

Proprioceptive Differences in Individuals with Anterior Knee Pain

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Declaration

Degree of confidentiality: A

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I, Carlyn Rhode, declare that the entire body of work contained in this research assignment is my own, original work; that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third-party rights, and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Carlyn Rhode

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Abstract of the Thesis

Introduction

Anterior knee pain (AKP) affects physically active as well as sedentary individuals and commonly leads to chronic knee pain among young adults. Anterior knee pain has a huge socioeconomic impact on those affected as management remains challenging with symptoms persisting for years even after medical intervention. Proprioception plays an important role in sensory motor control of the knee and impacts motor action and knee joint stability. There are conflicting reports in the current literature on whether people with AKP have altered proprioception.

Objectives

The purpose of this study was to investigate the proprioceptive abilities of individuals affected with anterior knee pain using a gold standard measurement tool. Proprioception was measured by compare active joint position sense during a weight bearing (single leg stance) and a none weight bearing task (active knee extension in sitting) between knees with AKP and knees without AKP.

Methodology

A laboratory based descriptive cross-sectional study design was used to conduct this study. The Vicon 3D motion analysis system was used to test proprioception. Twenty-five participants who met the inclusion criteria and gave informed consent, were included in the study. Fifty knees were evaluated; 37 knees with AKP and 13 without AKP. Proprioception was measured by means of two active joint position sense testing in both a weight bearing (single leg squat) and a non-weight bearing (active knee extension) test position. Target angles were self-determined based on each participant's capabilities and pain levels. The absolute error (AE) was used as the main outcome measure to assess proprioception. A normative criterion of an AE equal and greater than five degrees was classified as altered proprioception. The proprioception of the knees with AKP were compared to that of the knees without AKP.

Results

The study participants were predominantly female (n=22) with a mean age of 27.8 years. Seventy-six percent (76%, n= 19) of the population were physically active and 44%, (n=11) reported being runners. The main finding of this study was that there was no significant

difference in proprioception when comparing the knees with AKP to the knees without AKP ($p < 0.05$). However, individuals with altered proprioception was identified in both the knees with AKP and the knees without AKP. The mean AE for the knees with AKP was 7.4° during SLS and 8.3° during active knee extension; whereas the mean AE for the knees without AKP were 8.3° during SLS and 5.9° during active knee extension. Insignificant differences were found via Chi-square calculations between the knees with AKP compared to the knees without AKP during single leg squat and during active knee extension.

Conclusion

The current study findings showed that proprioception is not significantly more impaired in knees with AKP compared to knees without AKP during active reproduction proprioceptive testing. This study did however identify a group of individuals with altered proprioception, in both the knees with AKP and the knees without AKP. A likely reason could be due to compensation during gait in patients with AKP as well as the accuracy of the Vicon 3D motion analysis system. There was a tendency towards a larger mean AE during active knee extension in sitting in the knees with AKP. This finding could be reflective of the proprioceptive abilities of the knee joint specifically. The findings in this study support the assessment of proprioception in both knees in individuals with AKP and not only the knees with AKP.

Opsomming

Inleiding

Anterior kniepyn (AKP) affekteer beide aktiewe en onaktiewe mense en kan lei tot kroniese kniepyn in jong mense. Anterior kniepyn het 'n groot sosio-ekonomiese impak op persone aangesien behandeling uitdagend is en simptome kan voortduur vir jare, selfs na mediese behandeling. Proprioepsie is baie belangrik tydens sensoriese-motoriese beheer van die knie en beïnvloed motoriese beheer en knie gewrig stabiliteit. Daar is teenstrydige bevindinge in die huidige literatuur oor of persone met anterior kniepyn, versteurde proprioepsie het.

Doelwit

Die doel van hierdie studie was om proprioepsie in persone met anterior kniepyn te evalueer deur gebruik te maak van 'n goue standaard meet instrument. Proprioepsie was gemeet deur aktiewe gewrigsposisiesin te vergelyk tydens n nie gewigdraende toets posisie (enkel been hurk) en n gewigdraende toets posisie (aktiewe knie ekstensie tydens sit), tussen knieë met AKP en knieë sonder AKP.

Metode

'n Laboratorium-gebaseerde beskrywende deursnit studieontwerp was gebruik om die studie uit te voer. Die Vicon 3D bewegingsontledingsstelsel was gebruik om proprioepsie te meet. Vyf en twintig persone wie voldoen het aan die insluitingsvereistes en ingeligte toestemming verskaf het, was ingesluit in die studie. Vyftig knieë was gemeet; 37 met AKP en 13 sonder AKP. Proprioepsie was gemeet deur middel van 2 aktiewe gewrigsposisiesin toetsing. Proprioepsie was getoets in twee posisies naamlik enkel been hurk (SLS) (gewigdraend) en aktiewe knie ekstensie tydens sit (nie gewigdraend). Die teikenhoek was self bepaal deur elke persoon volgens hulle vermoë en pynvlakke. Die absolute fout (AE) was die hoof uitkomstmeting vir proprioepsie. 'n Waarde gelyk aan of groter as vyf grade was gebruik om veranderde proprioepsie te klassifiseer. Die knieë met AKP was vergelyk met die knieë sonder AKP.

Resultate

Die studie deelnemers was hoofsaaklik dames (n=22) met 'n gemiddelde ouderdom van 27.8 jaar. Ses-en-sewentig persent (76%) van die deelnemers was aktief en 44% hardloop vir oefening. Die hoof bevinding van die studie was dat daar geen beduidende verskil was in

proprioepsie tussen die knieë met AKP en die knieë sonder AKP ($p < 0.05$). Daar was individue geïdentifiseer met geïmmiteerde proprioepsie in beide die knieë met AKP en die knieë sonder AKP. Die gemiddelde AE vir knieë met AKP was 7.4° tydens SLS en 8.3° tydens aktiewe knie ekstensie in sit in vergelyking met 'n gemiddelde AE van 8.3° tydens SLS en 5.9° tydens aktiewe knie ekstensie in die knie sonder AKP. Onbeduidende resultate was gevind met Kwadrat (Chi-square) berekeninge tussen die knieë met AKP tydens SLS en aktiewe knie ekstensie in sit.

Gevolgtrekking

Die huidige studie kon nie 'n beduidende verskil in proprioepsie vind tussen die knieë met AKP en die knieë sonder AKP nie tydens aktiewe gewrigsposisiesin toetsing. Die studie het wel abnormale proprioepsie gevind in individue, in beide die knieë met AKP sowel as die knieë sonder AKP. Hierdie bevindinge kan toegeskryf word aan kompensatie tydens loop in persone met AKP asook die akkuraatheid van die Vicon 3D bewegingsontledingsstelsel. Daar was 'n tendens van 'n groter gemiddelde AE tydens aktiewe knie ekstensie in sit in die knieë met AKP. Hierdie bevinding mag die spesifieke proprioepsiewe vermoë van die kniegewrig weerspieël. Hierdie studie ondersteun die insluiting van proprioepsiewe toetsing van albei knieë in persone met AKP, en nie net die knie met AKP nie.

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Acronyms and Abbreviations

ADLs	Activities of Daily Living
AE	Absolute error
AKP	Anterior Knee Pain
AKPS	Anterior Knee Pain Scale
CAF	Central Analytical Facility
CAT	Clinical Appraisal Tool
COP	Centre of Pressure
ES	Effect Size
ICC	Intra-Class Correlation
IACP	Idiopathic anterior knee pain
JPS	Joint position sense
LEFS	Lower Extremity Functional Scale
NWB	Non-weight bearing
OA	Osteoarthritis
PFJ	Patellofemoral joint
PFJS	Patellofemoral joint stress
PFP	Patellofemoral pain
PFPS	Patellofemoral Pain Syndrome
RA	Reproduced angle
RE	Relative error
ROM	Range of motion
SEM	Standard Error of Measurement
TA	Target angle
TIPPS	Targeted Interventions for Patellofemoral Pain Syndrome
VAS	Visual analogue pain scale
WB	Weight bearing

Glossary

Anterior Knee Pain

Peri-patellar or retro-patellar knee pain with an insidious onset that is exacerbated under conditions of increased patellar-femoral joint stress (Dutton et al., 2016, Plataras et al., 2015; Yosmaoglu et al., 2013; Hossain et al., 2011; Earl et al., 2010).

Joint angle error

Joint angle error (JAE) is the difference between the test joint angle and the reproduced angle. Normal angular error can range between 0.7 degrees and 6 degrees in normal subjects (Orgard et al., 2011).

Joint position sense

Joint position sense, also known as joint position reproduction, is the ability of a subject to accurately reproduce a specific joint angle or target angle (Selfe et al., 2006; Baker et al., 2002).

Proprioception

Proprioception is defined as the sense of joint position and joint movement and results from mechanoreceptors stimulation in joint and muscle tissue (Clark et al., 2016; Hillier et al., 2016; Han et al., 2016).

Chapter 1: Introduction

Anterior knee pain (AKP) is a common disorder of the knee joint and affects both physically active and sedentary individuals (Plastaras et al., 2015; Werner, 2014; Coppack et al., 2011). The term AKP is a synonym for patellofemoral pain (PFP) which is used interchangeably in the literature (Crossley, Stenanik et al., 2016; Petersen et al., 2014; Roush et al., 2012). AKP includes all conditions where no causative explanation for pain or identifiable structures can be found despite a thorough investigation of the patellofemoral joint (PFJ). AKP accounts for 25% to 40% of all knee problems presenting at sports medicine clinics; one in four of the active population is affected, leading to chronic knee pain among young adults (Dutton et al., 2016; Nunes et al., 2013; Cook et al., 2012; Coppack et al., 2011; Earl et al., 2011). AKP is prevalent among runners, particularly distance runners. AKP has a higher prevalence among active women, with an incidence two to three times more than that of men (Almeida et al., 2016; Neal, 2016).

The typical pattern of symptoms of AKP is characterised by anterior, peri-patellar or retro-patellar pain with an insidious onset, and is exacerbated under conditions of increased patellofemoral joint stress (Dutton et al., 2016; Plastaras et al., 2015; Yosmaoglu et al., 2013; Earl et al., 2010). AKP symptoms are often described as a dull intermittent pain with episodes of sharp acute pain arising at the anterior aspect of the knee (Sanchis-Alfonso et al., 2016; Hazneci et al., 2005). Aggravating factors for AKP include activities causing repetitive strain or movements that increase patellofemoral joint compression or produce mechanical force in the surrounding soft tissue structures. These aggravating activities include ascending or descending stairs, prolonged sitting, squatting, and running (Dutton et al., 2016; Plastraras et al., 2015; Green et al., 2014; Werner, 2014).

The aetiology of AKP is unclear and a source of debate in the current literature (Green et al., 2014; Cook et al., 2012). There appears to be some consensus, however, regarding the multifactorial nature of AKP and its development secondary to functional or structural malalignment of the patellofemoral joint (Green et al., 2014). Patellofemoral joint dysfunction could include anatomical patella abnormalities, or extensor mechanism disorder resulting in patellar malalignment during flexion and extension of the knee joint (Plastraras et al., 2015; Werner 2014; Green et al., 2014; Hossain et al., 2011; Barton et al., 2008). There are multiple interacting factors causing malalignment of the patella, such as muscle strength, timing of

vastus medialis oblique, altered tissue extensibility and body morphology (Bennell et al., 2010; Barton et al., 2008).

Accurate motor action requires well integrated information from the visual, vestibular and the somatosensory system, which includes proprioception. Altered proprioception, as evident during knee injuries, may lead to destruction of mechanoreceptors (Hillier et al., 2015, Callaghan, 2011) and may be associated with impaired joint-muscle reflexes as well as abnormal movement patterns, resulting in loss of movement control. Mechanoreceptor damage is indicated as one of the main reasons for altered proprioception in the AKP population (Guney et al., 2015). Mechanoreceptor damage as evident in AKP, or as a result of patellar mal-tracking, may influence proprioceptive feedback from mechanoreceptors. Proprioceptive changes have been documented in patients with AKP (Guney et al., 2016; Cyrillo et al., 2014; Aseki et al., 2008; Baker et al., 2002) and can have detrimental effects in the sporting community, leading to injury, and if not addressed can lead to costly rehabilitation in the long term (Röijezon et al., 2015). The importance of proprioception in the aetiology, treatment and prevention of sporting injuries and joint disease is increasingly clear due to its vital function in motor control. A thorough understanding of proprioceptive function amongst individuals with AKP is essential to understand its contribution to, and implications for, this population group to address rehabilitation in this clinical population (Orgard, 2011). Proprioception plays an integral part in sensori-motor control, control of movement, balance, posture and joint stability which one needs to consider in a population with AKP (Röijezon et al., 2015).

Recent reviews of AKP have focused on risk factors, diagnostic tests, lower extremity biomechanics and exercise treatments (Dutton et al., 2016; Papadopoulos et al., 2015). There is limited research on investigating proprioception in individuals with AKP (Yosmaoglu et al., 2013). The findings of these studies investigating AKP and proprioception prove to be inconclusive, with contradictory results. Yosmaoglu (2013) and Naseri (2012) conducted studies investigating joint position sense (JPS) and AKP in a general population group, and athletes with patellofemoral pain syndrome, respectively. An earlier study by Banelle (2005) evaluated the effect of experimentally induced anterior knee pain on JPS in healthy subjects. None of these investigators were able to show that proprioception was affected in their respective population groups. Contradicting these findings, Baker (2002), Hazneci et al. (2005), Akseki (2008) and more recent studies by Cyrillo et al. (2014) and Guney et al. (2016) evaluated JPS in individuals with AKP and found a significant difference in proprioception in individuals with AKP, compared to controls. Comparing these studies, the methodologies

varied greatly with regard to measurement tools, weight bearing or non-weight bearing testing positions, as well as the joint angles measured. The variation in methodology could be due to the lack of a gold standard test to assess proprioception, and the tests used have poor clinical applicability and are poorly evaluated and reported by the respective authors (Hillier et al., 2015).

More research is needed to establish if individuals with AKP present with altered knee proprioception. If such an association exists between proprioception and AKP, clinicians should be encouraged to include proprioceptive testing in their clinical evaluations of individuals presenting with AKP. In cases of altered proprioception this can form a key component in the rehabilitation of patients with AKP, as well as other knee conditions. Rehabilitating proprioception in patients with AKP will help promote normal knee function and accelerate the healing process, and return the patients to their previous functional level (Naseri et al., 2012; Orgard et al., 2011; Pánics et al., 2008; Callaghan, 2002). The aim of this study, therefore, is to determine if proprioception is altered in individuals with AKP. None of the previous studies investigating AKP and proprioception have used a gold standard testing tool such as the Vicon Nexus 3D motion analysis system.

The study aims to:

1. Describe the proprioceptive deficits in individuals with AKP;
2. Assess JPS with a gold standard measurement tool, the Vicon 3D motion analysis system in participants with unilateral and bilateral AKP;
3. Compare JPS in the knees with AKP to the knees without AKP;
4. Make use of a normative criterion for the grading of knee JPS. A mean AE equal or bigger than five degrees will be described as altered knee proprioception during this study.

Chapter 2: Literature Review

Anterior knee pain and proprioception: An overview of what is currently known

2.1 Introduction

The aim of this literature review is to describe the relevance and need to assess knee proprioception in patients/individuals affected by anterior knee pain (AKP). The current literature on key concepts surrounding AKP and knee proprioception will be evaluated.

The literature search was performed using the following electronic databases: Google Scholar; Pub-med; and Medline between June 2016 and September 2017. There were no date restrictions to published literature included, from inception till September 2017. The following key search terms were used: anterior knee pain; retro-patellar pain; patellofemoral pain; patellofemoral pain syndrome; proprioception; joint position sense. A search of reference lists, pearling of all retrieved articles was used to identify any additional publications with similar topics meeting the aim of this review.

2.2 Anterior Knee Pain: The Prevalence and Population Affected

Anterior knee pain (AKP) can be defined as pain around or behind the patella aggravated by at least one activity that loads the patellofemoral joint (PFJ) during weight bearing on a flexed knee (Crossley, Stefanik et al., 2016; Petersen et al., 2014). AKP is often described as a dull intermittent pain with episodes of sharp acute pain (Sanchis-Alfonso et al., 2016). Symptoms usually have an insidious onset and aggravating activities include squatting, prolonged sitting, stair ambulation, hopping, jumping and running (Crossley, Stefanik et al., 2016; Kurt et al., 2016).

The term AKP is a synonym for patellofemoral pain (PFP) which is used interchangeably in the literature (Crossley et al., 2016; Petersen et al., 2014; Roush et al., 2012). For the purpose of this review the term anterior knee pain (AKP) will be used. The term AKP will include all conditions where no causative explanation can be identified for AKP despite a thorough investigation of the PFJ, referring to idiopathic anterior knee pain (IAKP) (Näsland et al., 2006). Anterior knee pain (AKP) affects physically active as well as sedentary individuals and accounts for 11% to 17% of knee pain complaints in general practices (Crossley et al., 2016; Plastaras et al., 2015; Werner 2014; Coppack et al., 2011). AKP accounts for 25% to 40% of all knee problems presenting in sport medicine clinics, affecting one in four of the active population (Crossley, Stefanik et al., 2016; Dutton et al., 2016; Coppack et al., 2011). For the

purpose of this literature review the term AKP will be inclusive of other pathologies that cannot be classified as anything else including Patellofemoral pain, anterior knee pain syndrome as well as patellofemoral joint dysfunction (Nunes et al., 2013; Näsland et al., 2006).

AKP commonly leads to chronic knee pain in young adults, with a high point of prevalence in adolescents aged between 12 and 17 years (Crossley, Stefanik et al., 2016; Dutton et al., 2016). AKP in adolescents has a prevalence of 7, 28% and an incidence of 9, 2% in the age group of 12 to 17 years (Crossley, Stefanik et al., 2016; Witvrouw et al., 2014). AKP is particularly common among runners; more so long-distance runners with a higher prevalence in women with an incidence rate two to three times more than that of men (Dutton et al., 2016). This increased incidence rate among women could be due to anatomical and biomechanical variations in women that predispose them to develop AKP (Almeida et al., 2016; Neal 2016; Prins & Van der Wurff (2009). Hip muscle strength is much debated in the literature as one of the leading contributing factors predisposing women to develop AKP.

AKP does not seem to be self-limiting but can persist for many years if the contributing factors are not properly recognised and addressed (Dutton et al., 2016; Witvrouw et al., 2014). The impact of AKP can be profound and often reduces the ability of patients to perform sporting and physical activities as well as work-related activities without pain (Crossley, Stefanik et al., 2016; Witvrouw 2000). AKP can be seen therefore as a chronic pain condition. Chronic AKP is often accompanied by feelings of anxiety and depression (kinesiophobia and catastrophising). These psychological factors can serve as a barrier to recovery (Sanchis-Alfonso et al., 2016; Petersen et al., 2014) and negatively affect patients' prognosis and quality of life (QOL). AKP has a socio-economic impact on individuals due to absence from work; lost productivity; and the economic expense of treatment (Sanchis-Alfonso et al., 2016). AKP commonly occurs in young working adults which negatively impacts their quality of life. Individuals with chronic AKP have an increased risk of developing patellofemoral osteoarthritis (PFOA) (Neal et al., 2016; Sanchis-Alfonso et al., 2016).

