Validation of an evidence-based biomechanical risk factor screening tool for patellofemoral pain

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Declaration

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Tanya Green

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Abstract

Background

Patellofemoral pain (PFP) is a musculoskeletal disorder of the knee commonly known to affect active adolescent and young adult populations. Altered lower-extremity biomechanics is recognised as a contributing factor resulting in increased stress of the patellofemoral joint (PFJ), which may ultimately cause PFP. Two-dimensional (2D) video gait analysis is a practical way to assess gait kinematics in a clinical setting. However, comparisons between 2D clinical observational gait analysis and the 'gold standard' three-dimensional (3D) motion analysis using an evidence-based biomechanical risk factor screening tool to identify biomechanical risk factors have not been established yet.

Aim and objectives

This study aimed to ascertain agreement between the identification of biomechanical risk factors in individuals with PFP using 2D observational gait analysis (clinical standard) by clinicians and 3D motion analysis (gold standard) by an experienced analyst. The interrater reliability and concurrent validity of 2D clinical observational gait analysis by employing an evidence-based biomechanical risk factor screening tool were investigated.

Methods

The data were collected using a cross-sectional, descriptive study design. Interrater reliability and concurrent validity of 2D clinical observational gait analysis were investigated by observing walking and running videos of 18 recreational runners. Two physiotherapists (raters) independently reviewed the recordings to identify kinematic risk factors constructed from the evidence-based biomechanical risk factor screening tool. Sixteen frontal, sagittal and transverse hip, knee and ankle kinematic variables were investigated and rated dichotomously (yes/no) at specific phases in the gait cycle. The percentage agreement and Cohen's kappa statistic were used to calculate agreement within raters and between 2D and 3D kinematic variables.

Results

Overall, 2D clinical observational gait analysis demonstrated moderate interrater reliability and concurrent validity based on the percentage agreement. The agreement for interrater reliability ranged widely for walking (percentage agreement = 50%–77.78%; kappa = -0.09–0.27) and running (percentage agreement = 44.44%–77.78%; kappa = -0.15–0.35). Only two of the eight kinematic variables for walking demonstrated a high percentage agreement, namely increased peak knee extension and increased overall ankle dorsiflexion (77.78%). Running showed a high percentage agreement in three of the eight kinematic variables, namely increased peak knee flexion (77.78%), increased ankle dorsiflexion and increased ankle eversion (72.22%). Observed agreement for 2D kinematics versus 3D kinematics observed differed significantly between raters. Rater 1's mean findings demonstrated a percentage agreement of 60.41% (with kappa = 0.05) in walking and 64.58% (with kappa = 0.09) in running. Rater 2's mean findings demonstrated a percentage agreement of 76.38% (with kappa = 0.15) in walking and 81.25% (with kappa = 0.20) in running.

Conclusion

The study findings invalidated the use of 2D clinical observational gait analysis employed for the identification of lower-extremity biomechanics and constructed from the evidence-based biomechanical risk factor screening tool in recreational runners with PFP. However, there was overall moderate to fair interrater reliability. The results show that 2D clinical observational gait analysis of certain kinematics included in the evidence-based biomechanical risk factor screening tool should be used cautiously, as the reliability and validity are not adequate for all the kinematic factors included. Clinicians should consider both the best available evidence and the reliability of clinical measurements when screening individuals with PFP in clinical practice to ensure that biomechanical analysis is accurate and relevant.

Opsomming

Agtergrond

Patellofemorale pyn (PFP) is ’n muskuloskeletale knieversteuring wat algemeen onder aktiewe adolessente en jong volwassenes voorkom. Veranderde laerekstremiteit-biomeganika word erken as ’n bydraende faktor tot verhoogde spanning van die patellofemorale gewrig (PFG), wat uiteindelik PFP kan veroorsaak. Gangontleding deur tweedimensionele (2D) video is ’n praktiese manier om gangkinematika in ’n kliniese omgewing te assesseer. Vergelykings tussen 2D gangontleding deur kliniese waarneming en die ‘goue standaard’, driedimensionele (3D) bewegingsontleding, met behulp van ’n bewysgebaseerde biomeganiese risikofaktor-siftingsinstrument vir die identifikasie van biomeganiese risikofaktore is egter nog nie voldoende bewerkstellig nie.

Doel en doelstellings

Die doel van hierdie studie was om ooreenstemming tussen die identifikasie van biomeganies geassosieerde risikofaktore by individue met PFP met behulp van 2D gangontleding deur kliniese waarneming (kliniese standaard) deur klinici en die gebruik van 3D bewegingsontleding (goue standaard) deur ’n ervare ontleder met behulp van die bewysgebaseerde biomeganiese risikofaktor-siftingsinstrument te bepaal. Die tussenbeoordelaar-betroubaarheid en gepaardgaande geldigheid van 2D gangontleding deur kliniese waarneming met behulp van ’n bewysgebaseerde biomeganiese risikofaktor-siftingsinstrument is ondersoek.

Metodes

Die data is ingesamel deur ’n deursnee-, beskrywende studie-ontwerp. Interbeoordelaar-betroubaarheid en gepaardgaande geldigheid van die 2D gangontleding deur kliniese waarneming is ondersoek deur waarneming van stap- en drafvideo’s van 18 ontspanningsdrawwers. Twee fisioterapeute (beoordelaars) het die opnames onafhanklik beoordeel ten einde kinematiese risikofaktore te identifiseer wat uit die bewysgebaseerde biomeganiese risikofaktor-siftingsinstrument saamgestel is. Sestien frontale, sagittale en transverse heup-, knie en enkel- kinematiese veranderlikes is ondersoek en tweedelig (ja/nee) by spesifieke fases in die gangsiklus beoordeel. Die persentasie-ooreenstemming en Cohen se

kappa-statistiek is gebruik om ooreenstemming tussen beoordelaars en tussen 2D en 3D kinematiese veranderlikes te bereken.

Resultate

In die algemeen het die 2D gangontleding deur kliniese waarneming matige interbeoordelaar-betroubaarheid en gepaardgaande geldigheid op grond van die persentasie-ooreenkoms getoon. Die ooreenstemming vir interbeoordelaar-betroubaarheid het aanmerklik gewissel vir stap (persentasie-ooreenstemming = 50%–77.78%; kappa = -0.09–0.27) en draf (persentasie-ooreenstemming = 44.44%–77.78%; kappa = -0.15–0.35). Slegs twee van die agt kinematiese veranderlikes vir stap het ’n hoë persentasie-ooreenstemming getoon, naamlik verhoogde piekknie-ekstensie en verhoogde algehele enkeldorsifleksie (77.78%). Draf het ’n hoë persentasie-ooreenstemming in drie van die agt kinematiese veranderlikes getoon, naamlik verhoogde piekkniefleksie (77.78%), verhoogde enkeldorsifleksie en verhoogde enkeleversie (72.22%). Waargenome ooreenstemming tussen 2D kinematika en 3D kinematika het aanmerklik tussen die beoordelaars verskil. Beoordelaar 1 se gemiddelde bevindinge het ’n persentasie-ooreenkoms van 60.41% (met kappa = 0.05) vir stap en 64.58% (met kappa = 0.09) vir draf getoon. Beoordelaar 2 se gemiddelde bevindinge het ’n persentasie-ooreenkoms van 76.38% (met kappa = 0.15) vir stap en 81.25% (met kappa = 0.20) vir draf getoon.

Gevolgtrekking

Die studiebevindinge het die gebruik van 2D gangontleding deur kliniese waarneming vir die identifikasie van laerekstremiteit-biomeganika by ontspanningsdrawwers met PFP saamgestel uit ’n bewysgebaseerde biomeganiese risikofaktor-siftingsinstrument ongeldig verklaar. Daar was egter algehele matige tot redelike interbeoordelaar-betroubaarheid. Die resultate toon dat 2D gangontleding deur kliniese waarneming vir sekere kinematika ingesluit by die bewysgebaseerde biomeganiese risikofaktor-siftingsinstrument omsigtig gebruik moet word, aangesien die betroubaarheid en geldigheid daarvan nie voldoende is vir al die kinematiese faktore wat daarby ingesluit is nie. Klinici moet sowel die beste beskikbare bewyse as die betroubaarheid van kliniese metings in ag neem wanneer individue met PFP in die kliniese praktyk gesif word ten einde akkurate en toepaslike biomeganiese ontleding te verseker.

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Acronyms and abbreviations

2D	Two-dimensional
3D	Three-dimensional
CI	Confidence interval
FPI	Foot Posture Index
FPPA	Frontal plane projection angle
ICC	Intraclass correlation coefficient
NRS	Numeric Rating Scale
PFJ	Patellofemoral joint
PFJS	Patellofemoral joint stress
PFOA	Patellofemoral osteoarthritis
PFP	Patellofemoral pain
Q-angle	Quadriceps angle
SE	Standard error
SLS	Single-leg squatting
VLO	Vastus lateralis oblique
VMO	Vastus medialis oblique

Glossary

Patellofemoral pain

Patellofemoral pain refers to diffuse retro-patellar or peri-patellar knee pain characterised by an insidious nature in the absence of intra-articular pathology. The pain is reproduced by activities that increase patellofemoral joint stress with a flexed knee joint and are commonly seen in activities such as walking, running, squatting, prolonged sitting, kneeling and stair climbing (Collins et al., 2016; Crossley, Stefanik, et al., 2016; Crossley, Van Middelkoop, et al., 2016).

Kinematics

Kinematic data or variables encompass the displacement and alignment of body segments, joint angles and spatio-temporal gait parameters (Lencioni et al., 2019). The kinematic analysis entails using 3D motion analysis systems to assist in the digital reconstruction of an individual's body as a multisegmented system and is measured in all three cardinal planes (frontal, sagittal and transverse) (Dicharry, 2010).

CHAPTER 1: INTRODUCTION

1.1 Introduction

Patellofemoral pain (PFP) is a common overuse musculoskeletal condition that affects the knee joint and is characterised by pain around or posterior the patella, intensified by activities that load the patellofemoral joint (PFJ) (Crossley, Stefanik, et al., 2016; Crossley, Van Middelkoop, et al., 2016; Waiteman et al., 2021). PFP can restrict an individual's ability to perform functional movements and activities, for instance negotiating stairs, performing a squat and running (Crossley, Stefanik, et al., 2016; Powers et al., 2017; Collins et al., 2018). There are numerous definitions and synonyms known to describe PFP, and it is often a diagnosis of exclusion, with pain typically depicted in the absence of other pathology (e.g. intra-articular pathology). The terminologies interchangeably used are anterior knee pain, runner's knee, patellofemoral pain syndrome, chondromalacia patellae, patella arthralgia and patellofemoral joint dysfunction (Crossley, Stefanik, et al., 2016; Powers et al., 2017; Collins et al., 2018).

PFP has an estimated annual prevalence of 23% in adults, 29% in adolescents and 29% in athletes (Smith et al., 2018) and is present among a large proportion of young, physically active individuals. However, PFP does not only affect the physically active population. The incidence is estimated to be as high as 11 to 14% in the sedentary population and 25 to 40% in those performing any physical activity aside from sports (Crossley, Stefanik, et al., 2016; Smith et al., 2018). PFP is also prevalent in runners and active women, with both groups being twice as likely to be affected as their counterparts (Almeida et al., 2016; Neal et al., 2016).

The aetiology of PFP is intricate and multifactorial (Bertelsen et al., 2017; Dingenen et al., 2019) and may depend on whether symptoms are acute or chronic (Leibbrandt & Louw, 2017b). Numerous pathways, such as mechanical, pathophysiological and psychological, have been proposed as ongoing pain sources (Leibbrandt & Louw, 2017b; Powers et al., 2017). Nevertheless, the origin of pain is hypothesised to be caused by unwarranted patellofemoral joint stress (PFJS) amid activities loading a flexed knee joint, ultimately resulting in articular cartilage pathology (Powers et al., 2017; Leibbrandt & Louw, 2019). The precise source of increased PFJS is unknown, which may pose treatment challenges to many clinicians. According to Collins et al. (2018), reduced contact space of the PFJ is caused by joint malalignment as a result of an alteration in bone structure or muscle imbalance (strength

deficits, activation timing of vastus medialis oblique [VMO], altered tissue extensibility) at the knee, femur and hip (Islam et al., 2015; Collins et al., 2018; Leibbrandt & Louw, 2019).

Altered biomechanics is often observed during functional activities in individuals with PFP (Willy et al., 2019). Multifactorial factors have been proposed during walking and running, including kinematic alterations proximal at the hip joint, local at the PFJ and distal at the foot and ankle, contributing to PFP (Powers et al., 2012; Leibbrandt & Louw, 2017a; Powers et al., 2017). The most common altered kinematic features described in the literature for these factors are increased hip adduction observed in running and single-leg squatting (SLS) (Noehren, Pohl, et al., 2012; De Oliveira Silva, Barton, et al., 2016; Neal et al., 2016), reduced knee flexion when ascending stairs (Dierks et al., 2011; De Oliveira Silva et al., 2015) and increased rearfoot eversion in running and walking (Barton et al., 2012; De Oliveira Silva, Barton, et al., 2016). Hip adduction is typically coupled with hip internal rotation when performing weight-bearing activities (Dingenen et al., 2019; Neal et al., 2019). These altered movement patterns in individuals with PFP are likely to add to the persistence and recurrence of symptoms (Powers et al., 2017; Kingston et al., 2020) by modifying PFJ and tibiofemoral kinematics and kinetics (Dingenen et al., 2019). As a result, this could lead to increased PFJ reaction forces, a reduced contact area of the PFJ and increased PFJS (Besier et al., 2009; Powers et al., 2017; Neal et al., 2019).

PFP tends to become chronic and can be a precursor to patellofemoral osteoarthritis (PFOA) (Thomas et al., 2010; Powers et al., 2017). The development of PFP can be debilitating due to its recurrence and persistence of symptoms and its role in an individual's levels of physical activity (Rathleff et al., 2016). In addition to its prevalence and chronicity, PFP is challenging to manage, as the causes are not well understood (Powers et al., 2017). Therefore, PFP remains a health concern for many clinicians because of the interplay of multiple facets contributing to pain, its effect on individuals' physical activity levels and its association with PFOA development.

The prognosis of PFP is often not favourable, as symptoms tend to persist and reoccur despite evidence-based interventions that are effective in the short term (Lankhorst et al., 2016; Ferrari et al., 2018). Conservative approaches, including physiotherapy, are the preferred alternative for managing PFP (Collins et al., 2012; Collins et al., 2018). Therefore, physiotherapy interventions should be individualised and should aim to address modifiable risk factors (such as altered biomechanics) involved in the development of PFP. The best available evidence-

based treatment recommended for PFP is a multimodal approach incorporating exercise therapy (a combination of knee- and hip-focused exercises), collective treatment modalities (manual therapy, patellar taping or exercise therapy with the use of foot orthoses) and foot orthoses to improve pain and function in people with PFP (Barton et al., 2015; Crossley, Van Middelkoop, et al., 2016; Collins et al., 2018). In addition, the combination of proximal (hip) and local (knee) exercises is proposed instead of knee exercises alone to obtain more desirable outcomes in the long term (Crossley, Van Middelkoop, et al., 2016; Collins et al., 2018).

Furthermore, substantial evidence is linked to higher levels of pain and kinematic changes throughout the lower extremity in individuals with chronic PFP compared to acute PFP groups and healthy controls (Ferrari et al., 2018; Fox et al., 2018). Therefore, recognising kinematic discrepancies linked to increased pain levels in individuals with PFP is essential, as it may indicate a poorer prognosis and may be associated with several biomechanical risk factors affecting the entire kinetic chain (Neal et al., 2016; Lack et al., 2018).

A systematic review by Leibbrandt and Louw (2017a) examined literature pertaining to biomechanical risk factors for PFP. They concluded that peak hip internal rotation and peak rearfoot eversion timing between subjects with PFP and controls were evident in the PFP group observed in walking (Leibbrandt & Louw, 2017a). The review also reported evidence of risk factors during SLS in individuals with PFP and found increased ipsilateral trunk lean, peak hip adduction and knee adduction in subjects with PFP compared to controls (Leibbrandt & Louw, 2017a). Furthermore, the authors categorised risk factors based on their level of evidence and significance and consistency in findings (Leibbrandt & Louw, 2019).

An evidence-based biomechanical risk factor screening tool was created (see Appendix 2), which included eight kinematic variables of the ankle, knee and hip for walking and running, respectively, in frontal, sagittal and transverse planes. This tool was developed to assist clinicians in future screening, prevention and management of PFP. However, all the included studies used three-dimensional (3D) motion analysis procedures to identify these associated risk factors in a movement laboratory. It is still unclear whether this tool can be used by physiotherapists using two-dimensional (2D) gait analysis methods such as video analysis and clinical gait observation.

3D motion analysis is regarded as the ‘gold standard’ for quantifying lower-extremity kinematics observing functional tasks due to its precision and reliability (Nakagawa et al., 2012;

Noehren, Pohl, et al., 2012; Kingston et al., 2020). However, this procedure imposes high financial costs, requires additional time and space, and relies on trained laboratory technicians (Maykut et al., 2015). Most clinicians managing people with PFP do not have access to these facilities, and therefore there is a need for clinical alternatives to screen for biomechanical risk factors (Maykut et al., 2015). 2D gait analysis is generally performed in the clinical setting and usually assesses many body postures and alignment in frontal and sagittal planes. However, there is still limited research on the reliability of clinicians' analyses of various lower-extremity kinematic variables in frontal and sagittal planes (Reinking et al., 2018). There are also conflicting findings in kinematic variables of interest, and it is unclear whether there is an agreement between 2D clinical gait analysis and 3D motion analysis for variables in both frontal and sagittal planes.

Maykut et al. (2015) compared frontal plane motion variables in healthy cross-country runners during treadmill running. Their findings concluded a strong correlation between 2D and 3D video analysis when investigating the hip adduction angle (Maykut et al., 2015). Hip adduction is associated with a degree of excessive pelvic drop (Neal et al., 2016) and excessive knee valgus, which is a common feature, with valgus forces most likely causing pain; however, the reliability and validity of 2D measurements in individuals with PFP are limited to running (Kingston et al., 2020; Neal et al., 2020). In contrast, a study investigating trunk and frontal and sagittal lower-extremity kinematics between 2D and 3D motion analysis during SLS reported a high correlation between the sagittal and poor correlations between the frontal variables (Schurr et al., 2017). Damsted, Nielsen and Larsen (2015) and Pipkin et al. (2016) investigated the intra- and interrater reliability of 2D running kinematics in healthy recreational runners and those with running-related injuries. They reported that reliability was sufficient between experienced raters (Damsted, Nielsen & Larsen, 2015; Pipkin et al., 2016). However, Damsted, Nielsen and Larsen's (2015) findings are limited to two sagittal variables (knee and hip flexion angles) and in Pipkin et al.'s (2016) study, only five of the 11 kinematic variables investigated showed significant interrater reliability.

Furthermore, most of the previous research conducted was based on laboratory studies and cross-sectional evidence. Consequently, more research is warranted through prospective studies on the reliability of 2D clinical observational gait analysis to identify lower-extremity kinematic variables in both frontal and sagittal planes. Especially in South African settings where physiotherapists lack access to 3D motion analysis systems, this can enable a more cost-

effective and clinical approach to assess biomechanical risk factors. Therefore, there was a need to investigate whether clinicians can accurately identify biomechanical risk factors for PFP using 2D clinical observational gait analysis during walking and running.

None of the previous studies investigating PFP and biomechanics using 2D gait analysis used an evidence-based biomechanical risk factor screening tool to identify kinematic variables of interest that may contribute to the development of PFP. More improved clinical biomechanical evaluation methods will allow clinicians to tailor treatment to address subject-specific risk factors, improving treatment outcomes. It will also validate the evidence-based biomechanical risk factor screening tool (Appendix 2) based on laboratory-based studies in a clinical setting to determine its usefulness when managing individuals with PFP who do not have access to expensive 3D motion analysis equipment.

1.2 Study aim and objectives

This study aimed to ascertain the agreement between biomechanical risk factors identified using 2D clinical observational gait analysis (clinical standard) by clinicians and 3D motion analysis (gold standard) by an experienced analyst using the evidence-based biomechanical risk factor screening tool.

The objectives of the study were the following:

1. To identify associated PFP biomechanical risk factors during walking and running using the evidence-based biomechanical risk factor screening tool in people with PFP using 2D clinical observational gait analysis
2. To assess the concurrent validity between the biomechanical PFP risk factors identified with 3D motion analysis compared to biomechanical factors identified using 2D clinical observational gait analysis using an evidence-based biomechanical risk factor screening tool
3. To assess the interrater reliability in identifying biomechanical PFP risk factors with an evidence-based biomechanical risk factor screening tool using 2D clinical observational gait analysis.

