance policy in the informed consent but do not mention having applied for this. Please see the relevant details below and apply to have the study covered by the policy.

*All new research applicants should contact the financial planning and asset management office to register their new research project with the Stellenbosch University insurance brokers. Please contact: Mr Wium van Kerwel, Assistant Accountant Financial Planning and Asset Management tel: 021 - 808 2809 fax: 021 - 808 3664 e-mail: [wvankerwel@sun.ac.za](mailto:wvankerwel@sun.ac.za)*

5. Please obtain permission from the Division for Institutional Planning before recruiting SU staff or students.

Please remember to use your HREC reference number (S17/09/177) on any documents or correspondence with the HREC concerning your research protocol.

Translation of the consent document(s) to the language(s) applicable to your study participants should now be submitted to the HREC.

Please note that this decision will be ratified at the next HREC full committee meeting. HREC reserves the right to suspend approval and to request changes or clarifications from applicants. The coordinator will notify the applicant (and if applicable, the supervisor) of the changes or suspension within 1 day of receiving the notice of suspension from HREC. HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

**After Ethical Review:**

Please note you can submit your progress report through the online ethics application process, available at: <https://apply.ethics.sun.ac.za> and the application should be submitted to the Committee before the year has expired. Please see [Forms and Instructions](#) on our HREC website for guidance on how to submit a progress report.

The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.

**Provincial and City of Cape Town Approval**

Please note that for research at a primary or secondary healthcare facility, permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Please consult the Western Cape Government website for access to the online Health Research Approval Process, see: <https://www.westerncape.gov.za/general-publication/health-research-approval-process>. Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.

For standard HREC forms and instructions, please visit: [Forms and Instructions](#) on our HREC website ([www.sun.ac.za/healthresearchethics](http://www.sun.ac.za/healthresearchethics))

If you have any questions or need further assistance, please contact the HREC office at 021 938 9677.

**Included Documents**

Investigator's declaration\_S Meiring

Investigator's declaration\_Q Louw

Investigator's declaration\_L Williams

Protocol Synopsis

Protocol

CV\_S Meiring

CV\_Q Louw

CV\_L Williams

Child Assent Form\_AKP

Child Assent Form\_Controls

Informed Consent Form\_AKP

Informed Consent Form\_Controls

Advert\_AKP

Advert\_Controls

Letter of Invitation

Anterior Knee Pain Scale (AKPS)

Initial Screening Questionnaire

Diagnostic Checklist

Marker Placements

Application form

Yours sincerely,

Francis Masiye,

HREC Coordinator,

Health Research Ethics Committee 2.

*Federal Wide Assurance Number: 00001372*

*Institutional Review Board (IRB) Number: IRB0005239*

*The Health Research Ethics Committee complies with the SA National Health Act No. 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles, Structures and Processes 2015 (Department of Health).*



## Appendix N: Ethics progress report approval letter



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### Progress Report Approval Letter

15/10/2018

**Project ID:** 1279

**Ethics Reference #:** S17/09/177

**Title:** The kinematic differences between individuals with patellefemorol pain compared to matched controls, during a single leg squat

Dear Miss Solane Meiring,

Your request for extension/annual renewal of ethics approval dated 09/10/2018 20:45 refers.

The Health Research Ethics Committee reviewed and approved the annual progress report you submitted through an expedited review process.

The approval of this project is extended for a further year.

**Approval date:** 15 October 2018

**Expiry date:** 14 October 2019

Kindly be reminded to submit progress reports two (2) months before expiry date.

#### **Where to submit any documentation**

Kindly note that the HREC uses an electronic ethics review management system, *Infonetica*, to manage ethics applications and ethics review process. To submit any documentation to HREC, please click on the following link: <https://applyethics.sun.ac.za>.

Please remember to use your **Project ID** [1279 ] and Ethics Reference Number [S17/09/177] on any documents or correspondence with the HREC concerning your research protocol.

National Health Research Ethics Council (NHREC) Registration Numbers: REC-130408-012 for HREC1 and REC-230208-010 for HREC2