2.3 Clinical Examination and Diagnosis of AKP

The diagnosis of AKP is made based on the exclusion of other knee disorders and exists without structural changes and has no significant pathological changes in articular cartilage of the PFJ (Petersen et al., 2014). Clinical examination is the cornerstone to diagnose AKPS but there is no definitive clinical test to diagnose AKPS (Crossley, Stefanik et al., 2016; Dutton et al., 2016). Diagnosis are often made after careful evaluation of complaints of pain in the anterior

area of the knee joint. When diagnosing AKP one should pay careful attention to symptom onset e.g. pain, location of symptoms and factors aggravating AKP. The best available test is to elicit AKP during a squatting manoeuvre (Crossley, Stefanik et al., 2016). In the literature, additional tests are described and used to diagnose AKP, but with limited evidence (Crossley, Stefanik et al., 2016, Fredericson & Yoon, 2006). These diagnostic tests include tenderness on palpation all around the patellar edge or retinaculum, patellar tilt tests, mediolateral glides, patellar mobility tests, patellar apprehension tests, patellar compression tests, patellar tracking tests as well as muscle flexibility and muscle strength tests to diagnose AKP (Crossley, Stefanik et al., 2016; Petersen et al., 2014, Fredericson & Yoon, 2006). A meta-analysis by Nunes et al (2013) could only account for two tests with good value namely patellar tilt test and squatting that showed a trend for the diagnosis of AKP. The PFJ is comprised of the patella and the femoral trochlea. The patella acts as a lever and increases the movement arm of the PFJ, the quadriceps and the patellar tendon. Stability of the PFJ involves dynamic and static stabilisers. These stabilisers control the movement of the patella within the trochlea. The control of PFJ movement is known as patellar tracking (Dixit et al., 2007). Mal-tracking of the patella occurs when an imbalance in these stabilising forces affects the forces along the PFJ articular surfaces, the patellar and the quadriceps tendon and adjacent soft tissue.

2.4 Etiology of AKP still Unclear

The etiology of AKPS is a source of debate in the current literature (Green et al., 2014, Cook et al., 2012). There appears to be some consensus, however, regarding the multi-factorial nature of AKPS and its development, secondary to functional and structural malalignment of the patellofemoral joint (PFJ) (Neal et al., 2016; Green et al., 2014). PFJ dysfunction could include anatomical patellar abnormalities, or knee extensor mechanism disorder resulting in patellar mal-alignment during flexion and extension of the knee joint (Plastraras et al., 2015; Green et al., 2014, Werner 2014). There are multiple interacting factors that could cause malalignment of the patella, such as muscle strength, timing of vastus medialis oblique (VMO), altered tissue extensibility and body morphology (Bennell et al., 2000). Identification of these factors depend on a thorough and skilled clinical examination.

2.5 Risk Factors Associated with the Development of AKP

It is important to identify underlying risk factors for developing AKP (Dutton et al., 2016; Popadopoulos et al., 2015; Nunes et al., 2014). In order to develop a framework to diagnose and treat AKPS one should have an understanding of the underlying risk factors (Leibrand &

Louw, 2017; Dutton et al., 2016; Lankhost et al., 2013; Prins & Wurff, 2009). Various risk factors could contribute to the development of AKPS. It is thought that various factors that challenge the loadbearing capabilities of the PFJ result in the symptoms of AKP (Dutton et al., 2016; Prins & Wurff, 2009). Dutton et al. (2016) categorised these factors as follows: (1) local joint impairments; (2) deficit in lower-extremity biomechanics; and (3) training errors. Local joint factors refer to stabilising structures of the PFJ having a direct influence on the joint's functioning. The position of the patella, patellar tracking, quadriceps weakness, including delayed VMO activation as well as the inflexibility of the soft tissue structures of the lower extremity are examples of local joint impairments (Chester et al., 2008 Witvrouw et al., 2002, Lankhorst et al., 2012). The lower extremity biomechanics include hip joint muscle dysfunction, hip abductor or internal rotation muscle weakness, rear foot eversion and gait aberrations. Training error should always be considered including rapid escalation in exercise duration, frequency, speed intensity and inadequate recovery time. Petersen et al. (2011) also described patellar mal-tracking and dynamic valgus in patients with AKP as risk factors for developing AKP. Causes for dynamic valgus include decreased strength of the hip abductors and rear foot eversion. Associations have been established between imbalance timing of the VMO and the vastus lateralis (VL), as well as tightness in the hamstring muscle group (Lankhorst et al., 2012).

The quadriceps muscle complex is associated with having a direct influence on the PFJ and tracking abilities of the patella. The quadriceps muscle is thought to be weakened in patients with chronic AKP (Guney et al., 2016). Concentric quadriceps strength has been documented as being 30% lower in patients with AKPS when compared to healthy controls. An important function of the patella is to displace the patellar tendon away from the centre of rotation of the knee, thus increasing the movement arm of the quadriceps muscles (Dixit et al., 2007). Jackson (2011) reported that at 60 degrees of knee flexion more than twice one's body weight is transmitted through the PFJ. Maltracking of the patella can lead to excess overload with sheer forces being applied to the articular cartilage of the PFJ. In severe cases it can lead to recurrent dislocations of the patella and can be damaging to the PFJ due to increased contact in the PFJ services (Jackson, 2001).

Weakness of the quadriceps muscles has been implicated in AKPS (Guney et al., 2016; Kaya et al., 2010). Guney et al. (2016) and Kaya et al. (2010) investigated quadriceps muscle strength and found a decrease in quadriceps strength in individuals with AKP. A decrease in muscle torque and muscle volume is associated with developing AKP, even more so among women

(Kaya et al., 2010). Knee extensor strength could be a predictor for developing AKP. More research is needed to support this notion. Witvrouw et al. (2000) conducted a prospective study identifying risk factors for developing AKP in an active population. Participants who developed AKP over the two-year study period had a quadriceps strength deficit and demonstrated lower explosive strength capacity when testing vertical jumps compared to controls (Lankhost et al., 2012; Witvrouw et al., 2000). A systematic review by Papadopoulos et al. (2015) concluded that even though there is still a lot of contradictory literature in terms of muscle strength deficits, based on the evidence, quadriceps muscle weakness is a possible risk factor for AKP. Callaghan and Oldham (2003) investigated the occurrence of quadriceps wasting in patients with PFPS. They were unable to find a significant difference in quadriceps muscle size when comparing individuals with PFPS with healthy controls. There was, however, a significant difference in quadriceps muscle torque. (Muscle torque refers to the measurement of muscle strength during isokinetic tests as measured in Newton). Callaghan and Oldham (2003) concluded that the quadriceps muscle demonstrated signs of dysfunction on the affected side such as decreased muscle torque, which was not related to the quadriceps muscle size.

It has been suggested that a delayed VMO activation compared to VL activation is a possible contributing factor in developing AKP due to the role of the VMO in patellar mal-tracking (Dutton et al., 2016; Petersen et al., 2014; Lankhost et al., 2012). There is, however, very little consensus in the literature regarding the nature of such a delay in the recruitment of the VMO within the AKP population (Chester et al., 2008). Chester et al. (2008) conducted a systematic review and meta-analysis and concluded that there was a trend towards a delayed onset of VMO relative to VL in subjects with AKP, compared to healthy controls. However not all AKP patients demonstrated this VMO and VL onset activation delay. Due to the heterogeneity of the studies included in the review by Chester et al (2008), the association of AKPS and delayed onset of VMO cannot be made conclusively (Lankhost et al., 2012).

Tightness in the soft tissue structures surrounding the knee joint and the PFJ pose as risk factor for developing AKPS. Excessive tightness in the lateral retinaculum and the transverse fibers of the iliotibial band (ITB), among others, may lead to lateral translation of the patella during normal activities, leading to increased contact forces on the PFJ (Dutton et al., 2016). There are possible associations between flexibility of the quadriceps muscle, gastrocnemius and hamstring muscles, and the development of AKP. Quadriceps muscle flexibility is not always as a result of AKP, as demonstrated by Witvrouw et al. (2000). Inflexibility of the quadriceps muscle was an existing condition before the development of AKP. These results by Witvrouw

et al. (2000) support the concept of tight quadriceps muscles creating high PFJ stress during sporting activities or ADLs. Gastrocnemius tightness is theorised to increase the posterior force of the patella against the femoral trochlea leading to increased PFJ stress (Dutton et al., 2016). Tightness of the hamstring muscle group can create a constant flexion movement in the patella, needing greater quadriceps power to extend the knee, resulting in increased PFJ reaction forces. Witvrouw et al. (2000) found significantly lower levels of hamstring muscle flexibility in those participants who developed AKP compared to controls. More research is needed to establish the relationship of these muscles (Quadriceps, Hamstring and gastrocnemius muscles) to the development of AKPS.

There remains a lack of evidence to prove or disprove the Q-angle's involvement and association in the development of AKP. Almeida et al. (2016) investigated the relationship between the Q-angle and AKP severity, functional capacity, dynamic knee valgus and hip abductor torque in a population of women diagnosed with AKP. The Q-angle is widely used as an evaluation measure especially in individuals with AKP. The Q-angle is formed by the intersection of two lines that cross at the centre of the patella (Almeida et al., 2016). One line goes from the anterior superior iliac spine (ASIS) to the center of the patella, and the other from the anterior tuberosity of the patella to the center of the patella (Powers, 2003). It is theorised that the greater the Q-angle the greater the lateralisation forces acting on the patella (Powers, 2003). Lateralisation of the patella can or may lead to the development of AKP. Almeida et al. (2016) hypothesised that the Q-angle would have a positive correlation with dynamic valgus of the knee and AKP intensity. That Q-angle could have negative correlation with peak isometric torque of hip abduction and functional capacity among women with AKP. Such an association, however, could not be established. These authors concluded that Q-angle evaluation of patients with AKP may not bring any additional information regarding the presents of AKP when evaluating this population group. This suggests that Q-angle may be problematic only in a subgroup of individuals with AKP (Almeida et al., 2016).

Females are significantly more at risk of developing AKP (Prins & Wurff, 2009). Anatomical and neuromuscular factors may contribute to the development of AKP in women. Strength deficits of the external rotators of the hip as well as weakened hip abductors are debated as major contributing factors in the development of AKP (Neal et al., 2016). Kinematics of the lower limb can change as a result of weakened hip muscle strength. Excessive hip adduction and internal rotation during functional activities could lead to lateralisation of the patella resulting in an increase in dynamic Q-angle (Dutton et al., 2016; Powers, 2003). It still remains

difficult to establish a relationship between weak hip muscles and AKP. The question remains whether weakness of the hip muscles is a result of AKP, or the causative factor for the development of AKPS. Hip muscle performance during dynamic tasks should be investigated looking at dynamic control of femoral internal rotation and not just static hip abductor strength as a risk factor for development of AKP (Dutton et al., 2016). Prins & van der Wurff (2009) found strong evidence supporting the idea that females diagnosed with AKP demonstrated a decrease in adduction external rotation strength compared to healthy controls. A systematic review and meta-analyses done by Neal et al. (2016) suggested limited evidence indicating increased peak hip adduction as a risk factor for AKP in female runners. The same review found moderate evidence relating AKP and increased peak hip abduction, internal rotation and contralateral pelvic drop and reduced peak hip flexion to the development of AKP.

A review done by Leibrandt & Louw (2017) investigated kinematic risk factors for AKP during common aggravating activities. Leibrandt & Louw (2017) concluded that the following kinematic risk factors were evident during gait of subjects with AKP, peak hip internal rotation and timing of peak rear foot eversion when comparing subjects with AKP to controls. Evidence was based on two cross-sectional studies with significant and consistent findings for kinematics during gait. Evidence during single leg squat identified increased ipsi-lateral trunk lean, increased knee adduction and increased hip adduction in subjects with AKP compared to controls. The authors concluded that, based on the current evidence, these abovementioned factors should be addressed during treatment of patients with AKP.

The literature provides evidence for rear foot abnormalities in AKP due to compensatory internal rotation of the femur (Powers, 2003). Disorders contributing to the development of AKP include delayed timing of peak rear-foot eversion, increased rear-foot eversion at heel strike and reduced rear-foot eversion range of motion (Petersen et al., 2014). During normal gait the foot pronates and the tibia internally rotates during early contact. Once the foot reaches mid-stance and the foot is in full contact with the ground the subtalar joint supinates and the tibia follows, externally rotating to move the knee into extension. In cases with excessive pronation of the forefoot the subtalar joint stays pronated at mid-stance. This prevents the tibia from externally rotating, forcing the femur to internally rotate on the tibia. The internal rotation of the hip leads to lateral displacement of the patella and increasing the PFJ strain (Dutton et al., 2016). Powers (2003) described a biomechanical rationale by which segmental motion of the lower extremity may affect the PFJ. Excessive motion of the tibia and the femur in the frontal and transverse plan can influence the PFJ and AKP. These abnormalities are not

universal findings according to Powers (2003).

2.6 Current Evidence Based on the Management of AKPS

Management of AKPS remains challenging with 91% of patients with AKP reporting persistent symptoms after extended follow-up and medical management and only 6% of patients are symptom free after 16 year follow ups (Dutton et al., 2016; Selfe et al., 2016). A unique treatment approach should be taken and treatment protocols should be according to the findings of the clinical examination, functional assessment and history of the patient (Crossley, Van Middelkoop et al., 2016; Dutton et al., 2016; Papadopoulus et al., 2015; Weiner et al., 2014, Witrouw et al., 2014). Initial management should be focused on reducing AKP and avoidance of aggravating factors. Strengthening of the knee extensors should be addressed once the timing balance has been restored between the VMO and the VL. Restoring the timing of the VMO muscle in correlation to the VL muscle should be done in combination with strengthening the hip abductors and external rotators (Gluteal muscles) (Weiner et al., 2014; Witrouw 2014). Patellar stabilisation should be addressed through bracing or patellar tapping if hypermobility of the patella exists. Soft tissue flexibility should be restored in the iliotibial band (ITB), quadriceps, hamstrings, gastrocnemius and other lateral muscular structures. Balance re-education, gait re-training, as well as sport specific training should be incorporated into the management plan (Crossley, Van Middelkoop et al., 2016).

A consensus statement was issued by the third and fourth International Patellofemoral Pain (PFP) research retreat of September 2013 and 2016 by an expert panel to guide medical and health practitioners in the treatment of patients with AKP (Witvrouw et al., 2014; Crossley, Van Middelkoop et al., 2016). According to this statement, conservative management of PFP can reduce symptoms of PFP and improve self-reported function of individuals with PFP. Conservative management refers to therapeutic exercises, multimodal physiotherapy (PT), foot orthosis and patellar tapping/taping. This statement does not recommend therapeutic modalities such as electrotherapy which had no benefit for patients with AKPS compared to controls (Witvrouw et al., 2014). The following recommendations were made after the 2016 International PFP research retreat; exercise therapy is recommended to reduce pain in the short, medium and long term; combining hip and knee exercises are recommended to reduce anterior knee pain and improve function in the short, medium and long term; combined interventions such a physiotherapy and strengthening are recommended for the treatment of AKPS. Foot orthoses can address rear foot eversion and is recommended to reduce anterior knee pain.

Passive mobilisation of the patellofemoral joint, knee joint and lumbar spine and electrotherapy agents are not recommended due to the lack of evidence for efficacy in recent reviews (Van Middelkoop et al., 2016., Witvrouw et al., 2014). In light of these treatment recommendations, AKP still remains the most common diagnosis of patients complaining of knee pain (Kurt et al., 2016) and it remains a contributing cause of chronic knee pain among young adults (Sanchis-Alfonso et al., 2016). Management of AKP remains challenging and controversial as standardised treatment protocols have not been described and reported (Kurt et al., 2016). Kurt et al. (2016) evaluated the short-term effect of kinesio-tape (KT) on knee JPS quadriceps strength and functional limitations in patients with PFPS compared to controls. They too found an improvement in joint position sense and functional limitations after KT application using the same method described as Gurney et al. (2016).

Recent reviews on the topic of AKP have focused on identifying various risk factors, diagnostic tests, lower extremity biomechanics and evidence based treatments (Dutton et al., 2016; Papadopoulos et al., 2015). There is still limited research investigating proprioception in individuals with AKP (Yosmaoglu et al., 2013). Based on the literature, proprioception could be a risk factor for the development of AKP or could contribute to the chronicity of the condition.

Proprioceptive changes have been documented in patients with AKP (Guney et al., 2016; Aseki et al., 2008; Baker et al., 2002). The physiological rationale explaining altered proprioception in a population with AKP could be due to small nerve damage in the lateral retinaculum of the patellar (Sanchis-Alfonso and Rosello-Sastre 2003). Mal-tracking of the PFJ is thought to cause secondary changes in the nerves innervating the lateral retinaculum of the PFJ (Sanchis-Alfonso and Rosello-Sastre 2003). Mechano-receptor damage remains one of the main reasons for altered proprioception in this population group. Pain may lead to abnormal driving of muscle spindles, leading to altered input from muscle receptors, leading to abnormal joint position sense (JPS). Abnormal knee joint position sense (JPS) can predispose to musculoskeletal pathologies by altering the alignment of the affected lower limb, as well as poor muscular control and joint stability. These mentioned factors in turn can lead to increased PFJ stress and AKP.

2.7 Defining Proprioception

The word proprioception comes from the Latin word “Proprius” meaning “one’s own” combined with the concept of perception: which translate to “perceiving one’s own” (Han et

al., 2016; Hillier et al., 2015; Ogaard, 2011). Proprioception is defined as the sense of joint position and joint movement and results from mechanoreceptor stimulation in the joint and muscle tissue (Clark et al., 2016; Lokhande et al., 2013; Selfe et al., 2006; Hewett et al., 2002). Proprioception can also be described as follows: (1) the sense of position referring to awareness of limb positioning compared to body positioning; (2) sense of movement, referring to the ability to perceive both direction and velocity of limb movement; (3) sense of force referring to one's ability to estimate the amount of muscular force needed to make movement or maintain the position of a joint against resistance (Golbe, 2016; Lokhande et al., 2013). Kinesthesia is also a term used to describe proprioception which can be defined as the sense of movement (Grob et al., 2002). Both these terms are still being used but with different interpretations. Some researchers define proprioception as joint position sense (JPS) only and kinesthesia as the conscious awareness of joint motion, whereas others consider kinesthesia as a sub-modality of proprioception (Han et al., 2016; Proske et al., 2012; Grob et al., 2002).

Proprioception plays an important role in sensorimotor control. The sensory motor system includes the complex interaction between the sensory pathways and the motor pathways that relays to the central nervous system (CNS) on control of movement, balance, posture or joint stability (Röijezon et al., 2015; Hewett et al., 2002). Accurate motor control requires well-integrated information from all the sensory systems, be it visual, vestibular and the somatosensory system that includes proprioception. The sensory receptor that sub-serve proprioceptive functions are located in various connective tissues including the skin, ligaments, joint capsules and muscle spindles throughout the limbs, trunk and neck (Golbe, 2016; Smith et al., 2013; Ogaard, 2011; Pincivero et al., 2000).

When proprioceptive stimuli are presented to the body, input occurs at three different locations: the visual system; the vestibular system; and at peripheral mechanoreceptors located throughout the body, including the skin, joints ligaments, tendons and muscles (proprioceptive receptors). This proprioceptive input is then processed by the CNS at three different levels. Firstly, processing takes place at spinal level for reflex response necessary for reflexive joint stability. Secondly, proprioceptive input is processed at the lower brain (brain stem) which involves timing of activities and thirdly, processing takes place at the cerebral level controlling voluntary movement (Hewett et al., 2002). Proprioception involves conscious or unconscious awareness of joint position sense (JPS), movement and force as well as heaviness and effort (Röijezon et al., 2015). Proprioception is processed at all levels of the central nervous system with integration from the somatosensory system to enable coordinated activation patterns of

the skeletal muscles. Proprioception is a subsystem of the somatosensory system that also includes pain, touch and temperature sensation from the skin and musculoskeletal structures (Hillier et al., 2015; Orgard, 2011).