1.3 Conclusion

PFP is a common condition affecting the young adult physically active population. In addition, altered lower-extremity biomechanics is proposed as one of the main contributing factors leading to increased PFJS and causing PFP. Considering the financial implications of 3D gait analysis for many clinicians and patients, more accessible alternatives are required to screen for biomechanical risk factors. Therefore, this study aimed to employ 2D clinical observational gait analysis to identify these risk factors to prevent and manage PFP. The following chapter presents a discussion of literature pertaining to the aetiology and the proposed underlying risk factors, particularly lower-extremity biomechanics, involved in PFP.

CHAPTER 2: LITERATURE REVIEW

2.1 Purpose

The purpose of the literature review was to outline the relevance of assessing lower-extremity biomechanics in people affected by PFP. The key concepts of PFP and biomechanics are discussed. The review primarily focused on the proposed biomechanical risk factors for the development of PFP and the underlying kinematic variables associated with walking and running. In addition, the evidence of validated physical assessment tools used to help clinicians detect these biomechanical risk factors in clinical practice during gait-related activities is discussed. The literature search was performed using the available electronic databases on Stellenbosch University's Library and Google Scholar. The following key search terms were used: patellofemoral pain; retro-patellar pain; patellofemoral pain syndrome; anterior knee pain; kinematics and/or biomechanics; risk factors; physical assessment; and walking and running gait analysis.

2.2 Introduction

PFP is described as self-reported diffuse pain around or behind the patella, characterised by insidious onset without any distinct cause in the absence of intra-articular pathology (Crossley, Stefanik, et al., 2016). Symptoms are commonly exacerbated during activities with the knee flexed, loading the PFJ (Witvrouw et al., 2014; Collins et al., 2016; Crossley, Stefanik, et al., 2016; Crossley, Van Middelkoop, et al., 2016). Several definitions and synonyms are used to describe PFP. Terminology interchangeably used in literature includes patellofemoral pain syndrome, chondromalacia patellae, patellofemoral joint dysfunction, runner's knee, patella arthralgia and anterior knee pain (Crossley, Stefanik, et al., 2016; Powers et al., 2017; Collins et al., 2018). For this review, the term 'patellofemoral pain' (PFP) is used.

PFP occurs in both women and men of all ages (Glaviano et al., 2015; Smith et al., 2018; Kingston et al., 2020) and is common among active adolescents (Hall et al., 2015; Crossley, Stefanik, et al., 2016). The association between specialising in specific sports and the risk of young female athletes developing PFP was investigated in a study by Hall et al. (2015). The authors concluded that participation in a single sport, contrary to involvement in multiple sports, was connected to a higher occurrence of PFP (Hall et al., 2015; Willy et al., 2019). It is reported that PFP has an estimated annual prevalence of 23% in adults and 29% in adolescents, and 29% in athletes (Collins et al., 2018; Smith et al., 2018; Pazzinatto et al., 2020). PFP mainly presents

in young, active individuals and contributes to approximately 25 to 40% of knee conditions observed in a sports injury clinic (Crossley, Stefanik, et al., 2016; Dutton, Khadavi & Fredericson, 2016). Furthermore, the onset of PFP can occur at any time in a person's life and may depend on his/her level of activity and the environmental risk factors involved (Crossley, Stefanik, et al., 2016; Willy et al., 2019).

Current literature supports evidence of women being a high-risk group to develop PFP (Neal et al., 2019). Smith et al. (2018) investigated the incidence and prevalence of PFP and reported that women working in the military were twice as likely to suffer from PFP compared to male recruits (Smith et al., 2018; Crossley et al., 2019). The knee joint is the most implicated joint in running-related injuries (Taunton et al., 2002; Linton & Valentin, 2018; Neal et al., 2019). In addition, PFP is one of the most typical conditions (Taunton et al., 2002), with an incidence of 6% among recreational runners (Neal et al., 2019).

PFP is not a self-limiting condition (Willy et al., 2019), as it may persist for many years (Lankhorst et al., 2016; Rathleff et al., 2016), causing a decline in participation in sport, physical activity and even work-related tasks (Crossley, Stefanik, et al., 2016; Rathleff et al., 2016). Long-term treatment outcomes for PFP were reported as inadequate, with more than 50% of people expected to report symptoms exceeding five years after diagnosis (Lack et al., 2018). PFP can significantly impact quality of life. However, this is not limited to the physical domains and can include thoughts of fear and confusion related to pain and even concern for the future (Smith et al., 2019; Willy et al., 2019). There are various factors of PFP, which may pose challenges to clinicians to assess, diagnose and manage this condition effectively, especially once it becomes chronic.

2.3 The proposed aetiological factors

The proposed aetiology of PFP is postulated as the interchange among structural (anatomical and biomechanical) and behavioural changes and psychological and social components (Powers et al., 2017; Sisk & Fredericson, 2019). PFP seems mainly to be the cause of atypical anatomy, predisposing the individual to biomechanical anomalies (e.g. patella maltracking) (Sherman, Plackis & Nuelle, 2014). Nevertheless, the relationship between these factors and the presentation of PFP continues to be poorly understood (Leibbrandt & Louw, 2017a; Powers et al., 2017). An underlying premise of the proposed pathomechanics of PFP is atypical loading of the joint, resulting in excessive PFJ stress (Powers et al., 2017; Crossley et al., 2019). An increase in joint stress affects various dynamic and static structures, which influences

nociception (Powers et al., 2017) and ultimately results in articular cartilage pathology; however, the precise structural tissue sources connected to PFP are unknown (Islam et al., 2015; Powers et al., 2017).

The key concepts described in the pathomechanics of PFP consist of the contact surface area of the PFJ, maltracking of the patella, joint kinematics and kinetics, together with associated muscle imbalances (Carlson, Boden & Sheehan, 2017; Powers et al., 2017; Crossley et al., 2019). Imbalances in muscle strength and the timing of trunk and lower-extremity muscle contractions, especially the quadriceps, are believed to influence the patella's tracking during loading of the PFJ (Dutton, Khadavi & Fredericson, 2016; Powers et al., 2017). The nature of PFP is intricate as a consequence of structural and functional PFJ malalignment (Neal et al., 2016; Bertelsen et al., 2017). According to Collins et al. (2018), a reduced contact area of the PFJ is caused by malalignment resulting from an alteration in bone structure or muscle imbalance at the hip, femur and knee.

Another proposed source of PFP is increased intraosseous pressure (Crossley et al., 2019). The increased pressure is ascribed to poor venous flow (tissue homeostasis model) (Ho et al., 2014; Van der Heijden et al., 2018). A disturbance of tissue homeostasis from an acute injury or repetitive overloading may exceed tissue homeostasis and result in pathology, followed by the experience of pain (Post & Dye, 2017). In addition to the other proposed risk factors, constant loading of the PFJ can elevate patellar bone metabolic activity (Dye, 2005; Draper et al., 2012; Powers et al., 2017; Dye & Dye, 2018), resulting in elevated levels of patellar bone water content (Ho et al., 2014). Subsequently, this contributes to greater loads being transferred to subchondral bone (Ho, Keyak & Powers, 2014), causing increased mechanical nociceptor stimulation (Ho et al., 2014). These external pressures can arise from overuse; poor running technique; rapidly increasing the intensity, speed, duration and frequency of training; irregular training surfaces; improper footwear; or insufficient recovery time between training sessions (Dutton, Khadavi & Fredericson, 2016; Sisk & Fredericson, 2019). Overuse as a risk factor has become more evident, particularly in novice runners. A study by Nielsen et al. (2014) in healthy novice runners reported that runners increasing their training distance with more than 30% mileage for two weeks were more prone to running-related injury (Ho et al., 2014; Sisk & Fredericson, 2019).

The presentation of PFP is reported to be more than just that of nociception (Maclachlan et al., 2017). Individuals who report persistent PFP symptoms tend to display atypical nociceptive processing (e.g. widespread mechanical hyperalgesia, diminished modulation of pain) (Noehren et al., 2016; Rathleff et al., 2016; Powers et al., 2017) and altered somatosensory processing (implying neuropathic pain) (Jensen, Kvåle & Baerheim, 2008). Impaired sensorimotor function (e.g. proprioception and balance) (Yelvar et al., 2017) and individual psychological factors (e.g. catastrophising and kinesiophobia) (Doménech, Sanchis-Alfonso & Espejo, 2014; De Oliveira Silva et al., 2019) have also been apparent in individuals with PFP. Recent research explores how non-physical influences on symptoms such as pain sensitisation and psychological status influence PFP (Willy et al., 2019). Current literature demonstrates moderate to strong evidence of these risk factors (Neal et al., 2019) that contrast with an array of physical, structural and associated psychological influences that have been recognised as impairments prevalent in individuals with PFP (Hart et al., 2017; Maclachlan et al., 2017; Coburn et al., 2018; Crossley et al., 2019).

Vicenzino, Maclachlan and Rathleff (2019) suggest that the pathophysiological model should consist of psychological and social aspects in conjunction with biological, structural and somatic elements (Crossley et al., 2019). Numerous people who experience PFP develop pain-related fear, for example fear avoidance and catastrophising thoughts relative to their pain (Maclachlan et al., 2017; Maclachlan et al., 2018; Smith et al., 2019). Maclachlan et al. (2017) investigated the psychological factors in individuals with PFP. The authors compared participants with PFP to healthy controls. Participants were grouped based on four psychological concepts, namely mental health, cognitive, behavioural and additional psychological factors (Maclachlan et al., 2017). The study demonstrated that mental health factors, which include anxiety and depression, cognitive factors (e.g. pain catastrophising) and behavioural factors (e.g. fear avoidance) could potentially be intensified and are linked to higher pain levels and lower function in individuals with PFP (Maclachlan et al., 2017; Willy et al., 2019).

Another cross-sectional study by Maclachlan et al. (2018) compared the psychological profiles of individuals with PFP and controls. The authors conducted a preliminary analysis in subgroups with PFP based on the severity of pain (according to the Knee Injury and Osteoarthritis Outcome Score) and reported no changes between groups for depression and anxiety, pain catastrophising and kinesiophobia (Maclachlan et al., 2018). However, individuals

with more severe pain demonstrated higher catastrophising and depression levels than controls; in addition, higher levels of depression, pain catastrophising and kinesiophobia were also demonstrated in the severe PFP group compared to the group who demonstrated less severe pain (Maclachlan et al., 2018). Persistent PFP and poor long-term outcomes can negatively impact a person's social engagement and participation in physical activities (Crossley, Stefanik, et al., 2016). In addition, individuals with prolonged symptoms, including increased severity of pain and limited function at baseline, are more likely to experience undesirable outcomes or unfavourable recovery (Willy et al., 2019). Therefore, early detection of these psychological factors is crucial, as it may affect long-term treatment outcomes in managing PFP.

The complexity of PFP and the minimal evidence of a direct causal relationship between the various aetiological factors and the reported intensity of pain experienced can obscure clinicians' ability to tailor person-specific interventions according to the underlying risk factors (Fick, Grant & Sheehan, 2020).

2.4 Associated or underlying risk factors

Success with preventing and managing PFP is dependent on identifying the associated risk factors (Crossley et al., 2019). Identifying these risk factors will help clinicians to personalise interventions according to the underlying risk factors presented during assessment and screening. As an overuse injury, there are various risk factors, including intrinsic and extrinsic factors involved in the pathogenesis and development of PFP. PFP is commonly ascribed to local, proximal or distal factors that increase or alter PFJ stress (Thomas et al., 2010; Leibbrandt & Louw, 2017a; Willy et al., 2019). Dutton, Khadavi and Fredericson (2016) further categorised these risk factors as local impairments, biomechanical dysfunction in lower-extremity biomechanics and common training errors. The local components consist of all structures stabilising the PFJ that directly influence joint position (patellar tracking) and function (Dutton, Khadavi & Fredericson, 2016).

Lower-extremity biomechanics mainly consists of hip muscle dysfunction or weakness, hip abductor and rearfoot eversion and deviations in gait kinematics (Dutton, Khadavi & Fredericson, 2016). Additional factors, including training errors, particularly a sudden escalation in duration, frequency, speed and intensity in exercise, with a short recovery period and changes in training surfaces and shoe wear, should be considered in the active population (Dutton, Khadavi & Fredericson, 2016). Petersen et al. (2014) and Petersen, Rembitzki and Liebau (2017) describe patellar maltracking and dynamic knee valgus in people with PFP as

proposed risk factors for developing PFP. Furthermore, Petersen, Rembitzki and Liebau (2017) suggest that decreased hip abductor strength and rearfoot eversion may contribute to dynamic knee valgus. Therefore, assessing hip strength and foot kinematics when screening people, especially athletes, may prevent the development of and guide the management of PFP.

An individual's characteristics, anthropometrics, body posture and alignment are frequently proposed essential factors resulting in PFP (Willy et al., 2019). Recent reviews indicate that the quadriceps angle (Q-angle), age, weight, height, body mass index and body fat percentage are not predictive factors for developing PFP (Lankhorst, Bierma-Zeinstra & Van Middelkoop, 2012; Neal et al., 2019; Willy et al., 2019). There is evidence suggesting that a larger proportion of women develop PFP (Crossley et al., 2019). The exact mechanism for gender disparity is unknown, but might be ascribed to certain PFP risk factors more predominant in women than men (Crossley et al., 2019). Typically, female participants have about half the quadriceps muscle strength than their male counterparts (Anderson et al., 2001; Crossley et al., 2019), potentially putting them at higher risk of developing PFP (Holden et al., 2017). Limited evidence exists for greater knee abduction as a risk factor for PFP, despite compelling evidence from multiple biomechanical studies reporting uninjured women displaying increased dynamic knee abduction when performing weight-bearing tasks compared to men (Cronström et al., 2016; Simon et al., 2018; Crossley et al., 2019).

Generalised quadriceps weakness and atrophy have long been associated with PFP (Lankhorst, Bierma-Zeinstra & Van Middelkoop, 2012; Neal et al., 2019) and are typically weakened in individuals suffering from chronic PFP (Werner, 2014). In addition, there is evidence that reduced quadriceps strength is associated with an increased risk of developing PFP, predominantly among the military population (Crossley et al., 2019; Neal et al., 2019), which is exposed to physical activity of greater rigour than that to which the general physically active population might be accustomed. However, quadriceps weakness cannot be generalised as a proposed risk factor in all subgroups, as it was not recognised in the adolescent population, thereby highlighting the heterogeneity of risk factors associated with PFP across a person's lifespan (Rathleff et al., 2015; Neal et al., 2019).

Concentric quadriceps strength is approximately 30% lower in PFP patients than healthy controls, while eccentric strength is decreased by approximately 40% (Guney et al., 2016). Functional activities demanding eccentric control of the quadriceps are usually more challenging and painful in people with PFP, and reduced quadriceps eccentric strength can be

expected in individuals with PFP (Werner, 2014). Quadriceps muscle forces play an essential role in regulating a balance between medial and lateral forces that influence contact force and pressure distribution within the patella (Besier et al., 2009). Therefore, the quadriceps muscles, particularly the VMO, are linked to directly impacting the patella's tracking capabilities. A muscle imbalance between VMO and vastus lateralis oblique (VLO) forces can alter patellar tracking, resulting in decreased contact areas, elevating the stress on the PFJ, and subsequent PFP (Besier et al., 2009; Sisk & Fredericson, 2019).

Isolated VMO atrophy has been reported inconsistently in individuals with PFP (Giles et al., 2015; Powers et al., 2017). In contrast, quadriceps weakness (Lankhorst, Bierma-Zeinstra & Van Middelkoop, 2012, 2013; Neal et al., 2019), along with a delay in VMO activation relative to the VLO (Witvrouw et al., 2000; Van Tiggelen et al., 2009; Powers et al., 2017), is suggested to be related to the development of PFP. Briani et al. (2016) found that physically active women with PFP have considerable differences in VMO/VLO activation times compared to women who exercise moderately and healthy controls (Sisk & Fredericson, 2019). Furthermore, the finding that activation timing of muscles is linked with PFP demonstrates that muscle imbalance factors for PFP do not occur in isolation (Sisk & Fredericson, 2019). In summary, deficits in strength and endurance, decreased isometric and isokinetic properties, decreased muscle torque and delayed activation of muscles surrounding the hip and knee are accepted to be linked with PFP (Glaviano & Saliba, 2016; Nunes et al., 2019; Steinberg et al., 2020).

Hamstring, quadriceps and gastrocnemius muscle flexibility have been previously reported in the development of PFP. The hamstring muscle's inflexibility can produce constant knee flexion motion in the patella, causing an increased load and resulting in PFJ stress. PFP resulting from gastrocnemius muscle tightness is caused by the posterior translation of the patella on the femoral trochlea (Dutton, Khadavi & Fredericson, 2016). Witvrouw et al. (2000) demonstrated significant hamstring muscle inflexibility in individuals with PFP compared to controls, but hamstring flexibility was not identified as a risk factor for the development of PFP. However, there is moderate evidence supporting the assessment of soft-tissue structures such as the rectus femoris, hip flexors, hamstrings, gastrocnemius and soleus muscles, including the iliotibial band, when screening for PFP (Witvrouw et al., 2000; Waryasz & McDermott, 2008; Dutton, Khadavi & Fredericson, 2016; Capin & Snyder-Mackler, 2018).

Soft-tissue structure extensibility around the knee plays an integral role in PFP. The lateral retinaculum comprises transverse fibrous tissue from the iliotibial band and quadriceps

aponeurosis that extends into the lateral facet of the patella, creating a dense piece of connective tissue (Merican & Amis, 2009; Sisk & Fredericson, 2019). The presence of excessive tautness in these lateral structures results in lateral forces overcoming medial forces, causing patellar maltracking (Dutton, Khadavi & Fredericson, 2016; Sisk & Fredericson, 2019). Lack et al. (2018) report an association of tightness and thickness of the iliotibial band and lateral retinaculum to be more significant in those with PFP than without, contributing to altered patellar kinematics. In addition, studies have also linked quadriceps and gastrocnemius inflexibility, delayed onset of VMO activation and excessive medial translation of the patella related to the incidence of PFP (Witvrouw et al., 2000; Waryasz & McDermott, 2008; Willy et al., 2019). Changes in all these soft-tissue structures can increase stress on the patella and irritate surrounding structures, resulting in PFP.

Hip abductors and external rotator muscles may cause exorbitant femoral internal rotation, which in exchange has been connected to the development of PFP (Lankhorst, Bierma-Zeinstra & Van Middelkoop, 2013; Van Cant et al., 2014; Dutton, Khadavi & Fredericson, 2016). However, based on previous reviews, prospective studies reported no correlation between reduced isometric hip rotators (internal and external), abductors and extensor strength and the risk of individuals developing future PFP (Rathleff et al., 2014; Willy et al., 2019). These findings contrast with multiple cross-sectional studies that provided evidence of reduced isometric hip muscle strength in individuals with PFP (Rathleff et al., 2014; Willy et al., 2019). In addition, more recent studies investigating the association between running-related injuries in long-distance runners and hip abduction strength reported conflicting findings demonstrating no correlation between reduced strength of the hip abductors and the incidence of PFP (Mucha et al., 2017; Willy et al., 2019).

Moderate evidence exists for increased isometric hip abduction strength as a predicting factor for the development of PFP among the adolescent population (Finnoff et al., 2011; Neal et al., 2019). Women with PFP are also reported to have decreased hip abduction strength (Bolgla et al., 2011; Leibbrandt & Louw, 2019). Bolgla et al. (2011) demonstrated that women with PFP had 26% less hip abduction strength than their matched controls. Although no causality was reported connecting hip muscle weakness and the occurrence of PFP (Mucha et al., 2017; Willy et al., 2019), hip muscle weakness can potentially be a result of PFP instead of a risk factor for developing PFP (Rathleff et al., 2014; Wyndow, Collins, et al., 2016; Sisk & Fredericson, 2019).

Muscular imbalance and inadequate neuromuscular control of the hip abductor muscles may contribute to the development of PFP (Ford et al., 2015; Leibbrandt & Louw, 2019). Hip musculature plays a crucial role in pelvic control and lumbopelvic stability. Discrepancies in gluteus medius strength could alter frontal plane movement patterns and correlated strongly with PFP in SLS and running in women (Souza & Powers, 2009; Nakagawa et al., 2012; Sisk & Fredericson, 2019). It is suggested that hip abductor muscle weaknesses, especially in women, may result in an inability to oppose knee valgus forces coupled with hip internal rotation motion in activities, for example running and SLS (Bolgla et al., 2011; Leibbrandt & Louw, 2019). There is also evidence supporting findings that runners with increased hip abductor eccentric strength have a lower risk of developing PFP (Ramskov et al., 2015; Willy et al., 2019). This emphasises the importance of dynamic and functional testing of the hip when screening for risk factors associated with PFP, especially in women and running subgroups, as risk factors may differ within groups (Neal et al., 2019).