Federal Wide Assurance Number: 00001372

Institutional Review Board (IRB) Number: IRB0005240 for HREC1

Institutional Review Board (IRB) Number: IRB0005239 for HREC2

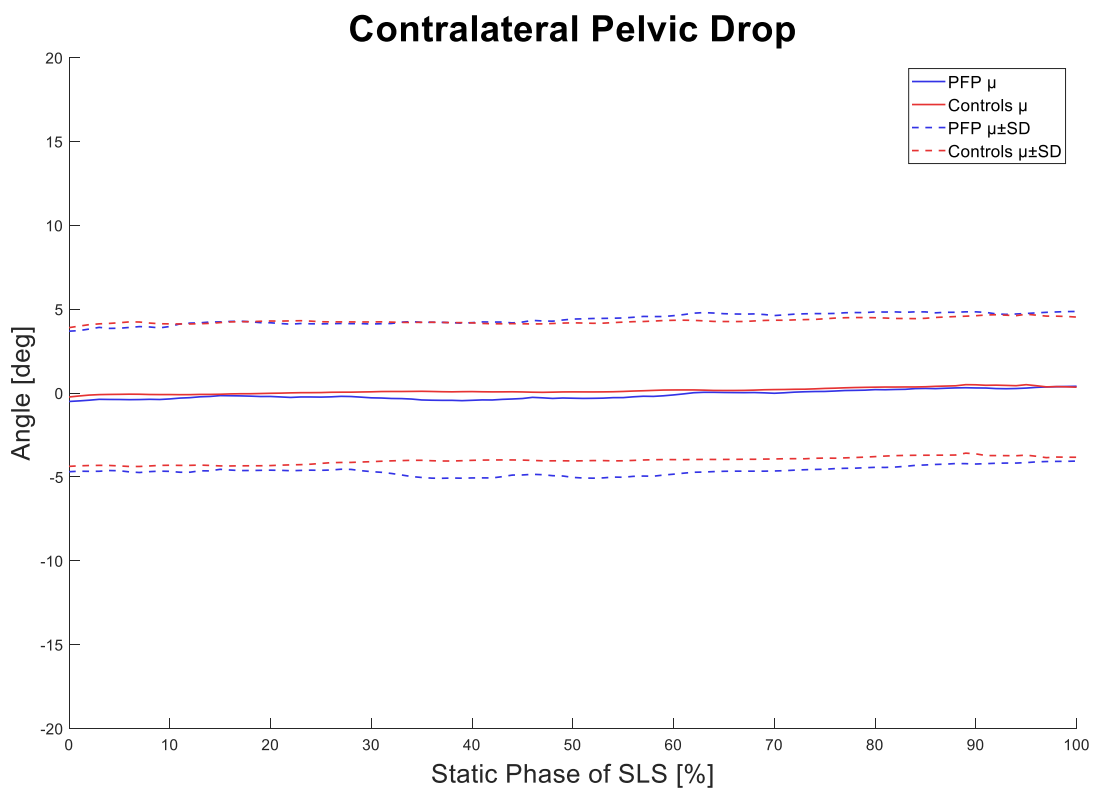
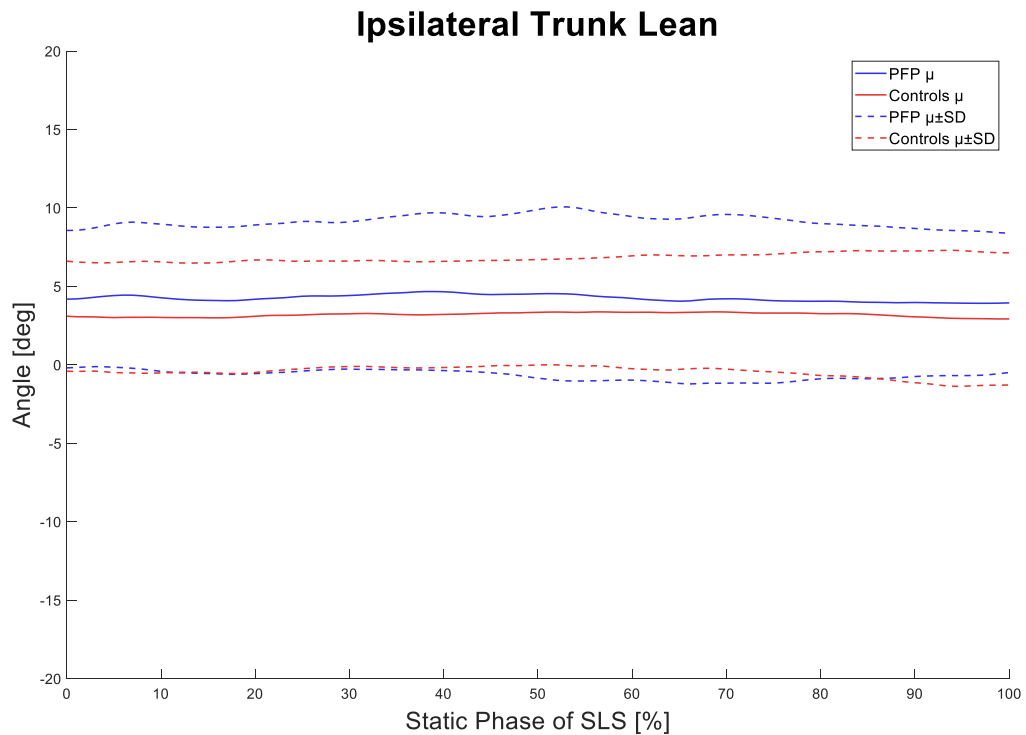
The Health Research Ethics Committee complies with the SA National Health Act No. 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles, Structures and Processes 2015 (Department of Health).