2.8 Knee Proprioception:

2.8.1 Physiology of proprioception.

Muscle spindles in the skeletal muscles are the most important source of proprioception (Röijezon et al., 2015; Hewett et al., 2002). These muscle spindle receptors are within muscle fibers and detect changes in muscle length and velocity of contractions (Röijezon et al., 2015; Smith et al., 2012; Hewett et al., 2002). Receptors in the skin also contribute to joint position and motion sense (Proske & Simon, 2012). Ruffini endings in the joint capsules, ligaments and menisci are slow adapting mechanoreceptors. These receptors detect static joint position, intra-articular pressure and joint motion. Pacinian corpuscle receptors are deeper in the joint connective tissue, detecting change in velocity acceleration and deceleration (Hillier et al., 2015, Rieman & Lephart et al., 2002). Free nerve endings in articular structures may play a role in detecting severe mechanical deformity and inflammatory changes. Golgi tendon receptors are found in the cruciate and collateral ligaments as well as the knee menisci (Rieman & Lephart et al., 2002). These mechanoreceptors are useful as limit detectors at extreme joint ranges. Muscle spindles provide most of the proprioceptive information in the middle range of joint action (Hillier et al., 2015; Proske & Simon, 2012). Based on the above-mentioned information, proprioception can be defined as an individual's ability to integrate the sensory signals from mechanoreceptors to determine body segment position and movement in space (Han et al., 2015; Hewett et al., 2002).

2.8.2 What happens to proprioception with trauma, pain and effusion

Degraded proprioception can result in loss of movement control, affecting feedback and feed forward motor control, regulation of muscle stiffness and difficulty improving quality of movement (Hillier et al., 2015; Röijezon et al., 2015). Clinically altered proprioception, as seen in knee injuries, may lead to destruction of mechanoreceptors (Clark et al., 2016; Hillier et al., 2015; Hewett et al., 2002) and may be associated with impaired joint-muscle reflexes and abnormal movement patterns. Balance may be disturbed and clumsiness may be reported or observed due to sensory motor dysfunction and disturbed reflex joint stabilisation (Clark et al., 2015).

Long-term effects of altered proprioception can lead to increased risk of injury, recurrent and

persistent pain disorders and this could lead to the onset of secondary osteoarthritis (Akins et al., 2015; Clark et al., 2015; Röijezon et al., 2015; Bennell et al., 2005). Pain, effusion, trauma and fatigue are some of the main contributing factors causing damage to the proprioceptive receptors leading to degraded or disturbed proprioceptive function (Röijezon et al., 2015, Clark et al 2015). Each of these factors influence proprioceptive response. (1) Pain resulting from acute or chronic musculoskeletal pain disorders can disturb proprioception due to altered reflex activity. Pain influences body perception at a central level, affecting proprioception on both a peripheral and central level of the nervous system (Hewett et al 2002). (Pain affects the afferent and efferent pathways influencing input and output of proprioceptive response) (Röijezon et al., 2015; Hewett, 2002). (2) Joint effusion could cause significant inhibition of skeletal muscles and lead to impaired extremity proprioception. Swelling of the joint or joint capsule, usually after joint injury, causes inhibition of skeletal muscles leading to impaired proprioception (Röijezon et al., 2015). (3) Trauma caused by physical injury can lead to disruption of musculoskeletal tissues causing damage and destruction of mechanoreceptors innervating those structures. (4) Fatigue, hypermobility and immobility, as well as age, have an effect on proprioception due to altered metabolic rates and changes in muscle activation patterns. (Clark et al., 2015; Han et al., 2015; Röijezon et al., 2015; Orgard et al., 2011).

2.8.3 What happens to proprioception in AKP

Most of the studies on knee proprioception have been done among patients with anterior cruciate ligament injuries (Boerboom et al., 2008, Hewett 2002). There is limited research on investigating proprioception in individuals with AKP. A summary of ten studies have been included which demonstrate published literature investigating proprioception in individuals with AKP. These studies assessed joint position sense (JPS) in this population group affected by AKP (Appendix A). The findings on JPS in AKP patients are inconclusive with contradictory results.

Earlier studies conducted by Bennell et al. (2005) could not prove proprioception to be affected in individuals with AKP. Naseri et al. (2012) investigating proprioception in an athletic population affected by AKP. Yosmaoglu et al. (2013) conducted an investigation into the relationship between tracking ability, JPS and functional levels in participants with patellofemoral pain syndrome (PFPS). These studies were unable to prove that knee JPS is affected in participants with AKP/PFPS. Banelle et al. (2005) examined the effect of experimentally induced AKP on knee JPS, but was unable to prove altered knee JPS.

Contrary to these findings, Baker et al. (2002), Hazneci et al. (2005); Aseki et al. (2008) and later Cyrillo et al. (2014) and Guney et al. (2015) investigated knee JPS in individuals with patellofemoral pain syndrome and found that proprioception was significantly affected in this population group compared to controls. JPS was used to describe knee proprioception in the studies by Yosmaoglu et al.(2013), Aseki et al. (2008) and Banelle et al.(2005), however the testing protocols differed greatly between these studies.

JPS testing methods ranged from active to passive reproduction, with some researchers testing only joint repositioning and some testing movement sense. Testing position for knee JPS was performed in either a non-weight bearing (NWB) or weight bearing (WB), affecting the proprioceptive feedback from mechanoreceptors. Measurement tools used to evaluate JPS differed in each study. Some researchers made use of reflective markers and computer analyses to measure reproduced angles (Baker et al., 2002; Bannell et al., 2005; Naseri et al., 2012). A digital and onscreen goniometer were used by Selfe et al. (2005); Aseki et al. (2008) and Cyrillo et al. (2014). More recent studies made use of a Biodex system dynamometer to measure knee JPS, which prove reliable but can only account for NWB JPS testing (Cyrillo et al., 2014; Guney et al., 2015).

Predetermined target angles (TA) varied between studies ranging from 30 to 60 degrees of knee flexion. Akseki et al. (2008) measured four different target angles. Selfe et al. (2005) conducted a study investigating the effect of a number of trials during proprioceptive testing, which proved that more than five test trials are needed for active JPS testing, and six test trials needed for passive knee joint position sense test for data to stabilise, (mean measurement of five to six trails) and to account for accurate measurements of the absolute error.

Comparing these studies, the methodologies varied greatly with regard to measurement tools, WB or NWB testing positions and the joint angles measured. The variation in methodology could be due to the lack of a gold standard test to assess proprioception and tests used have poor clinical applicability and are poorly evaluated and reported by the respective authors (Hillier et al., 2015).

Clark et al. (2016) investigated reliability and measurement precision of concentric-to-isometric and eccentric-to-isometric knee JPS tests in healthy individuals using motion analysis. This study demonstrated good and moderate reliability for prone knee extension and prone knee flexion tests respectively. Gurney et al. (2016) investigated the relationship between quadriceps strength and JPS, functional outcome and pain activities in patients with PFPS. In

this specific study, 46 women were diagnosed with unilateral PFPS. Participants' quadriceps strength and JPS (active joint reproductive) test were tested by means of a Biodex System 3. It was found that eccentric and concentric quadriceps strength was significantly lower on the affected side compared to the unaffected side (Guney et al., 2016). JPS was poorer on the painful knee compared to the unaffected side. Gurney et al. (2016) concluded that quadriceps eccentric strength correlated more with JPS than concentric strength. It is well known that the loss of eccentric quadriceps strength provokes pain when descending stairs due to diminished control of the PFJ and increased patellofemoral reaction forces in individuals with AKP (Guney et al., 2015; Kaya et al., 2010). Testing quadriceps muscle strength proves important as it directly relates to knee proprioception, pain and knee function in AKP patients.

Cug et al. (2016) investigated the effect of sex, limb dominance and soccer participation on knee proprioception and dynamic postural control. These authors compared female and male sub-elite soccer players to sedentary individuals. JPS was tested using passive positioning on a Biodex isokinetic dynamometer. Dynamic postural control was tested using a three-star excursion balance test, this is an adaptation from the star excursion test making use of only a anterior, medial and lateral reach to establish and compare dynamic postural control between the sub-elite soccer players and the sedentary individuals. It was hypothesised that elite soccer players would have superior JPS and dynamic postural balance compared to sedentary individuals (Cug et al., 2016). These authors expected noticeable differences between males and females when comparing results. The key findings from their study were to the contrary. It was concluded that sporting history, sex and limb dominance did not influence knee joint proprioception when tested in an open kinetic chain using passive repositioning (Cug et al., 2016). Results may indicate that testing proprioception in an open kinematic chain (NWB) may have minimum proprioceptive inputs of muscle spindle receptors. Possible passive testing techniques may have masked true proprioceptive differences under active movements.

2.9 Possible Reasons for Conflicting Findings

Smith et al. (2013) and Naseri et al. (2012) discussed a number of reasons why significant loss in JPS could not be proved. One reason mentioned was that study participants' pain severity levels, and activity levels differed. The extent of knee pathology also varied among participants from study to study, which could have a direct effect on proprioception. Level of pain proved to be an important impairment among AKP participants/patients and this impairment was not assessed in all the studies (Baker et al., 2002). Most of the participants were athletes with a high level of motor function. Athletic abilities and high levels of motor function could account

for proprioceptive feedback from adjacent joints and muscles (Smith et al., 2013; Naseri, 2012). Passive testing techniques and open kinematic testing procedures may affect proprioceptive feedback. Passive testing techniques may stimulate different proprioceptive receptors as during active testing where as NWB testing can only account for proprioceptive feedback from the joint (knee) alone. Studies using passive methods to determine target angles during active JPS testing procedure may influence proprioceptive feedback (Grob et al., 2002).

2.10 Measurement of Proprioception

2.10.1 General proprioceptive testing

Proprioception can be measured in a laboratory using three main testing techniques: (1) threshold to detection of passive motion (TTDPM), (Orgard et al., 2011, Boerboom et al., 2008); (2) joint position reproduction (JPR) also known as joint position matching (Olsson et al., 2004, Pánics et al., 2008); and (3) active movement extent discrimination assessment (AMEDA). Threshold to detect passive motion test (TTDPM) can be defined as the point at which subjects can sense a change in limb-segment position as well as when and in what direction the movement is happening (Hewett et al., 2002). Joint position reproduction (JPR), which is mainly used in the assessment of proprioception in knee pathologies, is the ability of a subject to accurately reproduce a specific joint angle or target angle (Golbe, 2016; Selfe et al., 2006; Baker et al., 2002). The difference between the test joint angle or target angle (TA) and the reproduced angle (RA) is the joint angle error or absolute error (AE). JPS is one of the first methods used to test proprioception and is easy to execute clinically. JPS has been criticised for its high measurement variability and JPS measures only one aspect of proprioception (Hewett et al., 2002). AMEDA refers to the measurement of muscle activation and latency of muscle reflexes after stimuli (Hewett et al., 2002). Assessing balance for postural control could also relate back to proprioceptive capabilities and neuromuscular control (Hewett, 2002). Standardising test methodologies for assessing proprioception proves difficult because each test varies from study to study and each has different concepts and they are conducted under different testing conditions (Han et al., 2016; Hillier et al., 2015). Comparing these test modalities, no significant association could be found in the test methods between TTDM and JPR testing.

Researchers usually use laboratory equipment, custom built devices, and computer-interfaced equipment, which are costly and not practical in a clinical setting (Clark et al., 2015; Hillier et al., 2015; Röijezon et al., 2015). Clinical proprioceptive tests described by Orgard (2011)

include: (1) in the absence of vision patients have to note when and in which direction a limb segment is being moved; (2) touching a point on the body accurately and matching limb/segment position or motion. Hillier et al. (2015) state that the distal proprioceptive test is not useful in clinical trials but proves helpful when used as a clinical screening tool to identify impaired proprioception in patients. The distal proprioceptive test is described by the clinician or tester as manually moving the distal body part and the patient having to indicate correctly in which direction the movement is taking place (Hillier et al., 2015). Clinical assessment of proprioception can be performed with goniometry, inclinometers, laser pointers and pressure sensors. These devices can be used in a clinical setting testing active JPS, kinesthesia and forces sense (Clark et al., 2016; Röijezon et al., 2015). Balance tests, like timed single leg stance, have been used to evaluate lower extremity proprioception. This would be measuring integrated sensory motor control and not solely proprioception because balance is an integrated function of the CNS, sensory and motor function system (Clark et al., 2016; Röijezon et al., 2015).

2.11 Testing of Knee Proprioception

2.11.1 Joint position sense test (JPS)

Joint position sense can be defined as the awareness of the location of the joint in space (Smith et al., 2012; Pincivero et al., 2000,). The joint position sense test assesses precision or accuracy in repositioning a joint at a pre-determined TA in the absence of vision (Golbe, 2016; Roijenzon et al., 2015; Lokhande et al., 2013; Stillman et al., 2001). The JPS test is the most common method used to measure knee joint proprioception (Smith et al., 2012; Ollson et al., 2002). JPS testing can be performed under active (biasing joint mechanoreceptors) or passive (stimulating joint and muscle tendon mechanoreceptors) conditions (Roijenzon et al., 2015; Smith et al., 2012; Stillman & McMeeken, 2001). It has been reported that joint position sense tests are more reliable when measured in a weight bearing position and this can be due to compressed mechanoreceptors during weight bearing and also due to JPS feedback from the ankle dorsi-flexor muscles, greater calf complex tension and increased resistance throughout the lower limb. Weight bearing proves more functional and involves all the cutaneous, articular and muscular receptors during normal daily tasks (Lokhande et al., 2013; Smith et al., 2012).

Gulbe (2016) describes two types of JPS matching test procedures commonly used to assess proprioception which clinicians and researchers can consider when testing JPS. The two types of JPS tests include “ipsilateral matching” and “contralateral matching”. Ipsilateral matching refers to when the participant is asked to reproduce the TA with the same reference joint or

limb; whereas with “contralateral matching” the participant is required to reproduce the target angle or position with the opposite limb or joint as the reference joint. During contralateral matching the established target angle remains as the reference point while the participant reproduces the TA with the opposite limb (Gulbe, 2016). With ipsilateral matching participants depend mainly on memory to accurately reproduce the TA. Contralateral matching eliminates the component of memory but is based on the anatomical pathways involved in the transmission of peripheral proprioceptive input to the brain and it requires greater interhemispheric communication (Gulbe, 2016). These factors should be considered by clinicians and researchers when deciding on a test method to test JPS for a specific clinical population.

There are a number of methods used to obtain the JPS (Hillier et al., 2015; Clark et al., 2015; Smith et al., 2013). These methods include the following: (1) image recorded where photography is used to assess knee joint angles; (2) electro-goniometry with knee angular error; (3) dynamometry; and (4) paper model replication. All four methods demonstrated good intra-rater reliability (Baker et al., 2002, Banell et al., 2005, Aseki et al., 2008, Hillier, 2015). There are, however, limitations to joint position testing as it is only one aspect of proprioception that is being assessed (Röijezon et al., 2015; Smith et al., 2013). When measuring JPS, there are possible confounders, such as participants having to rely on memory. The cognitive and concentration element to testing JPS and joint pain can influence the accuracy of the reproduced angle during testing or assessment of JPS (Clark et al., 2015).

The main outcome measurements for knee JPS testing are: (i) relative error (RE); (ii) absolute error (AE); and (iii) variable error (VE). RE is defined as the arithmetic difference between the test or target angle and the response angles. RE represents accuracy with directional bias. Directional bias refers to the participant being able to reach the TA or undershooting, not being able to reach the TA which could result in a negative RE (Baker et al., 2002; Bennell et al., 2005; Lokhande et al., 2013). AE refers to the difference between the test or target angles and the response angle. AE represents accuracy without directional bias (Baker et al 2002). VE refers to the standard deviation from the mean of each of the five relative errors. Previous researchers have stated that AE variables are the most appropriate for expressing JPS (Orgard, 2011; Han et al., 2015; Hillier et al., 2015; Röijezon et al., 2015). The smaller the AE the better the proprioceptive function. When testing proprioception of normal subjects the AE variables have been found to range between 0.7 degrees and greater than six degrees (Orgard, 2011). Callaghan (2002) classified good proprioception as less than five-degree error, and an error

greater than five degrees as poor proprioception in healthy participants. In a more recent study by Clark et al. (2016), the AE ranged between 3.18 and 5.97 degrees in uninjured, physically-fit, active adults. Olsen et al (2004) investigated the test retest reliability of knee JPS in 39 healthy participants comparing the measurement method in sitting and in prone. JPS was expressed as the difference between the target angle and estimated angle (reproduced angle). Olsen made the following recommendations regarding JPS testing: JPS should be calculated as the AE between TA and RA; sitting should be preferred to prone as the testing position; ipsilateral matching should be used compared to contralateral matching; and the test angle or TA should be in the middle range of knee flexion and extension (40 degrees to 80 degrees of knee flexion).

2.11.2 Weight bearing and non-weight bearing testing methods

Traditionally JPS was measured in a non-weight bearing position (NWB) with more recent studies testing in a weight bearing (WB) position. Stillman & McMeeken (2001) compared WB and NWB JPS in a clinical setting in healthy participants. Their study concluded that WB JPS assessment in unilateral WB stance with eyes closed and finger support produced more accurate and reliable results when testing proprioception compared to NWB testing procedures (both in RE and AE). Even though the WB position proved to be more accurate, NWB knee JPS had the greatest potential for revealing the proprioceptive status of only the knee joint. During NWB testing there is no movement or weight bearing through the adjacent joints. With the WB position, on the other hand, it is argued that proprioceptive feedback is obtained from other joints and possible greater muscle resistance throughout the lower limb. Stillman & McMeeken (2001) found that WB and NWB results were not correlated and that the one procedure cannot replace the other. Lokhande et al. (2013) repeated the same test procedure assessing knee JPS in WB and NWB position in 40 healthy subjects. Lokhande et al. (2013) found a significant difference between the test procedures (WB and NWB testing). In this study relative error in the WB position was higher compared to the NWB position, suggesting better accuracy in the NWB position. The authors reported lack of balance requirements during WB as a possible explanation for this finding (Lokhande et al., 2013). This finding suggests that WB testing of JPS could have greater relevance in a sporting population. An athletic population may be better equipped to adhere to WB testing and is more likely to meet the criteria for WB testing compared to inactive individuals. Test procedures for JPS can also make provision to support individuals to eliminate the effect of balance on the measurement outcomes.

2.12 Rationale for the Study

Proprioception remains an important sensory function for all normal movement activities, including the ability to maintain dynamic balance and to move accurately. More research is needed in this field to determine whether individuals with AKP have altered knee proprioception compared to those without AKP. Proprioceptive abnormalities could be a possible risk factor and if not identified during assessment or addressed during treatment can add to the chronicity of AKP. The outcomes of this study can guide clinicians to include proprioceptive testing in their clinical evaluation of individuals who present with AKP. Restoring proprioceptive status is widely accepted as a key component in the rehabilitation of other knee pathologies such as anterior cruciate ligament injuries and reconstruction.

Chapter 3: The Manuscript

The manuscript to be submitted to the Journal of Sports Rehabilitation

The guideline for the journal is attached as Appendix 8

Proprioceptive Differences in Individuals with Anterior Knee Pain

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Abstract

Context: Anterior knee pain affects both physically active and sedentary individuals and commonly leads to chronic knee pain amongst young adults. Altered proprioception impacts accurate motor action and knee joint stability. There are conflicting reports in the literature on whether people with AKP have altered proprioception.

Objectives: The purpose of this study was to investigate the proprioceptive abilities of individuals with anterior knee pain.