PFP is reported transversely in different life stages and could be a precursor to PFOA (Crossley, 2014; Powers et al., 2017). Therefore, understanding and acknowledging the risk factors linked to PFP development, its incidence and its prevalence in diverse populations are essential to prevent the recurrence of symptoms and the development of chronicity (Neal et al., 2019). Dingenen, Barton et al. (2018) support the evidence of previous research, acknowledging that altered lower-extremity biomechanics during dynamic weight-bearing activities may be involved in the development of PFP. Due to functional malalignment or dynamic knee valgus, patellar maltracking can occur and can be an underlying premise for developing PFP (Petersen, Rembitzki & Liebau, 2017). In addition, multiple factors have been implicated as risk factors causing PFP, ranging from quadriceps imbalance, adjacent muscle tightness (gastrocnemius and hamstring), decreased hip muscle strength and abnormal foot biomechanics (Petersen, Rembitzki & Liebau, 2017; Powers et al., 2017). Identification of these underlying risk factors and their clinical significance is essential in order to develop a tailored person-specific treatment plan (Petersen, Rembitzki & Liebau, 2017). Therefore, the following section discusses biomechanical risk factors associated in individuals with PFP.

2.5 Biomechanical factors

Biomechanical dysfunctions are known as probable factors causing PFP (Boling et al., 2009), accounting for increased cartilage stress and bone strain across the PFJ (Ho et al., 2014; Powers et al., 2017). The source of altered biomechanics in individuals with PFP is multifactorial, and numerous key factors have been proposed for walking and running. Alterations in the kinematics and alignment of the PFJ that promote joint stress include tibia varum, increased genu valgum, increased dynamic Q-angle, a lateral shift of the patella and muscle imbalances (Lankhorst, Bierma-Zeinstra & Van Middelkoop, 2012; Leibbrandt & Louw, 2017a; Collins et al., 2018; Leibbrandt & Louw, 2019). The most common altered kinematic features reported in the literature include increased hip adduction during running and SLS (Noehren, Hamill & Davis, 2013; De Oliveira Silva, Magalhães, et al., 2016; Neal et al., 2016). Studies have also reported evidence of reduced knee flexion when ascending stairs and increased rearfoot eversion during walking and running in individuals with PFP (Barton et al., 2012; De Oliveira Silva, Magalhães, et al., 2016).

Altered hip kinematics in female runners and during SLS has strongly been linked with PFP (Nakagawa et al., 2012; Sisk & Fredericson, 2019; Boling et al., 2021). Furthermore, hip adduction when performing certain weight-bearing activities is frequently combined with hip internal rotation (Powers, 2010; Dingenen et al., 2019) and correlates with knee abduction, resulting in medial displacement of the knee (dynamic knee valgus) (Powers et al., 2017). Both increased hip adduction and internal rotation have been observed in female runners with PFP (Noehren, Sanchez, et al., 2012; Esculier, Roy & Bouyer, 2015; Neal et al., 2019), but these changes are not essentially seen in male runners (Neal et al., 2019).

Although a hip adducted position was not directly associated with PFP during the jump-landing task, women who landed with 10 degrees or less hip abduction compared with those who landed with more than 10 degrees hip abduction were almost twice inclined to develop PFP (Boling et al., 2021). The same study also investigated men and found that individuals landing with less than 20 degrees knee flexion at initial contact were more than twice as likely to develop PFP than men landing with 20 degrees or more knee flexion. In addition, men who exhibited external hip rotation more than 5 degrees at 50% of the stance phase were almost doubly expected to obtain PFP than men landing between 0 to 5 degrees external hip rotation (Boling et al., 2021). Subsequently, the authors speculate that decreased knee flexion at heel strike and femoral

rotation could lead to altered patellofemoral contact stress and, eventually, the development of PFP in men (Boling et al., 2021).

Limited evidence has been reported for increased peak hip adduction as a risk factor for developing PFP in female runners (Noehren, Hamill & Davis, 2013; Neal et al., 2016). A systematic review and meta-analysis by Neal et al. (2016) also provided moderate evidence from studies suggesting increased contralateral pelvic drop, peak hip adduction and hip internal rotation related to the development of PFP (Dierks et al., 2011; Bazett-Jones et al., 2013; Esculier, Roy & Bouyer, 2015; Neal et al., 2016). A prospective study by Noehren, Hamill and Davis (2013) investigated 3D instrumental gait analysis in 400 healthy female runners and tracked the participants for running-related injuries developed over two years. The findings reported 15 cases of PFP whose initial running kinematics were equally compared to several runners who remained uninjured (Noehren, Hamill & Davis, 2013). They also reported that female runners who acquired PFP displayed significantly greater hip adduction (Noehren, Hamill & Davis, 2013). Leibbrandt and Louw (2017a) reviewed the lower-extremity kinematic factors related to PFP during common aggravating activities. The authors report that peak hip internal rotation and peak rearfoot eversion timing were evident in subjects with PFP compared to controls during walking (Leibbrandt & Louw, 2017a). The review also reports evidence of risk factors during SLS, including increased ipsilateral trunk lean, increased peak hip adduction and increased knee adduction in individuals with PFP compared to healthy controls (Leibbrandt & Louw, 2017a).

Excessive lower-extremity frontal plane kinematics (dynamic knee valgus) can lead to extensive loading of the lateral facet of the patella when performing dynamic tasks such as squatting (Lee, Morris & Csintalan, 2003; Powers, 2010; Neal et al., 2016). As a result, individuals who experience PFP frequently present with larger frontal plane projection angles (FPPAs), which is a 2D substitute for 3D measures of hip adduction, hip internal rotation, knee abduction and knee external rotation and have been demonstrated in SLS (Willson & Davis, 2008b; Herrington, 2014; Willy et al., 2019) and hop-landing task (Herrington, 2014). In addition, athletes have the tendency to transfer into significant FPPAs when executing jump-landing tasks and may therefore be more prone to develop PFP (Holden et al., 2017; Willy et al., 2019).

Altered ankle and foot biomechanics are inconsistent when observed in individuals with PFP (Powers et al., 2017; Willy et al., 2019). Previous prospective research assessed navicular drop

(Boling et al., 2009), Foot Posture Index (FPI) (Thijs et al., 2008), lower leg-heel frontal plane alignment (Witvrouw et al., 2000) and heel-to-forefoot frontal plane alignment (Witvrouw et al., 2000; Waryasz & McDermott, 2008) as risk factors for PFP. An increased navicular drop was the only foot posture measure significantly associated with a risk of developing PFP, but this finding was not specific to gender (Boling et al., 2009; Neal et al., 2014; Lack et al., 2018). Another study reported no relationship between the navicular drop and development of PFP when analysed in men and women separately and no conclusive evidence to support foot posture measures as risk factors for developing PFP in men or women (Boling et al., 2021).

Neal et al. (2019) report in their systematic review on two studies that investigated foot kinetics in individuals with PFP during walking and running (Thijs et al., 2007; Thijs et al., 2008) and found moderate evidence indicating that there was no significant association in time peak force at several aspects of the foot. Pronation of the subtalar joint is a typical phenomenon during gait (Sisk & Fredericson, 2019). However, it does become atypical when it occurs in the incorrect phase of gait or does not resupinate (Sisk & Fredericson, 2019). Excessive subtalar joint pronation could contribute to increased tibia and femur rotation through coupling mechanisms (Powers, 2003; Powers et al., 2017), thereby creating a larger Q-angle and increasing lateral forces on the patella (Powers, 2003; Souza et al., 2010).

Overpronation of the foot has been previously linked to the development of PFP in some prospective studies (Boling et al., 2009). Furthermore, rearfoot eversion can also be attributed to internal tibial rotation (Levinger & Gilleard, 2007), resulting in increased foot pronation. Low associations between rearfoot eversion and hip adduction have been reported in individuals with PFP and healthy people (Barton et al., 2012; Kedroff et al., 2019). Kedroff et al. (2019) investigated foot posture observed during walking kinematics in individuals with PFP. These authors also identified peak rearfoot eversion and internal tibial rotation as evident only in the PFP group, suggesting that tibial rotation is implicated in PFP (Kedroff et al., 2019). In contrast, other studies refute a relationship between peak rearfoot eversion and tibial rotation (Luz et al., 2018) and foot pronation (Powers et al., 2002). Luz et al. (2018), who investigated running kinematics, found no differences within the PFP and control group for peak rearfoot eversion and internal tibial rotation. However, they did report a strong correlation between increased peak rearfoot eversion and increased peak femoral adduction in runners with PFP (Luz et al., 2018).

Delayed timing of peak rearfoot eversion, decreased rearfoot eversion range of motion and increased rearfoot eversion at heel strike are some of the foot kinematics reported to be involved in the onset of PFP (Petersen et al., 2014). These findings are supported by previous studies that reported that a decreased rate of peak rearfoot eversion and increased rearfoot eversion at initial contact were evident in individuals while walking (Barton et al., 2009; Petersen et al., 2014; Willy et al., 2019) and that individuals with PFP displayed less rearfoot eversion range of motion during running (Barton et al., 2009; Willy et al., 2019). Therefore, to summarise, there are limited studies with moderate evidence of a correlation between rearfoot eversion and lower-extremity kinematics in individuals with PFP (Barton et al., 2012; Powers et al., 2017).

Dynamic foot function was not identified as an emerging factor for the development of PFP (Noehren, Hamill & Davis, 2013; Dowling et al., 2014; Powers et al., 2017). However, altered plantar pressures are also thought to be present in people with PFP (Dowling et al., 2014; Powers et al., 2017). Thijs et al. (2007) demonstrated significantly greater lateral rearfoot pressures, signifying a less pronated foot in individuals with PFP during walking. In addition, during running, an increased peak force rate in the lateral heel and midfoot was reported in individuals who developed PFP (Dowling et al., 2014; Willy et al., 2019). However, inconsistencies between altered foot kinematics and the presence of PFP development continue to exist due to a lack of supporting evidence (Willy et al., 2019).

PFP can cause changes in affected people's gait (Arazpour et al., 2013), causing them to walk slower than healthy controls (Nourbakhsh et al., 2018). Kinematic changes during walking, such as increased hip adduction, delayed peak rearfoot eversion and significant reduction of the knee flexion angle and step length, have been observed among individuals with PFP (Barton et al., 2011; Willson et al., 2014). Arazpour et al. (2016) in their review included increased contralateral pelvic drop and a reduced knee extensor moment during walking. In addition, different kinematic results are reported for female and male runners. Female runners demonstrated increased hip adduction and internal rotation (Sakaguchi et al., 2014) during stance compared to controls, while male runners showed increased contralateral pelvic drop with hip adduction (Esculier, Roy & Bouyer, 2015; Neal et al., 2016). Leibbrandt and Louw (2017a) summarised the evidence for walking and running kinematics to screen biomechanical risk factors for PFP and developed a clinical evidence-based biomechanical risk factor screening tool (see Appendix 2).

Numerous factors have been proposed relating to PFP; however, increased knee valgus has been reported as a standard feature in PFP (Rees, Younis & MacRae, 2019). Therefore, the evaluation of this movement pattern (knee valgus) should be included in the clinical assessment of PFP, as it is often present during functional movements such as squatting and running (Manske & Davies, 2016).

3D motion analysis is considered the 'gold standard' when quantifying movement during functional tasks and is superior to other methods due to its high-level accuracy and reliability (Nakagawa et al., 2012; Noehren, Pohl, et al., 2012; Knorz et al., 2017; Ferrari et al., 2018). To conclude, most of the biomechanical risk factors associated with PFP discussed in this section were identified using 3D motion analysis systems, highlighting its superiority over other methods. The following section discuss more clinical accessible alternatives to assess and identify biomechanical risk factors related to PPP.

2.6 Validity of physical assessment tools for PFP

There is no definitive gold standard for the clinical diagnosis of PFP (Nunes et al., 2013), yet clinical evaluation remains the cornerstone of the diagnostic criteria (Crossley, Callaghan & Van Linschoten, 2015). Furthermore, there continues to be limited evidence for the diagnostic validity of physical assessment tests for PFP (Décary et al., 2017; Décary et al., 2018), and evidence suggests that when used in isolation, clinical tests may not have the ability to diagnose PFP accurately (Cook et al., 2012; Nunes et al., 2013; Décary et al., 2017; Décary et al., 2018).

The best available and most accurate test, according to literature, is to provoke pain while performing the squat manoeuvre (Nunes et al., 2013; Crossley, Stefanik, et al., 2016). In a recent study, the step-down test or SLS (squatting manoeuvre) (Halabchi et al., 2017) was more predictive of PFP than other functional tasks such as the single-leg hop test, gait or stair negotiation (Lopes Ferreira et al., 2019). Additional tests to diagnose PFP, but with limited evidence, include assessing for palpation tenderness of the patella edges, patellar mobility, patella tilt, patellar compression and apprehension tests, along with muscle strength and flexibility tests (Fredericson & Yoon, 2006; Nunes et al., 2013; Petersen et al., 2014; Crossley, Stefanik, et al., 2016).

The clinical examination of active individuals and athletes may require testing to be more demanding with highly dynamic testing (e.g. SLS or drop vertical jump test) to expose more subtle conditions (Halabchi et al., 2017). The diagnosis of PFP is made collectively according

to the physical findings that result in changes to the extensor mechanism, specifically in altered biomechanics, which predisposes individuals to develop PFP (Sisk & Fredericson, 2019). Subsequently, no single test in isolation is able to diagnose PFP accurately, therefore, a cluster of tests to aid clinicians' diagnostic process is suggested (Décary et al., 2018). Furthermore, the screening for potential risk factors can guide clinical assessment and assist clinicians in establishing a differential diagnosis (Sisk & Fredericson, 2019).

2.7 Physical assessment tools for assessing influences on biomechanical parameters

Clinical screening methods to evaluate lower-extremity biomechanical dysfunctions are essential, yet it is not easy to translate these findings into clinical practice (Ortiz & Micheo, 2011). Functional performance measures simulating activities of daily living, such as walking, running and stair negotiation (Leibbrandt & Louw, 2019), are often explored to objectively measure altered movement patterns in people affected by PFP. The following clinical tests can facilitate the assessment of movement patterns in a clinical setting.

2.7.1 Functional tests

2.7.1.1 Frontal plane projection angle

FPPA is a 2D substitute for 3D frontal kinematic measures of the knee (abduction and external rotation) and hip (adduction and internal rotation) in SLS (Willson & Davis, 2008a; Herrington, 2014; Willy et al., 2019), during a hop landing (Herrington, 2014; Holden et al., 2017) and for hip adduction in running (Creaby et al., 2017). The FPPA is a reliable (Munro, Herrington & Carolan, 2012) and valid 2D measure (Milner, Westlake & Tate, 2011) for generating 2D knee kinematics findings equivalent to 3D kinematic analysis (Mizner et al., 2012; Rees, Younis & MacRae, 2019). The test is calculated by determining the mean of the first three successful attempts (Herrington, Munro & Comfort, 2015; Wyndow, De Jong, et al., 2016; Rees, Younis & MacRae, 2019). Similarly, the knee valgus position is recorded as a positive, and the knee in varus is recorded as a negative angle (Rees, Younis & MacRae, 2019).

2.7.1.2 Single-leg squatting

The SLS test is clinically used to detect dynamic knee valgus and identify poor hip muscle strength and control (Crossley et al., 2011). As demonstrated in previous studies, individuals with PFP displayed greater ipsilateral trunk lean, contralateral pelvic drop, hip adduction and knee abduction during SLS (Nakagawa et al., 2012; Manske & Davies, 2016; Halabchi et al., 2017). The test is performed with individuals crossing their arms over their chest while lowering

into the squatting position in a slow and controlled manner (Crossley et al., 2011). To be considered acceptable, individuals need to achieve four out of five criteria in five trials. Performance is considered flawed if participants do not meet all prerequisites for at least one criterion for all the attempts and is appraised as good, fair or poor (Crossley et al., 2011). The five criteria are (1) overall impression for the five trials, (2) posture of the trunk over the pelvis, (3) posture of the pelvis, (4) hip joint posture and movement, and (5) knee joint posture and movement (Crossley et al., 2011). The SLS test is quick, reliable and straightforward (Crossley et al., 2011) to utilise in a clinical setting to demonstrate hip muscle dysfunction in people with PFP.

2.7.1.3 Step-down

The step-down test is performed similarly to the SLS; apart from using a step, individuals are required to perform the test in a precise manner by slowly lowering until the heel reaches the ground while keeping their balance (Halabchi et al., 2017). Scoring is based on the knee, hip, pelvis and trunk kinematic aberrations, which can help identify muscle imbalances throughout the kinematic chain (Manske & Davies, 2016; Halabchi et al., 2017). Markers are set on the tibial tuberosity and the step, aligned with the second toe and performed with the involved knee at 60 degrees flexion. Scoring is calculated as follows: good quality of movement = 0 to 1 point, moderate quality of movement = 2 to 3 points and poor movement = 4 to 5 points. This test reported excellent reliability (Crossley et al., 2011; Halabchi et al., 2017).

2.7.1.4 Lateral step-down

This test is an adapted version of the step-down test, with movement in a lateral direction instead of the frontal plane (Rabin et al., 2014; Halabchi et al., 2017). First, a step of approximately 15 cm is used to stand on, where the involved knee is required to bend at about 60 degrees (Halabchi et al., 2017). Next, individuals are requested to slowly lower the uninvolved leg until the heel touches the surface and to resume the initial position again (Halabchi et al., 2017). Scores are based on criteria related to steadiness, arm strategy, and knee, pelvis and trunk alignment (Manske & Davies, 2016; Halabchi et al., 2017).

2.7.1.5 Drop vertical jump

The drop vertical jump requires individuals to stand on a box of approximately 31 cm, with their hands on their hips and their feet shoulder-width (Holden et al., 2017). Instructions include

dropping directly off the box and, once landing, instantly performing a maximum exertion vertical jump (Holden et al., 2017). Three drop vertical jump attempts can be recorded, and trials are excluded if participants cannot maintain their balance or remove their hands from their hips (Holden et al., 2017). Research by Boling et al. (2009) and Holden et al. (2017) indicates that knee valgus angle during a jump land task is not a risk factor for future PFP.

2.7.2 Quadriceps angle

The Q-angle is measured at the junction, drawing a line from the anterosuperior iliac spine to the centre of the patella and from the proximal tibial tubercle extension to the centre of the patella (Smith, Hunt & Donell, 2008). The reliability of measuring the Q-angle using the goniometer has been established, and the correction through magnetic resonance imaging investigation is moderate (Draper et al., 2011). Nevertheless, a greater Q-angle may create larger lateral forces on the patella and potentially result in lateral patellar tracking and increased retro-patellar pressure compared to a smaller Q-angle (Witvrouw et al., 2000; Brechter & Powers, 2002). Furthermore, due to the inconsistency of measurement techniques of the Q-angle (with quadriceps contracted or relaxed, in supine and standing), the clinical utility of this measurement cannot be recommended, as it is more of a subjective measurement and clinically cannot easily be quantified (Smith, Hunt & Donell, 2008). However, 2D video analysis might be more appropriate to assess Q-angle during functional and dynamic activities (Almeida et al., 2016).

2.7.3 Foot posture

Foot posture is customarily assessed in standing, and excessive pronation can usually be observed in a relaxed standing position and during walking and running. Multi-segmental kinematic models for the foot have been recognised; the Oxford Foot Model (Carson et al., 2001) evaluates the tibia and three-foot segments and demonstrates good reliability and repeatability (Kedroff et al., 2019). Another kinematic model of the forefoot, rearfoot and shank demonstrated high repeatability (Redmond, Crosbie & Ouvrier, 2006; Kedroff et al., 2019). Static foot posture is often used to assess pronation, which may be associated with PFP (Kedroff et al., 2019). Foot posture tests frequently used include arch height ratio (Williams & McClay, 2000); navicular drop, the only measurement assessed prospectively accounting for PFP (Neal et al., 2014); and FPI (Barton et al., 2010), evaluating multi-segmental signs of pronation (Kedroff et al., 2019).

Navicular drop measures the sagittal navicular movement from a neutral subtalar position to a relaxed calcaneal stance (Neal et al., 2014; Kedroff et al., 2019). This test is performed while standing with the bodyweight equally distributed through both legs, measuring the vertical height from the surface to the navicular tuberosity (anteroinferior aspect) during a relaxed stance, and is deducted from the height attained in a neutral stance (Kedroff et al., 2019). The navicular drop has been reported to be a reliable test (Barton et al., 2010), with average scores ranging between 2 and 8 mm (Nielsen et al., 2009). In addition, individuals with PFP have reported higher navicular drop and FPI scores than controls (Barton et al., 2010; Kedroff et al., 2019). While a low arch height ratio is frequently associated with knee pain among runners (Williams et al., 2001; Kedroff et al., 2019), these findings are widely inconsistent with other case-control studies, suggesting no differences in arch height ratio (Lankhorst, Bierma-Zeinstra & Van Middelkoop, 2013; Kedroff et al., 2019) related to knee pain.

The FPI-6 measures the rearfoot, midfoot and forefoot in the three cardinal planes (Redmond, Crosbie & Ouvrier, 2006; Kedroff et al., 2019). Individuals must march on the same spot, followed by a natural stance position with their weight evenly distributed through their legs (Kedroff et al., 2019). The calcaneal angle is defined by the curvature surrounding the lateral malleoli, talonavicular prominence, medial longitudinal arch, forefoot to rearfoot alignment and talar head position (Kedroff et al., 2019). Scores range from -12 to 12 representing supination, 0 to 5 neutral and 6 to 12 pronating foot posture (Kedroff et al., 2019). The index demonstrated good reliability and sensitivity to group differences in individuals with PFP (Barton et al., 2010; Kedroff et al., 2019).