Yours sincerely,

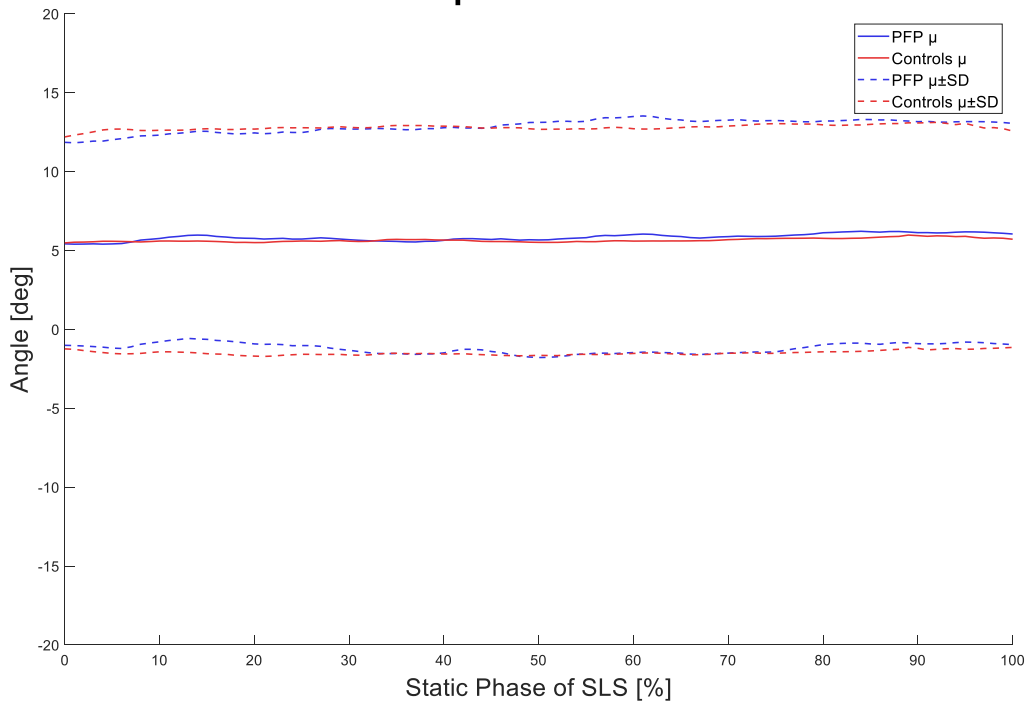
Francis Masiye,

HREC Coordinator,

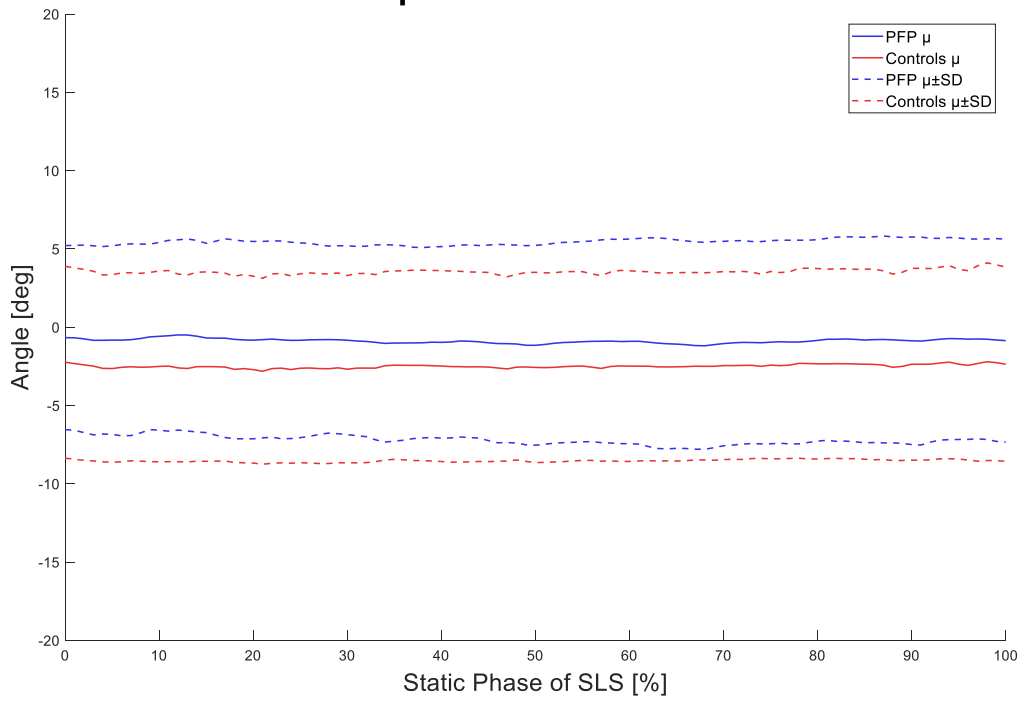
## Appendix O: Joint kinematics during the static phase of the single leg squat



### Hip Adduction



### Hip Internal Rotation



### Rearfoot Eversion