Design: Descriptive cross-sectional study.

Setting: Laboratory based.

Participants: Twenty-five participants with unilateral or bilateral AKP were included. Participants were predominantly female (n=22), with a mean age of 27.8 years.

Intervention: The Vicon 3D motion analysis system was used to assess proprioception. Fifty-knees were evaluated; 37 with AKP and 13 without AKP. Proprioception was measured by means of active joint position sense testing during single leg squat and active knee extension in sitting. Target angles were self-determined based on each participant's capabilities.

Main Outcome measures: The absolute error (AE) was used to assess proprioception. A normative criterion of an AE equal of greater than five degrees was used to classify altered proprioception. Descriptive statistics were used to report study findings.

Results: There were no significant differences in proprioception when comparing the knees with AKP to the knees without AKP ($p < 0.05$). A group with altered proprioception was identified in both the knees with AKP and the knees without AKP. There was a tendency towards a larger AE in the knees with AKP during active knee extension in sitting.

Conclusion: The study findings showed that proprioception is not significantly more impaired in knees with AKP compared to knees without AKP. A group was identified with altered proprioception in both the knees with and without AKP. This finding could be due to compensatory gait patterns and the precision of the Vicon 3D motion analysis system. Proprioception should be assessed in both knees in individuals with AKP.

3.1 Introduction

Anterior knee pain (AKP) is a common disorder of the knee joint and affects both physically active and sedentary individuals.^{1 2 3 4} AKP accounts for 25% to 40% of all knee problems presenting at sports medicine clinics; one in four of the active population is affected, leading to chronic knee pain among young adults.^{4 5 6 7 8} AKP is prevalent among runners, particularly distance runners. AKP has a higher prevalence among active women, with an incidence two to three times more than that of men.^{9 10}

AKP is characterised by anterior, peri-patellar or retro-patellar pain with an insidious onset, and is exacerbated under conditions of increased patellofemoral joint stress.^{5 8 11 12} Aggravating factors for AKP include activities causing repetitive strain or movements that increase patellofemoral joint compression or produce mechanical force in the surrounding soft tissue structures. These aggravating activities include ascending or descending stairs, prolonged sitting, squatting, and running.^{3 13 14}

The aetiology of AKP is unclear and a source of debate in the current literature.^{7 14} There appears to be some consensus, however, regarding the multi-factorial nature of AKP and its development secondary to functional or structural mal-alignment of the patellofemoral joint.¹⁴ Patellofemoral joint dysfunction could include anatomical patella abnormalities, or extensor mechanism disorder resulting in patellar malalignment during flexion and extension of the knee joint.^{3 11 14} There are multiple interacting factors causing malalignment of the patella, such as muscle strength, timing of vastus medialis oblique, altered tissue extensibility and body morphology.^{15 16}

Altered proprioception, as evident during knee injuries, may lead to destruction of mechanoreceptors^{17 18} and may be associated with impaired joint-muscle reflexes as well as abnormal movement patterns, resulting in loss of movement control. Proprioceptive changes have been documented in patients with AKP.^{19 20 21 22} This can have detrimental effects in the sporting community, leading to injury, and if not addressed can lead to costly rehabilitation in the long term.²³

Proprioception is defined as the sense of joint movement and results from mechanoreceptor stimulation in joints and muscles.^{17 24 25 26} Clinical symptoms of altered proprioception may include disturbed balance and clumsiness due to disturbed motor function and joint reflex stabilisation. Long-term effects of altered proprioception among individuals with AKP may lead to recurrent and persistent pain with a secondary onset of joint osteoarthritis.^{17 23}

Recent reviews of AKP have focused on risk factors, diagnostic tests, lower extremity biomechanics and exercise treatments.^{5 15} There is limited research on investigating proprioception in individuals with AKP.¹² The findings of these studies investigating AKP and proprioception prove to be inconclusive, with contradictory results. Previous studies in this field reported on insignificant differences in altered proprioception between individuals with and without AKP.^{12 27 28} Contrary to these findings it has been reported that proprioception was significantly affected in an AKP population compared to controls.^{19 20 21 22 29} Comparing these studies, the methodologies varied greatly with regard to measurement tools, weight bearing or non-weight bearing testing positions, as well as the joint angles measured. The variation in methodology could be due to the lack of a gold standard test to assess proprioception. Furthermore, the tests used in previous studies have poor clinical applicability and are poorly evaluated and reported on by the respective authors.¹⁸

More research is needed to establish if individuals with AKP present with altered knee proprioception. If such an association exists between proprioception and AKP, clinicians should be encouraged to include proprioceptive testing in their clinical evaluations of individuals presenting with AKP. In cases of altered proprioception this can form a key component in the rehabilitation of patients with AKP. The aim of this study, therefore, is to determine if proprioception is altered in individuals with AKP. None of the previous studies investigating AKP and proprioception have used a gold standard testing tool such as the Vicon 3D motion analysis device.

3.2 Research Methodology

3.2.1 Research Design

A cross-sectional, descriptive study design was used to collect data.

3.2.2 Study Population

The target population consisted of 25 physically active and sedentary individuals between the ages of 14 and 40 years. The target population was sourced from the Cape Town Metropolitan area, in the Western Cape Province. Informed consent was obtained and completed by all participants prior to the study procedure. Where participants were under the age of 18 years an assent form was obtained as well as informed consent from the parents/guardians. Participant informed consent forms are attached as Appendix 3. Ethical approval was obtained from the

Health Research Ethics Committee of Stellenbosch University. Ethics reference: S16/10/197. Ethics letter of approval is attached as Appendix 11.

3.2.3 Study Setting

The study was conducted at the CAF Human motion analysis Unit, at the Tygerberg medical campus, Division of Physiotherapy, Faculty of Medicine and Health Sciences, Stellenbosch University.

3.2.4 Inclusion and Exclusion Criteria

3.2.4.1 Inclusion criteria

Participants who adhered to the criteria listed below were considered for inclusion.

Males or females aged between 14 and 40 years who were physically active, with an insidious onset of clinical signs and symptoms of AKP. Participants were included if symptoms were provoked by prolonged sitting, squatting, stair-climbing and/or running. Participants who complied with the AKP screening tool (Appendix 1) and the diagnostic checklist (Leibbrandt and Louw 2017). (Appendix 2) Participants with unilateral and bilateral AKP were considered for inclusion. In cases where both knees were affected with AKP, both knees were tested for altered proprioception and compared to the knees without AKP.

3.2.4.2 Exclusion criteria

Participants were excluded if any of the following conditions prevailed.

AKP had resulted from a traumatic event such as a motor vehicle accident, previous knee surgery or patellar tendonitis. 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 OA of the knee or as demonstrated by a radiograph. There was clinical evidence of other knee pathologies. Participants were excluded if they did not comply with the initial AKP screening tool (Appendix 1) and diagnostic checklist (Leibbrandt and Louw 2017). (Appendix 2)

3.2.5 Sample Size

A pragmatic approach was adopted to determine the sample size. Key factors used to determine the sample size included: the scope of this Master's project; project costs; and the study duration. The sample size of the study was based on a review of published research on the same topic.^{12 21 22 24 27} Based on these findings, a sample of 30 participants had to be recruited for

this study. The findings of this study provide baseline data that can be used to formally calculate sample size for larger studies in the future, on the topic of proprioception among participants with AKP. A flow diagram of the study procedure is attached as Appendix 4.

3.2.6 Sampling and Recruitment

Sample recruitment was aimed to attract individuals with AKP from different socio-economic backgrounds, sporting codes and areas in the Cape Metropolitan area. Letters of invitation were sent to various universities, sports clinics, physiotherapy practices and sporting clubs in the Cape Town Metropole. Emails with study details were sent to various orthopaedic surgeons and general medical practitioners to request referral of participants who met the inclusion criteria of this study. The advertisement and letter of invitation are attached as Appendix 9 and 14.

3.2.7 Measurement Tools

3.2.7.1 Vicon 3D motion analysis system

The eight-camera Vicon T-20-series motion analysis system (Vicon Motion Systems Ltd., Oxford, UK) with Nexus 1.7 software was used to assess joint position sense (JPS). The Vicon Motion Analysis (Ltd) (Oxford, UK) system is a 3D system and it was used to obtain 3D movement analysis data. The Vicon has demonstrated high accuracy and reliability³⁰ and has been shown to have less than a 1.5-degree error.³¹ The T 20 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 grey scale images using 1120 x 896 pixels, with the ability to capture speeds of up to 250 frames per second.³² Retro-reflective markers with a diameter of 9.5 mm were used.

Dynamic calibration was performed according to standard laboratory protocol, with the bio-engineer walking through the capturing volume, while moving a standard Vicon T-wand in scooping movements. The Vicon T-wand was also used for system-marker orientation. The ability of the cameras to detect movement within the capturing volume was calculated by the software. To test the ability of the cameras to accurately detect the orientation of the markers to one another and within the capturing volume, the Vicon T-wand was placed on a 3D Bertec force plate (Bertec Corporation Ltd.), which is synchronized with the Vicon motion analysis system.

3.2.7.2 H-Frame

An H-frame was constructed (Figure 3.2) based on a study by Clark et al 2016.³³ The H-frame was constructed with PVC pipes. The two upright pipes were inserted into a weighted plastic base to aid the stability of the structure. The crossbar was formed by an elastic tubing stretched between the two upright poles. The function of the H-frame is that of a range of motion (ROM) guide when establishing the target angle (TA) for participants during the test trial. The H-frame is positioned in such a way that the rubber band (cross bar) makes contact with the distal part of the patella during single leg squat and that the crossbar touches the skin overlying the anterior ankle joint line in sitting.

3.2.7.3 Kujala/anterior knee pain scale (AKPS) questionnaire (Appendix 5)

The AKPS is a 13-item knee functional questionnaire. This scale is scored out of 100, with a higher score indicating less disability. The AKPS demonstrated high reliability and responsiveness in a population of patients with AKP.^{14 34 35 36}

3.2.7.4 Visual analogue pain scale (VAS)

This VAS scale is a well-known and used outcome measure to evaluate levels/intensity of pain.³⁶ The VAS is scored from 0 (no pain) to 10 (maximum pain). The visual analogue scale (Figure 3.1) demonstrates good reliability and responsiveness among a population of patients with AKP.^{14 34 36}

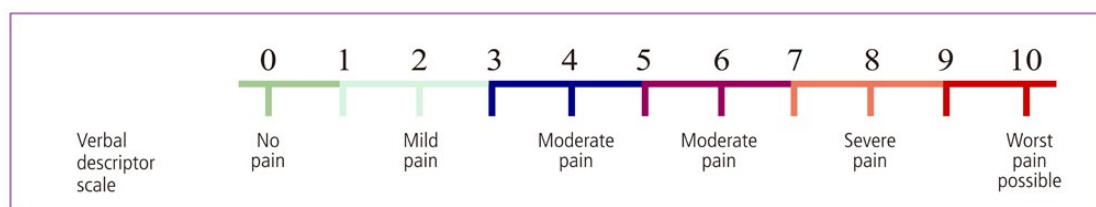


Figure 3.1 VAS (Green et al., 2014; Crossley et al., 2004; Bennel et al., 2000)

3.2.7.5 Lower extremity functional scale (LEFS) questionnaire (Appendix 6)

The LEFS consists of 20 items that measure the ability to perform various functional activities and activities of daily life. The LEFS is scored out of a maximum score of 80. The LEFS demonstrates high reliability and responsiveness in the population of patients with AKP.^{14 34 35 36}

3.2.8 Criteria for positive and negative knee joint position sense

The main outcome measurements for knee JPS testing are (i) Absolute error (AE), (ii) Relative error (RE). RE is defined as the arithmetic difference between the test or target angle and the response angles. RE represents accuracy with directional bias.^{22 24 28} AE refers to the difference between the test or target angles and the reproduced angle. Absolute error represents accuracy without directional bias.

The absolute difference between the target angle (TA) and the reproduced angle (RA) are calculated and the absolute error (AE).^{33 37} Previous researchers have stated that AE variables are the most appropriate for expressing JPS.^{18 23 38 39} The smaller the AE the better the proprioceptive function. When testing proprioception of normal subjects the AE have been found to range between 0.7 degrees and >6 degrees.³⁹ Callaghan (2002) classified proprioception as <5 degrees error as good proprioception and an error >5 degrees as poor proprioception in healthy participants. In a more recent study by Selfe (2006)²⁵ the AE ranged between 3.18 and 5.97 degrees in uninjured, physically fit, active adults. For the purpose of this study, abnormal proprioception is defined as an AE greater than five degrees. The two dependent variables AE and RE were calculated at each test position. The mean AE from five trails for each test was used for statistical analysis.^{25 33} The JPS findings of the knees with AKP were compared to that of the knees without AKP.

3.2.9 Testing Procedures

3.2.9.1 Initial screening

Data collection commenced as soon as the participant was referred to the study and informed consent was obtained. The participants completed a screening process by means of a screening questionnaire (Appendix 1) to verify inclusion via email.

Prior to proprioception testing, participants completed the AKP scale questionnaire (AKPS) and the LEFS questionnaire. A data collection form (Appendix 10) was used to collect participant personal details and variables including age, gender, body length, episodes and duration of AKP, area of symptoms, type of treatment received for AKP and sport participation.

3.2.9.2 Physical examination and diagnosis

Participants attended the FNB-3D motion analysis laboratory for a 90 minute scheduled appointment. Prior to conducting the motion analysis, the diagnostic checklist (Appendix 2)

was completed and the physical examination (Appendix 13) was performed on each participant to confirm a diagnosis of AKP and exclude other knee pathologies. The physical examination (P/E) was conducted by the main researcher (CR) who is an experienced physiotherapist. The P/E tests included functional movement tests (squats, lunges), palpation of the patella, hip, knee and ankle muscle lengths, as well as range of motion (ROM) of the hip, knee and ankle joint. Additionally, anthropometrics (weight, BMI, leg length) were measured for each participant. Data were captured as part of participant demographics to describe this population group/participants.

3.2.9.3 Preparation for Vicon testing

Participants were asked to attend Vicon testing dressed in short pants, barefoot, with clean shaven legs with no lotion on legs to ensure effective marker placement. Thirty retro-reflective markers were placed on bony landmarks according to lower limb Plug-in Gait model (PIG)³³ (Appendix 12). Additional pelvic markers, a sacral wand, two extra shin markers and extra anterior and posterior thigh markers were added, to ensure joint position sense accuracy. The main researcher (CR) performed the marker placement assisted by a research assistant who is a qualified physiotherapist. Two testing positions were used namely: standing and sitting. Reflective markers were placed in standing position in preparation for single leg squat. Reflective markers were removed and reapplied with the participant in the seated position to assure accurate positioning of markers placements. Once of the participants resumed the test position, a static and dynamic calibration was performed in standing followed by a static calibration in sitting. Each participant performed two active reproduction knee joint position sense tests in two positions, namely: single leg squat in standing and active knee extension in sitting.

3.2.9.4 Pain measurement

During the test trials the participants were asked to verbally indicate the severity of their pain using the VAS pain scale. Pain severity was measured at the start and end of knee-joint position sense testing. Pain was measured to determine if there is a correlation between proprioception and severity of pain levels as well as to describe the population group's pain levels during testing.

3.2.10 Proprioceptive Testing

All participants were familiarised with the test procedure by means of explanation, demonstration and a practice opportunity. The participants were asked to resume the test

position i.e. (i) standing, (ii) sitting. The target angle was determined by each participant according to his/her capabilities and comfort level. The target angle was therefore unique (specific) to each participant. A detail description of knee joint position sense testing is attached as Appendix 7.

3.2.10.1 Single leg squat

Starting position

For the single leg squat the participants were barefoot with one hand's fingers supported on a chair for balance. The participants were standing on the tested leg, while the other leg was flexed at the hip and knee to a degree that was comfortable for the participant, with a neutral hip joint and with an estimate of 70 to 90 degrees of flexion at the knee.²²

Instructions to participant

Participants were asked to do a single leg squat and stop in the mid-range at an angle that was comfortable for the participant. The participant was asked to briefly hold this mid-range angle to position the H-frame indicating this angle as the target angle.

Test trial

Once the test trial commenced the participants were asked to squat down till they felt the cross bar of the H-frame. The participants were verbally cued to hold the single leg squat for five seconds to establish the target angle, and familiarise themselves with the target angle. Participants were cued to return to the starting position of erect standing with zero degrees of knee flexion. The test trial was repeated five times.

Test procedure

The participants were blindfolded and the H-frame was removed. The participants were instructed to repeat the test trial, this time indicating to the researcher and bio-engineer once they had reproduced the TA by shouting STOP. This indicated the reproduced angle (RA). The participants maintained the RA for five seconds to record the data. Testing was repeated five times. The test procedure was repeated on the knees without AKP for comparison. Data were collected by the Vicon Nexus software. The same method as described by Clark et al. (2016) was used.

3.2.10.2 Sitting: active knee extension

Starting position

The participants were seated on an 800mm high bar stool, with both feet supported. Participants were positioned with the popliteal fossa approximately 5cm from the edge of the chair. The

participant's arms were crossed over their chest comfortably to avoid obstruction of the pelvic markers.

Instructions to participants

Participants were asked to actively extend the knee through 90 degrees of knee flexion to zero degrees of knee extension, ROM and stop in mid-range of this movement. The participants were asked to briefly hold this mid-range angle to position the H-frame indicating this position as the TA. The participant was verbally cued to resume the starting position.

Test trial

The participants were instructed to actively extend the knee from the starting position of 90 degrees of knee flexion to the TA. In this position the participant was able to feel the cross bar of the H-frame indicating the TA to the participant. The participants were verbally cued to hold this position for five seconds to establish the target angle and to concentrate and familiarise themselves with the target angle. Thereafter the participants were asked to return to the starting position of the knee in 90 degrees flexion. The test trail was repeated five times.

Testing

Participants were blindfolded and the H-frame was removed at the commencement of testing. The participants were asked to repeat the test trial, moving from 90 degrees of knee flexion to the TA. This time indicating to the researcher and bio-engineer once they had reproduced the TA, by shouting STOP. This indicated the reproduced angle (RA). Participants maintained the RA for five seconds to mark the data. Participants were verbally cued to return to the starting position. Testing was repeated five times. The test procedure was repeated on the knees without AKP for comparison. Data were collected by the Vicon Nexus software.



Figure 3.2 Joint position testing in a weight bearing position, SLS



Figure 3.3 Joint position sense testing in sitting (frontal view and Lateral view)

3.2.11 Data Management

Each participant was assigned a study-specific code which was linked to the research project code. Access to the data computer was restricted and the computer was password protected. The computer was stored in a safe and secure location when not in use. Participant-specific documentation and information e.g. signed consent forms (Appendix 3) and completed data collection forms (Appendix 10) were kept in a safe and secure place at the FNB-3D motion analysis laboratory. Regular data backups were done and stored on a password-protected external hard drive.

3.2.12 Statistical Analyses

All descriptive data (demographic information, functional and pain scales) were analysed using descriptive statistics to indicate central tendencies. Each participant completed five trials in each test position for both knees. Data was captured through the Vicon Nexus 3D motion analyses system. Chi-square calculations was performed to determine a significant difference in proprioception between the knees with AKP and the knees without AKP during single leg stance and active knee extension. A non-pragmatic approach was used to illustrate descriptive statistics.

3.3 Results

3.3.1 Participant demographics

A total of 25 participants complied with the inclusion criteria (Table 3.1). Of the 25 participants, the majority were female (n=22) and the group had a mean age of 27.8 years. The mean BMI of the participants was 28.2 kg/m² (range of 20.9- 45.7kg/m). Twelve (52%) of the participants reported having AKP symptoms in both knees and ten (40%) participants reported their right knee as most affected. Nineteen (76%) of the 25 participants reported being physically active and six (24%) were sedentary. The participants' mean usual pain level according to the VAS was 4.5/10.