In summary, the functional tests, measuring Q-angle and foot posture are quick and simple tests that can assist clinicians, aside from gait analysis, to screen for aberrant biomechanics. These tests can also be used in conjunction with clinical gait analysis to detect biomechanical risk factors associated with the development of PFP.

2.7.4 Gait deviations/analysis

The fundamentals of gait analysis are based on the relationship between a person's functional capabilities, limitations and gait pattern to enhance performance while preventing injury (Dicharry, 2010). According to Baker (2006), clinical gait analysis usually requires clinicians to discriminate amid abnormal and normal gait patterns and evaluate these gait changes over time. Clinical gait assessment is a practical tool for elucidating biomechanical dysfunctions causing people's symptoms (Dicharry, 2010). However, gait assessment should be performed

together with a comprehensive subjective and physical evaluation and functional screening tests (Dicharry, 2010). Gait analysis can be conducted with or without the use of computerised recording analysis equipment to assist diagnosis, target treatment goals and evaluate treatment outcomes (Harradine, Gates & Bowen, 2018).

The current methods for quantifying kinematics during movement are 3D motion capture systems, deemed 'the gold standard' (Maykut et al., 2015; Knorz et al., 2017). Walking and running kinematics observed on a treadmill have shown to be comparable and reasonably replicated to overground in some studies (Firminger et al., 2018; Sinclair et al., 2013), but there still appears to be conflicting findings. As observational or qualitative gait assessments are reported to be moderately reliable (Chmielewski et al., 2007) and sensitive (Ekegren et al., 2009), the application of 2D video analysis to assess biomechanics and objectively quantify kinematic patterns is an effective way to recognise various gait (walking and running) styles. Both sagittal plane (Teng & Powers, 2014; Willson et al., 2015) and frontal plane (Barton et al., 2009; Noehren, Hamill & Davis, 2013) kinematic measures have been associated at initial contact and midstance of the gait cycle in individuals with PFP.

Although 3D video assessment is ideal, as it allows one to analyse considerably more than 2D, in a clinical setting, 2D analysis has demonstrated to be a more feasible, accurate and reliable tool (Pipkin et al., 2016; Souza, 2016; Esculier et al., 2018; Reinking et al., 2018). Observational gait analysis is believed to improve and bridge the outcome of special tests and equipment required to assess dynamic function in gait in a clinical setting (Dicharry, 2010). 2D video analysis of gait kinematics using high-speed cameras is a standard method of clinical practice (Pipkin et al., 2016). Pipkin et al. (2016) demonstrated that video running analysis investigating joint kinematics using a qualitative approach (visual categorial rating) could be reliably achieved in clinical practice, depending on measured variables. The authors reported excellent intrarater reliability, while only moderate reliability was reported for interrater reliability (Pipkin et al., 2016).

Dingenen, Barton, et al. (2018) showed a substantial correlation between peak 2D hip adduction, contralateral pelvic drop, femoral adduction and 3D hip adduction running kinematics. Dingenen, Staes et al. (2018) also demonstrated a significant relationship between peak 2D and 3D contralateral pelvic drop throughout the larger portion of the stance phase. This study's findings agreed with a previous study conducted by Maykut et al. (2015). These authors reported excellent intra- and interrater reliability among all frontal plane angles measured,

including hip and femoral adductions and contralateral pelvic drop, when videos were assessed on different days (Maykut et al., 2015). However, studies have reported different kinematic outcomes for sagittal plane variables resulting from 2D video analysis at heel strike and midstance, such as foot and tibia inclination (Pipkin et al., 2016; Souza, 2016; Dingenen, Barton, et al., 2018) and knee flexion (Damsted, Nielsen & Larsen, 2015; Souza, 2016; Dingenen, Barton, et al., 2018). In addition, 2D knee flexion demonstrated sufficient intra- and interrater reliability (Damsted, Nielsen & Larsen, 2015), whereas tibia inclination and knee flexion angles demonstrated moderate to poor interrater reliability (Pipkin et al., 2016).

Many 2D validity and reliability studies were conducted among healthy runners or included participants with running-related injuries (not specific to only PFP) and exclusively investigated running kinematics. Previous research was also conducted based on laboratory studies and cross-sectional evidence. Therefore, more research is warranted through prospective studies on the clinical use of gait analysis to reliably analyse 2D lower-extremity kinematic variables in frontal and sagittal planes in people with PFP in a clinical setting.

2.8 Development of a validated screening tool for the screening of biomechanical risk factors

The clinical implications of biomechanical factors remain unclear (whether the cause or a result thereof); therefore, the best available evidence is warranted to assist clinicians on which factors to address during treatment (Leibbrandt & Louw, 2017a; 2019). Subsequently, this has directed the development of a clinical evidence-based algorithm (Leibbrandt & Louw, 2017a) for biomechanical risk factor screening and management of PFP. The evidence-based algorithm (screening tool) was initially created by Aderem and Louw (2015) to identify biomechanical risk factors linked with iliotibial band syndrome (Leibbrandt & Louw, 2019). The evidence-based biomechanical risk factor screening tool was modified to guide clinicians when screening predictive kinematic variables that can influence the development and chronicity of PFP.

The effect sizes determined for the categories “must consider” and “maybe consider” and with an outcome “must consider” were classified when there was supporting evidence based on at least two cross-sectional studies, with findings being significant and consistent (Leibbrandt & Louw, 2017a; 2019). The kinematic variables based on the evidence and categorial inclusion for walking and running can be found in Appendix 2. To the best of my knowledge and according to preliminary research by Leibbrandt and Louw (2017a), no other risk factor screening tools for associated biomechanical factors exist and have been validated in clinical

practice to screen people with PFP. Therefore, the aim was to utilise expert opinion from a preliminary study by Leibbrandt and Louw (2017a) in conjunction with the clinical biomechanical risk factor screening tool to validate it against the gold standard, 3D motion analysis.

2.9 The rationale for the study

Improved clinical management of PFP is mainly dependent on a better understanding of the roles that biomechanical risk factors play in the pathogenesis of PFP. In their systematic review, Leibbrandt and Louw (2017a) summarised the biomechanical risk factors for PFP during common aggravating activities and created a clinical algorithm for risk factor screening. However, all the included studies in the review used 3D movement analysis procedures to identify these risk factors in a movement laboratory. Therefore, it is unclear whether this screening tool can be used by clinicians using 2D gait analysis methods such as video analysis and observation. Nevertheless, such evidence would be clinically valuable, as kinematic variations could indicate a more severe condition associated with poor prognosis to help clinicians in clinical practice (Lankhorst et al., 2016).

The use of 3D motion analysis imposes financial, spatial and temporal costs, suggesting that more clinically practical alternatives to assess biomechanical risk factors are necessary (Maykut et al., 2015). Clinical evaluation of biomechanical factors is crucial for recognising gait deviations, guiding clinicians' clinical decision making, tailoring person-specific treatment, monitoring individual progress and proving treatment benefits in a clinical setting (Leibbrandt & Louw, 2019). This study aimed to determine whether biomechanical risk factors for PFP could be accurately identified using 2D observational gait analysis in a clinical setting. It also aimed to validate a biomechanical risk factor screening tool based on laboratory-based studies to determine its usefulness for clinicians treating patients with PFP who do not have access to expensive 3D movement analysis equipment in clinical practice.

2.10 Conclusion

In summary, altered lower-extremity biomechanics during functional activities is evident as potential risk factors in people who present with and develop PFP. Therefore, early identification of these biomechanical factors during activities such as gait is essential. Furthermore, the analysis of gait in a clinical setting can immediately guide clinicians to tailor their management plan and prevent the development of chronic PFP according to the biomechanical factors detected. The following chapter discusses the methodology employed by observing recreational runners' gait to identify associated biomechanical risk factors and achieve the study objectives.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research methodology of my study. It also describes the larger PFP project and how the preliminary research links my study to the larger PFP project.

3.2 Preliminary research

My master's research project was a substudy of an existing, ongoing PFP project conducted by the supervisory team, led by D.L. Ethical approval for the ongoing project was obtained from the Health Research and Ethics Council of Stellenbosch University (ethics reference number N19/05/063). The ethics approval letter is attached as Appendix 6. Publications emanating from the ongoing PFP project have also been incorporated into the methodological design of my project. The first publication (Leibbrandt & Louw, 2017b) describes a clinical 'diagnostic' checklist (Appendix 1), which was applied in my study to select participants with PFP. The second publication was a systematic review reporting on a screening tool for biomechanical risk factors in individuals with PFP (Appendix 2) (Leibbrandt & Louw, 2017a). The reliability and validity of this screening tool were tested in the present study, which formed the basis of my project (see section 3.3).

The larger PFP study (led by D.L.) included the investigation of lower-extremity kinematics during walking and running gait in 18 recreational runners with PFP using 3D motion analysis (Vicon Motion Analysis Systems Ltd, Oxford, UK). The aim was to test the 3D risk factor screening algorithm based on the systematic review (Leibbrandt & Louw, 2017a) for tailored rehabilitation addressing individual needs depending on each individual's unique kinematic profile. The 3D kinematic factors were identified using the screening tool based on objective 3D kinematic outcomes produced by the Vicon system. The Vicon has demonstrated high accuracy and reliability (Ehara et al., 1997). The system has a resolution of 1 megapixel and captures 10-bit greyscale images using 1120 x 896 pixels, with the ability to capture speeds of up to 250 frames per second (Windolf, Götzen & Morlock, 2008).

A detailed description of the Vicon 3D motion analysis output and preparation according to the plug-in gait model can be found in Appendix 8. The principal investigator (D.L.) had seven years' experience in biomechanical motion analysis, specifically with the Vicon system and the system's kinematic output (Leibbrandt, 2020). She underwent additional training at Salford University in the United Kingdom in 2014. The kinematic factors identified in each of the PFP

participants based on the Vicon objective output served as the gold standard for my validation and reliability study. More information on the methodology of the larger PFP study is available in Appendix 7.

3.3 Master's research study

3.3.1 Study design

A cross-sectional descriptive study design was used to address the research objectives of the current study.

3.3.2 Study population

The study population included physiotherapists from the Cape Metropolitan region and surrounding Cape Winelands working predominantly with musculoskeletal conditions.

3.3.3 Study sample

The study sample comprised two physiotherapists residing in the Cape Winelands and the northern suburbs of the Cape Metropolitan region in the Western Cape, South Africa. Both physiotherapists had over 10 years' experience managing individuals with musculoskeletal conditions, including PFP. (Refer to section 3.3.7 for the study sample size based on published studies investigating interrater reliability).

3.3.4 Eligibility criteria

The physiotherapists were eligible for inclusion in the study if they had two years or more of clinical experience managing musculoskeletal conditions and individuals with PFP. In addition, they were required to be registered practitioners with the Health Professions Council of South Africa. Experience or formal training in biomechanical gait analysis was not a requirement. The participants had to reside in the Cape Metropolitan region or the Cape Winelands to attend face-to-face training. They were also required to attend the training session using the biomechanical PFP risk factor screening tool; therefore, only therapists who completed the training session were considered eligible to participate.

3.3.5 Sample recruitment

Pragmatic sample recruitment was designed to attract clinicians who had experience in musculoskeletal conditions, with a particular interest in biomechanical assessment and management of PFP. Participants had to be from the surrounding area, either residing in the Cape Winelands or the Cape Metropolitan region. The principal investigator (T.G.) sent a letter of invitation (Appendix 4) and an advertisement (Appendix 5) attached via email to various sports clinics and physiotherapy practices in these two regions. The physiotherapists had to respond via email or WhatsApp. The aim was to recruit four potential physiotherapists to complete the training session, should any dropouts occur during the study. Three physiotherapists responded to the invitation letter and received training within one week of consent to participate in the study.

3.3.6 Study setting

The principal investigator conducted the training of the two physiotherapists separately at a venue of their convenience. The intention was for the training session to occur at one venue; however, to adhere to government regulations and ensure social distance amid the global Covid-19 pandemic, this was the preferred alternative. Accordingly, Rater 1 was trained in Stellenbosch at the Stellenbosch Academy of Sport and Rater 2 in Kuils River (both sessions were conducted at the physiotherapists' workplace at the time).

3.3.7 Sample size

Key factors informing the study's sample size included the scope of this master's project, the project aims, the project costs and study duration, and the impact of the Covid-19 pandemic. Based on these factors, a minimum of two physiotherapists was required to participate. This is also in agreement with similar published research. The two physiotherapists included (based on eligibility) assessed the video recordings of 18 recreational runners. This was also in line with the number of participants included in similar, published reliability and validity studies (Damsted, Nielsen & Larsen, 2015; Maykut et al., 2015; Pipkin et al., 2016; Dingenen, Staes, et al., 2018; Reinking et al., 2018).

3.3.8 Ethical considerations

Ethical approval for the study was obtained from the Stellenbosch University Health Research Ethics Committee (ethics reference number S19/10/236). The ethics approval letter is attached as Appendix 9. After confirming the two participants' eligibility, the principal investigator (T.G.) obtained informed consent from both participants before the data collection for the study commenced. The principal investigator informed the physiotherapists of the study procedure, aims, requirements, risks and benefits of participation, which can be seen in the study information leaflet along with the informed consent form (Appendix 3). Feedback on the assessment for agreement from participants in the study remained anonymous, and participants were provided with a copy of the informed consent document. Where photographs were used, the investigator from the preliminary research obtained written permission from the research participants, and their faces were hidden. A recent annual progress report was submitted, and approval of the report is attached as Appendix 10. In addition, all new Covid-19 ethical requirements for observational research studies implemented in 2020 were adhered to throughout the study according to the Stellenbosch University Health Research Ethics Committee's Covid-19 guidelines.

3.3.9 Data collection tools

Evidence-based biomechanical risk factor screening tool

A previous systematic review by Leibbrandt and Louw (2017a) reviewed and summarised the literature on lower-limb biomechanical risk factors associated with PFP. These risk factors were classified according to their level of evidence and the consistency of findings (Leibbrandt & Louw, 2017a). Subsequently, this led to the development of an evidence-based clinical decision-making algorithm for clinicians to use as a screening tool to prevent and manage individuals with PFP. The evidence-based biomechanical risk factor screening tool created by D.L. is attached in Appendix 2. The participating physiotherapists used this screening tool to identify the biomechanical risk factors in 18 individuals with PFP by reviewing 2D video recordings.

3.3.10 Study procedures

The main PFP study and current study's procedures are depicted in figures 3.1 and 3.2.

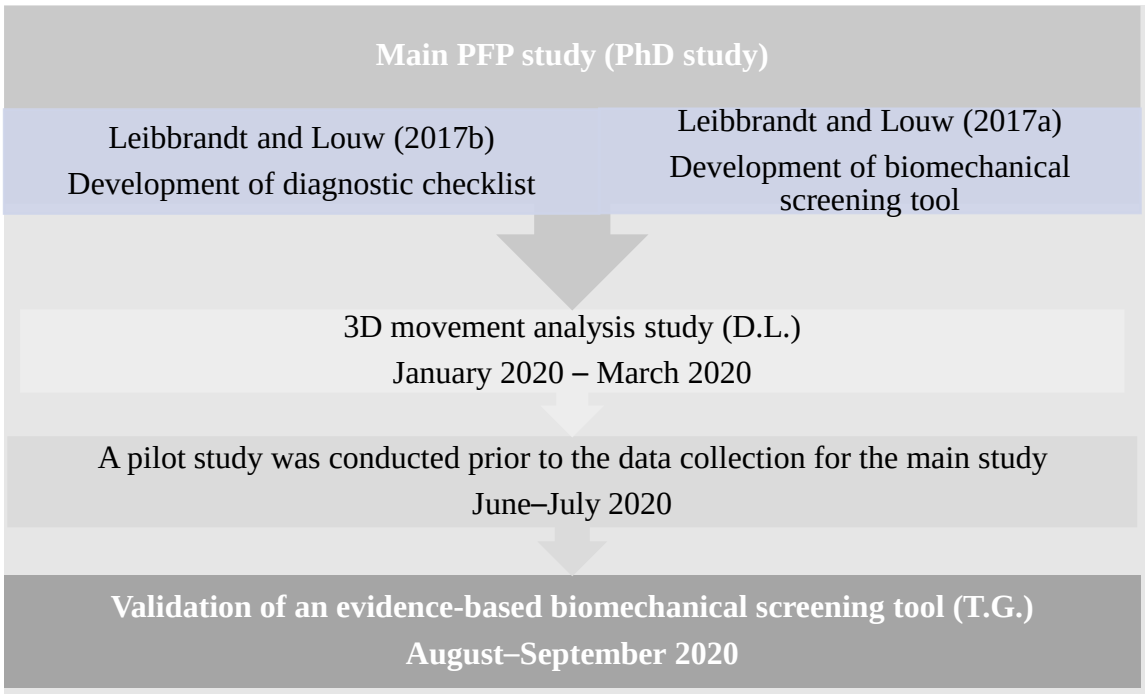

Figure 3.1. Illustration of main PFP study with various substudies and data collection tools

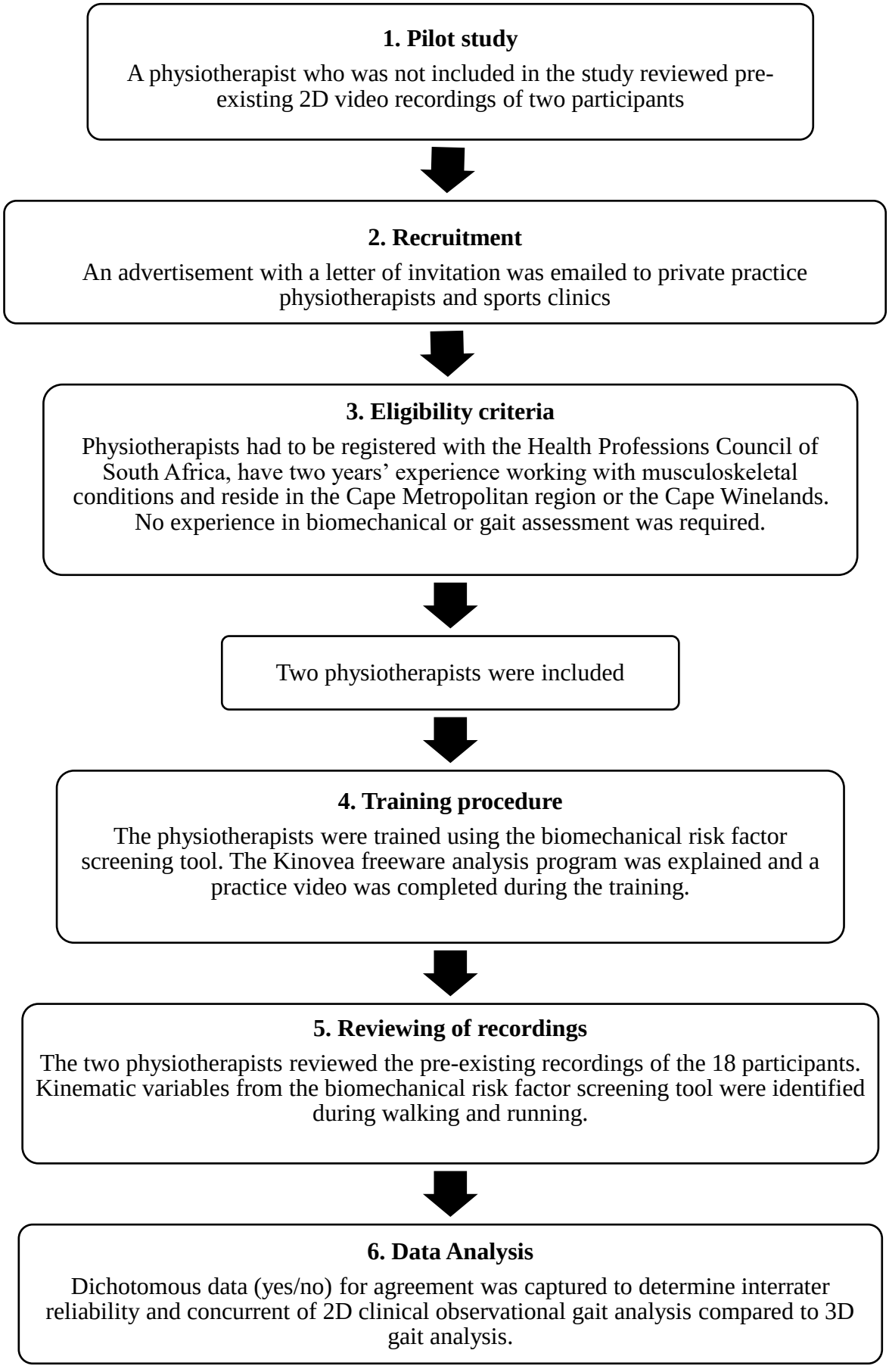

Figure 3.2. Flow diagram of study procedures

3.3.10.1 Pilot study

The pilot study aimed to assess the proposed methodology of the current study. An independent physiotherapist was asked to review 2D video recordings of two participants from D.L.'s preliminary study. The physiotherapist was required to perform an observational gait analysis to identify associated biomechanical risk factors during walking and running. The physiotherapist, E.C. (who did not form part of the main study), received a short training session. The evidence-based biomechanical risk factor screening tool (Appendix B) and video analysis software program (Kinovea, version 0.8.15, http://www.kinovea.org) were used to review 2D video recordings. During this session, the investigator (T.G.) obtained verbal and written consent, and according to the evidence-based biomechanical risk factor screening tool, the 16 kinematic variables of interest were highlighted. The physiotherapist (E.C.) was asked to complete a 'practice' 2D walking and running analysis at the end of the session to address any questions or concerns about the risk factor identification procedures or video analysis software. Questions were mainly asked on the different functions of the analysis software to slow down and pause gait cycles to identify the kinematic variables.