Table 3.1 Participant demographics (n=25)

Gender	
Female	n=22
Male	n= 3
Age	
Mean (SD)	27,8 (7,6)
Range (min-max)	14 - 40
Height (cm)	
Mean (SD)	1,6 (0,0)
Range (min-max)	1.53 - 178
Weight (kg)	
Mean (SD)	78 (18.3)
Range (min-max)	49.6 - 112
BMI (kg/m²)	
Mean(SD)	28.2 (7.4)
Range (min-max)	20.9 - 45.7
Activity levels of participants	
Sedentary	n=6 (24%)
Physically active	n= 19 (76%)
Affected side of participants	
Left knee	n= 15
Right knee	n= 10
Both knees	n= 13
Usual knee pain (VAS)	
Mean (SD)	4.5/10 (2.0)
Range (min-max)	0-9/10

3.3.2 Symptom presentation

Participants' duration of symptoms ranged from two months to 11 years with a mean duration of 28.4 months (Table 2). Participant's area of symptoms was predominantly in the front of the patella (n=10; 40%) or in front and just below the patella (n=10; 40%) and five participants (20%) reported their area of symptoms to be behind the patella. The most frequently reported aggravating activities were squatting (n=19; 76%), prolonged sitting (n=10; 40%) and going up stairs (n=11; 44%).

3.3.3 Participant activity level

The participants who stayed active through physical exercise reported a mean training frequency of 2.8 times per week and training ranged from zero to six times per week. The participants' sporting activities were predominantly gym (n=12; 48%) and running (n=11; 40%), with two (8%) participants reporting being dancers. Fourteen (56%) of the participants

reported not seeking any medical treatment for their AKP symptoms, whereas nine (36%) reported using NSAIDs as needed. Three participants received physiotherapy treatment and one participant reported having acupuncture for pain relief. Fifteen (60%) of the participants were able to do all activities of daily living (ADL) and reported living with the pain. Nine (36%) participants stopped all physical activity due to the severity and intensity of the AKP. One participant admitted he found exercise and physical activity difficult and struggled to stay active.

Table 3.2 Participant symptom presentation and activity level (n=25)

Duration of symptoms (months)	
Mean (SD)	n=28.4
Range (min-max)	2-132
Area of symptoms	
Front of knee cap	n=10 (40%)
Front and below knee cap	n=10 (40%)
Behind knee cap	n=5 (20%)
Aggravating activities	
Squats	n=19 (76%)
Prolonged sitting	n=11 (44%)
Running	n=3 (12%)
Kneeling	n=6 (24%)
Lunging	n=4 (16%)
Going up stairs	n=11 (44%)
Going down stairs	n=2 (8%)
Going up and down stairs	n=4 (16%)
Treatment history	
No treatment	n=14 (56%)
NSAID	n=9 (36%)
Other	n=1 (4%)
Exercise per week	
Mean (SD)	2.8 (2.0)
Range	0-6
Sport participation	
Gym	n= 12 (48%)
Running	n=11 (44%)
Dance	n=2 (8%)
Functional limitations	
Can do all ADL	n=15 (60%)
Stopped physical activity	n=9 (36%)
Other (Struggles to stay active)	n=1(4%)

3.3.4 Outcome measures

The participants anterior knee pain score (AKPS) ranged from 52 to 92 with an average of 72 out of 100 points. A lower AKPS is indicative of greater pain and disability. A score of 70 represents moderate disability.⁴⁰ The lower extremity functional score (LEFS) ranged from 31 to 77 with an average of 58 out of 80 points. The lower the LEFS score the greater the functional impairment; a mean of 58 might imply moderate functional impairment. Participants reported that pain levels during proprioceptive testing procedure ranged from zero to 9/10 on the VAS scale with a mean pain level of 4.5 out of 10.

Table 3.3 Outcome measures

AKPS	
Mean (SD)	72/100 (13.1)
Range (min-max)	52-92
LEFS	
Mean (SD)	58/80 (12.5)
Range	31-77
Pain levels during testing (VAS)	
Mean (SD)	4.5 (2.5)
Range	0-9

3.3.5 Physical examination

During the physical examination participants performed a series of functional activities to reproduce AKP symptoms (Table 3.4). The aggravating functional activities that reproduced the participants known AKP symptoms were predominantly squats (n=25; 100%), going both up and down stairs (n=5; 20%) and going down stairs respectively (n=4; 16%).

Table 3.4 Aggravating functional activities (n=25)

Functional Activities	Participants with a positive test
Squats	n=25
Up and down stairs	n=5
Upstairs	n=4
Down stairs	n=2
Kneeling	n=2
Isometric quads	n=1

During the physical examination of the patella-femoral joint (PFJ), the passive accessory movements easily reproduced the patients' symptoms. A positive patellar compression test was reported by 22 (88%) of participants. Other PFJ accessory movements were also positive in 11 (44%) of the participants and palpation of the patella border reproduced six (24%) of the participants' pain.

Table 3.5 Patellar accessory movements (n=25 knees)

Patellar accessory movements	Total of participants with positive test
Compression test	n=22 (88%)
All PFJ accessory mvmt	n=11 (44%)
Med/lateral glide	n=6 (24%)
Patella border	n=6 (24%)
Distraction	n=5 (20%)
Long cephalad/caudad	n=5 (20%)
Isometric quads	n=2 (8%)

3.3.6 Proprioceptive results

Proprioceptive testing was performed for both knees of every participant (n=25); therefore 50 knees were assessed. Proprioception was tested in two test positions, namely single leg squat and active knee extension in sitting. Thirty-seven of the fifty knees were classified as affected with AKP (knees with AKP) and thirteen were classified as unaffected with no reported symptoms of AKP (knees without AKP). Descriptive statistics were used to demonstrate central tendencies in data (means and standard deviations). A non-pragmatic test approach was adopted by illustrating the ranges. The proprioceptive results for the knees with AKP and the knees without AKP is presented in Tables 3.6 and 3.7.

3.3.6.1 Single leg squat comparing knees with AKP and knees without AKP

The mean target angle (TA) of the knees with AKP (n=37) was 39.5 degrees compared to 44.4 degrees in the knees without AKP (n=13). The knees with AKP had a bigger variation in the TA range compared to the knees without AKP. When comparing the absolute errors (AE) the knees with AKP had a smaller AE compared to the knees without AKP, with a greater variation in the range of the AE of the two groups.

The relative error (RE) was smaller in the knees with AKP (1.4 degrees) with a greater range (-12.1 to 4.5) compared to the knees without AKP (-10.8 to 3.8). There was no difference

between the AE or the RE of the knees with AKP compared to the knees without AKP during proprioceptive testing in single leg squat.

Table 3.6 Single leg squat: Comparing JPS results between the knees with AKP (n=37) and knees without AKP (n=13)

Knees with AKP			
	Target Angle (TA)	Absolute Error (AE)	Relative Error (RE)
Mean (SD)	39.5 (9.6)	3.9 (2.6)	-1.4 (4.3)
Range	16- 59.8	0.6 – 12.1	-12.1 – 4.5
Knees without AKP			
Mean (SD)	44.4 (9.4)	5.2 (3.3)	-3.7 (4.7)
Range	27.6 – 62.3	1.8 – 10.8	-10.8- 3.8

3.3.6.2 Sitting: Active knee extension, comparing knees with AKP to knees without AKP

JPS testing was conducted during active knee extension in sitting for the 25 participants. The mean TA of the knees with AKP (n=36) was 31.7 degrees compared to 33.5 degrees in the knees without AKP. The AE was the same (AE=4.2 degrees) for both the knees with AKP and the knees without AKP. However, there was a difference when comparing the standard deviation and the range of the AE between the two groups. The group with AKP displayed greater variability compared to the group without AKP. The RE for knees with AKP was -1.8 degrees compared to 1.2 degrees in the knees without AKP. When comparing the RE, the knees with AKP demonstrated a greater variation in range (-16–8.7) compared to the knees without AKP (-7.2 – 6.1).

Table 3.7 Sitting: Active knee extension: Comparing JPS results between the knees with AKP (n=36) and without AKP (n=13)

Knees with AKP			
	Target Angle (TA)	Absolute Error (AE)	Relative Error (RE)
Mean (SD)	31.7 (9.2)	4.2 (3.1)	-1.8 (4.7)
Range	16.2 – 51.8	0.9 - 16	-16 – 8.7
Knees without AKP			
Mean (SD)	33.5 (7.4)	4.2 (1.5)	1.2 (4.4)
Range	18.5 – 44.8	1.6 – 7.2	-7.2 – 6.1

3.3.6.3 Knees with AKP with altered proprioception compared to knees without AKP with altered proprioception (n=50 knees)

A total of thirty-seven knees (37/50) presented with AKP (Table 3.6). During single leg squat 10/37 (27%) of the knees with AKP presented with altered proprioception with an AE equal or greater than five degrees. The mean AE of the ten knees with AKP and altered proprioception was 7.4 degrees with a range of five to twelve degrees. Twenty-seven (73%) of the knees with AKP had an AE of less than five degrees, with a mean AE of 2.6 degrees and a range of 0.6 to 4.5 degrees.

During active knee extension 10/36 (28%) of the knees with AKP presented with altered proprioception with an AE equal or greater than five degrees. The mean AE of the ten knees with AKP and altered proprioception was 8.3 degrees and ranged between five and 16 degrees, compared to a mean AE of 2.6 degrees and a range of 0.9 to 4.6 degrees for the 26 knees with AKP and good proprioception.

Table 3.8 Knees with AKP comparing the AE results

	Absolute error > 5 degrees	Absolute error < 5 degrees
Single leg squat (SLS) n=37		
Total participants	10 (27%)	27 (73%)
Mean (SD)	7.4 (2.1)	2.6 (1.0)
Range	5 – 12.1	0.6 – 4.5
Sitting Active knee extension (n=36)		
Total participants	10 (28%)	26 (72%)
Mean (SD)	8.3 (2.9)	2.6 (1.0)
Range	5 - 16	0.9 – 4.6

A total of thirteen of the fifty knees 13/50 (26%) were unaffected with no symptoms of AKP (knees without AKP). During single leg squat six of the thirteen 6/13 (46%) knees without AKP had altered proprioception with an AE equal or greater than five degrees. The mean AE during single leg squat for the knees without AKP was 8.3 degrees, with a range of 5.4 to 10.8 degrees. Compared to the AE of the knees without AKP during active knee extension, 7/13 (53%) had a mean AE of 2.6 degrees and a range of 1.8 to 3.9 degrees.

During active knee extension in sitting four of the thirteen 4/13 (30%) knees without AKP presented with altered proprioception with an AE equal or greater than five degrees. The mean AE was 5.9 degrees with a range of 5.2 to 7.2 degrees. Compared to the 9/13 (69%) with a mean AE of 3.5 degrees and a range of 1.6 to 4.9 degrees.

Table 3.9 Knee without AKP comparing the AE results (n=13)

	Absolute error > 5 degrees	Absolute error < 5 degrees
Single leg squat (SLS)		
Total participants	6 (46%)	7 (54%)
Mean (SD)	8.3 (2.0)	2.6 (0.8)
Range	5.4 – 10.8	1.8 – 3.9
Sitting Active Knee extension		
Total participants	4 (31%)	9 (69%)
Mean (SD)	5.9 (0.9)	3.5 (1.1)
Range	5.2 – 7.2	1.6 – 4.9

A Chi-square calculation was done to determine a significant difference in altered proprioception between knees with AKP and knees without AKP during single leg squat. The Chi-square statistic was 1.61. The p-value was 0.20. The result no significant difference $P < 0.05$.

Table 3.8 Chi-square calculation for significance in proprioception during SLS between knees with AKP compared to knees without AKP

Knees with AKP (n=37)			
	Impaired	Not impaired	Marginal Row Totals
Total participants	10 (11.84) [0.29]	27 (25.16) [0.13]	37
Knees without AKP (n=13)			
Total participants	6 (4.16) [0.81]	7 (8.84) [0.38]	13
Marginal column totals	16	34	50 (grand total)

A Chi-square calculation was done to determine a significant difference in altered proprioception between knees with AKP and knees without AKP during active knee extension in sitting. The Chi-square statistic was 0.04. The p-value was 0.08. The result no significant difference $P < 0.05$.

Table 3.9 Chi-squared calculation for significance in proprioception during sitting, active knee extension between knees with AKP and knees without AKP

Knees with AKP (n=36)			
	Impaired	Not impaired	Marginal Row Totals
Total participants	10 (10.29) [0.01]	26 (25.71) [0]	36
Knees without AKP (n=13)			
Total participants	4 (3.71) [0.02]	9 (9.29) [0.01]	13
Marginal Column totals	14	35	49 grand total)

3.4 Discussion

The aim of this study was to investigate proprioceptive changes in individuals with AKP. Proprioception was evaluated by means of joint position sense (JPS) testing making use of active reproduction tests in both a weight bearing (single leg squat) and a non-weight bearing position (active knee extension in sitting). Twenty-five participants were included and 50 knees were evaluated. Thirty-seven knees were affected with AKP compared to 13 unaffected knees. The absolute error was used as the main outcome measure to describe proprioception (joint position sense), with a value equal or greater than five degrees being interpreted as altered proprioception.³⁷ The relative error was evaluated to give an indication as to size and directional bias of JPS measurements.

3.4.1 Main Findings

The present study showed that there was no a significant difference in proprioceptive abilities when comparing the knees with AKP to the knees without AKP. This finding is supported by similar published studies which also reported no, or statistically insignificant, differences in proprioception between individuals with and without AKP.^{12 27 28} These authors investigated proprioception in an athletic population,²⁷ in females diagnosed with PFP¹² and Benelle et al (2005) looked at the effect of self-induced AKP among healthy subjects. In comparison with the current study similar methods were used by Naseri et al (2012) and Benelle et al 2005,^{12 27 28} i.e. active JPS testing, however Yosmaoglu et al (2013) made use of active JPS testing through a horizontal squat to evaluate JPS. The measurement tools used differed to the methods used in the current study. These authors^{12 27 28} made use of reflective markers, computer analyses, digital photography and a computerised squat system to evaluate JPS. The variable

errors which refers to the standard deviation of the RE of all trails were calculated to express JPS by these authors and healthy controls were used for comparison.

A number of reasons could explain why a significant difference in impaired proprioception could not be established between the knees with AKP group and the knees without AKP group. A possible reason for these findings could be that only participants with unilateral and bilateral AKP were included in this study. In retrospect, a group with no AKP would have been useful to better identify differences in proprioceptive abilities. Naseri et al. (2012) reported no significant difference between an athletic population with AKP and controls. This was thought to be due to the severity of the knee pathology, the pain levels of the participants and their activity levels as athletes. The pain levels of the population group in the current study had a big range (0-9) and mean pain levels (4.5/10) according to VAS was of a moderate level (Table 3.1). One can debate that the severity of pain levels needed to be higher than moderate to influence proprioceptive abilities.²⁷ In the current study both active and sedentary participants were included. The activity levels of the participants in the current study also may have played a role in the study findings. Seventy-six percent of participants were physically active and activity levels ranged up to six times per week with an average activity level of 2.8 times per week. The athletic abilities and higher levels of motor function could account for proprioceptive feedback from adjacent joints and muscles.^{27 41}

It is important to note, however, that whether proprioception is affected or not remains inconclusive. There is a reasonable number of published papers stating that proprioception is affected more in people with AKP compared to individuals without AKP.^{19 20 21 22 29} The physiological rationale explaining altered proprioception in a population with AKP could be due to small nerve damage in the lateral retinaculum of the patella.⁴² Maltracking of the PFJ is thought to cause secondary changes in the nerves innervating the lateral retinaculum of the PFJ.⁴² Mechano-receptor damage is described by many authors as a reason for altered proprioception in individuals with AKP.^{26 38} Muscle spindles in the skeletal muscles are the most important source of proprioceptive feedback.²³ AKP may lead to altered proprioceptive input from muscle spindles, caused by weak quadriceps muscles, altered timing of the VMO and altered tissue flexibility of the quadriceps, hamstring muscles.^{19 43 44} Disturbed proprioceptive input could result in altered motor reaction resulting in altered proprioception in individuals with AKP.²⁶

To interpret the findings of my study, it is important to understand the nature and interpretation using JPS as the proxy measure indicating the level of proprioception. The test procedure in the present study made use of active reproduction of a joint position sense to determine proprioception. JPS best expresses proprioception in the knee joint and is the most common method used to measure knee joint proprioception.⁴¹ The JPS test assesses precision and accuracy in repositioning a joint at a pre-determined target angle (TA) in the absence of vision.⁴⁵ To establish the JPS in the knee joint during testing the AE was calculated as the mean difference between the TA and the reproduced angle. The AE has been found to be a reliable measure to express proprioceptive function and is well documented in previous studies in this field.^{13 21 22 26} The interpretation of this test indicates that a relatively smaller AE indicates better proprioception than a larger AE. When comparing the AE for the knees with AKP to the knees without AKP, a number of studies described the AE in normal participants as less than 5 degrees AE.^{33 37 39} Based on these studies it was decided to use a normative value of an AE equal to and greater than five degrees as the criterion for poor proprioception. Although this criterion was applied in a study by Callaghan et al. (2002), the generalisability of this criterion remains debatable. This criterion has not been established among individuals with AKP, and has only been used in healthy subjects to grade proprioceptive function when applying patellar tapping. A criterion for altered proprioception is still debatable due to the lack of evidence and consensus on the appropriate value of AE. It proves difficult to establish a normative value for altered proprioception due to a lack of homogeneity regarding methodologies.^{19 21 29} More research is needed in larger groups to assist in refining this criterion.

Comparing published studies in the field is hampered by the use of different measurement tools. The current study made use of the Vicon 3D motion analysis system as the measurement tool. The Vicon 3D motion analysis system is regarded as the gold standard in motion analyse³⁰ and is considered a reliable measurement tool.³³ Clark et al. (2016) reported on the reliability and measurement precision of knee joint JPS testing in healthy individuals using the Vicon 3D motion analysis system. Clark et al. (2016) found JPS in prone knee flexion and prone knee extension to demonstrate moderate to good reliability. The measurement tools used in previous studies to evaluate knee proprioception ranged from reflective markers and computer analyses^{22 27 28} to digital and onscreen goniometers.^{21 25} These measurement tools may prove reliable to measure knee JPS, however, due to the difference between these measurement tools it is difficult to compare JPS results to the findings in the current study. More recent studies made use of the Biodex system to measure proprioception.^{19 20} The Biodex is considered a

reliable measurement tool to evaluate proprioception but can account only for non-weight bearing testing of proprioception. In addition to the reliability of the Vicon 3D motion analysis it also enables proprioceptive testing in both a weight bearing and non-weight bearing position; therefore, increasing the clinical and functional applicability of the system. Therefore, the Vicon 3D motion analyses system offers the advantage of testing proprioception in functional positions which may improve the validity of translating laboratory findings in real life.

Another valuable finding in this study was that proprioception was altered in the knees with AKP as well as the knees without AKP. Similar results have been reported by Baker et al. (2002) and Cyrillo et al. (2014) when comparing proprioception in individuals with PFPS compared to healthy controls. These authors found proprioception to be altered in both the knees with AKP and the knees without AKP. These authors could not provide reasons for their findings of altered proprioception in the knees without AKP. An explanation to interpret altered proprioception in the knees without AKP is still unclear and is thought to be due to compensatory mechanisms during gait.^{46 47} Patients with AKP may develop a quadriceps avoidance gait pattern to decrease PFJ reaction forces and to avoid pain.⁴⁸ As proprioception is processed at a central level and abnormal sensory and proprioceptive information is processed, an abnormal motor response can therefore present bilaterally.²⁶ It is thought that biomechanical abnormalities present in AKP might present or manifest bilaterally, clinical asymptomatic biomechanical changes. The knees without AKP of individuals with AKP might have an inherent genetic predisposition to poor proprioception in both knees with AKP and the knees without AKP. Further research is needed to clarify the possible reasons for altered proprioception being present in the asymptomatic knee of individuals with AKP.

The AE of the knees with AKP displayed a bigger variation in the range during SLS (5-12.1) and active knee extension (5-16) compared to the knees without AKP. The range of the AE exceeded 12° and 16° respectively during the two test positions for the knees with AKP (Table 3.6). Even though the value of the AE was similar between the two knee groups, the variation in range could be due to uncertainty to reproduce the TA of the knees with AKP (Tables 3.6, 3.7). The variation in range could also reflect poorer proprioceptive abilities in the knees with AKP. In the present study the AE and the range of the AE are remarkably larger than documented in published studies in this population. Yosmaoglu et al. (2013) reported a mean AE of 2.8° compared to 3.0° in healthy controls and Naseri et al. (2012) documented a mean AE that ranged from 3.2° to 6.1° in an athletic population with AKP. The current study had an AE of 7.4° during SLS and 8.3° during active knee extension. These findings could also be due

to the measurement precision of the Vicon 3D motion analysis system.³² The Vicon 3D motion analysis system has been shown to have less than a 1.5-degree error.³¹

The results (Table 3.6) reflected a tendency towards a bigger AE (8.3) during active knee extension (sitting) of the knees with AKP compared to SLS (7.4). The differences in the AE could be due to the weight bearing and non-weight bearing test positions and the effect on the proprioceptive functioning of the knee. Stillman and McMeeken (2001) compared JPS testing during a weight-bearing and non-weight bearing test position. They found WB testing to be more reliable and accurate for JPS compared to NWB test procedures. However, NWB testing had a greater potential to reveal proprioceptive status of the knee joint only. During WB testing one can argue that proprioceptive feedback is also obtained through other joints and greater muscle resistance throughout the lower limb.^{24 41 49} This tendency towards a bigger AE during sitting could justify our findings that the AE during SLS could have been influenced by proprioceptive feedback from adjacent joints like the hip and ankle as well as increased muscle resistance throughout the lower limb. During active knee extension, we believe the AE to be a true representation of the proprioceptive function of the knee joint.

The TA (Table 3.8, 3.9) displayed a tendency to be smaller in both the SLS and active knee extension test positions in the knees with AKP compared to the knees without AKP. These findings could be reflective of the participants' pain levels as well as an increase of PFJ compression during SLS and knee extension.^{50 51} The TA in the current study was self-determined by each participant to his/her own capabilities and comfort levels, as well as their individual pain levels. It was evident during the pilot study that participants found it difficult to reach a pre-determined target angle of 60 degrees as described in previous studies.^{19 22 21 25} Cyrill et al. (2014) reported not using a target angle of 60 degrees due to high levels of instability and participants being unable to stay in place during testing. In the current study the TA was self-determined and set by means of an H-frame which acted as a target indicator as described by Clark et al. (2016). During the pilot study a real time TA indication was used to indicate the TA to participants. This method proved unreliable compared to the Vicon 3D motion analysis system. This method used during the pilot study led to a large standard deviation in the TA findings.

The RE of the knees with AKP reflected a negative value throughout the two test positions. This negative value indicates that during SLS and active knee extension knees with AKP were in most cases unable to reach the TA (undershooting of the TA). This could also be a

representation of poorer proprioceptive functioning of the knees with AKP. Another reason for the undershooting of the TA could be decreased eccentric strength of the quadriceps muscle. The quadriceps muscle strength and delayed timing of the VMO muscle are reported as risk factors for the development of AKP.^{19 43 44} These risk factors are thought to play a role in muscle spindle feedback and can influence proprioceptive feedback. Quadriceps strength was not tested for in this population group and therefore we cannot report whether it played a role in the proprioceptive outcome of this study population.

The knees with AKP (Table 3.8: -16-8.7) had a larger range of the RE compared to the knees without AKP (-7.2- 6.1) during active knee extension. The greater range of the RE during a NWB position could be due to the sole dependency on the knee joint for proprioceptive feedback and no influence of the rest of the lower limb joints during a NWB test position.^{43 49}

The literature suggests that AKP is common among active individuals (more so runners) and has a higher incidence in females.^{10 52 53} The current study population is reflective of these findings. Females constituted the majority of the study population, two-thirds were active individuals and 44% were runners. The population group was not restricted, however, to active individuals alone and highlights the fact that AKP can affect sedentary individuals as well.⁵⁴ AKP symptoms in this study population were not restricted to just one knee, and more than half the individuals reporting both knees being symptomatic at times. The literature also makes note of this as previous studies in this field have indicated that AKP can be present in both knees.^{13 22}

AKP is aggravated through a series of functional activities that load the PFJ and this was also evident during the physical examination of this study's participants.¹ All of the study participants reported squats as the most common aggravating functional activity and this proved evident during the physical examination. The study participants had a mean AKPS score 72 (Table 3.3) that is reflective of moderate levels of pain and disability.⁴⁰ The mean levels of the LEFS indicated functional limitations and could reflect poor prognosis with symptoms likely to persist for many years in this population group.⁴⁸ Participants in this current study reported living with the dysfunction and mostly managing the condition themselves. More than 50% reported not seeking medical advice to treat AKP symptoms. AKP does not seem to be self-limiting with participants being able to perform all ADL; however, this population group suggested that AKP can lead to a decrease in physical activity as a result of AKP severity.

What is evident in this study population is that AKP symptoms can be persistent for many years, even after medical intervention. The mean symptom duration reported in previous studies ranged from three to 120 months,²⁷ compared to two to 132 months in this population group. The longer the duration of symptoms, more than two months is reflective of a poor prognostic outcome.⁵⁵ The chronicity of AKP is evident that treatment of AKP remains challenging, thus a better understanding of the aetiology of the condition needs to be established.^{5 56}

3.4.2 Clinical Applicability of the Study

AKP remains a disorder that proves difficult to manage due to its multifactorial nature and long duration of symptoms in this current population group. AKP affects both physically active and sedentary individuals and can lead to moderate functional impairments and disability in those affected with AKP. Knee proprioception plays an important part in motor control and the ultimate stability of the knee joint, as seen in the current study and previous studies in this population group. Altered proprioception does not only affects the knees with AKP but can also exist in knees without AKP. When evaluating patients with AKP clinicians should test both knees for signs of AKP and altered proprioception. The test procedure and methods used to assess knee proprioception could be easily reproduced in a clinical setting. The test positions used in this study are functional activities already used as part of the physical examination of the knee joint by physiotherapists. JPS active reproduction of a self-determined TA can be measured by means of a digital goniometer which is easily accessible on a smart phone.⁵⁷ The digital goniometers are able to take images of the patient and the joint angles during a functional activity. The joint angles displayed by the goniometer can be used to interpret JPS. The AE can be calculated from these values obtained by the digital goniometer application on a smart phone. This can be used as a screening to assess knee joint proprioception and guide clinicians whether to address proprioceptive changes during rehabilitation. One should take in to account, however, that at least five trials need to be done to account for an accurate display of proprioceptive abilities.²⁵ The number of trials could influence available treatment time, however, and have a monetary implication for the patients as well as for clinicians with a heavy workload.

3.4.3 Limitations

In this study only JPS testing was done, which is only one aspect of proprioceptive testing. Kinesthesia or movement sense was not assessed during this current study and should be explored in future studies. Testing kinesthesia could give insight into participant conscious awareness of joint motion. Only a small percentage of the knees with AKP and the knees without AKP had an AE greater than five degrees. These findings cannot be generalised to the rest of the population due to the small sample group. Adding healthy controls to the study could allow for a fairer comparison of proprioceptive abilities, but selection of suitable controls is crucial to allow for matching of specific characteristics and can pose some difficulty. A study done by Clark et al. (2016) suggested that testing active knee JPS in prone (prone knee flexion and prone knee extension) proved reliable and useful in estimating how proprioception contributes to knee function and knee stability. This test position could bring new findings when testing in a population group with AKP. Testing JPS in prone should be considered in future studies. As this was a laboratory based study these measurements cannot be replicated in a clinical setting as the Vicon 3D motion analysis system is not portable.

3.4.5 Recommendations for Future Research

There is still limited research on investigating proprioceptive changes in individuals with AKP, and conflicting results still remain a cause of concern. The use of larger sample groups and being able to match cases to healthy controls with unaffected knees should be addressed in future studies, maybe the elastic band in the H-frame can be replaced with an rigid band to control the variation in setting the TA. The best test procedure still needs to be described to assess proprioception as it still remains challenging to conclude findings due to variation in testing methods and measurement tools. A normative value for abnormal proprioception, e.g. absolute error or a grading scale to grade proprioceptive abilities should be addressed in future studies.

3.5 Conclusion

This study investigated proprioceptive changes in individuals with AKP. The findings showed that proprioception is not significantly more impaired in knees with AKP compared to knees without AKP during active reproduction proprioceptive testing. The use of the Vicon 3D motion analysis system added to the measurement precision and clinical applicability of the

test procedure. The test procedure can be easily reproduced in a clinical setting as the test positions are already part of the clinical assessment of the knee joint. A group of knees was identified with altered proprioception with an absolute error equal to or greater than five degrees in both the knees with AKP and the knees without AKP. This finding could be due to compensatory gait patterns in patients with AKP. There was a tendency toward a larger mean AE in the knees with AKP during active knee extension in sitting. The larger mean AE during sitting could be due to non-weight bearing testing that is more reflective of the proprioceptive status of the knee joint. During proprioceptive testing in a weight bearing position, feedback is also obtained through other joints and greater muscle resistance is generated throughout the lower limb. This finding supports that researchers and clinicians should consider testing specifically for knee proprioception in a non-weight bearing position. A normative value of the AE to establish a criterion for altered proprioception requires further investigation. A normative criterion to classify altered proprioception can aid researchers and clinicians to better identify altered proprioception in a population with AKP. The findings in this study highlight that a group of individuals with altered proprioception exists in a population with AKP. When assessing individuals with AKP both knees should be assessed for altered proprioception and proprioceptive rehabilitation should be included in the management of population groups with AKP.

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Chapter 4 Summary and Conclusion

The main objective of this study was to assess proprioceptive abilities in a population with AKP. A cross sectional descriptive study design was used to collect data. Participants were recruited from various parts of the Cape Metropolitan area as well as from different economic and social back rounds. Twenty-five participants responded to the study advert and complied with the inclusion criteria and provided informed consent to participate. The diagnosis of AKP was confirmed with the use of a screening tool, a diagnostic checklist as well as a physical examination of the knees with AKP prior to proprioceptive testing. Participants completed the AKPS and the LEFS questionnaires to assess their functional impairments and their degree of disability. The VAS pain scale was used to assess usual pain and pain during testing. The Vicon 3D motion analysis system was used to assess joint position sense of the knee joint. The Vicon 3D motion analysis system has been used previously and is considered a gold standard measurement tool with a measurement error of 1.5 degrees (Richards 1999, Clark et al 2016). Joint position sense is a well-documented method used to assess proprioception of the knee joint (Lokhande et al 2013). Joint position sense tests the precision and accuracy in repositioning a joint angle. An H-frame was constructed as described by Clark et al 2016. The purpose of the H- frame was to establish the target angle (TA) for the participants and aided as a TA indicator during the trial testing.

The proprioception test procedure included active knee joint position sense testing in two test positions namely single leg squat and active knee extension in sitting. Participants were dressed in shorts and thirty reflective markers were placed on key bony areas of the lower limb of each participant in preparation for motion analyses testing. Each participant was familiarised with the test procedure by means of explanation and demonstration of the test procedure. The TA was self-determined by each participant according to his or her own capabilities and pain levels. During the test trail participants were asked to move through full range of motion of the knee joint and stop somewhere in the midrange of the knee joint. Participants were asked to maintain that position for a short while to position the H-frame at that specific TA. Once the TA was set participants performed five test trials moving from the start position to the TA, holding the TA for five seconds to record the TA as well as to familiarize themselves with the TA. During testing participant were blindfolded and the H-frame was removed. Participant were cued to reproduce the TA and indicate to the researcher

once they have reached the TA. The participants were asked to maintain the TA for five seconds to capture the TA (reproduced angle). Participants were cued to return to the start position. The test procedure was repeated five times for each leg and for each test position (single leg squat and active knee extension).

Data analyses was done by the Vicon 3D motion analyses system for interpretation. The absolute error and the relative error was the main outcome measures used to describe proprioceptive abilities. A criterion with a normative value for altered proprioception was used according to previously published studies testing JPS and who reported on the absolute error in healthy individuals. An AE of equal or greater than five degrees was considered as altered proprioception in this population group with AKP. The data of five trials were used to ascertain the variability in error. The normative criteria of the AE equal or greater than 5 degrees was used for interpretation. All descriptive data (participant demographics, functional and pain scales) was analysed using descriptive statistics (means, standard deviations) to indicate central tendencies. A non-pragmatic test approach was adopted by illustrating the ranges. Chi-square statistical calculations were performed to test for differences in the proportions between the knees with AKP compared to the Knees without AKP.

Analyses of the participant demographics revealed that (88%) of the study participants were predominantly female, with a mean age of 27.8 years and a mean BMI of 28.2. More than half of the study population had AKP symptoms in both knees. The mean pain levels according to VAS pain scale was 4.5/10 with the mean duration of participants symptoms ranged from two to 132 months. Seventy six percent (76%) of the participants' symptoms were aggravated with squatting. Seventy six percent (76%) of participants reported being active with 44% reported being runners. The mean AKPS scores were 72/100 and the LEFS score was 58/80. These scores are reflective of moderate levels of functional impairment and disability. Sixty percent (60%) of the study population reported being able to do all ADL however 36% stopped physical activity due to the severity of AKP.

The main findings in this study was that an insignificant difference in proprioception exists between the knees with AKP compared to the knees without AKP. However, we found a group of participants with altered proprioception in both the knees with AKP and the knees without AKP. These findings are supported by previous studies (Naseri et al 2012, Yosmaoglu et al (2013), Bennell et al (2005). Contrary to these findings by (Baker et al (2002) Haznezi (2005) and Cyrillo et al (2014) reported significant differences in

proprioceptive function in participants with AKP compared to healthy controls. Participant's severity of knee pathology, pain levels and activity levels are thought to have played a role in the findings in the current study. The population group in the current study demonstrated moderate pain levels and high activity levels which could have influenced the findings. The pain level of participants may need to be of a higher level to influence proprioceptive abilities in certain individuals with AKP. The participants' high activity level could have compensated for the poor proprioception through other joints. A valuable finding in this study was that proprioception was altered in both the knees with AKP and the knees without AKP. Baker et al (2002) and Cyrillo et al (2014) found similar findings and postulated that compensatory or altered gait patterns to reduce loading on the PFJ and to avoid pain (Nadeau et al 1997, Barton et al 2009) may have an effect on the proprioceptive abilities of the asymptomatic knees in the participants with AKP.

The absolute error (AE) had a tendency towards a larger range in the knees with AKP during both test positions compared to the knees without AKP. This finding could be reflective of the proprioceptive function of the knees with AKP and participant uncertainty during testing to locate the TA. The AE in the current study is larger than reported in previous studies (Baker et al 2002, Aseki et al 2008) and could be due to testing both in a weight bearing and none weight bearing position as well as the accuracy of the Vicon motion analysis system (Clark et al 2016).

There was a tendency toward a larger AE as well as a larger range in the AE during active knee extension compared to SLS in the knees with AKP. Studies done by Lokhande (2013) found JPS testing in a weight bearing position as in SLS to be more reliable and functional compared to a none weight bearing test procedure. However, the non-weight bearing test position is a truer representation of the proprioceptive function of the knee. The TA of the knees with AKP were smaller than the TA in the knees without AKP. It is thought that pain avoidance due to increased PFJ pressure may be responsible for a smaller TA in the knees with AKP (Powers 2003). The relative error (RE) across tests in the knees with AKP had a negative value. This finding indicates that participants were undershooting the TA and therefore not reaching their TA. Decreased or insufficient eccentric control of the quadriceps muscle is thought have an influence on this finding (Guney 2016, Kaya et al 2010). Quadriceps strength was however not assessed during the physical examination of this study and therefore we are unable to make any definitive associations.

A significant difference in proprioception could not be established between the knees with AKP compared to the knees without AKP during active reproduction proprioceptive testing during single leg stance and active knee extension. The inclusions of a group of healthy matched controls could have made for a better comparison of proprioceptive findings. However the study was able to identify a group of knees with altered proprioception in both the knees with AKP and the knees without AKP. When comparing the knees identified with altered proprioception, in both the knees with AKP and the knees without AKP, to the healthy knees, no similarities or differences could be identified. Based on this no further associative studies were performed. The absolute error in the knees with altered proprioception proved bigger than previously published studies in this field. The use of the Vicon 3D motion analyses system added to the measurement precision in this current study (Richards 1999).

A normative value of the AE to establish a criterion for altered proprioception requires further investigation. The findings in this study highlights that a group of individuals with altered proprioception exist in a population with AKP. When assessing individuals with AKP both knees should be assessed for signs of AKP as well as altered proprioception. Proprioceptive rehabilitation should be considered for inclusion during management of patients with AKP.

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Appendix A: Summary of Studies on AKP and Proprioception used in the Literature Review

Author and country	Research Topic	Type of study and setting	Population group	Aim of study	Methods	Materials used to obtain results	Data Analyses	Results	Conclusion
Baker et al., 2002 Australia	Abnormal joint position sense in individuals with patellofemoral pain syndrome	Cross-sectional study. Laboratory setting	20 participants with AKP compared to 20 healthy controls (15 females and 5 males)	The aim was to compare Joint position sense (JPS) in 20 individuals with AKP to healthy controls.	5 active tests with ipsilateral matching response performed at 20 and 60 degrees Flexion, NWB. 40 degrees flexion under unilateral and bilateral WB was tested	4 reflective markers were placed on the knee joint. Response angles was determined using computer analyses of videotape images.	Three dependent variables (Relative error, Absolute error and Variable error) were calculated for NWB and WB test positions	JPS was significantly less accurate and less consistent in the (i) knees with AKP compared to controls in each of the test positions. (ii) Less accurate when comparing the affected to unaffected knee. (iii) Less accurate when comparing the asymptomatic less of AKP participants to controls.	This study provide further evidence that proprioception is disturbed in individuals with AKP.