The pilot results comparing the physiotherapist's 2D clinical observational gait analysis findings to 3D gait analysis based on percentage agreement were as follows: Two participants' (one male and one female) video recordings were assessed in the pilot. Six of the eight kinematic variables for walking and seven of the eight for running demonstrated 100% agreement when comparing 2D clinical observational gait analysis to 3D gait analysis. Increased peak rearfoot eversion and increased peak knee extension were the only two kinematic variables that demonstrated 50% agreement during walking. In addition, increased peak knee varus also demonstrated a 50% agreement for running. However, these findings were limited to only two out of the 18 participants' pre-existing 2D recordings used in the main study.

3.3.10.2 Training of participants

Prior to 2D clinical observational gait analysis, both physiotherapists who participated as raters, having no experience in biomechanical gait analysis, received a short training session of two hours by the principal investigator (T.G.). The two training sessions were held separately, and the principal investigator met with each physiotherapist individually (see section 3.3.6 for the training venues). In the first hour of training, both raters were given written and verbal instructions on what the research and reviewing process of recordings entailed. The principal investigator carefully explained the evidence-based biomechanical risk factor screening tool

and how they could screen for associated biomechanical risk factors by applying the screening tool. The participants were also trained to access and use the free video analysis software program (Kinovea, version 0.8.15). Kinovea is a video player used for sports analysis, providing a set of tools to capture, slow down, study, compare, annotate and measure technical performance. The freeware analysis software was used to slow down and freeze frames in the various gait cycles to identify kinematic variables of interest.

Furthermore, raters were asked to complete a practice 2D walking and running analysis on a runner who was not included in the study. The analysis of the practice runner was conducted independently by each rater. The principal investigator was then available for the remainder of the session to address any questions or concerns regarding the risk factor identification procedures or video analysis software.

3.3.10.3 Procedure for assessing agreement between raters

The two raters independently reviewed the pre-existing 2D video recordings of all 18 participants with PFP obtained from D.L.'s preliminary research. Video recordings were imported into the freely available software package Kinovea and analysed independently of the 3D movement analysis data.

Raters were asked to complete reviews within a week. Each participant from the pre-existing video recordings (n = 18) had four 30-second clips: two for walking and two for running (sagittal and frontal views). The raters were allocated 30 to 40 minutes to review all four clips per participant and, within that timeslot, viewed the clips as many times as needed. They were not to view participant clips again beyond the allocated time. The physiotherapists were instructed to identify whether specific biomechanical PFP risk factors (as listed in the PFP evidence-based biomechanical risk factor screening tool) were present or not based on their 2D clinical observational analysis of the 18 participants with PFP. Both raters were provided with their own Microsoft Excel spreadsheet (Appendix 11). Therefore, they could capture their findings using dichotomous data (yes/no) for each of the 16 kinematic risk factors listed on the biomechanical risk factor screening tool. Figures 3.3 and 3.4 depict examples of the 2D walking and running recordings, respectively.

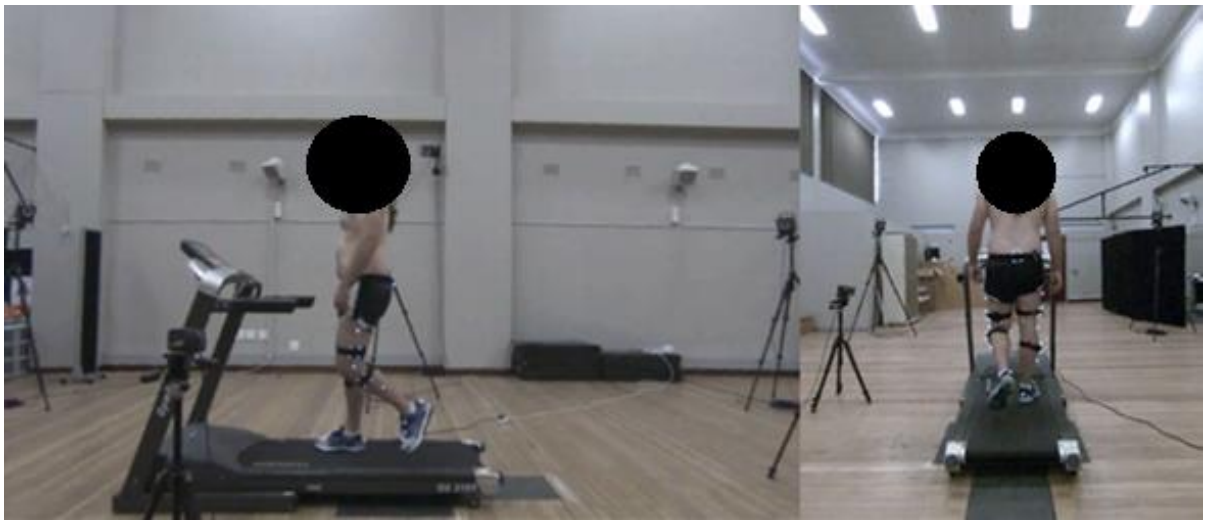

Figure 3.3. 2D video walking gait analysis of sagittal and frontal plane

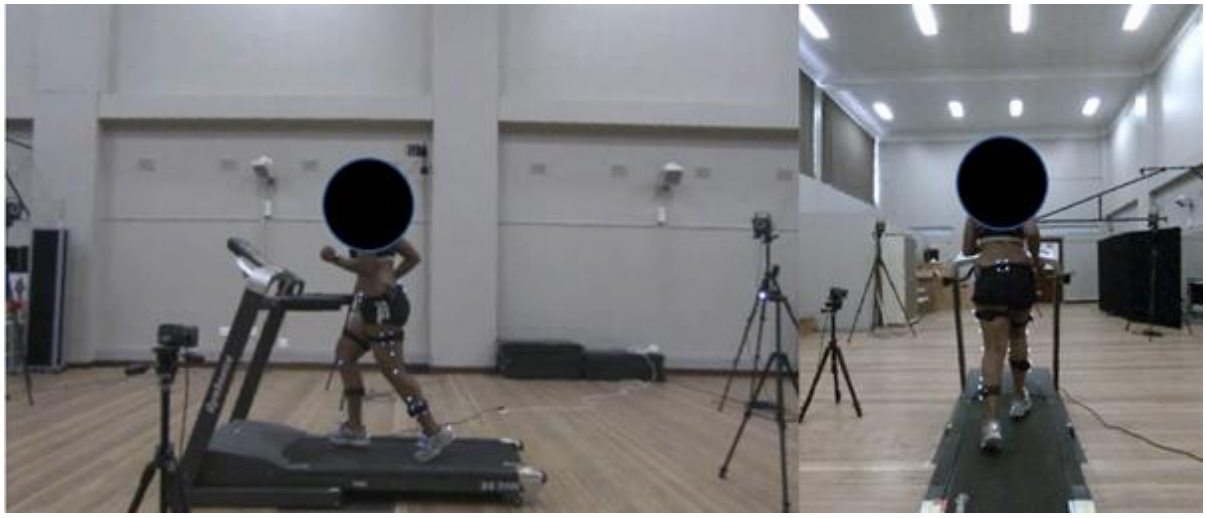

Figure 3.4. 2D video running gait analysis of sagittal and frontal plane

3.3.11 Data management

A study-specific code was assigned to both raters and the 18 individuals used for the 2D video recordings collected in the previous study linked to the research project code. Therefore, no personal information of the participants in the study materials could be used to identify them. Subsequently, both raters' findings were captured by the blinded research assistant (who was blinded to the aims of the study), and data were imported into a Microsoft Excel spreadsheet see (Appendix 11). Data were stored in a Dropbox folder and on Stellenbosch University's OneDrive on the principal investigator's password-protected office computer and personal laptop, stored in a secure location. Back-ups were regularly performed on the Dropbox folder, and the principal investigator's private external hard drive was also password-protected. In addition, hard copies of all study documents, such as informed consent forms, were stored in a

locked room at the Campus Health Physiotherapy rooms and will be kept for five years in a secure place. This approach to data management ensured the confidentiality, safety and security of all collected data.

3.3.12 Outcomes for analysis

The reliability and validity of 2D clinical gait analysis were investigated by comparing frontal and sagittal plane ankle, knee and hip kinematics derived from the 2D video recordings to kinematic variables obtained by 3D motion analysis during walking and running trials at a self-selected pace. The kinematic variables for walking were increased peak hip external rotation, increased peak rearfoot eversion, early hip internal rotation, increased peak hip adduction, decreased knee flexion at heel strike, decreased knee flexion in stance, increased peak knee extension and overall ankle dorsiflexion.

The kinematic variables for running were increased peak hip adduction, increased hip internal rotation, increased peak knee varus, increased peak knee external rotation, increased peak knee flexion, increased rearfoot eversion, increased peak ankle eversion and increased ankle dorsiflexion. Table 3.1 shows an example of how data of the project were captured and recorded for analysis.

Table 3.1. Example of data collected by raters for one individual with PFP

Biomechanical risk factor for PFP	**2D video clinical analysis (Rater 1)**	**2D video clinical analysis (Rater 2)**	**3D analysis (reference standard)**
E.g. increased DF	Yes (present)	No (risk factor absent)	Yes
Variable 2	Yes	Yes	Yes
Variable 3	No	No	Yes

3.3.13 Data/Statistical analysis

The IBM SPSS Statistics (version 27) program was used to perform all data analyses. The principal investigator also consulted a biostatistician (L.S.) to assist with the statistical analysis and interpretation of results where needed.

Only data concerning the affected leg were included in the analysis for interrater reliability and validity to reduce type 1 error (see Menz, 2005). Therefore, the most affected limb with the highest rating with the Numeric Rating Scale (NRS) were observed when participants presented bilateral symptoms. In addition, where the participants reported equivalent symptoms and NRS scores, the raters were instructed only to assess the dominant limb. As a result, eighteen knees were included in the analysis.

3.3.13.1 Interrater reliability

The principal investigator analysed the data collected from both raters to determine the level of agreement on kinematic variables of interest identified from the pre-existing 2D video recordings. The dichotomous data (yes/no) were descriptively analysed for kinematic variables of interest for walking and running. Furthermore, interrater reliability was investigated for each kinematic variable, followed by calculating an overall agreement for walking and an overall agreement for running.

3.3.13.2 Concurrent validity

Following the procedure of interrater reliability, the principal investigator analysed the concurrent validity of the kinematic variables of interest investigated, comparing the collected 2D clinical observational gait analysis data to 3D kinematic variables obtained using the Vicon motion analysis system. Each kinematic variable for all 18 participants was assessed to establish an agreement for walking and running gait analysis. Finally, the principal investigator captured all the data on agreement on a Microsoft Excel spreadsheet comparing both raters' data to the 3D motion analysis kinematic variables from D.L.'s study.

3.3.13.3 Statistical analysis for interrater reliability and concurrent validity

The percentage of observed (raw) agreement and Cohen's kappa statistic were used to calculate the agreement for interrater reliability and concurrent validity between 2D and 3D frontal, sagittal and transverse plane kinematic variables of interest. Subtracting that percentage from the value of 1.00 presents the data that are incorrect or misrepresent the collected data (McHugh, 2012). This statistic is often employed to test interrater reliability and extend the collected data to correct representations of the kinematic variables under investigation (McHugh, 2012). The percentage of observed agreement, followed by the kappa statistic with 95% confidence interval (CI) and standard error (SE), are demonstrated in the results.

Agreement according to Cohen's kappa was categorised as disagreement (0.00 to -0.10), poor (≤ 0.00), slight (0.01 to 0.20), fair (0.21 to 0.40), moderate (0.41 to 0.60), substantial (0.61 to 0.80) or almost perfect (0.81 to 1.00) using accepted approaches (Landis & Koch, 1977; McHugh, 2012; Pipkin et al., 2016). Where a kappa value was not able to compute (calculate) and kappa = 0.00, such a result could be ascribed to a rater's findings for a specific variable that was a constant. Kinematic variables, for example, were not observed by one of the raters for any of the 18 participants' recordings analysed, therefore having zero in one or more of the cross-tabulations when calculating kappa values. Another possible explanation for a kappa value of 0.00 is that there were 50% agreement and 50% disagreement for a specific variable.

An overall (mean) percentage agreement was also calculated for interrater reliability and concurrent validity. This was analysed by comparing all the kinematic variables across the 18 participants for walking and running separately. The next chapter will discuss the study results for the agreement of kinematic variables identified between the two raters and compare the findings of each raters to the 3D kinematic variables identified.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter reports on the findings on the interrater reliability and validity of 2D clinical observational gait analysis using a biomechanical risk factor screening tool and the correlation of kinematic variables identified using 3D motion analysis.

4.2 Participating physiotherapists

One physiotherapist missed the deadline for responding to the invitation and advertisement, and another declined and dropped out within two days after receiving training and initially agreeing to participate. Therefore, the remaining two out of the four who responded received training and were included in the study. Rater 1 was a 35-year-old woman working in a private musculoskeletal physiotherapy practice in Stellenbosch. She completed a BSc degree in Physiotherapy at the University of the Witwatersrand and obtained an MPhil in Sports Physiotherapy at the University of Cape Town. Rater 2 was a 35-year-old man who owned a private practice in Kuils River. He obtained a BSc degree in Physiotherapy and a master's degree in Physiotherapy at the University of the Western Cape. Both raters were involved in a broad spectrum of sports, with the most experience working in rugby, and were actively involved with rugby teams on provincial and national levels.

4.3 Participants with PFP demographics

A total of 18 participants with PFP from the pre-existing 2D video recordings was included in the study. The participants comprised 10 men and eight women, with a mean age of 33.89 years. The demographics of the participants (n = 18) are presented in Table 4.1.

Table 4.1. Participant' characteristics (2D video recordings)

Variables	Mean (SD)
Age (years)	33.89 (3.95)
Height (cm)	171.72 (11.14)
Weight (kg)	74.67 (16.28)
BMI (kg/m^2)	25.05 (4.29)
Symptom duration (months)	10.28 (11.15)
NRS (at time of recordings)	4.28 (1.41)
Walking speed (k/h)	5.67 (0.48)
Running speed (k/h)	9.83 (1.98)

4.4 Preliminary data

The 3D kinematic data findings from the preliminary research conducted by D.L. are presented in figures 4.1 and 4.2. The results indicate the biomechanical risk factors that were identified during 3D motion analysis.

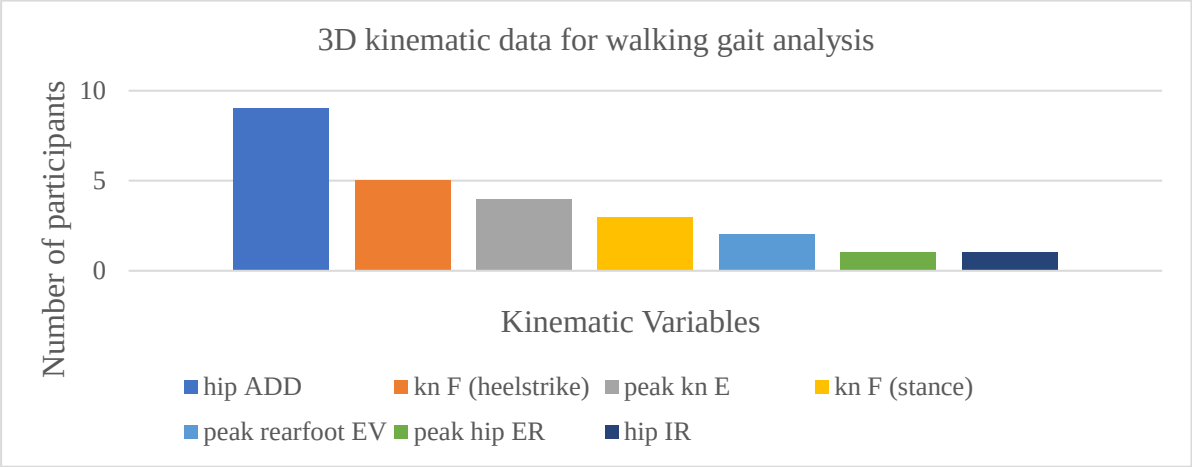

Figure 4.1. 3D walking kinematic data

Of the 18 participants from the pre-existing recording of 3D kinematic data, nine (50%) presented with increased hip adduction and four with decreased knee flexion at heel strike. Only one participant presented with peak hip external rotation and another with early hip internal rotation during walking.

The 3D kinematic running analysis presented in Figure 4.2 shows that seven of the 18 participants presented with increased hip adduction (38.89%) and only two with increased ankle eversion.

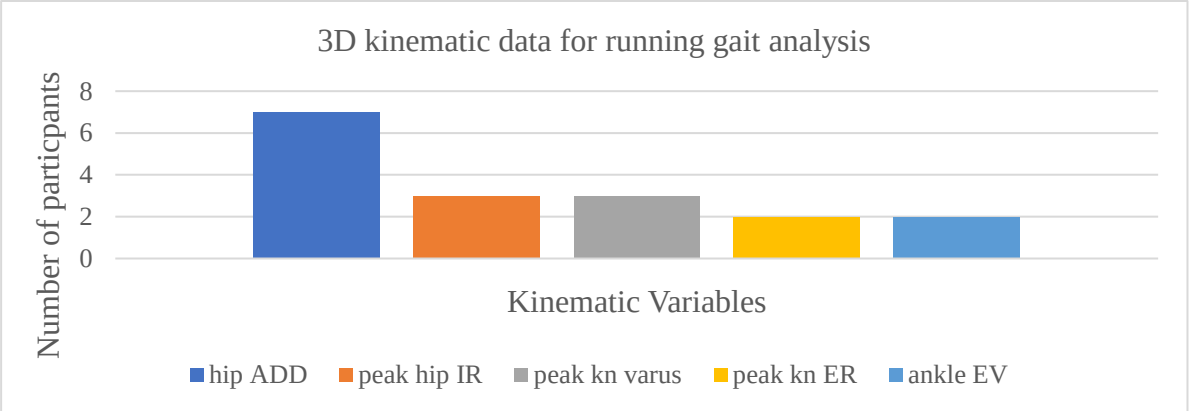

Figure 4.2. 3D running kinematic data

4.5 Interrater reliability

The percentage agreement for 2D clinical observational gait analysis between the two physiotherapists for all the kinematic variables of interest across all 18 participants ranged from 50% to 77.78% for walking (mean = 61.81%) (Table 4.2) and 44.44% to 77.78% for running (mean = 63.89%) (Table 4.3). The highest percentage agreement for 2D clinical observational gait analysis during walking for individual kinematic variables was observed for increased peak knee extension (kappa = fair agreement) and increased overall ankle dorsiflexion. Moderate percentage agreement was demonstrated for increased peak external hip rotation (kappa = fair agreement) and increased peak hip adduction (kappa = slight agreement). The lowest percentage agreement was presented by decreased knee flexion at heel strike and midstance (kappa = slight agreement).

Table 4.2. Interrater reliability between physiotherapists for walking gait analysis (n=18) based on 2D clinical observational gait analysis

Outcome	**% agreement**	**Kappa value**	**Interpretation**	**SE**	**P-value**	**95% CI**
↑ Peak hip ER	66.67%	0.27	Fair	0.17	0.09	(-0.56, 0.60)
↑ *Peak rearfoot eversion*	*50%*	*0.00*	*No agreement*	*0.15*	*1.00*	*(-0.29, 0.29)*
Early hip IR	*50%*	*0.00*	*nc[a]*	*nc[a]*	*nc[a]*	*nc[a]*
↑ Peak hip ADD	61.11%	0.16	Slight agreement	0.19	0.40	(-0.21, 0.54)
↑ Peak knee E	77.78%	0.26	Fair agreement	0.22	0.10	(-0.16, 0.70)
↓ Knee F at heel strike	55.56%	0.06	Slight agreement	0.24	0.78	(-0.40, 0.53)
↓ Knee F in stance	55.56%	0.01	Slight agreement	0.23	0.95	(-0.43, 0.46)
↑ Overall ankle DF	77.78%	-0.09	Disagreement	0.07	0.64	(-0.23, 0.05)

nc = not computed; no statistics were computed because:
[a] = Rater 2 early hip IR is a constant

The interrater reliability for running 2D clinical observational gait analysis between physiotherapists, presented in Table 4.3, showed the highest percentage agreement for increased peak knee flexion (kappa = fair agreement), increased ankle eversion (kappa = fair agreement) and increased dorsiflexion. Moderate percentage agreement was identified for increased hip adduction (kappa = fair agreement), and the lowest percentage agreement was demonstrated in increased rearfoot eversion (kappa = slight agreement).