Author and country	Research Topic	Type of study and setting	Population group	Aim of study	Methods	Materials used to obtain results	Data Analyses	Results	Conclusion
Selfie et al 2005 United Kingdom (Manchester)	An investigation into the number of trails during proprioceptive testing in patients with Patellofemoral pain syndrome	Laboratory setting	32 patients diagnosed with Patellofemoral pain was admitted to the study (17 male and 15 female)	The aim was to investigate the effect of number of test trails in the assessment of JPS in patients with Patellofemoral pain.	Knee JPS was measured by active ipsilateral matching at 20 and 60 degrees of knee flexion. Two techniques were used; Passive Angle reproduction (PAR) and Active angle reproduction (AAR)	A Dynamometer was used for both PAR and AAR. Knee angles were recorded with a on screen goniometer.	The arithmetic difference between the TA and RA were found. The effect of number of trails were investigated by calculating the Cumulative mean and standard deviation	Results show that 5 repetitions are required for AAR and 6 repetitions for PAR. They found no significant difference between the two joint angles measured. However, a significant difference between the two tests.	Results show that once of ipsilateral JPS testing may have erroneous data. Stability of data was achieved after 5 repetitions of active reproduction and 6 for passive
Hazneci et al 2005 Ankara, Turkey	Efficacy of Isokinetic exercise on Joint position sense and muscle strength in Patellofemoral pain syndrome	Military medical academy	24 males with AKP and 24 healthy individuals	The aim was to demonstrate the impairment of knee JPS in individuals with PFPS and investigate the effects of isokinetic exercises on JPS and muscle strength	Isokinetic exercises protocols were carried out at angular velocity of 60degrees/s and 180 degrees/s over period of 6weeks/3 times per week. JPS and muscle strength was tested before and after.	JPS was measured using passive joint position sense (PJPS). Reproduction of Passive positioning using Cybex Norm dynamometer. NWB seated position at 40 degrees TA from a starting position of 25 degrees of flexion (extension mvmt). 50 degrees TA from a starting position of 65 degrees of flexion (flexion mvmt)	Angular displacement was recorded as error in degrees between the TA and RA. Mean of 2 trails was calculated to determine an average error. Isokinetic dynamometry was used evaluate muscle strength. VAS for pain rating during ADL before and after exercise testing.	After the isokinetic exercise flexion peak torque, extension peak torque, flexion total work, extension total work. Passive reproduction of knee JPS for 40 degrees of knee flexion and 50 degrees of extension and pain scores improved after 6 weeks.	Isokinetic exercise had a positive effect on passive position sense of the knee joint. Muscle strength and muscle work increased. Isokinetic exercise can be beneficial to patients with PFPS
Bennell et al 2005 Melbourne Australia	Effects of experimentally-induced anterior knee pain on	Repeated measures within	16 (11 female, 5 male) individuals	The aim was to evaluate the effect of experimentally	Knee JPS was measured using active ipsilateral limb response at	Four reflective markers were place on the lateral thigh and leg. These	Three variables were calculated for each JPS test (i) Relative error	Knee JPS was not altered by acute knee pain in any of the tested	Knee JPS was reduced by an attention-demanding

Author and country	Research Topic	Type of study and setting	Population group	Aim of study	Methods	Materials used to obtain results	Data Analyses	Results	Conclusion
	knee joint position sense in healthy individuals	subject design. Laboratory setting	with no history of knee pathology (Aged 18-25)	induced knee pain on knee JPS in healthy individuals	20 and 60 degrees NWB and 20 degrees single leg stance (WB). Knee JPS was under three experimental conditions(i) base control (ii)whiles performing an distraction task (iii) during experimentally induced knee pain	markers facilitated computer measurements of videotaped knee joint test and response positions. Freidmans test was used for pain assessment. JPS error determined by (ANOVA)	(ii) absolute error and (iii) variable error.	positions. Distraction tasks resulted in poorer concentration and greater JPS absolute error at 20 degrees NWB as well as WB position. There was no significant correlation between levels of pain and JPS error	task but not by experimentally induced pain
Akseki et al 2008 Turkey	Proprioception of the knee joint in patellofemoral pain syndrome.		28 patients (18 female and 10 male) with a clinical diagnose of unilateral PFPS (aged between 16 and 48) compare to 27 (13 females and 14 males) normal volunteers (aged between 19 and 32)	The purpose of the study was to investigate knee proprioception in patients with patellofemoral pain syndrome (PFPS)	Knee proprioception was measured by active JPS at four different angles (15, 30, 45 and 60 degrees) in supine NWB.	A digital goniometer was fixed to the patients and controls knees. Indicating target and reproduced angles.	The deviation of the average of six measurements from the target angle were recorded for all angles, this was expressed as the Reproduction error.	Proprioceptive error was greater at all target angles in the affected knee compared to the contralateral knee of the participants and compared to controls.	Results indicate that patients with PFPS have impaired proprioception in the affected knee as well as contralateral knee. (AE =3,8 degrees)
Naseri and Pourkazemi (2012)	Difference in knee joint position sense in	Descriptive, cohort study	20 athletes (10 men and 10 woman)	The purpose of the study was to evaluate knee	Knee JPS was test in NWB position sitting with a TA	JPS was evaluated using digital photography, skin	Data analyses was done based on Baker et al 2002.	There was no significant difference between	Due to limited number in participants

Author and country	Research Topic	Type of study and setting	Population group	Aim of study	Methods	Materials used to obtain results	Data Analyses	Results	Conclusion
Tehran and Australia	athletes with and without patellofemoral pain syndrome		with PFPS compared to 20 aged matched healthy controls with the same physical activity level	JPS in athletes with PFPS and compare to healthy controls under WB and NWB conditions	of 20 and 50 degrees. Participants leg was passively move to TA. Participant was asked to reproduce the TA (Three times) WB JPS was test with a single leg squat with a target angle of 40 degrees (Three times)	markers and AutoCAD software. Pain was measured using Visual analogue scale (VAS)	JPS was expressed by AE by subtracting TA from the RA. An average of three trails were used for each test. AE of 1,1 degrees would be of interest. T-test were used to compare AE between two groups.	the two groups with regard to AE in all tree test conditions	with low level of PFPS, no difference in JPS was found compared to controls.
Yosmaoglu et al 2013 Turkey	Is there a relationship between tracking ability, joint position sense and functional levels in patellofemoral pain syndrome	Prospective cohort study	43 women diagnosed with patellofemoral pain syndrome where included compared to 31 healthy controls.	The purpose of the study was to investigated proprioception and motor control changes in patients with PFPS and how these changes related to knee function, pain, muscle strength and muscle endurance.	Peak quadriceps femoris and hamstring muscle iso-kinetics torque were recorded at 60 and 180 degrees (Functional squat system) JPS was tested by active reproduction joint position during horizontal squat (NWB). Muscle co-ordination and muscle control tested by means of tracking-trajectory test. Muscle endurance by means of a computerized	JPS was measured by a functional squat system. error (once off).	The linear difference between the reference and reproduced trail was calculated as the active reproduction. Muscle function endurance test consisted of 20 SLS with 20%of body weight, software determined the squat force. Muscle torque was tested with a dynamometer.	Active reproduction of JPS did not differ between PFPS and control groups. Tracking-trajectory error, hamstring and quadriceps peak isometric torque, muscle endurance scores were significantly lower in the PFPS compared to controls.	Knee JPS was not impaired in PFPS, this group had significant impaired muscle endurance and strength compared to controls. PFPS related more to motor control performance but not JPS. Knee pain and impaired strength related more to functional performance impairment

Author and country	Research Topic	Type of study and setting	Population group	Aim of study	Methods	Materials used to obtain results	Data Analyses	Results	Conclusion
					squat system. Severity of pain with VAS. Functional levels by means of Kujala patellofemoral scores.				then JPS in patients with PFPS
Cyrillo et al 2014 Sao Paulo, Brasil	Patellofemoral pain syndrome alters joint position sense: Case control study	Case control study design	Twenty-nine woman (15 healthy and 14 with PFPS)	The aim of this study was to evaluate knee JPS in participants with and without PFPS. Comparing the symptomatic and asymptomatic knee of participants with PFPS in open and close chain exercises and active and passive reproduction.	JPS was tested using active reproduction NWB at 45 degrees and 60 degrees using open kinetic exercises. JPS was tested with active reproduction 45 degrees WB, bilateral squat, closed chain kinetic exercises. Tests were performed 3 times.	JPS was evaluated in a NWB seated position with a isokinetic dynamometer (Cybex Norm) and a electrogoniometer (model GN 360) in WB bilateral squat.	The absolute error was defined as the difference between the RA and TA. Relative error was defined as the difference between RA and TA considering the value of the sign (direction bias/ over of under estimating)	AE in the active reproduction of 45 degrees in open chain exercises was significantly higher in experimental group. AE and relative error was significantly different at 45 degrees of active reproduction of knee JPS compared to controls.	This study suggests that PFPS alters JPS during active reproduction of 45 degrees angle in both open and closed kinetic chain exercises AE 3,6 degrees in experimental group.

Author and country	Research Topic	Type of study and setting	Population group	Aim of study	Methods	Materials used to obtain results	Data Analyses	Results	Conclusion
Guney et al 2015 Ankara Turkey	The relationship between quadriceps strength and joint position sense, functional outcome and painful activities in patellofemoral pain syndrome	Prospective case-control study design.	43 women diagnosed with unilateral PFPS (aged between 20-40) were included.	The aim of this study was to investigate how strongly the concentric and eccentric quadriceps strength were correlated with JPS, functional outcomes and painful activities in patients with PFPS.	Eccentric and concentric quadriceps strength was recorded at 60 and 180 degrees/s. Active JPS was measured at 20 and 60 degrees of flexion NWB. Functional levels were determined with Kujala PF scores, pain levels during functional activities were measured using VAS.	Eccentric and concentric strength and JPS was measured using a Biodex system 3 Dynamometer, VAS used to measure pain during functional activities, Kujala PFP score were used to describe perceived knee functional capabilities.	The relationship of isokinetic quadriceps strength with JPS results, Kujala scores and pain levels were evaluated using Spearman's correlation coefficient	Eccentric and concentric quadriceps strength were significantly lower on the involved leg compared to the uninvolved leg. JPS results were poorer on the painful side when compared to the uninvolved side. Eccentric strength correlated with both JPS angles concentric strength was correlated only with 20 degrees of knee flexion.	Quadriceps eccentric strength was correlated more to JPS then concentric strength. Both eccentric and concentric quadriceps strength related to pain and functional levels in PFPS patents.

Author and country	Research Topic	Type of study and setting	Population group	Aim of study	Methods	Materials used to obtain results	Data Analyses	Results	Conclusion
Kurt et al 2016 Turkey	Short-term effects of kinesio tape on joint position sense, isokinetic measurements, and clinical parameters in patellofemoral pain syndrome	Single blind randomized controlled trail. Outpatient clinic setting, University of Ahi Evran.	90 patients with patellofemoral pain were included (45 for KT group and 45 placebo group) (36 males, 54 females), aged between 20 and 40.	The purpose of the study was to evaluate the short-term effect of Kinesio tape on joint position sense, isokinetic measurements, kinesiophobia, symptoms and functional limitations in patients with PFPS.	Baseline isokinetic quadriceps muscle tests and measurements of JPS were performed in both groups. Pain was measured with VAS, kinesiophobia with Tampa kinesiophobia scale, Kujala was used to measure symptoms and functional limitations. Measurements were repeated 2 days after K tape application.	Isokinetic dynamometer was used to evaluate quadriceps strength, in a seated position 90 degrees of knee flexion/angular velocities of 60 and 180 degrees/s, 3 repetitions. JPS was measures through PAR, 60 degrees NWB position with dynamometer.	JPS was measured as the deviation from TA (60 degrees) mean of 3 repetitions. Continues data was described as arithmetic means, standard deviation and categorical described as percentages.	No difference was found between baseline isokinetic muscle measurements taken 2 days after application. Significant improvement was observed in kinesio tape group compared to control group with regards to JPS, pain, kinesiophobia, symptoms and functional limitations after treatment. AE 8,7 degrees before tape, 6,7 degrees after tape.	Short term Kinesio tape application did not increase hamstring muscle strength it may have improved JPS, pain, kinesiophobia, symptoms and daily functional limitations.

Appendix 1: Screening Tool

Once the potential participant makes contact to partake in this study, an email was sent as a screening tool to verify whether they comply with the inclusion criteria and whether they have known signs and symptoms of AKP.

Dear potential participant

Thank you for your interest in our knee pain research. Attached is a short list of questions that we would like you to answer. The questionnaire serves as an initial screening tool to determine whether or not you are eligible to participate in the next step of the process (the clinical assessment).

Please complete the questionnaire and email your responses back to this email address.

Kind regards,
The SU Research Team

SCREENING QUESTIONNAIRE :

(Compiled by D Leibrandt, MSc Physiotherapy, 2015)

NAME:

GENDER:

AGE:

CELLPHONE NUMBER:

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

Current pain level on a scale of 0-10:

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

	YES	NO
At the front of the knee cap		
Behind the knee cap		
At the front of the knee just below the knee cap		

2. For how long have you had knee pain?

	YES	NO
Less than 3 months		
More than 3 months		

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

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

4. Have you ever had surgery for the painful knee?

	YES	NO

Appendix 2: Checklist for Diagnosis of Anterior Knee Pain

Created by Leibrandt and Louw 2017)

Subjective information:

Area (must be yes)

	YES	NO
Front of knee or retropatella ^{3, 12, 16, 23}		

Chronicity

Longer than 3 months ^{3, 6, 14, 17}		
--	--	--

Aggravated by (must be yes for 2 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 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
Lachmen'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 3: Participant Information Leaflet and Consent Form

TITLE OF THE RESEARCH PROJECT: Proprioception changes in individuals with Anterior knee pain.

REFERENCE NUMBER:

PRINCIPAL INVESTIGATOR: Carlyn Rhode

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

CONTACT NUMBER: 021 938 9667

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

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

What is this research study all about?

Adolescents and young adults often experience pain in front of the knee, referred to as a condition called anterior knee pain. The cause and factors contributing to pain in front of the knee are still unknown.

The purpose of this research project is to determine whether people with pain in front of the knee have difficulty in sensing the precise position of their knee joint during movement (this sense of position is called proprioception).

This study will take place at the FNB-3D movement analysis clinic, Stellenbosch University, Tygerberg Medical School Campus. This project will include 30 individuals, aged between 14 and 40 years who experience anterior knee pain.

Participants will be assessed for anterior knee pain by the senior physiotherapist at the FNB-3D movement analysis clinic. Reflective markers will be placed on bony landmarks of the lower limb to allow the researcher to evaluate the affected knees sense of position. Each participant will perform 3 active knee tests movements in 3 different test positions; Extending the knee in sitting, bending the knee in prone and single leg squat in standing in a full weight-

bearing position. The duration of testing is 90 minutes. We will also measure your height, weight, leg length and other body dimensions.

All these procedures are non-invasive. Participants will be carefully instructed and guided through each test position and a practice trial just to familiarize them with the test movements. Participants will be blindfolded at the commencement of testing to prevent any visual guiding during testing. We will also measure the intensity of your knee pain and functional problems using questionnaires.

Why have you been invited to participate?

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

What will your responsibilities be?

You will be required pay a once-off visit to the FNB-3D movement analysis clinic for knee testing.

Will you benefit from taking part in this research?

You will contribute to updating the evidence on anterior knee pain. The knowledge gained may help to improve future rehabilitation of persons with anterior knee pain.

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

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

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

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

Who will have access to your medical records?

All information obtained from you will be treated as strictly confidential. Only the researchers involved in the study will have access to the data collected.

We will publish the findings of the study in a scientific journal and will also present it at scientific meetings/conferences; anonymity of your identity will be maintained.

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

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

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

No but you will be reimbursed for your time and travel costs with an amount of R200. There are no cost involved for taking part in the study.

Is there anything else that you should know or do?

- You can contact Prof Q. Louw at tel 021 9389667 if you have any further queries or encounter any problems.
- You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study physiotherapist.
- You will receive a copy of this information and consent form for your own records.

Declaration by participant

By signing below, I agree to take part in a research study entitled (Is proprioception affected in individuals with anterior knee pain?)

I declare that:

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

Signed at (*place*) on (*date*) 2017.

.....
Signature of participant

.....
Signature of witness

Declaration by investigator

I (*name*) declare that:

- I explained the information in this document to
- I encouraged him/her to ask questions and took adequate time to answer them.

- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*)

Signed at (*place*) on (*date*) 2017.

.....
Signature of investigator

.....
Signature of witness



PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM



TITLE OF THE RESEARCH PROJECT:

Proprioceptive changes in individuals with Anterior knee pain.

RESEARCHERS NAME(S): Mrs Carlyn Rhode, Prof QA Louw, Mrs Leoné Williams

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

CONTACT NUMBER: 0219389667/ 0839485959

What is RESEARCH?

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

What is this research project all about?

Adolescents and young adults often experience pain in front of the knee, referred to as a condition called anterior knee pain. The cause and factors leading to pain in front of the knee are still unknown.

The purpose of this research project is to find out whether people with pain in front of the knee have difficulty in sensing the precise position of their knee joint during movement (this sense of position is called proprioception).

This study will take place at the FNB-3D movement analysis clinic, Stellenbosch University, Tygerberg Medical School Campus. This project will include 30 individuals, aged between 14 and 40 years who experience pain in the front of the knee.

Participants will be assessed for pain in the front of the knee by the senior physiotherapist at the FNB-3D movement analysis clinic. Reflective markers will be placed on bony landmarks of the lower limb to allow the researcher to evaluate the affected or painful knees sense of position. Each participant will perform 3 active knee tests movements in 3 different test positions; straightening the knee in sitting, bending the knee whiles lying on your tummy and single leg squat whiles standing. The duration of testing is 90 minutes. We will also measure your height, weight, leg length and other body measurements.

All these procedures are non-invasive. Participants will be carefully instructed and guided through each test position and a practice chance will be given just to familiarize them with the test movements. Participants will be blindfolded at the start of testing to prevent participants from using their sight to influence testing results. We will also measure the intensity of your knee pain and functional problems using questionnaires.

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

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

Who is doing the research?

The main researcher, Carlyn Rhode, is performing the research as part of her Master's degree.

What will happen to me in this study?

You will be required to visit the FNB-3D movement analysis clinic once-off for testing your knee.

Can anything bad happen to me?

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

Can anything good happen to me?

You will contribute to the knowledge of pain in front of the knee (anterior knee pain), so that in future people with this type of knee pain can be helped by better treatment and rehabilitation.

Will anyone know I am in the study?

No, you will be given a code and all of your information will be stored in a way that no one can identify you and will be treated confidentially. Only the researchers involved in the study will have access to data collected and your photographs.

Who can I talk to about the study?

You can contact Prof Q.Louw or Carlyn Rhode at tel 021 9389667/ 0839485959 if you have any further queries or encounter any problems.

You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been clearly addressed by your referring doctor or the physiotherapist.

What if I do not want to do this?

You may choose to leave the study at any time and will not be used against you in any way.

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

YES

NO

Has the researcher answered all your questions?

YES

NO

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

YES

NO

Signature of Child

Date

Appendix 4: Flow Diagram of Study Procedure

1. Recruitment

Study advert send out, placed at various sport clinics, Dr's rooms, running clubs and posted on social media.

2. Initial screening

On referral of participants, contact was made via email or telephonic. Screening questionnaire was completed to assess illegibility for inclusion.

3. Inclusion criterion

25 participants met the inclusion criterion. 50 knees where assessed for anterior knee pain

37 knees with anterior knee pain

13 knees without anterior knee pain

4. Testing procedure

Anterior knee pain diagnosis confirmed with AKP diagnostic tool. Physical examination performed to excluded other knee pathologies. Participants completed the VAS, AKPS and LEFS.

Preparation for motion analysis testing. Participants dressed in short, bear foot and reflective markers placed.

5. Proprioceptive testing

Test position 1: single leg stance

Test position 2: Sitting, active knee extension

6. Data Analysis

To determine a significant difference between the knees with AKP and the knees without AKP.

Appendix 5: Anterior Knee Pain Questionnaire

(Green et al 2014, Watson et al 2005, Crossley et al 2004, Bennell et al 2000).

ANTERIOR KNEE PAIN (Sheet code: _____)

Name: _____ Date: _____ Age: _____

Knee: L/R

Duration of symptoms: _____ years _____ months

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

1. Limp

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

2. Support

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

3. Walking

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

4. Stairs

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

5. Squatting

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

6. Running

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

7. Jumping

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

8. Prolonged sitting with the knees flexed

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

9. Pain

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

10. Swelling

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

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

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

12. Atrophy of thigh

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

13. Flexion deficiency

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

Appendix 6: Lower Extremity Functional Scale

(Green et al 2014, Watson 2005, Bennell et al 2000, Crossley et al 2004)

Lower Extremity Functional Index

We are interested in knowing whether you are having any difficulty at all with the activities listed below because of your lower limb problem for which you are currently seeking attention. Please provide an answer for each activity.

Today, do you or would you have any difficulty at all with:

(Circle one number on each line)

Activities	Extreme Difficulty or unable to perform activity	Quite a bit of difficulty	Moderate difficulty	A little bit of difficulty	No difficulty
a. Any of your usual work, housework or school activities.	0	1	2	3	4
b. Your usual hobbies, recreational or sporting activities	0	1	2	3	4
c. Getting into or out of the bath.	0	1	2	3	4
d. Walking between rooms.	0	1	2	3	4
e. Putting on your shoes or socks.	0	1	2	3	4
f. Squatting.	0	1	2	3	4
g. Lifting an object, like a bag of groceries from the floor.	0	1	2	3	4
h. Performing light activities around your home.	0	1	2	3	4
i. Performing heavy activities around your home.	0	1	2	3	4
j. Getting into or out of a car.	0	1	2	3	4
k. Walking 2 blocks.	0	1	2	3	4
l. Walking a mile.	0	1	2	3	4
m. Going up or down 10 stairs (about 1 flight of stairs).	0	1	2	3	4
n. Standing for 1 hour.	0	1	2	3	4
o. Sitting for 1 hour.	0	1	2	3	4
p. Running on even ground.	0	1	2	3	4
q. Running on uneven ground.	0	1	2	3	4
r. Making sharp turns while running fast.	0	1	2	3	4
s. Hopping.	0	1	2	3	4
t. Rolling over in bed.	0	1	2	3	4
COLUMN TOTALS					

Score variation ± 6 LEFIS points
MDC & MCID = 9 LEFIS points

Score ____/80

Appendix 7: Description of Knee Joint Position Sense Testing

Testing of knee joint position sense

All participants were familiarised with the test procedure by means of explanation, demonstration and a practice opportunity.

- (1) The participants were asked to resume the test position i.e. (i) standing, (ii) sitting.
- (2) The target angle was determined by each participant according to his/her capabilities and comfort level. The target angle was therefore unique (specific) to each participant.
- (3) The participants were asked to move the knee with AKP through the full range of motion and stop in the middle range for that specific movement.
- (4) The participants were asked to briefly hold the mid-range position while the H-frame was positioned to record this position as the TA.
- (5) During the test trail participants were familiarized with the test procedure. Each participant was verbally cued to slowly move from the starting position (start angle of the knee) to the target angle, and hold the target angle for five seconds to familiarise themselves with the target angle. When holding the target angle participants were verbally cued to hold the leg there and concentrate on the feeling in the knee.
- (6) Participants were cued to return to the starting position.
- (7) This action was repeated five times on both the knees with AKP and the knees without AKP and for each test position (knee flexion and extension during single leg squat as well as knee flexion and extension in sitting).^{21 22 27 28 33} Followed by the test procedure.
- (8) During testing the H-frame was removed. The participants were blindfolded and asked to reproduce the target angle (reproduced angle).²⁴
- (9) The participants indicating to the researcher and bio-engineer once they have reproduced the target angle by shouting STOP. Once the participant reproduced the target angle the participant remained in this position for five seconds to capture this angle (the reproduced angle).
- (10) Participants were cued to resume the starting position.

The testing was repeated five times on both the knees with AKP and the knees without AKP for each test position.²⁵ The knees with AKP where compared to the knees without AKP .²²

Appendix 8: Journal Guidelines

About JSR

The *Journal of Sport Rehabilitation (JSR)* is your source for the latest peer-reviewed research in the field of sport rehabilitation. All members of the sports-medicine team will benefit from the wealth of important information in each issue. *JSR* is completely devoted to the rehabilitation of sport and exercise injuries, regardless of the age, gender, sport ability, level of fitness, or health status of the participant. *JSR* is expanding from 4 to 6 issues per year in 2017 (January, March, May, July, September, and November).

Mission

The editorial mission of *JSR* is to advance the understanding of all aspects of sport rehabilitation, particularly in the areas of therapeutic exercise, therapeutic modalities, injury evaluation, and the psychological aspects of rehabilitation. *JSR* publishes peer-reviewed original research, systematic reviews/meta-analyses, critically appraised topics (CATs), case studies/series, and technical reports that directly affect the management and rehabilitation of injuries incurred during sport-related activities, irrespective of the individual's age, gender, sport ability, level of fitness, or health status. The journal is intended to provide an international, multidisciplinary forum to serve the needs of all members of the sports medicine team, including athletic trainers/therapists, sport physical therapists/physiotherapists, sports medicine physicians, and other health care and medical professionals.

Original Research Reports. *JSR* publishes original research reports on all aspects of the sport and exercise rehabilitation process.

Manuscript Guidelines

The *Journal of Sport Rehabilitation* publishes peer-reviewed original research, systematic reviews/meta-analyses, critically appraised topics (CATs), case studies/series, and technical reports that directly affect the management and rehabilitation of injuries incurred during sport-related activities.

Format/Preparation Guidelines

Submissions must be prepared in English as a typed Microsoft Word document. The document must be double-spaced, include page and line numbers, and use margins of at least 1 in. Author information should not be included any place in the manuscript (ie, title page, subjects, methods), and any identifying information created within Microsoft Word settings should be removed. A cover letter with author information should be included during the submission process. While completing the submission process you will be required to provide the title of the manuscript, name(s) of author(s), institutional affiliation(s), a short title for the running head (15 word limit), mailing address, e-mail address, and fax and phone numbers of the author who is to receive the proofs.

Manuscripts should be written in first person using the active voice. Writing should be concise and direct. Avoid using unnecessary jargon and abbreviations, but use an acronym or abbreviation if it is more commonly recognized than the spelled-out version of a term. Formats of numbers and units and all other style matters should follow the *AMA Manual of*

Style, 10th edition. All manuscripts must contain an abstract of no more than 300 words, with formatted subheadings. All tables and figures must be clearly labeled and should be submitted as separate files. *JSR* discourages the use of already printed and copyrighted materials. If necessary, the author must include a letter granting permission to reprint the material. The required structure of the manuscript is detailed below.

Parts of the Manuscript

There are structure requirements that apply to all manuscript submissions:

- **Structured Abstract:** Abstracts must be structured as described in the *AMA Manual of Style*, 10th edition, and contain 300 words or fewer.
 - *Original research* abstracts must include the following headings: Context, Objective, Design, Setting, Patients (or Other Participants), Intervention(s), Main Outcome Measures, Results, Conclusions
 - *Systematic review or meta-analysis* abstracts must include the following headings: Context, Objectives, Evidence Acquisition (data sources, study selection, quality assessment, and data extraction), Evidence Synthesis (data synthesis), Conclusions
 - *Critically appraised topic* abstracts must include the following headings: Clinical Scenario, Clinical Question, Summary of Key Findings, Clinical Bottom Line, Strength of Recommendation
 - *Technical report* abstracts should comply with original research guidelines for the abstract and references.
- **Manuscript Body:** The body of the manuscript is specific to the type of manuscript submission (each is detailed below).
- **References:** References must follow the *AMA Manual of Style*, 10th edition; details are provided below.
- **Figures, Tables, Videos (if applicable):** Details are provided below.

Original Research. These reports of original data should include the following parts:

Introduction, Methods, Results, Discussion, and Conclusions.

- **Introduction:** In this section, build the problem and specifically state the purpose and hypotheses of the study. Do not label the introduction section.
- **Methods:** This section should include the following subheadings: Design (study design, not statistical design should be included with respective independent and dependent variables), Patients or Participants (subject information including a statement that institutional review board approval was granted [without indicating author's affiliation], in the spirit of the Helsinki Declaration), Procedures (clearly and succinctly describe interventions and outcome measures), and Statistical Analyses.
- **Results:** This section should include a presentation of results relevant to the stated objectives. Do not explain why the results turned out as they did or justify the use of a specific statistical procedure in this section. This section should not contain statistical jargon that may confuse readers. If tables or figures are used, the information should not be repeated in the text.
- **Discussion:** The discussion is a formal consideration and critical examination of the study. The research hypotheses of the study should be addressed and considered in the context of other published works. The study's limitations and generalizability should also be addressed.
- **Conclusions:** This section should summarize the most clinically pertinent findings of the study. Conclusions should be directly supported by the data and should highlight the clinical importance of the work that was performed while avoiding overgeneralizations.

References. Each citation in the text must be designated by a superscripted numeral, and full information must appear in the reference list. Reference information must be accurate. References must be limited to directly pertinent published works or papers that have been accepted for publication; usually this can be achieved with less than 30 references, although review papers might have more extensive reference lists. The reference list is to be double-spaced, arranged in the order the works are first cited, and numbered serially, with only 1 reference per number. Entries in the reference list should be consistent with [Index Medicus](#) for journal abbreviations and follow the *AMA Manual of Style*, 10th edition, as follows:

- *Journal Articles:* Surname of first author, initials, then surname and initials of each coauthor; title of article (capitalize only the first word and proper nouns), name of the journal (italicized and abbreviated according to style of Index Medicus), year, volume, and inclusive page numbers:
- Jacobs C, Mattacola CG. Gender comparison of eccentric hip abductor strength and knee joint kinematics when landing from a jump. *J Sport Rehabil.* 2005;14:346–355.
- *Book References:* Author(s) as above, title of book (italicized and all major words capitalized), city and state/province of publication, publisher, and year:
- Starkey C, Johnson G. *Athletic Training and Sports Medicine.* Salisbury, MA: Jones & Bartlett;2005.
- *Chapter in an Edited Book:* Same as book references, but add the name of the chapter author(s) and title of chapter (capitalize first word and proper nouns) before the book information and the page range at the end:
- Perrin DH. The evaluation process in rehabilitation. In: Prentice WE, ed. *Rehabilitation Techniques in Sports Medicine.* 2nd ed. St Louis, MO: Mosby Year Book; 1994:253–276.

Figures and Tables. Figures should be professional in appearance and have clean, crisp lines. They should be no larger than 8 by 10 in, but keep in mind that they might have to be reduced to fit the journal’s format. Hand drawing and hand lettering are not acceptable. Use black and white or gray shading only, no color. Photographic images should be submitted as separate files and must be either JPEG or TIFF format at a resolution of 300 dots per inch (dpi). Authors are urged to submit illustrations rather than tables. When tabular material is necessary, it should not duplicate the text. Tables should be double-spaced on separate sheets and include brief titles.

Appendix 9: Electronic Letter of Invitation for Research Participation

Title of Study: Proprioceptive changes in individuals with Anterior knee pain.

Principal Investigator: Carlyn Rhode, MSc Candidate, Division of Physiotherapy, Stellenbosch University

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

Co-supervisor: Mrs Leoné Williams, Lecturer, 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: 083 948 5959/ email: carlynrhode@mweb.co.za (C.Rhode)

Dear Colleague

My name is Carlyn Rhode and I am a Masters student at the Division of Physiotherapy, Stellenbosch University (SU). I would like to invite you to participate in a research project that aims to investigate whether patients suffering from acute or chronic onset of anterior knee pain have deficient or disturbed proprioception.

Please take some time to read the information presented here, which will explain the details of this project and contact me if you require further explanation or clarification of any aspect of the study. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

I have applied for ethics approval through the **Health Research Ethics Committee (HREC) at Stellenbosch University** 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 if people diagnosed or suffering from the signs and symptoms anterior knee pain have affected or disturbed proprioception. The clinical signs and symptoms of anterior knee pain include pain in front of or in the area of the kneecap. Pain and symptoms are usually aggravated by activities like prolonged sitting, squatting and climbing stairs, as well as pain during sporting activities.

Should you choose to participate, you will be asked to complete an initial screening questionnaire and a physical examination by a physiotherapist to confirm whether you comply with the inclusion criteria of the study.

During the test procedure you will be asked to perform three short function examinations of the knee (bending the knee in sitting, while lying on your stomach and while standing) this will take place in a motion analysis laboratory. For this, you will need to change into shorts and a sleeveless sports top (females)/ no shirt (males) and remove your shoes. Before performing the three functional knee tests, small reflective markers and motion sensors will be stuck to your legs and lower limb joints using special double-sided tape. These will be removed after testing. The expected duration of such a testing session will be about 90 minutes. Four participants will be tested per day.

All personal details will be kept confidential, and you will participate in this project on an anonymous basis. Your privacy will be respected throughout. Participation in this project will not cost you anything, and there is also a small remuneration of R200 for participating to compensate for time and transport to and from the motion laboratory at Tygerberg campus.

If you are willing to participate in this study please reply to this email address:
carlynrhode@mweb.co.za- further information and arrangements will then be forwarded to you.

Yours sincerely

Carlyn Rhode
Principal Investigator

Appendix 10: Data Collection Form

DATA COLLECTION FORM			DATA COLLECTION CODE:				
			DATE OF DATA COLLECTION:				
DEMOGRAPHICS:							
DATE OF BIRTH:							
AGE:							
HEIGHT:							
WEIGHT:							
LOCATION OF SYMPTOMS:	ANTERIOR		POSTERIOR		LATERAL BORDER:		MEDIAL BORDER:
ONSET OF SYMPTOMS:	INSIDIUS:		OTHER:				
DURATION OF SYMPTOMS:	LESS THEN 3MONTHS:		MORE THEN 3MONTHS:		OTHER:		
SEVERITY OF SYMPTOMS:	MILD: (0-4)		MODERATE: (4-7)		SEVERE: (7-10)		
ACTIVITY LEVEL:	NONE		1-3 TIMES PER WEEK		MORE THEN 5TIMES		
(how often do you train/exercise or partake in sport)							
SPORTING ACTIVITY:	RUNNING		GYM		OTHER SPORT:		NONE:
CURRENT TREATMENT:	MEDICAL:		CONSERVATIVE:		NONE:		
FUNCTIONAL IMPAIRMENT:	UNABLE TO DO ADL:		CAN DO ADL:		STOPPED SPORT:		NONE:
MEDICATION FOR PAIN:							

Appendix 11: Ethics Letter of Approval



UNIVERSITEIT • STELLENBOSCH • UNIVERSITY
jou kennisvenoot • your knowledge partner

02-Dec-2016 Rhode, Carlyn C

Approved with Stipulations Response to Modifications- (New Application)

Ethics Reference #: S16/10/197 Title: Proprioception changes in individuals with Anterior Knee Pain

Dear Mrs Carlyn Rhode,

The **Response to Modifications - (New Application)** received on **25-Nov-2016**, was reviewed by members of **Health Research Ethics Committee 1** via Expedited review procedures on **30-Nov-2016**.

Please note the following information about your approved research protocol:

Protocol Approval Period: **02-Dec-2016 -01-Dec-2017**

The Stipulations of your ethics approval are as follows:

ICF form and child assent forms are still written at too high a level. This is important as participants will be recruited via advertising which means participants from all sectors may apply to participate.

Please remember to use your **protocol number (S16/10/197)** 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 a template of the progress report is obtainable on www.sun.ac.za/rds and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit. Translation of the consent document to the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372 Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 3981). 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 documents please visit: www.sun.ac.za/rds

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

Included Documents:

CV L Williams.pdf Declaration C Rhode.pdf Application form.pdf 20161128 MOD HREC Modifications Required letter CV C Rhode.docx Protocol.docx Declaration L Williams.pdf Protocol Synopsis proprioceptive changes in individuals with AKP..doc CV Q Louw.doc 20161128 MOD Cover letter Declaration Q Louw.pdf Checklist.doc 20161128 MOD Protocol

Sincerely,

Franklin Weber HREC Coordinator Health Research Ethics Committee 1

Appendix 12: Placement of Retro-reflective Markers

Placement of the head markers:

- LFHD/RFHD - front approximately over temples
- LBHD/RBHD - in horizontal plane of front head markers

The markers over the temples define the origin, and the scale of the head. The rear markers define the head's orientation.

Placement of the torso markers:

- Clavicle – supero-sternal notch
- Sternum – xiphoid process of sternum
- RBACK - place in the of the right scapula
- C7 – spinous process
- T10 – spinous process
- Placements of the arm markers:
- Left shoulder/Right shoulder – acromioclavicular joint
- Left elbow/R elbow– lateral epicondyle approximating elbow joint axis
- LWRA/RWRA – wrist bar, thumb side
- LWRB/RWRB – wrist bar, pinkie side
- Left finger/Right finger – dorsum of the hand just below the head of the second metacarpal

Placement of the pelvis markers:

- Left ASIS/Right ASIS – directly over the anterior superior iliac spines
- Left PSIS/Right PSIS – directly over the posterior superior iliac spines

Placement of knee markers:

- Left knee/Right knee– lateral epicondyle of the femur
- Left thigh/Right thigh - lower lateral 1/3 surface of the thigh, just below the swing of the hand
- Place the marker in a line from the greater trochanter and knee marker

Placements of the tibia markers:

- Left tibia/Right tibia – lower lateral 1/3 of the tibia to determine the alignment of the ankle flexion axis. The marker is placed in a line joining the knee and the ankle markers
- A wand mounted marker may be used

Placement of the ankle markers:

- Left ankle/Right ankle - lateral malleolus along an imaginary line that passes through the transmalleolar axis
- LMMAL/RMMAL – medial malleolus of the ankle (only used during the Oxford correction static subject calibration)

- The tibial marker should lie in the plane that contains the knee and ankle joint centres and the ankle flexion/extension axis.

Placement of the foot markers:

- LTOE/RTOE - second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot
- LHEE/RHEE - Place on the calcaneus at the same height above the plantar surface of the foot as the toe marker.

Appendix 13: Physical Examination

Physical examination:

Study code:

Observation:

Joint integrity tests: Have been included in AKP diagnostic tool as diagnostic exclusions.

Knee functional test: Have been included in AKP diagnostic tool.

Knee active and passive joint movements:

Knee flexion/extension:	
Hyper extension:	
Medial/lateral rotation:	
Flexion/abduction: Flexion/adduction:	
Extension/abduction: Extension/adduction:	

Other joints

Clearing tests: (if indicated)

Hip joint: Hip quadrant

Lumbar spine& Sacroiliac joint: lumbar quadrant

Ankle joint: Plantar flexion/dorsiflexion and inversion/eversion.

Muscle tests:

Muscle strength:

Quadriceps

Hamstrings

Muscle length:

Quadriceps

Hamstrings

Gastrocnemius

Isometric muscle tests:

Special tests:

Leg length: Right leg: Left leg:

Palpation:

Base of patella/ lateral tilt/ anterior-posterior tilt/rotation:

Accessory movements:

Patello-femoral joint:

Medial transverse/ lateral transverse
Longitudinal cephalad/caudad oblique
Medial/Lateral rotation
Medial tilt/lateral tilt
Compression
Distraction

Appendix 14: Study Advertisement

Do you suffer from anterior knee pain?

As part of my Master's degree at the University of Stellenbosch I am conducting a study investigating if individuals suffering from anterior knee pain have altered proprioception.

Contact: Carlyn Rhode 0839485959/carlynrhode@mweb.co.za



Do you suffer from pain in the front of the knee during:

- Prolonged sitting, squatting
- Ascending or descending stairs
- As well as running
- Are you between the ages of 14 and 40?
- Are you willing to partake in a research study?