Table 4.3. Interrater reliability between physiotherapists for running gait analysis (n=18) based on 2D clinical observational gait analysis

Outcome	% agreement	Kappa value	Interpretation	SE	P-value	95% CI
↑ Peak hip ADD	61.11%	0.22	Fair	0.14	0.13	(-0.06, 0.50)
↑ Peak hip IR	61.11%	0.06	Slight	0.18	0.73	(-0.30, 0.41)
↑ Peak knee varus	61.11%	-0.03	Disagreement	0.23	0.89	(-0.48, 0.41)
↑ *Peak knee ER*	*61.11%*	*0.00*	*nc* [a]	*nc* [a]	*nc* [a]	*nc* [a]
↑ Peak knee F	77.78%	0.20	Fair	0.28	0.40	(-0.35, 0.75)
↑ Rearfoot EV	44.44%	0.03	Slight	0.15	0.83	(-0.25, 0.32)
↑ Ankle EV	72.22%	0.35	Fair	0.23	0.14	(-0.11, 0.81)
↑ Ankle DF	72.22%	-0.15	No agreement	0.07	0.50	(-0.30, -0.01)

nc = not computed; no statistics were computed because:
[a] *= Rater 2 peak knee ER is a constant*

4.6 Concurrent validity

4.6.1 Concurrent validity for Rater 1

The percentage agreement for kinematic variables identified by Rater 1 during walking comparing 2D clinical observational gait analysis to 3D gait analysis ranged from 44.44% to 94.44% (mean = 60.41%) (Table 4.4) and 38.89% to 83.33% (mean = 64.58%) (Table 4.5). The highest percentage agreement was exhibited during walking for increased overall dorsiflexion, followed by increased peak hip external rotation (kappa = slight agreement) and increased peak rearfoot eversion (kappa = fair agreement). The lowest percentage agreement was calculated for decreased knee flexion at heel strike.

Table 4.4. Concurrent validity between 2D clinical observational walking gait analysis and 3D walking analysis (n=18) (Rater 1)

Outcome	**% agreement**	**Kappa value**	**Interpretation**	**SE**	**P-value**	**95% CI**
↑ Peak hip ER	61.11%	0.14	Slight	0.13	0.25	(-0.11, 0.39)
↑ Peak rearfoot eversion	61.11%	0.22	Fair	0.14	0.13	(-0.61, 0.50)
Early hip IR	55.56%	0.11	Slight	0.11	0.30	(-0.99, 0.32)
↑ *Peak hip ADD*	*50%*	*0.00*	*No agreement*	*0.23*	*1.000*	*(-0.46, 0.46)*
↑ Peak knee E	61.11%	-0.03	Poor	0.23	0.89	(-0.48, 0.41)
↓ Knee F at heel strike	44.44%	-0.23	Poor	0.20	0.31	(-0.63, 0.17)
↓ Knee F in stance	55.56%	-0.04	Poor	0.20	0.83	(-0.43, 0.34)
↑ *Overall ankle DF*	*94.44%*	*0.00*	*nc*[a]	*nc*[a]	*nc*[a]	*nc*[a]

nc = not computed; no statistics were computed because:
[a] *= 3D overall ankle DF is a constant*

The percentage agreement for running kinematic variables presented in Table 4.5 shows that the highest percentage agreement for validity was observed in increased peak knee flexion, increased ankle dorsiflexion and increased ankle eversion (kappa = slight agreement). A moderate percentage agreement was found in peak knee external rotation and increased hip adduction (kappa = slight agreement) and the lowest in increased rearfoot eversion. Comparison between 2D clinical observational gait analysis by Rater 1 and 3D gait analysis also demonstrated a higher percentage agreement for kinematic variables identified during running than walking.

Table 4.5. Concurrent validity between 2D clinical observational running gait analysis and 3D running analysis (n=18) (Rater 1)

Outcome	**% agreement**	**Kappa value**	**Interpretation**	**SE**	**P-value**	**95% CI**
↑ Hip ADD	55.56%	0.11	Slight	0.23	0.63	(-0.34, 0.56)
↑ Peak hip IR	55.56%	-0.04	Disagreement	0.20	0.83	(-0.43, 0.34)
↑ Peak knee varus	66.67%	0.05	Slight	0.23	0.81	(-0.40, 0.51)
↑ Peak knee ER	61.11%	0.06	Slight	0.18	0.73	(-0.30, 0.41)
↑ *Peak knee F*	*83.33%*	*0.00*	*nc*[a]	*nc*[a]	*nc*[a]	*nc*[a]
↑ *Rearfoot EV*	*38.89%*	*0.00*	*nc*[b]	*nc*[b]	*nc*[b]	*nc*[b]
↑ Ankle EV	72.22%	0.15	Slight	0.23	0.46	(-0.30, 0.61)
↑ *Ankle DF*	*83.33%*	*0.00*	*nc*[c]	*nc*[c]	*nc*[c]	*nc*[c]

nc = not computed; no statistics were computed because:
[a] *= 3D peak knee F is a constant*
[b] *= 3D rearfoot EV is a constant*
[c] *= 3D ankle DF is a constant*

4.6.2 Concurrent validity for Rater 2

Table 4.6 shows the agreement between 2D clinical observational gait analysis by Rater 2 and 3D gait analysis during walking. The percentage agreement ranged from 55.56% to 94.44% (mean = 76.38%) for individual kinematic variables. The highest percentage agreement for walking was identified in early hip internal rotation, increased peak hip external rotation, increased peak knee extension (kappa = fair agreement), increased overall dorsiflexion and increased peak rearfoot eversion. A moderate percentage agreement was found in identifying increased peak hip adduction (kappa = fair agreement) and decreased knee flexion in stance and the lowest for decreased knee flexion at heel strike.

Table 4.6. Concurrent validity between 2D clinical observational walking gait analysis and 3D walking analysis (n=18) (Rater 2)

Outcome	**% agreement**	**Kappa value**	**Interpretation**	**SE**	**P-value**	**95% CI**
↑ Peak hip ER	83.33%	-0.08	Disagreement	0.06	0.72	(-0.19, 0.03)
↑ Peak rearfoot eversion	77.78%	-0.12	Disagreement	0.06	0.60	(-0.25, -0.03)
Early hip IR	*94.44%*	*0.00*	*nc*[a]	*nc*[a]	*nc*[a]	*nc*[a]
↑ Peak hip ADD	66.67%	0.33	Fair	0.17	0.06	(0.01, 0.66)
↑ Peak knee E	83.33%	0.34	Fair	0.26	0.05	(-0.17, 0.85)
↓ Knee F at heel strike	55.56%	0.01	Slight	0.23	0.952	(-0.43, 0.46)
↓Knee F in stance	66.67%	0.05	Slight	0.23	0.814	(-0.40, 0.51)
↑ *Overall ankle DF*	*83.33%*	*0.00*	*nc*[b]	*nc*[b]	*nc*[b]	*nc*[b]

nc = not computed; no statistics were computed because:
[a] *= 2D early hip IR is a constant*
[b] *= 3D overall ankle DF is a constant*

The percentage agreement comparing 2D clinical observational gait analysis by Rater 2 and 3D running gait analysis ranged from 72.22% to 88.89% (mean = 81.25%), as presented in Table 4.7. All eight kinematic variables of interest demonstrated a high percentage agreement during running gait analysis. The highest percentage agreement was peak knee external rotation and increased ankle dorsiflexion. This was followed by increased peak hip internal rotation (kappa = fair agreement), increased ankle eversion (kappa = fair agreement), increased hip adduction (kappa = fair agreement) and peak knee varus (kappa = slight agreement).

Table 4.7. Concurrent validity between 2D clinical observational running gait analysis and 3D running analysis (n=18) (Rater 2)

Outcome	**% agreement**	**Kappa value**	**Interpretation**	**SE**	**P-value**	**95% CI**
↑ Hip ADD	72.22%	0.33	Fair	0.19	0.06	(-0.04, 0.70)
↑ Peak hip IR	83.33%	0.31	Fair	0.30	0.18	(-0.28, 0.90)
↑ Peak knee varus	72.22%	0.12	Slight	0.26	0.61	(-0.38, 0.62)
↑ *Peak knee ER*	*88.89%*	*0.00*	*nc*[a]	*nc*[a]	*nc*[a]	*nc*[a]
↑ *Peak knee F*	*83.33%*	*0.00*	*nc*[b]	*nc*[b]	*nc*[b]	*nc*[b]
↑ *Rearfoot EV*	*83.33%*	*0.00*	*nc*[c]	*nc*[c]	*nc*[c]	*nc*[c]
↑ Ankle EV	77.78%	0.40	Fair	0.21	0.03	(-0.01, 0.81)
↑ *Ankle DF*	*88.89%*	*0.00*	*nc*[d]	*nc*[d]	*nc*[d]	*nc*[d]

nc = not computed; no statistics were computed because:

[a] *= 2D peak knee ER is a constant*

[b] *= 3D peak knee F is a constant*

[c] *= 3D rearfoot EV is a constant*

[d] *= Ankle DF is a constant*

4.7 Conclusion

The interrater reliability of 2D clinical observational gait analysis for walking and running demonstrated overall moderate agreement based on percentage agreement and slight agreement based on kappa interpretation. Concurrent validity demonstrated overall poor to fair validity based on kappa values and moderate to high percentage agreement compared to kinematic variables identified using the Vicon 3D motion analysis system. 2D clinical gait analysis by Rater 2 compared to 3D gait analysis also obtained higher percentage agreement than the findings of Rater 1. A higher percentage agreement and kappa values were demonstrated for interrater reliability and validity of 2D clinical observational gait analysis during running than walking. The sagittal kinematic variables of interest during 2D clinical observational gait analysis showed more reliability than frontal and transverse plane kinematic variables of interest. The following chapter presents the main findings of the study, potential clinical implications, the limitations of the study and recommendations for future research for 2D clinical observational gait analysis.

CHAPTER 5: DISCUSSION

5.1 Introduction

This study aimed to determine whether physiotherapists can use 2D clinical observational gait analysis to identify person-specific, evidence-based biomechanical factors in individuals with PFP during walking and running. The risk factors for PFP were identified using an evidence-based biomechanical risk factor screening tool (Appendix 2). In addition, frontal, sagittal and transverse plane hip, knee and ankle kinematics derived from pre-existing 2D video recordings were assessed for the interrater reliability between two raters and validity between kinematic variables identified during 2D clinical observational gait analysis and objective 3D gait analysis.

5.2 Main findings

5.2.1 3D kinematic variables identified in participants with PFP

This study's findings revealed that half of the participants presented with increased hip adduction during walking, of which more than half were identified among women. The 3D kinematics for running also identified increased hip adduction among seven participants, six of whom were women. Therefore, this study provided evidence supported by previous studies identifying increased hip adduction during running in women and a higher risk in this population of developing and experiencing persistent and recurrent PFP symptoms (Willson & Davis, 2008a; Noehren, Hamill & Davis, 2013; Almeida et al., 2016). In addition, peak hip internal rotation and peak knee varus were also identified in participants with PFP during running. Other important kinematic factors commonly identified during 3D motion analysis for walking were decreased knee flexion at heel strike (Powers et al., 1999), decreased knee flexion in stance (Nadeau et al., 1997) and increased peak knee extension (Salsich & Long-Rossi, 2010). These risk factors identified are typical in individuals with PFP.

5.2.2 Interrater reliability

The comparison of 2D clinical observational gait analysis between the two raters demonstrated higher interrater reliability (agreement) for identifying kinematic variables of interest during running than walking. These results may be ascribed to the increased variability of gait kinematics in recreational runners and individuals with PFP investigated in this study, compared to more consistent kinematic findings in elite or competitive athletes (Clermont et al., 2017). Running is also a more demanding task than walking. Walking gait consists of a

period of double support with both legs in contact with the ground, while running gait exhibits single-leg support or double-leg float periods (Dicharry, 2010). Subsequently, running requires more neuromuscular control of the hip, knee and ankle to maintain single-leg support during the stance phase of the running gait cycle. Therefore, if an individual exhibits altered kinematics, it can easily be detected during the single-leg support phase, as deficits in hip and knee may provide more reliable and robust indicators of changes in lower-extremity kinematics (Kedroff et al., 2019).

The current study's results also indicated overall moderate reliability (see tables 4.2 and 4.3) based on percentage agreement and slight agreement based on kappa interpretation when identifying kinematic variables of interest constructed from the evidence-based biomechanical risk factor screening tool (Leibbrandt & Louw, 2017a). According to the study findings, increased peak knee extension and increased overall ankle dorsiflexion during walking are considered reliable between the two raters using 2D clinical observational gait analysis. Three of the eight running kinematic variables of interest, namely increased peak knee flexion, increased ankle dorsiflexion and increased ankle eversion, were found to be reliable between the raters. Findings from previous studies suggest that the reliability of 3D knee and ankle sagittal plane kinematics was slightly higher than that of coronal and transverse plane kinematics (McGinley et al., 2009). Similarly, the interrater findings for 2D sagittal plane kinematics were more reliable based on percentage agreement and are supported by studies by Reinking et al. (2018) and Schurr et al. (2017), who also investigated the reliability of 2D video analysis. However, these studies quantified joint angles, and therefore knee and ankle joint angles might have been easier to measure than hip, knee and foot frontal and transverse joint angles.

Previous research investigating interrater reliability of 2D hip and knee kinematics during treadmill running reported substantial intra- and interrater reliability between experienced raters (Damsted, Nielsen & Larsen, 2015; Pipkin et al., 2016). In addition, the studies included experienced raters who were accustomed to using high-quality and high-speed video analysis as a tool to observe and quantify joint angles during running and trained in biomechanical gait analysis (Damsted, Nielsen & Larsen, 2015; Pipkin et al., 2016). In contrast, the two raters from the current study had no previous experience in biomechanical gait analysis. Therefore, their lack of training and the use of clinical observational gait analysis without quantifying joint angles may have impacted the results of this study.

Damsted, Nielsen and Larsen (2015) found that the reliability was sufficient to justify using 2D video analysis in a clinical setting. However, these findings were limited to two sagittal variables (knee and hip flexion angles), supporting the current study's findings that 2D sagittal plane variables are more reliable than frontal plane variables. Pipkin et al. (2016) investigated 15 individual kinematic variables; however, only five reported substantial interrater reliability. The authors evaluated ankle dorsiflexion (midstance) and knee flexion angles at initial contact and midstance. The results showed poor to moderate interrater reliability, similar to the findings of the current study, based on kappa values that ranged from 0.00 to 0.68 following a qualitative approach using a visual categorical rating to identify gait event and kinematic variables (Pipkin et al., 2016).

Another study investigating the reliability of 2D knee flexion (sagittal plane), hip adduction and rearfoot angles (frontal plane) demonstrated substantial to almost perfect agreement between experienced and inexperienced raters (Reinking et al., 2018). These authors also concluded that interrater reliability levels were higher for the sagittal plane kinematic variables assessed than kinematic variables observed in the frontal plane (Reinking et al., 2018). A more recent study by Neal et al. (2020) showed moderate interrater reliability for 2D measurements of peak knee flexion (intraclass correlation coefficient [ICC] = 0.71) and poor interrater reliability for peak hip adduction (ICC = 0.31). The latter study's findings were more similar to the reliability of peak hip adduction that demonstrated only a moderate percentage (61.11%) and slight agreement (kappa = 0.16) in the current study.

5.2.3 Concurrent validity

The findings suggest that 2D clinical observational gait analysis of lower-extremity kinematic variables of interest showed overall poor to fair validity compared to kinematic variables identified using the Vicon 3D motion analysis system. The findings for validity were similar to those of Neal et al. (2020), who investigated the validity and reliability of markerless, smartphone 2D videos to measure peak knee flexion and peak hip adduction in participants with PFP. These videos were analysed using the 'Hudl technique' (Hudl, Agile Sports Technologies Inc., Nebraska, USA), a running software analysis application designed for smartphones that aids in identifying joint kinematic variables during running (Neal et al., 2020). This study established poor validity for 2D measurements of hip adduction (ICC = 0.06, 95% CI -0.35, 0.45) and peak knee flexion (ICC = 0.42, 95% CI -0.10, 0.75) (Neal et al., 2020), where again validity was higher in the identification of the sagittal plane variable. In contrast, studies by

Maykut et al. (2015) and Dingenen, Staes, et al. (2018) compared frontal plane motion variables and suggested a strong correlation for peak hip adduction between 2D and 3D analysis measurements. However, these studies only investigated running and did not include any walking kinematics.

The findings regarding the 2D clinical observational gait analysis by Rater 2 and the 3D motion analysis demonstrated an overall higher percentage agreement compared to those of Rater 1. In addition, both raters had no previous experience in biomechanical gait analysis, had the same amount of clinical experience and relied on their observational skills to identify kinematic variables. Therefore, the data indicate that kinematic variables derived from 2D clinical observational gait analysis using a biomechanical risk factor screening tool during gait of individuals with PFP do not provide sufficient accuracy in identifying kinematic variables compared to 3D gait analysis.

Although the current findings between the raters were inconsistent for some kinematic variables compared to 3D motion analysis (see sections 4.6.1 and 4.6.2), higher percentage agreement was still demonstrated for sagittal kinematic variables than frontal and transverse plane kinematic variables. The findings also showed a higher percentage agreement for kinematic variables for running than walking, similar to interrater reliability findings. The only kinematic variable that demonstrated good validity based on percentage agreement between both raters was increased overall ankle dorsiflexion during walking. In running, increased peak knee flexion, increased ankle dorsiflexion and increased ankle eversion demonstrated good validity for the two raters' 2D clinical observational gait analysis compared to 3D gait analysis.

Concluding on the findings of overall poor to fair reliability and validity of 2D gait analysis, it seems that clinical observational screening may not be adequate to identify evidence-based biomechanical risk factors in people with PFP. It appears that clinicians first need to consider the most reliable factors that obtained the highest percentage agreement and kappa values, as demonstrated in the current study, when screening individuals with PFP in clinical practice. The study's findings also indicated that the reliability and validity of sagittal plane kinematics were slightly higher than those of frontal plane kinematics. This may direct physiotherapists to screen for these factors first during gait analysis and alternatively employ other functional tasks, such as SLS, which is more reliable to obtain frontal kinematic variables in a clinical setting.

A recent study by Kingston et al. (2020) investigated the validity and reliability of the frontal plane trunk, hip and knee kinematics during functional tasks in women with PFP. The authors

investigated frontal plane peak angles during drop vertical jumps, single-leg hops and SLS and reported good to excellent reliability, with only 2D hip joint angles valid for all three tasks (Kingston et al., 2020). Therefore, these tasks might be more reliable to observe frontal hip and knee kinematics in clinical practice than gait kinematics as presented in this study, especially for physiotherapists who do not have experience in biomechanical gait analysis.

There are several reasons why a significant difference in 2D kinematic factors identified using the evidence-based biomechanical risk factor screening tool between raters and 2D versus 3D objective measurements demonstrated poor to fair reliability and concurrent validity. When comparing the present study to similar 2D reliability and validity published research, the other studies only investigated running kinematics, and different methods and measurement tools were applied (Damsted, Nielsen & Larsen, 2015; Maykut et al., 2015; Pipkin et al., 2016; Dingenen, Staes, et al., 2018; Reinking et al., 2018; Neal et al., 2020). The majority of previous research performed was laboratory-based and based on cross-sectional evidence (Damsted, Nielsen & Larsen, 2015; Maykut et al., 2015; Dingenen, Staes, et al., 2018; Neal et al., 2020). Pipkin et al. (2016) and Reinking et al. (2018) also used pre-existing 2D recordings in their studies; in contrast to the current study investigating walking and running gait, these authors only analysed running gait. The outcomes of studies on kinematic variables all involved a quantification process of joint angle measurements when correlating the interrater reliability and comparing measurements to the gold standard, objective 3D measures (Damsted, Nielsen & Larsen, 2015; Maykut et al., 2015; Dingenen, Staes, et al., 2018; Neal et al., 2020).

Previous research also used different gait analysis software applications, such as Dartfish (Fribourg, Switzerland) (Maykut et al., 2015; Dingenen, Staes, et al., 2018) and QuickTime (Apple Inc, Cupertino, CA) (Pipkin et al., 2016), which may have improved the identification process. Although Damsted, Nielsen and Larsen (2015) and Reinking et al. (2018) used the same free software analysis program, Kinovea, both studies quantified kinematic variables of interest by measuring joint angles and body posture alignment. In contrast, the findings of the raters in my study were based purely on observational gait analysis to identify kinematic variables. The primary explanation for disagreement in the current study results compared to previous studies may be its methodology. This study used the evidence-based biomechanical risk factor screening tool (Appendix 2). The 2D video recordings that were analysed purely relied on the two raters' observational skills, without any measurement or quantification process

to identify joint kinematic variables of interest. The raters had to review recordings and observe the presence of each kinematic variable during walking and running.

Percentage agreement and Cohen's kappa were used to determine interrater reliability and concurrent validity between kinematic variables derived from 2D video gait analysis and 3D motion analysis. Various statistical tests and methods were applied in previous studies investigating the reliability and validity of 2D gait analysis. Frequently employed methods included ICC, Pearson's product correlation and Bland-Altman limits of agreement (Damsted, Nielsen & Larsen, 2015; Maykut et al., 2015; Dingenen, Staes, et al., 2018; Reinking et al., 2018; Neal et al., 2020), which are more applicable when quantifying kinematic variables and investigating validity. Pipkin et al. (2016) calculated interrater reliability values for individual kinematic variables by employing weighted kappa.

The participants from the 2D video data represented a specific PFP subgroup with chronic pain (> 3 months) and presented with a mean symptom duration of 10.28 months, moderate pain levels (4.28/10) and a higher BMI (mean 25.05) than those of previous studies investigating healthy participants and athletes. These findings may also have influenced the accuracy of 2D video digitisation by affecting and increasing visual misinterpretation (Neal et al., 2020). Furthermore, the PFP participants in this study might have had lower physical activity levels than the healthy collegiate and elite runners investigated in previous studies (Maykut et al., 2015; Dingenen, Staes, et al., 2018; Reinking et al., 2018). The literature reports elite runners and athletes to have more reliable kinematic gait deviations than recreational runners (Clermont et al., 2017), thereby increasing the likelihood of agreement between 2D and 3D measurement (Dingenen, Barton, et al., 2018).

5.3 Clinical applicability of the study

Although not as precise and detailed as 3D motion analysis, 2D clinical observational gait analysis can enhance a clinician's ability to bridge the outcome of using special investigative equipment when performing gait analysis (Dicharry, 2010). The test and methods could be easily employed in a clinical setting, forming part of the physical assessment of the knee by physiotherapists. The 2D video capture and its ability to slow down and freeze frames can vastly improve gait visualisation (Dicharry, 2010), which can be implemented in clinical practice. Simple 2D video gait analysis for detecting altered kinematics can be measured using smartphone applications and free analysis software with digital goniometers during real-time clinical gait analysis. In addition, clinicians could tailor person-specific rehabilitation and

management strategies by identifying aberrant kinematic variables and less optimal movement patterns in their clinical setting.

The evidence-based biomechanical risk factor screening tool could help physiotherapists screen for altered lower-extremity biomechanics in individuals with PFP. Reliability and validity findings specified that running kinematic variables were more easily identified than walking. The findings also indicated sagittal plane kinematic views to be more reliable than frontal kinematic views. This study's 2D clinical observational gait analysis could still be clinically applicable and employed to identify specific kinematic factors based on the more easily identified factors. The kinematic factors observed that resulted in a higher percentage agreement and fair kappa agreement of specific individual kinematics (sections 4.5 and 4.6) should be considered first when assessing gait in individuals with PFP.

The outcomes constructed from the evidence-based biomechanical risk factor screening tool are still of clinical importance and recommended when screening using 2D video gait analysis. Based on this study's findings (highest percentage agreement) and previous research, sagittal plane peak knee kinematics and ankle dorsiflexion obtained consistent high percentage agreement between raters and compared to 3D gait analysis. Frontal plane kinematics, ankle eversion, knee varus and hip adduction demonstrated moderate percentage reliability and validity. Hip rotation and foot kinematics (rearfoot eversion) findings were inconsistent between the two raters, suggesting that these factors might be difficult to detect on video, especially without quantifying joint kinematics. Based on the evidence and this study's findings, running analysis is more useful and recommended above walking analysis. Gait analysis is recommended for runners with PFP, but these findings might not be generalisable to other groups.

5.4 Limitations

This study was not without any limitations. According to the evidence-based biomechanical risk factor screening tool, the findings were particular to the 16 kinematic variables: eight for walking and eight for running. Biomechanics was assessed during self-selected walking and running speeds in individuals with PFP. Therefore, the findings cannot be generalised to other running-related conditions or kinematic measures obtained from 2D videos. The study only investigated interrater reliability and did not consider the intrarater reliability of raters. Testing was completed once, and no in-between-day testing was conducted. In addition, the method chosen to identify kinematic variables of interest was limited to the two raters' clinical

observational skills in the study, without a standardised protocol on identifying the kinematic variables constructed from the evidence-based biomechanical risk factor screening tool. Previous research was laboratory-based and kinematic variables included quantifying joint angles and joint positions.

While 3D motion analysis (Vicon system) is considered the 'gold standard', specific outcomes are more accurate than others. Sagittal plane knee and hip are the most accurate, and transverse is the least (McGinley et al., 2009). As demonstrated, sagittal plane kinematic variables showed the highest percentage agreement when identifying individual kinematic factors. However, it was limited to only six out of 16 kinematic variables of interest investigated in the present study, which can advocate for the fair to moderate overall (mean) interrater reliability and validity findings. This study's findings also revealed that running kinematics was more easily identifiable than walking. Another limitation could be that gait analysis might be useful for runners with PFP, but might not be relevant and cannot be generalised to other subgroups. The pre-existing 2D video recordings were recorded with high-quality and high-speed cameras in a laboratory, which might not be readily available or feasible in most physiotherapy practices.

Therefore, more appropriate, portable and inexpensive clinical movement analysis equipment and methods are needed that can provide clinicians with accurate feedback in clinical settings. In addition, although having vast clinical experience, the present study's physiotherapists had little to no biomechanical gait analysis experience, which could have influenced the reliability and validity findings. Another limitation can also include that the physiotherapists had to reside in the Cape Metropolitan region or the Cape Winelands to be considered eligible. In summary, the study findings also revealed that physiotherapists might require more formal biomechanical gait analysis training in addition to simple, affordable 2D video cameras, software analysis programs and smartphone applications to employ during real-time clinical gait analysis.

5.5 Recommendations for future research

There is still limited research on clinical observational gait analysis methods for identifying kinematic factors in individuals affected by PFP without objectively quantifying joint kinematics. The poor to fair interrater reliability and validity and the wide range of percentage agreement and kappa values demonstrated in this study's results remain a cause for concern in identifying kinematic variables during gait analysis in clinical practice, particularly in settings where high-quality video cameras and gait analysis software programs or applications are lacking. An investigation of more improved methodologies is warranted, aiming to enhance 2D

clinical observational gait analysis accuracy to predict 3D laboratory-based kinematics in a clinical setting. Furthermore, studies should also employ clinicians with more standardised, structured and detailed protocols or recommendations (e.g. from expert opinion) together with screening tools similar to the evidence-based biomechanical risk factor screening tool to increase the reliability and validity of observational gait analysis performed in a clinical setting. To conclude, future research should explore less expensive and portable methods for accurately measuring and identifying kinematics during clinical gait assessments.

CHAPTER 6: SUMMARY AND CONCLUSION

This study's main objective was to ascertain the agreement between biomechanical risk factors derived from 2D clinical observational gait analysis and 3D gait analysis by utilising an evidence-based biomechanical risk factor screening tool (Appendix 2) based on a systemic review by Leibbrandt and Louw (2017a). A cross-sectional descriptive study design was used to collect the data. The 3D lower-extremity biomechanics in 18 recreational runners with PFP was obtained as part of a preliminary study conducted by one of the co-investigators (D.L.). The pre-existing 2D video data used in this study were collected concurrently with the 3D objective measures using the Vicon 3D motion analysis system. The Vicon system was previously used for 3D gait analysis and is deliberated as the 'gold standard' approach for detailed running analysis (Maykut et al., 2015).

Participants for this study were recruited from the Cape Metropolitan region and the Cape Winelands. Two eligible physiotherapists responded to the study's electronic invitation and advertisement and provided informed consent to participate in the study. Both physiotherapists had over 10 years' experience working with musculoskeletal conditions and treating individuals with PFP. The raters received a short training session where the kinematic variables of interest were specified according to the evidence-based biomechanical risk factor screening tool (Appendix 2). The reviewing procedure of the recordings was done separately by each rater (at a venue of their convenience) and independent of the 3D gait analysis by D.L., who has clinical and research experience in movement analysis. The raters performed visual clinical observational gait analysis to identify the lower-extremity kinematic variables of interest during walking and running in sagittal and frontal views.

Dichotomous data were collected for each of the pre-existing recordings (n = 18) and raters were instructed to identify the 16 sagittal, frontal and transverse kinematic variables of the hip, knee and ankle. 2D clinical observational gait analysis data were analysed by raters using the free software video analysis application Kinovea (version 0.8.15) to pause and slow down video clips in specific gait cycles to identify kinematic variables during walking and running. Percentage agreement and Cohen's kappa statistical calculations were performed to test the interrater reliability of 2D clinical observational gait analysis and concurrent validity compared to 3D gait analysis.

This study's main findings demonstrated that 2D kinematic variables of interest identified using the evidence-based biomechanical risk factor screening tool had low validity levels. Validity was better for running than walking. Poor to fair interrater reliability for the identification of frontal, sagittal and transverse plane kinematics of the ankle, knee and hip in walking and running was noted. Studies that support these findings include those of Neal et al. (2020) and Pipkin et al. (2016). Contrary to these findings, Damsted, Nielsen and Larsen (2015), Maykut et al. (2015), Reinking et al. (2018) and Dingenen, Staes et al. (2018) reported substantial to excellent reliability and strong correlation between 2D and 3D gait analysis, but these studies were limited to running kinematics. The current study's findings also demonstrated that sagittal kinematics was more reliable than frontal and transverse kinematics and running kinematics also showed higher percentage agreement and kappa values than walking kinematics. Studies by Reinking et al. (2018) and Neal et al. (2020) supported these findings for sagittal plane variables.

The severity of PFP (symptom duration, NRS), the BMI and the activity levels of participants from the pre-existing video recordings are believed to have contributed to this study's findings, compared to previous research conducted in healthy participants and elite runners. These poor findings may be ascribed to the study's statistical analysis and methodology, where raters relied solely on their observational skills to identify kinematic variables. The findings can also be attributed to the increased variability of gait kinematics in runners with PFP (Neal et al., 2020).

Although this study's overall outcomes resulted in poor to fair findings, not all findings on the kinematic variables of interest were relevant. However, there are still individual kinematic factors that clinicians could consider when screening individuals with PFP, especially in the running subgroups. Kinematic variables constructed from the evidence-based biomechanical risk factor screening tool that are still of clinical importance based on this study's findings (highest percentage agreement) and previous research are sagittal plane increased peak knee extension and overall ankle dorsiflexion during walking and increased peak knee flexion and increased ankle dorsiflexion in running. Frontal plane kinematics ankle eversion also demonstrated a high percentage agreement, followed by knee varus and hip adduction, which demonstrated moderate percentage reliability and validity. The findings from this study also propose kinematic factors to be slightly easier to identify during running than walking. This finding could be ascribed to compensatory gait patterns that are more evident during running, demanding greater lower-extremity neuromuscular control than walking, especially in this

population. Therefore, investigating running analysis is recommended over walking gait analysis in recreational runners with PFP.

The test procedure for 2D video gait analysis is reproducible in a clinical setting. Physiotherapists should include a basic gait analysis as part of their clinical physical assessment of the knee joint and lower-limb biomechanical assessment. Based on highlighted findings for individual kinematics, 2D clinical observational gait analysis using the evidence-based biomechanical risk factor screening tool could potentially be considered reliable for some PFP biomechanical risk factors. Still, poor to fair interrater reliability and validity were noted for many of the evidence-based biomechanical risk factors using 2D clinical observational gait analysis compared to 3D gait analysis. Therefore, clinicians are recommended to use the best available evidence and the reliability of relevant clinical measurements when screening individuals with PFP to ensure that biomechanical analysis is accurate and applicable in clinical practice.

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LIST OF APPENDICES

Appendix 1: Diagnostic Checklist

Checklist for diagnosis of patellofemoral pain

Created by Leibbrandt & Louw (2017)

SUBJECTIVE INFORMATION:

Area (must be yes for one)

	YES	NO
Front of the knee or retropatella[3, 12, 16, 23]		
Local tendon pain[11, 15]		

Chronicity

Longer than three months[3, 6, 14, 17]		

Aggravated by (must be yes for two or more of the following)

Squatting[4,7,16]		
Prolonged sitting[4,7,16]		
Stairs (ascending or descending)[4,7,16]		
Kneeling[8,12, 1]		
Lunging[23, 15, 9, 11, 22, 20]		
Jumping[23, 15, 9, 11, 22, 20]		

Excluded if any of the below known

Previous lower limb surgery[16, 19, 1, 23]		
History of trauma[1, 23]		
Rheumatological conditions		
Known intra-articular pathology: ligament and osteoarthritis[16, 19, 1, 23]		
Referred pain from the lumbar spine or hip[23]		
Stress fracture of patella[23]		
Patellar instability[1, 23]		
Knee effusion[1, 23]		
Patella subluxation/ dislocation[1, 23]		
Fat pad impingement/ bursitis[1, 23]		
Osgood Schlatter[1, 19]		

OBJECTIVE TESTS:

Symptom reproduction with (must be positive for at least 2 of the following activities)

Squatting[3, 4, 6, 7, 13, 14, 16, 21]		
Kneeling[3, 4, 6, 7, 13, 14, 16, 21]		
Ascending or descending stairs[3, 4, 6, 7, 13, 14, 16, 21]		

OR

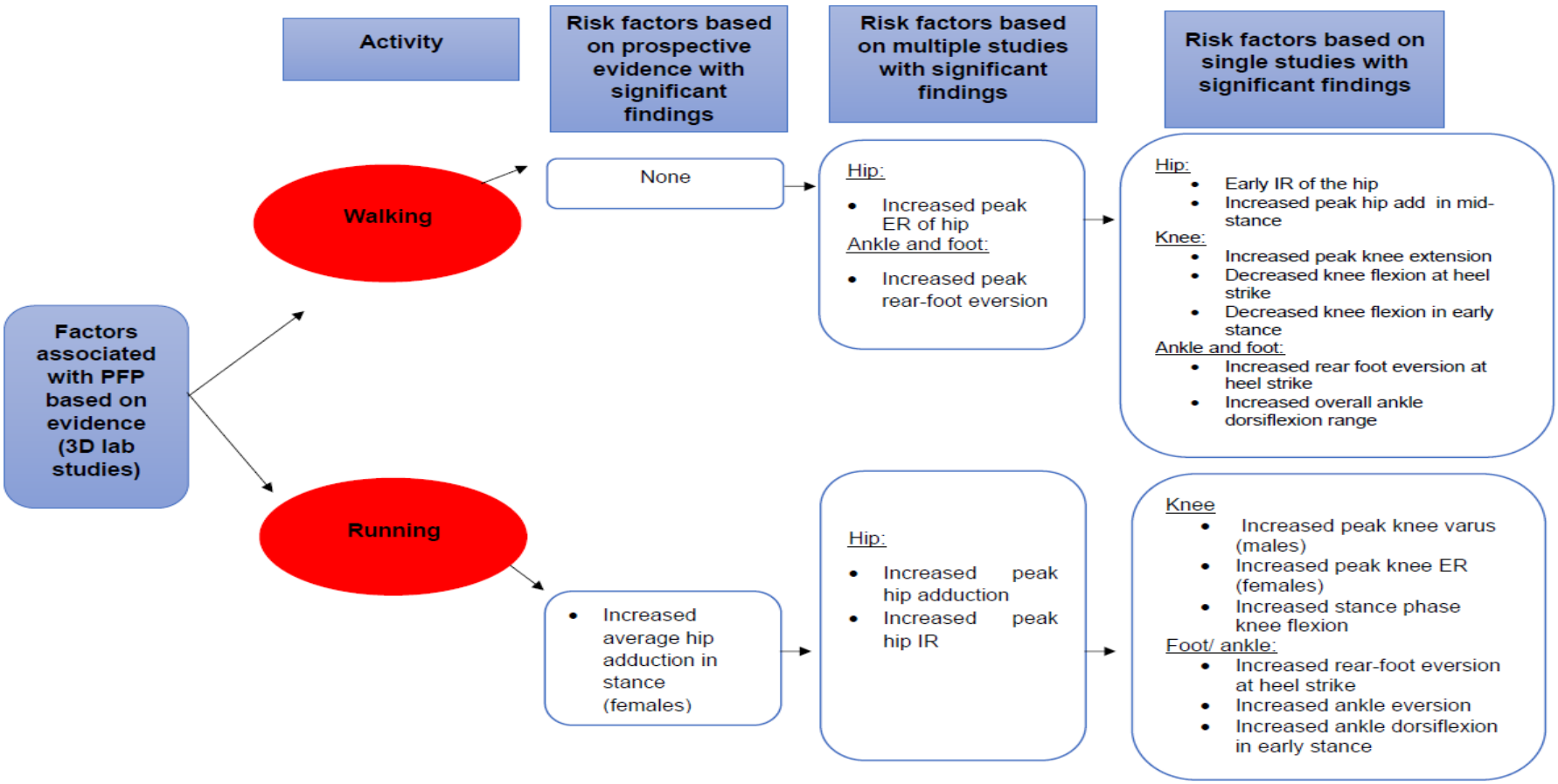
(Minimum 2/3) positive for combination of

Squatting[3]		
Isometric quads[3]		
Palpation of patella borders[3]		

Excluded if positive for

		Yes	**No**
Lachman's Test[2, 5, 10]	ACL		
Posterior Drawer Test[2, 10]	PCL		
Valgus Stress Test[2, 10]	MCL		
Varus Stress test[2, 10]	LCL		
McMurray's Test[2, 10]	MENISCUS		

Appendix 2: Combined evidence-based biomechanical risk factor screening tool for walking and running



Appendix 3: Informed consent forms

TITLE OF THE RESEARCH PROJECT:

Validation of an evidence-based biomechanical risk factor screening tool for patellofemoral pain

PROJECT ID: 11912

ETHICS REFERENCE NUMBER: S19/10/236

PRINCIPAL INVESTIGATOR: Tanya Green

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

CONTACT NUMBER: 021 808 3392

You are invited to partake in a research project. Please take ample time to read the information presented below, which entails all the details of this project. Please ask the principal researcher any questions about any part of this project that you do not entirely understand. It is essential that you understand how you could be involved and what this research project entails. Your participation is also entirely voluntary, and you are free to decline participation. Feedback given on reviewed recordings will be anonymous. Should you do decide to decline, this will not affect you negatively. As a participant, you have the right to withdraw from the study at any point, even if you agree and signed consent to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University.** The study will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, the South African Guidelines for Good Clinical Practice (2006), the Medical Research Council (MRC) Ethical Guidelines for Research (2002), and the Department of Health Ethics in Health Research: Principles, Processes and Studies (2015).

What is this research study about?

Patellofemoral pain (PFP) frequently affects the knee joint and may limit an individual's ability to perform everyday activities of daily living (ADLs) such as running, squatting and stair climbing. The overall aim of this research is to establish whether an evidence-based decision-

making biomechanical risk factor screening tool can be used to identify associated kinematic factors for PFP in a clinical setting.

The preliminary research prior to this study will be conducted at the Tygerberg CAF Motion Analysis Laboratory. Eighteen individuals with PFP will undergo 3D gait analysis during walking and running. Biomechanical laboratory analysis will be done by D. L, a postdoctoral researcher who has been trained in movement analysis procedures and interpretation of data. A second researcher (Q. L) will also analyse the data independently to screen for associated biomechanical risk factors.

In the light of the global COVID-19 pandemic, training of participants for this study will no longer be held at Campus Health Services physiotherapy rooms in Stellenbosch. The principal investigator (T.G.) will meet each participant (physiotherapist) at a venue of their convenience (while maintaining social distancing and adhering to government regulations), where she will deliver a short training session on how to screen for common biomechanical risk factors using the screening tool. The review of data (videos) will also be taking place at a venue of your convenience. You will be required to analyse the gait videos and attempt to identify gait-related associated biomechanical risk factors. These findings will be analysed and compared to the gold standard, 3D motion analysis, to validate the evidence-based clinical decision-making biomechanical risk factor screening tool and ascertain the level of agreement between laboratory analysis and clinical assessment in recognising associated kinematic factors for participants with PFP.

Why have you been invited to participate?

You have been invited to participate in this study because you are a qualified and registered physiotherapist with the Health Profession Council and have at least two years of clinical experience in treating PFP, therefore meeting the inclusion criteria and responded to our invitation or advertisement.

What will your responsibilities be?

You will be required to complete a short training session using the clinical decision-making biomechanical risk factor screening tool and video analysis software program that will be used to review recordings. This will assist you in assessing the 2D video gait analysis to identify biomechanical risk factors during walking and running in subjects with PFP.

Will you benefit from taking part in this research project?

By participating in this study, you will have the opportunity to improve and upskill yourself in biomechanical assessment and analysis. You will also be introduced to an evidence-based clinical decision-making biomechanical risk factor screening tool that has not yet been implemented in a clinical setting and can prove relevant in clinical practice.

Are there any risks involved in your taking part in this research project?

There are no risks in taking part in this research.

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

- There are no costs to you should you decide to participate in the study. You will not pay anything if you do take part.
- Compensation for your time includes a standard hourly market-related rate for participating in this project.

Is there anything else that you should know or do?

- You can contact the principal researcher Tanya Green at 021 808 3392 if you have any further queries or encounter any problems.
- You can contact the Health Research and Ethics Committee at 021 938 9207 if you have concerns or complaints that your study investigator did not adequately address.
- You will receive a copy of this information and a consent form for your records.

Declaration by participant

By signing below, I …… agree to take part in a research project entitled, *(Patellofemoral Pain: Validation of an evidence-based clinical decision-making algorithm to identify associated risk factors).*

I declare that:

- I have read or had this information read to me on the consent form and it is written in a language with which I am fluent and comfortable.
- I have had enough time to ask questions and all my questions have been answered to my satisfaction.

- I understand that taking part in this study is voluntary and I have not been pressured to participate.
- I may choose to leave the study at any time and will not be penalized for doing so in any way.
- I may be asked to leave the study before it has finished if the researcher feels it is in my best interest or if I do not follow the study guide agreed upon.

Signed at (place) …… on (date)……...

…….. …….

Signature of participant **Signature of witness**

Additional Clinician/ Participant information

Name of participant:

Email address:

Contact number:

Occupation:

Years treating individuals with PFP:

Declaration by investigator

I (name) …… declare that:

I explained the information in this document to…….

I encouraged him/her to ask questions and too adequate time to answer them.

I am satisfied that he/she adequately understand all aspects of the research project, as discussed in detail 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 investigator **Signature of witness**

Appendix 4: Electronic Letter of Invitation for Research Participation

Title of study: Validation of an evidence-based biomechanical risk factor screening tool for patellofemoral pain (PFP)

Principal Investigator: Tanya Green, M in Physiotherapy Candidate, Division of Physiotherapy, Stellenbosch University

Supervisor: Prof Quintette Louw, Professor, Division of Physiotherapy, Stellenbosch University

Co-supervisor: Ms. Dominique Leibbrandt, Post-Doctoral Candidate, Division of Physiotherapy, Stellenbosch University

Address: Division of Physiotherapy, Department of Interdisciplinary Health Sciences, Faculty of Medicine and Health Sciences, Stellenbosch University, Francie van Zijl Drive, Tygerberg, Cape Town, 8000

Contact number: 073 33240 20/ email: tanyagreen@sun.ac.za

Dear Colleagues

My name is Tanya Green, and I am a master's student at the Division of Physiotherapy, Stellenbosch University (SU). I invite you to participate in a research project that aims to investigate whether an evidence-based decision-making screening tool can be used to identify associated kinematic factors for patellofemoral pain (PFP) in a clinical setting.

Please take ample time to read the information presented below, which explains the details of this project, and contact me if you require further explanation or clarification regarding any aspect of the study. Participation in this study is **entirely voluntary,** and you are free to decline to participate. If you decline, this will not affect you negatively. You are also free to withdraw from the study at any point, even if you agree to participate.

This study has been approved by the **Health Research Ethics Committee (HREC) at Stellenbosch University:** S19/10/236, and the research will be conducted according to accepted and applicable National and International ethical guidelines and principles.

The purpose of this research project is to determine whether clinicians can accurately identify biomechanical risk factors for PFP using 2D video analysis. Furthermore, it will also validate a risk factor screening tool created on laboratory-based studies in a clinical setting to determine

its usefulness for clinicians treating patients with PFP who do not have access to expensive 3D motion analysis equipment.

Should you choose and accept participating in this study, you will be required to analyse the 2D gait videos and attempt to identify gait-related associated biomechanical risk factors. Before reviewing the recordings, the principal investigator (T.G.) will deliver a short training session explaining the biomechanical risk factor screening tool. In this session, you will also receive training on how to use the freeware motion- analysis software Kinovea (version 0.8.15, available for download at http://www.kinovea.org), which will assist you to slow down, pause and stop videos to capture specific frames in the various cycles of gait to identify kinematic variables of the hip, knee and ankle in both frontal and sagittal views. You will be allocated 30-40 minutes to review a subject's recordings for walking and running. A data capturing spreadsheet will be provided to you along with the recordings, where you can import your dichotomous data (yes/no) for each of the risk factors identified.

All personal details will be kept confidential throughout the study, and you will participate in this project on an anonymous basis respecting your privacy.

If you are willing to participate in this study, please reply to this email address:
tanyagreen@sun.ac.za - further information and arrangements will then be sent to you via email.

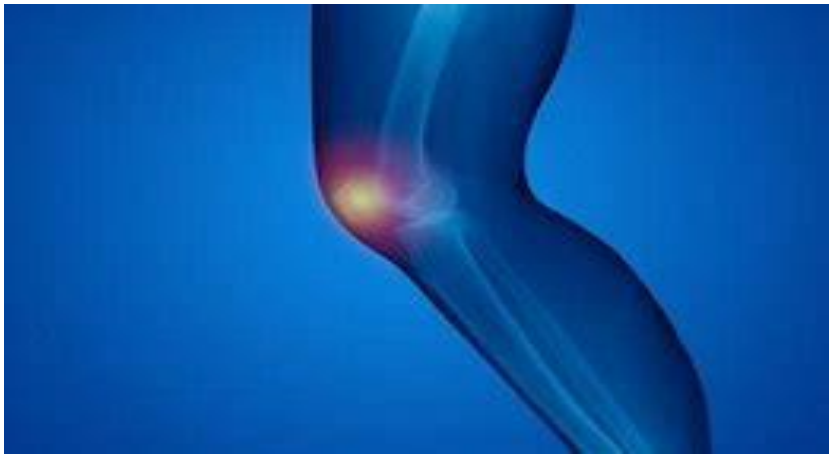
Yours sincerely

Tanya Green
Principal Investigator

Appendix 5: Study Advert

Do you often treat individuals with Patellofemoral Pain (PFP)?

- Are you a qualified and registered physiotherapist?
- Have at least two years of working experience?
- Work in Cape Metropolitan/Cape Winelands region?



Campus Health Services Physiotherapy, Stellenbosch University, invites you to participate in a research project as part of my master's degree investigating biomechanical risk factors associated with PFP. Participants will review 2D video gait analysis to identify associated biomechanical risk factors in subjects with patellofemoral pain. Additionally, you will be required to complete a short training session before reviewing the recordings.

If you are interested, please contact the principal researcher for further inquiries regarding the study

021 808 3392 or tanyagreen@sun.ac.za

Appendix 6: Ethics Letter of Approval Larger PFP Project

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

Approval Letter
Progress Report

16/11/2020

Project ID: 10135

Ethics Reference No: N19/05/063

Project Title: The Effect of a Targeted Functional Movement Retraining Intervention on Anterior Knee Pain and Underlying Biomechanical Mechanisms (2)

Dear Dr Dominique Leibbrandt

We refer to your request for an extension/annual renewal of ethics approval dated 12/08/2020.

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

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

Approval date: 16 November 2020

Expiry date: 15 November 2021

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 10135 and ethics reference number N19/05/063 on any documents or correspondence with the HREC concerning your research protocol.

Please note that for studies involving the use of questionnaires, the final copy should be uploaded on Infonetica.

Yours sincerely,

Mrs. Melody Shana
Coordinator: Health Research Ethics Committee 1

National Health Research Ethics Council (NHREC) Registration Number:
REC-130408-012 (HREC1)•REC-230208-010 (HREC2)

Federal Wide Assurance Number: 00001372
Office of Human Research Protections (OHRP) Institutional Review Board (IRB) Number:
IRB0005240 (HREC1)•IRB0005239 (HREC2)

The Health Research Ethics Committee (HREC) complies with the SA National Health Act No. 61 of 2003 as it pertains to health research. The HREC abides by the ethical norms and principles for research, established by the World Medical Association (2013). Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects; the South African Department of Health (2006).Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa (2nd edition); as well as the Department of Health (2015). Ethics in Health Research: Principles, Processes and Structures (2nd edition).

The Health Research Ethics Committee reviews research involving human subjects conducted or supported by the Department of Health and Human Services, or other federal departments or agencies that apply the Federal Policy for the Protection of Human Subjects to such research (United States Code of Federal Regulations Title 45 Part 46); and/or clinical investigations regulated by the Food and Drug Administration (FDA) of the Department of Health and Human Services.

Appendix 7: Methodology of Larger PFP Study

Research objectives

The research aims to establish whether an evidence-based biomechanical risk factor screening tool can be used to identify kinematic risk factors for PFP in a clinical setting and create an evidence-based screening tool for clinicians to decide which risk factors to address the treatment of PFP. This evidence-based algorithm is based on a systematic review by Leibbrandt & Louw (2017). The first objective is to obtain expert feedback on the current evidence-based risk factors for PFP identified in a previous systematic review (Leibbrandt & Louw, 2017a). The second objective is to compare the risk factors identified using 3D motion analysis in a laboratory to the risk factors identified in a clinical setting. Creating a clinical algorithm will be the last step following my master's study and the focus group interviews (clinical expert opinion).

Study Setting

The data collected was at the CAF Human Motion Analysis Unit, Faculty of Medicine and Health Sciences, Stellenbosch University, South Africa.

Sampling and Recruitment

This study population consisted of recreational runners residing in the Cape Metropolitan. Participants were recruited through advertisements placed in the community, university, and school-based newspapers to attract a range of participants from a broad spectrum of activities, backgrounds, sports, and ages. In addition, social media platforms for running club groups such as Facebook and advertisements were posted in the weekly university bulletin and on noticeboards. Convenient sampling was employed, and ten males and eight females with an average age of 33.89 years were included in the larger study.

Eligibility criteria

- **Inclusion criteria**

All participants were screened for eligibility with the PFP evidence-based clinical diagnostic checklist (Appendix 1) by D.L. Participants included males and females aged between 18 and 40 who were physically active, with an insidious onset of clinical signs and symptoms of PFP. According to the diagnostic checklist, participants were included if symptoms were elicited by prolonged sitting, squatting, stair-climbing, and or running. Participants with unilateral and

bilateral PFP were considered for inclusion. In cases where both knees were affected with PFP, the most affected knee was tested for altered lower limb biomechanics.

- **Exclusion criteria**

Participants were excluded if PFP resulted from a traumatic event such as a motor vehicle accident, previous knee surgery, or patellar tendonitis. Prior history of patella subluxation/dislocation and pain due to neurological involvement, such as referred pain from the lumbar spine or referred pain from the hip joint. Reported degenerative changes, including osteoarthritis of the knee, or as demonstrated by a radiograph. If there was any clinical evidence of other knee pathologies.

Data collection tools

- **Vicon 3D motion analysis system**

The Vicon Motion Analysis (Ltd) (Oxford, UK) 3D system was used to obtain the 3D movement analysis data. The Vicon has demonstrated high accuracy and reliability (Ehara et al., 1997). The T-10-series is a motion-capturing system with a unique combination of high-speed accuracy and resolution. The system has a resolution of 1-mega pixels and captures 10-bit greyscale images using 1120 × 896 pixels, capturing speeds of up to 250 frames per second. Retro-reflective markers with a diameter of 9.5 mm were used. The standard plug-in gait model was used, as the model provides the angle output sought in the current study. VICON-specific anthropometric measurements obtained are height, weight, leg length, knee, and ankle diameter. The researcher (D.L.) did all marker placements; she previously received training in marker placement and has two years of experience in marker placement. This serves to reduce marker bias.

- **2D Motion analysis equipment and set-up**

2D video recordings were captured in parallel with 3D motion capture. Two high-definition cameras were be placed in front and lateral to the treadmill to record frontal and sagittal views. 2D recordings were done in Noraxon MyoResearch software with the myovideo module (https://www.noraxon.com/our-products/video-analysis/). The Ninox 250 (resolution of 704x1088, framerate: 99 FPS, orientation: portrait) and Ninox 125 (resolutions: 1088x704, framerate: 60FPS (max of camera for that resolution), orientation: landscape). Cameras were placed 2 meters from the treadmill to obtain frontal and sagittal views.

Study procedures

- **Vicon 3D motion analysis system**

3D kinematic analysis for walking and running gait was performed. The participants performed six shod walking trials at a self-selected pace for walking and running gait. The lead researcher (D. L.) analysed the 3D kinematic trials for the larger study to identify the biomechanical risk factors using the biomechanics screening tool published in (Leibbrandt & Louw, 2017a). This method to identify biomechanical risk factors has been published in 'Physical Therapy reviews' in 2017.

- **2D recordings procedure**

Video capture for 2D analysis was conducted concurrently during 3D movement analysis data collection. Two Ninox cameras were placed 2 meters behind and lateral of the treadmill to obtain frontal and sagittal views. Both cameras were set up on standard camera tripods and at the participants' approximated hip height when they were on the treadmill, which was raised, to minimize distortion due to the view. Walking and running videos (of 30 seconds) were recorded in frontal and sagittal views, respectively. Participants were given ample time to warm up to ensure video clips represent the most acclimated walking and running pattern. The warm-up included a 2-minute walk and run, followed by a fatigue protocol, which consisted of a 2-minute wall sit and 2-minute alternating lunges. Each speed for walking and running was self-selected based on their average 10-kilometre pace.

Outcomes of larger PFP study applied masters' project

The 3D biomechanical data collected and the identification of biomechanical risk factors (using the published screening tool) for the larger study also served as the reference (gold standard) for the validation study.

The 2D video recordings were used in my master's study to investigate the interrater reliability and validity of 2D observational clinical gait analysis using the biomechanical screening tool between raters and the 3D biomechanical data collected in D. L's study.

Appendix 8: Description of 3D analysis output

3D analysis output

Gait analysis data was collected using the Vicon T-10- series motion-capturing analysis system (Vicon Motion Analysis Ltd., Oxford, UK). The Vicon Motion Analysis (Ltd) (Oxford, UK) is a 3D motion capture system employed to obtain the 3D motion gait analysis data. The Vicon has demonstrated high accuracy and reliability (Ehara et al., 1997). The T-10- series is a motion-capturing system with a unique combination of high-speed accuracy and resolution. The system has a resolution of 1- megapixels and captures 10- bit greyscale images using 1120 x 896 pixels, with the ability to capture speeds of up to 250 frames per second (Windolf, Götzen & Morlock, 2008). Retro-reflective markers with a diameter of 9.5 mm were used. The standard plug-in gait model was used, as the model provides the angle output sought in the current study.

Vicon-specific anthropometric measurements to acquire are height, weight, leg length, and knee and ankle diameter. The researcher who received training in marker placements and has seven years of experience in marker placement (D.L.) prepped the marker placements of participants, which reduces marker bias.

Preparation

The Vicon specific anthropometrics measured are height, weight, leg length, and knee and ankle diameter. The lead investigator (D.L.) conducted the placement of the retro-reflective marker on participants' bony landmarks. The skin over the bony areas was prepped with alcohol swabs to ensure that the markers stick firmly on the participant's skin. The placement of the markers was performed according to the plug-in gait model. A static calibration trail and a dynamic calibration trial were performed before commencing the formal testing.

(https://docs.vicon.com/display/Nexus25/Lower+body+modeling+with+Plug-in+Gait).

Procedure

Participants were required to perform six successful shod walking trials at a self-selected speed. After that, all participants were instructed to run naturally on a motorised treadmill at their preferred running speed. A treadmill acclimatisation period of 6 minutes was used before running kinematics was measured. One clinician identified contributing risk factors from the 3D motion analysis assessments using individual participant gait arrays, a second researcher

(Q.L.) assessed the 3D kinematic data independently to identify associated biomechanical risk factor's reliability.

Appendix 9: Ethics Study Letter of Approval

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Approval Notice

New Application

18/11/2019

Project ID :11912

HREC Reference No: S19/10/236

Project Title: Validation of an evidence-based biomechanical risk factor screening tool for patellofemoral pain

Dear Ms. Tanya Green,

The **New Application** received on 22/10/2019 10:23 was reviewed by members of **Health Research Ethics Committee 2 (HREC2)** via **expedited** review procedures on 18/11/2019 and was approved.

Please note the following information about your approved research protocol:

Protocol Approval Date: 18 November 2019

Protocol Expiry Date: 17 November 2020

Please remember to use your Project ID **[11912]** and Ethics Reference Number **[S19/10/236]** on any documents or correspondence with the HREC concerning your research protocol.

Please note that the 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: Links Application Form Direct Link and the application should be submitted to the HREC before the year has expired. Please see *Forms and Instructions* on our HREC website (www.sun.ac.za/healthresearchethics) for guidance on how to submit a progress report.

The HREC 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 Departement 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 https://applyethics.sun.ac.za/ProjectView/Index/11912

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

Yours sincerely,

Mr. Francis Masiye,

HREC Coordinator,

Health Research Ethics Committee 2 (HREC2).

National Health Research Ethics Council (NHREC) Registration Number:

REC-130408-012 (HREC1)·REC-230208-010 (HREC2)

Federal Wide Assurance Number: 00001372
Office of Human Research Protections (OHRP) Institutional Review Board (IRB) Number:
IRB0005240 (HREC1)·IRB0005239 (HREC2)

The Health Research Ethics Committee (HREC) complies with the SA National Health Act No. 61 of 2003 as it pertains to health research. The HREC abides by the ethical norms and principles for research, established by the World Medical Association (2013). Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects; the South African Department of Health (2006). Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa (2nd edition); as well as the Department of Health (2015). Ethics in Health Research: Principles, Processes and Structures (2nd edition).

The Health Research Ethics Committee reviews research involving human subjects conducted or supported by the Department of Health and Human Services, or other federal departments or agencies that apply the Federal Policy for the Protection of Human Subjects to such research (United States Code of Federal Regulations Title 45 Part 46); and/or clinical investigations regulated by the Food and Drug Administration (FDA) of the Department of Health and Human Services.

Appendix 10: Ethics Study Letter of Approval of Annual Progress Report

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Approval Letter
Progress Report

02/11/2020

Project ID: 11912

Ethics Reference No: S19/10/236

Project Title: Validation of an evidence-based biomechanical risk factor screening tool for patellofemoral pain

Dear Ms. Tanya Green

We refer to your request for an extension/annual renewal of ethics approval dated 12/10/2020 13:24.

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

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

Approval date: 18 November 2020

Expiry date: 17 November 2021

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 11912 and ethics reference number S19/10/236 on any documents or correspondence with the HREC concerning your research protocol.

Yours sincerely,

Mrs. Brightness Nxumalo
Coordinator: Health Research Ethics Committee 2

National Health Research Ethics Council (NHREC) Registration Number:
REC-130408-012 (HREC1)•REC-230208-010 (HREC2)

Federal Wide Assurance Number: 00001372
Office of Human Research Protections (OHRP) Institutional Review Board (IRB) Number:
IRB0005240 (HREC1)•IRB0005239 (HREC2)

The Health Research Ethics Committee (HREC) complies with the SA National Health Act No. 61 of 2003 as it pertains to health research. The HREC abides by the ethical norms and principles for research, established by the World Medical Association (2013). Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects; the South African Department of Health (2006).Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa (2nd edition); as well as the Department of Health (2015). Ethics in Health Research: Principles, Processes and Structures (2nd edition).

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Appendix 11: Data Collection Spreadsheet for Risk Identification

Participant ID	Gender	Activity	Affected side	↑ peak hip ER	↑ peak rear foot EV	Early hip IR	↑ peak hip ADD	↑ peak kn E	↓ kn F at heel strike	↓ kn F in stance	↑ overall ankle DF
1	M	Walking	R	Yes							
2	F	Walking	R		Yes / No						
3	M	Walking	R								
4	M	Walking	R								
5	M	Walking	L								
6	F	Walking	L								
7	M	Walking	R								
8	F	Walking	L								
9	F	Walking	L								
10	F	Walking	R								
11	M	Walking	R								
12	M	Walking	L								
13	M	Walking	L								
14	M	Walking	L								
15	F	Walking	R								
16	F	Walking	L								
17	F	Walking	R								
18	M	Walking	R								

Participant ID	Gender	Activity	Affected side	↑ hip ADD	↑ peak hip IR	↑peak kn varus	↑ peak kn ER	↑ peak kn F	↑rearfoot EV	↑ ankle EV	↑ ankle DF
1	M	Running	R	No	No						
2	F	Running	R								
3	M	Running	R								
4	M	Running	R								
5	M	Running	L								
6	F	Running	L								
7	M	Running	R								
8	F	Running	L								
9	F	Running	L								
10	F	Running	R								
11	M	Running	R								
12	M	Running	L								
13	M	Running	L								
14	M	Running	L								
15	F	Running	R								
16	F	Running	L								
17	F	Running	R								
18	M	Running	R								

Yes
No